Photo: Prue Loney

CGIAR Research Program 5

Water, Land and Ecosystems

Improved natural resources management for food security and livelihoods

September 2011

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Foreword

Sustainable management of the natural resource base supporting agriculture is one of the three major strategic objectives of the Consultative Group on International Agricultural Research (CGIAR). The CGIAR Research Program on Water, Land and Ecosystems (CRP5) combines the resources of 14 CGIAR and numerous external partners to provide an integrated approach to natural resource management (NRM) research, and to the delivery of its outputs.

The program focuses on the three critical issues of water scarcity, land degradation and ecosystem services, as well as the CGIAR System Level Outcome of sustainable natural resource management. It will also make substantial contributions to the System Level Outcomes on food security, poverty alleviation and, to a minor extent, health and nutrition. Water, Land and Ecosystems focuses on how we can develop sustainable agricultural management systems in the face of the agricultural intensification needed to feed a rapidly growing global population.

Overcoming NRM problems and adapting to climate change will be achieved only by understanding and managing the dynamics of water and nutrient flows across the whole landscape and through the complete hydrological cycle. Solutions to water scarcity and variability, land degradation, nutrient management and deteriorating ecosystem services must be developed with a view to what works for communities across landscapes, not just what works on the farm.

Water, Land and Ecosystems differs from crop-based programs in that it takes a river basin and landscape view of these issues to provide solutions to widespread declines in soil fertility, land degradation including erosion and salinization, and the critical phenomenon of water scarcity. Where other CGIAR Research Programs operate at the levels of field and farm, CRP5 will consider how resources can be accessed and shared equitably, better governed and more effectively managed. To do this it will develop and adopt evidence-based approaches to increasing food production, improving livelihoods and delivering ecosystem services – including clean water and habitat – sustainably.

Our centers are ready, willing and able to tackle these challenges, which have been defined in discussion with partners and stakeholders at regional level and in electronic fora organized to formulate the Water, Land and Ecosystems program. They are immense challenges, but we believe that by scaling up research outputs from farm to landscape to major river basins, we can overcome them and contribute to a more sustainable planet, even in the face of increased demand for food and water. Equally importantly, we contend that the improved NRM that emanates from the program will improve the livelihoods of at least 300 million poor women and men.

This is the revised draft of the proposal. It has undergone a very significant rewrite following useful comments and suggestions made by the Independent Science and Partnership Council and several CGIAR Fund Council members in mid 2011.

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Executive Summary

The global population in 2050 will be about 9 billion, with most of the increase between now and then taking place in developing countries. To feed the world in 2050 and beyond, we will need to intensify agricultural production. Many observers consider that intensification will cause unacceptable harm to the environment, perhaps undercutting the ecosystems that support agriculture. CRP5 challenges this perspective and examines how we can intensify agriculture while protecting the environment and lifting millions of farm families out of poverty.

To achieve the vision of sustainable intensification, we must redouble our efforts to increase agricultural productivity, while protecting the environment we must conduct new and integrative research on agricultural and ecosystem interactions. Consequently the objective of Water, Land and Ecosystems is:

> *To learn how to intensify farming activities, expand agricultural areas and restore degraded lands, while using natural resources wisely and minimizing harmful impacts on supporting ecosystems.*

Conceptual framework
CRP5 is based around a conceptual framework that examines how changes in external drivers affect production systems and how management responses in production systems in turn impact ecosystem services and the broader environment. We aim to determine how these changes will impact natural resources at basin and landscape scales, how to measure changes in critical ecosystem services and how to use this information to improve land and water policy decisions and management responses.

If changes in key processes (e.g. water flow, erosion rates and vegetation) can be observed and measured at basin and landscape scales, we can use that information to provide policy advice and further adjust management practices. Given that management practices may act independently, we need also to determine the cumulative impacts of management practices at landscape and basin levels through modeling and mapping. Hence CRP5 will be supported by a strong foundation of analysis and information.

We view the relationships involving drivers and responses of the production system and its underpinning natural resources through a nested, spatial approach. At the broadest level we focus on major regions. Where possible, we will develop knowledge of broader agroecological zones (e.g. international public goods on nutrient cycling, soil fertility and water scarcity). By working at the basin level, we can quantify water flows and uses, and thus examine upstream–downstream environmental changes and socioeconomic trade-offs. We will use basic tools of water accounting and new approaches to monitoring land health, to quantify the impacts of agriculture on the environment, and vice versa.

Strategic Research Portfolios

Within the broad topic of Water, Land and Ecosystems, we have identified five Strategic Research Portfolios (SRPs). These are Irrigated Systems, Rainfed Systems, Resource Reuse and Recovery, River Basins and Information Systems. They encompass irrigated and rainfed agricultural systems, in which improved policy and management practices will have to be implemented if we are to sustainably intensify agriculture. Resource Reuse and Recovery focuses on the pressing need to improve the recovery and reuse of water and nutrients in agriculture while at the same time limiting environmental pollution. We use landscape and river-basin perspectives to understand how changes imposed by external drivers and management practices will affect ecosystem services at broader scales. The SRP on the development of better information systems is vital to support science-based policy development and its implementation as well as improved natural resources management practices.

In addition to the five SRPs, we have established two cross-cutting themes that will influence and enhance our research: 1) Ecosystem Services, and 2) Institutions and Governance. Within each SRP we will promote ecosystem resilience and minimize negative impacts on ecosystem services. We will seek to enhance, and increase the value placed upon, ecosystem services. In doing so, we will work to improve resilience and provide farmers and pastoralists with production systems that are better adapted to environmental change.

With regard to institutions and governance, we will examine measures for building capacity and enhancing policy and institutional effectiveness across the SRPs. Throughout the program, gender and equity considerations will be emphasized in project planning, targeting of potential beneficiaries, and communication strategies.

Regional setting

We will work initially in eight regions that are centered on large river basins:

Region	**Basin**
Southeast Asia	Mekong
South Asia	Indus and Ganges
Central Asia	Amu Darya and Syr Darya
Middle East	Tigris and Euphrates
West Africa	Volta and Niger
East Africa	Nile
Southern Africa	Limpopo and Zambezi
Latin America	Andes basins

Each basin contains a mixture of agro-ecological zones, urban and rural landscapes, and social, economic and political entities. In each, the natural resource base supporting agriculture and livelihoods is under stress. During the first five years of the CRP we will focus our research around key ‘problem sets.’ These contain a mixture of regional, basin-specific, global and methodological issues. The precise nature of problem sets is specific to research sites, but cross-regional parallels and similarities are not uncommon.

Our initial estimates suggest that at least 300 million people can benefit from the outcomes of CRP5 during the next 10 to 20 years. Additionally the work on the *Resource Recovery and Reuse* and *Rainfed Systems* SRPs may help another 200 million poor people, including some in urban communities.

Integration of CRP5 with other CRPs

Whereas other CRPs will conduct research at the commodity, field and farm levels, CRP5 researchers will work primarily at larger scales (landscapes and basins), with an emphasis on interventions that influence the environment and natural resources. However, to predict the consequences of actions and interventions we will also examine interactions – and describe the implications – at the plot and farm levels, to predict the consequences of actions and interventions, thus enabling us to describe the implications of our results at the landscape and basin scales.

CRP5 researchers have a unique opportunity to integrate research at basin and landscape scales, and to investigate the spatial consequences of the site-specific work undertaken in CRP1 (Integrated Agricultural Systems) and CRP3 (Wheat, Maize and Rice). The nested strategy adopted in our conceptual framework facilitates this approach. We will work in locations where other CRPs are conducting crop and field management trials that have implications for research questions at the basin and landscape scales. For example, drought-tolerant crop varieties may have beneficial impacts on the hydrological cycle. Conservation tillage can increase groundwater recharge while reducing runoff and erosion. Improved water management in rainfed settings may increase crop production but reduce water flow in wetlands and streams, thus affecting biodiversity. To improve long-term analysis, we will work with researchers in other CRPs to select sentinel monitoring sites.

We will also focus on improving the understanding of hydrological and land degradation processes in key basins with a view to better modeling water flow and guiding sustainable land management strategies. Such work will be linked with the climate change analysis in CRP7 (Climate Change, Agriculture and Food Security). We will work with CRP2 (Policies, Institutions, and Markets to Strengthen Assets and Agricultural Incomes for the Poor) with respect to the policy changes needed to achieve better water and land governance.

Success through collaboration

By crafting new partnerships and enhancing existing relationships, CRP5 researchers will strengthen links with universities, national research institutes and global organizations. The program's partnership strategy recognizes the different roles of 'core research partners,' 'implementing partners' and 'influencing and outreach partners.' We will develop new partnerships with private-sector entities as we examine opportunities for businesses to provide agricultural and environmental services.

Box ES.1. Key problem sets for each Strategic Research Portfolio

Irrigated Systems SRP

- Finally unlocking Africa's irrigation promise
- Revitalizing public irrigation systems in Asia
- Managing groundwater overexploitation in India through the energy–irrigation nexus
- Revving up the 'Ganges Water Machine' through intensive groundwater use for livelihoods and environmental benefits
- Managing salt–water balance in Indus and Central Asian irrigation systems

Rainfed Systems SRP

- Recapitalizing African soils and reducing land degradation
- Revitalizing productivity on responsive soils
- Using agro-biodiversity to sustain agricultural production
- Reducing risk by ensuring water access for pastoralists
- Reducing risk by providing farmers with supplemental irrigation

Resource Recovery and Reuse SRP

- Creating wealth from waste
- A grey revolution in wastewater management

Basins SRP

- Payment for Environmental Services (PES) as a water management tool: Andes group of basins
- Water storage to reduce regional drought risk: Volta–Niger
- Integrating environmental water allocations and climate change impacts with water resources development: Ganges–Indus
- Harmonizing the water–energy–environment nexus in the Mekong Basin
- Managing water resources to reduce poverty and improve wetland management in the upstream Nile
- Solutions for transboundary water management hotspots in transition economies: Aral Sea basins

Information Systems SRP

- Monitoring longer-term spatial and temporal change in agroecosystems
- Harnessing water and land information to improve management

Implementation of CRP5

The International Water Management Institute (IWMI) will be the lead center for CRP5, which will have an advisory steering committee that will focus on scientific strategy, partnerships and impact. The program will have a management committee under the leadership of the program director and comprise a monitoring and evaluation specialist, SRP leaders and Working Group leaders.

In the first six months we will develop annual work plans with milestones and deliverables, and analyze the expected benefits of the work. Subsequently, a prioritization process led by the program steering committee will advise management and the lead center on program strategy and funding allocations across SRPs. To ensure that the program's benefits are realized, an

innovative marketing, communication and knowledge management strategy will be a feature of all activities.

CRP5's gender and poverty strategy will ensure that its outcomes target not only to the poor in general, but also women farmers. A conference on gender will be held in the inception phase to ensure that projects will incorporate key local and regional gender issues.

Considerable emphasis will be given to building the capacity of key target groups, including policymakers and land and water managers, to capitalize on the availability of better information. We will conduct tailored workshops to educate NARES staff about key issues, technical methodologies and uptake strategies. IWMI and the International Rice Research Institute (IRRI) already are planning an agricultural water management training course that will be rolled out across CRP5 and CRP3.3 (Global Rice Science Partnership).

The program will have a strong focus on communicating its findings to users via different strategies targeted at farmers and policymakers. We will emphasize monitoring and evaluation of impacts, as well as our delivery process.

The three-year budget (2011–13) is estimated at US$246 million. This considers 2010 actual expenditures and allows a modest average annual increase of 6.8%. The sums of first-year funding for each of the SRPs are influenced significantly by existing restricted funding. However, prioritization processes may change this distribution in later years. More than one quarter (29%) of first-year funding will go to partners, with an increasing proportion of new funding earmarked for partnerships. The Food and Agriculture Organization of the United Nations (FAO) has offered to provide in-kind support, valued at US$33 million over the three years.

Finally, as we conduct the research of CRP5, we will generate policy recommendations for increasing agricultural productivity, improving NRM and enhancing food security. We will work with uptake specialists to ensure that our recommendations are considered by public officials and others responsible for managing agricultural and natural resources and enhancing livelihoods in developing countries. Our success in conducting good science and policy analysis will contribute to achieving several changes we hope to see in the world by 2020 (Box ES.2).

Box ES.2. Looking back from 2020
Consistent with the vision that motivates our work, we look forward to seeing the following potential outcomes in 2020:

- The pace of aquifer decline in the Western Indo-Gangetic plains is slowing, while previously untapped water resources in the eastern plains are enabling 8 million farm households to secure alternative livelihood activities. CRP5 researchers and their national partners are continuing to model the groundwater hydrology and explore alternative livelihood options.
- Irrigation has been made possible for 12 million households in sub-Saharan Africa. CRP5 agronomists and hydrologists joined forces with economists to develop the scientific and policy recommendations that enabled successful irrigation interventions. Our research has inspired irrigation development in 14 countries including Burkina Faso, Niger and Zimbabwe.
- We have provided scientific and policy support for the expansion of irrigation in South Sudan. CRP5 researchers determined the best ways to develop irrigation potential, while minimizing harm to flora and fauna in large wetland areas adjacent to irrigated farmland. An estimated 8 million households in South Sudan are food secure as a result.
- We have reduced the vulnerability and improved the incomes of 17 million smallholder households in rainfed and pastoral areas of sub-Saharan Africa and South Asia. We achieved this by improving access to fertilizer while minimizing financial risk in the face of unpredictable rains, and promoting agriculture that supports rather than degrades ecosystem services. CRP5 agronomists developed the crop, fertilizer and sustainable land management recommendations, while economists crafted the risk-reducing safety net programs taken up by donor organizations.
- We have enhanced the livelihoods of 9 million households in peri-urban areas (i.e. at the edges of cities and towns) of Asia and Africa by developing safe ways to use polluted water for irrigation. An estimated 48 million consumers face less risk of illness, and healthier farmers are using nutrients recovered from wastewater.
- We have resolved the longstanding issue of competition between food and energy for land and water. Government subsidies for producing biofuels have largely been eliminated, and markets reward farmers for producing moderate amounts from non-food plants. CRP5 research on the implications of biofuel programs catalyzed changes in policy that have lowered food prices for 1 billion residents of low- and middle-income countries.
- We have slowed the pace of and increased the benefits provided by hydropower development in the Mekong Basin. With national partners and ministry officials, CRP5 scientists developed innovative protocols for protecting the environment and enhancing the livelihoods of smallholder families in hydropower watersheds throughout Cambodia, Laos and Vietnam. CRP5 economists developed measures for slowing the rate of growth in energy demands while maintaining vigorous economic development. An estimated 45 million urban and rural residents in the Mekong Basin benefit from lower energy prices.

1. Motivation for new research on water, land and ecosystems

Our vision: agriculture and ecosystems thrive

Our vision is of a world in which agriculture thrives alongside vibrant ecosystems, and those engaged in agriculture live in good health, enjoy food and nutritional security, and have access to the inputs and resources they need to continuously improve their livelihoods. We see a future in which the increasing numbers of urban residents, particularly in developing countries, have access to safe and affordable food and water, made possible by gains in agricultural productivity and public investments in food safety and water quality. We envision a world in which sustainable management of water, land and ecosystems is the norm, food security is ensured for most of humanity, and poverty has indeed become history.

To achieve this vision, we must redouble our efforts to increase agricultural productivity, while protecting the environment. Agriculture provides essential food and fiber, and generates employment for most residents of many poor countries. Hence, agriculture powers both the supply and demand components of household food and nutritional security. To achieve long-term growth and economic development, we must ensure that advances in agriculture do not degrade the natural resource base on which agriculture depends. To this end, we must build on past successes of the CGIAR in boosting agricultural growth through scientific inquiry and policy analysis. We must conduct new research on agricultural and ecosystem interactions.

1.1. Background – successful past, challenging future

In the late 1960s, the prospect of widespread famine threatened many areas of the developing world. In response, CGIAR scientists and their partners in national research centers developed new crop varieties that produced much higher yields. Fertilizers were made available to support the new seeds, and massive investments in irrigation provided reliable water supplies to nurture the crops and give farmers the confidence to invest in change. Millions of farmers became food secure, rural livelihoods were transformed and new food supplies drove down prices for urban consumers.

That early success of the CGIAR had a number of factors in its favor. Those making the changes benefited directly. Farmers saw the benefits of growing improved seed varieties that generated better yields and higher incomes. Feedback was direct and easy to measure and adoption increased quickly. Politicians could easily understand the issues and benefits. Thus, there was strong political support for policy changes that led to subsidies on fertilizer and energy, and construction of large irrigation schemes. The technical and engineering solutions were at hand.

Yet the improvements in productivity made possible by the technical innovations could not be fully sustainable, because the institutions and policies influencing farmer decisions did not always take into account the unintended impacts of change. Farmers had too little information or incentive to consider the off-farm or long-term impacts of their intensive use of fertilizer, pesticides or irrigation water. This situation resulted in land degradation, off-farm pollution and excessive use of water resources, all of which compromised the ecosystem services on which

farming depends. Working at the level of farm and plot provided the technology needed to quickly expand food production, but failed to focus on larger-scale, longer-term implications.

Looking forward, we must not only reverse the degradation and reduce the excessive use of scarce resources through the development of new technical interventions; we must also put in place the right institutions to ensure that new research contributions generate sustainable gains in resource productivity and livelihoods.

The CGIAR is well placed to conduct this research for two reasons: 1) NRM specialists within the CGIAR are uniquely placed in that they can work across national borders, form partnerships with advanced research institutes (ARIs) and work with NARES and the private sector to guide and implement the technical and institutional components of this truly interdisciplinary research program; 2) CGIAR NRM scientists while having a strong commitment to agriculture and food production, also have the experience of working with non-traditional partners including the Ramsar Convention on Wetlands and the larger environmental nongovernmental organizations (NGOs); and 3) The research outputs will serve as international public goods. Indeed, the CGIAR is precisely the organization that can take the larger-scale, longer-term view that is needed to achieve sustainable outcomes. The time is ripe for this initiative because of the magnitude of the problem and because a previous effort to integrate NRM across the CGIAR was only partially successful (see Box 1.1).

Box 1.1. Integrated NRM in the CGIAR

Between 1999 and 2003, the Interim Science Council of the CGIAR and the Center Directors Committee on Integrated Natural Resources Management undertook a process to define the Integrated NRM (INRM) concept; describe the history of INRM research in the CGIAR; portray the role of systemwide and ecoregional programs in operationalizing INRM; and illustrate successful INRM research through seven case studies. The process featured four workshops (Bilderberg 1999, Penang 2000, Cali 2001 and Aleppo 2002) and culminated in a summary publication (Harwood and Kassam, 2003). In the summary, INRM was defined as "a conscious process of incorporating multiple aspects of natural resource use into a system of sustainable management to meet explicit production goals of farmers and other uses (e.g. profitability and risk reduction) as well as goals of the wider community (sustainability)."

To some extent the Challenge Program on Water and Food followed up on these integrated approaches after 2002, but few systematic studies have examined agriculture, NRM and their environmental impacts in a comprehensive manner. CRP5 aims to fill this void.

1.2. The challenge – expand, intensify, restore and protect

The conditions that challenge agriculture today are quite different to those of the 1960s. Rivers are drying up, groundwater is being depleted, and 'water crisis' is now a commonly used term. Widespread land degradation is reducing productivity in many areas and more resources are needed to maintain output. Agricultural intensification is harming the ecosystems on which agriculture depends, resulting in salinity, waterlogging and other negative impacts. The expansion of agriculture is imposing unacceptable costs on others who rely on natural resources for their livelihood activities. Such problems arise through the 'tragedy of the

commons,' or the fact that markets do not exist to deal with the basin-wide and long-term impacts of agriculture. Developing solutions to such problems requires research that goes beyond farm and plot-level analyses.

But our current challenge is not only to solve existing problems. With demands on agriculture increasing, we must contend with many new pressures (Chartres and Varma, 2010). Two billion people will be added to the global population by 2050. Higher incomes, changing diets, and urbanization will impose new demands on farming systems, and the resources that underpin them. With increasing energy demands, biofuel production will continue to compete with food production for available resources. Climate change will bring more frequent droughts and floods, and will influence temperature regimes in ways that will increase the challenges faced by farmers in many areas. Economic growth will deepen competition between agricultural and non-agricultural uses of resources. Although much of this can be resolved through political discourse, conflict will be an increasing worry.

We know also that we have not yet solved the rural poverty challenge in much of the world, and that large numbers of the rural poor will continue migrating to cities in search of employment. Increasing urbanization will place additional pressure on agriculture to produce sufficient food, in light of increasing competition for land and water. Affordable food is critical for the urban poor and to support economic development. Thus, efforts to improve agricultural productivity will benefit both the urban and rural poor in many developing countries.

The increasing global demands for food, fiber and energy will place new stresses on the land, water and ecosystems that support agriculture. It will not be possible to satisfy global demands in 2050 and beyond without increasing the land area devoted to agriculture and intensifying crop production on lands already farmed. Most of the needed increase in agricultural output will come from intensification, which can include increasing the use of fertilizer, greater use of genetically modified organisms (GMOs), using farm chemicals, providing irrigation, or increasing the amounts of labor and machinery used each season. Intensification will have impacts on supporting ecosystems, but those impacts can be moderated through policies and incentives informed by the research we propose in this portfolio.

1.3. Our objective – improve agriculture, protect ecosystems

We derive the objective for this CGIAR Research Program from the challenge we describe above. In brief, our objective is the following:

> *We must learn how to intensify farming activities, expand agricultural areas and restore degraded lands, while using natural resources wisely and minimizing harmful impacts on supporting ecosystems. Our goal is to achieve the sustainable improvements in agricultural productivity required to produce enough food for all and generate sufficient income to lift millions of smallholder households from poverty, while also ensuring their food and nutritional security.*

In pursuing this objective, we will build upon previous successes of the CGIAR centers in improving agriculture and addressing NRM issues. We will enhance those earlier successes by

giving greater attention to the impacts of agriculture on ecosystems, and the importance of ecosystems in supporting agriculture. The science we conduct and the recommendations we produce will promote wise use of natural resources, in support of thriving agricultural sectors and healthy ecosystems. We consider addressing this objective will contribute significantly to the System Level Outcomes defined in the CGIAR Strategy and Results Framework (see Box 1.2) and Figures 1.1–1.3.

Box 1.2. Addressing the CGIAR's Strategy and Results Framework

CRP5 plays a critical role within the CGIAR to deliver on NRM objectives. The CGIAR Strategy and Results Framework has four System Level Outcomes:

- reducing rural poverty
- improving food security
- improving nutrition and health
- sustainable management of natural resources.

CRP5 focuses on the fourth of these outcomes, but improved NRM is central to all four and improving water quality also strongly relates to health and nutrition.

Figures 1.1–1.3. How CRP5 contributes to the strategic level outcomes of the CGIAR Strategy and Results Framework (detailed sdescriptions of the Strategic Research portfolios (SRPs) are given in subsequebt chapters).

Figure 1.1.

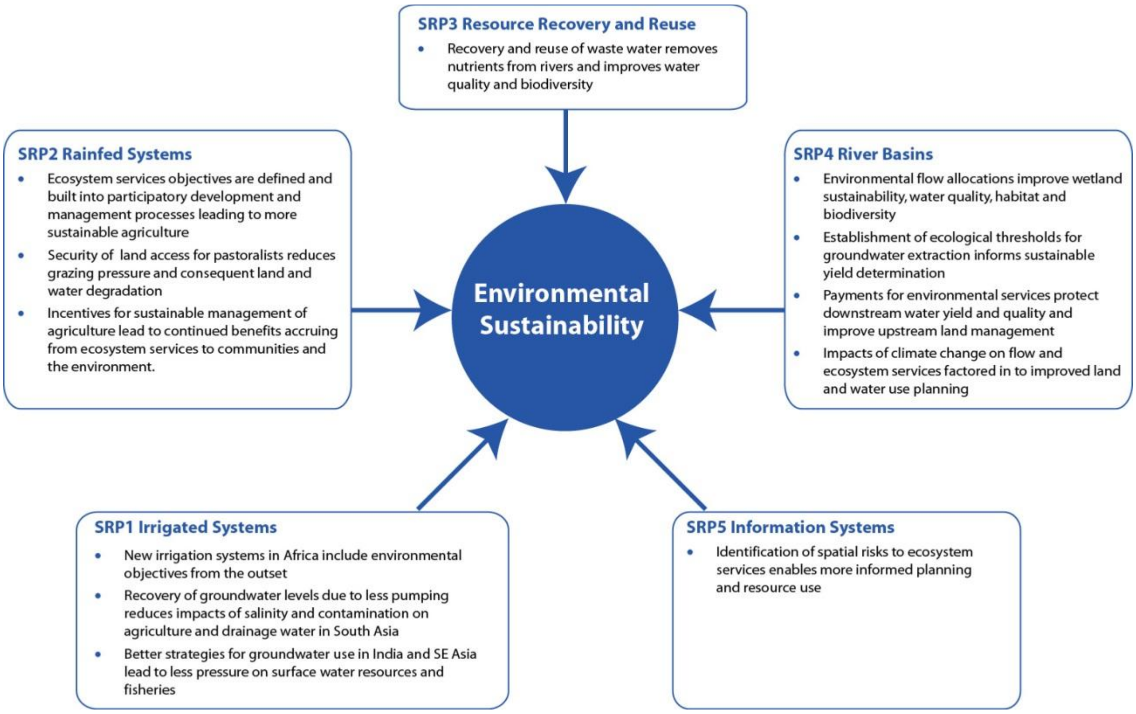


Figure 1.2.

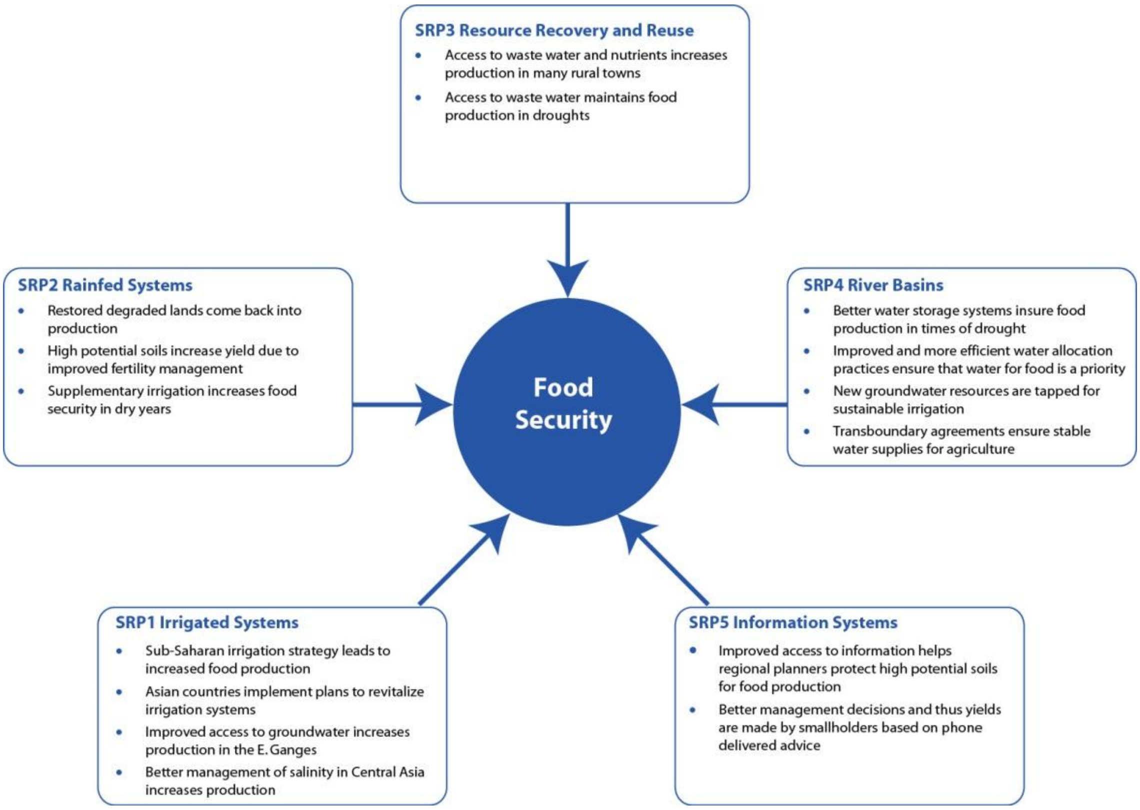
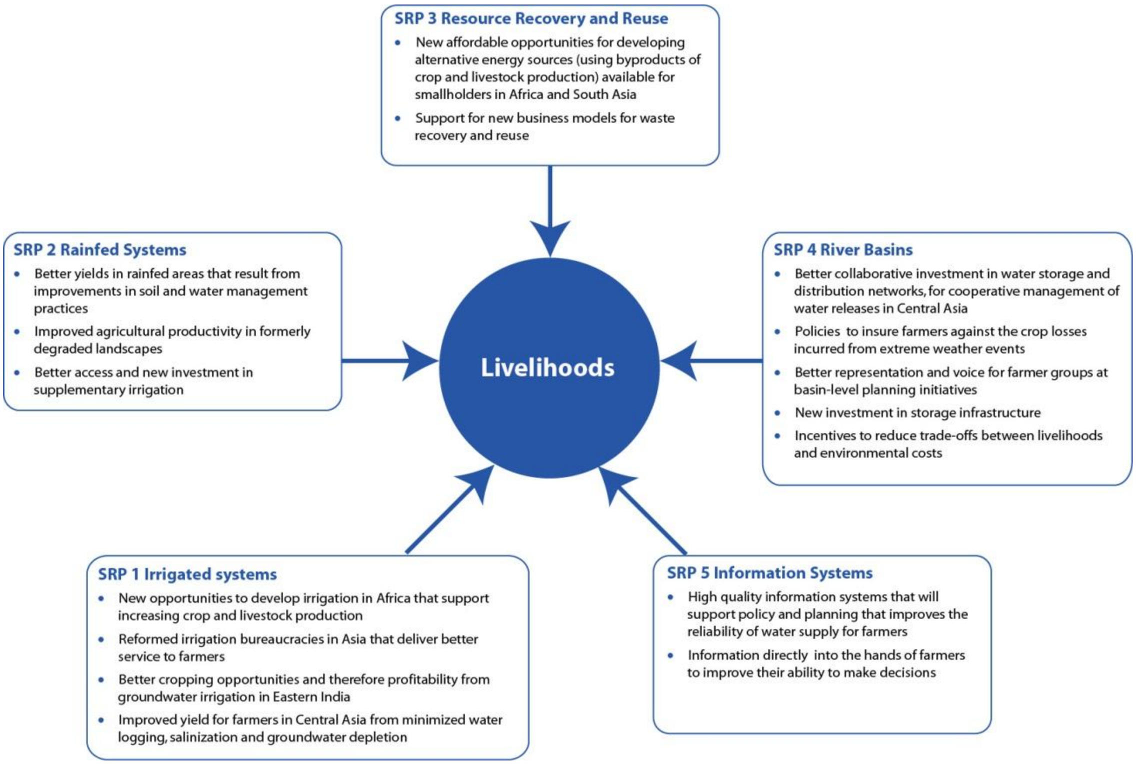


Figure 1.3.



1.4. Our perspective – water, land and ecosystems

Given the challenges ahead, we will focus our research efforts on improving global understanding of critical interactions involving water, land and ecosystems in agriculture. We will examine both technical and policy aspects of resource allocation and use, while studying also the many ways in which ecosystems support, enhance and are affected by agricultural production. To this end, we will address three overarching research questions:

1. In an era of increasing water scarcity and variability in water supplies, what improvements are needed in governance, institutions and management to achieve wiser use of water in agriculture, to ensure that we meet global food production targets and enhance household-level food and nutritional security in developing countries?

2. What are the most effective interventions for ending land degradation in many areas of Asia and Africa, and beginning the long process of restoring productivity to degraded lands?

3. What are the trade-offs between agricultural intensification and ecosystem services, and how can these be measured to facilitate the development of sustainable land and water management practices and sound rural policy?

These three topics – water scarcity and variability, land degradation and ecosystem support for agriculture – represent the current major threats to agricultural output in many developing countries. Yet they also represent opportunities: they are the areas of research that hold the greatest potential for increasing agricultural production and ensuring food security for millions of smallholder households across Asia and Africa. Below, we summarize our perspective regarding each of the three questions.

1.4.1. Water scarcity and variability

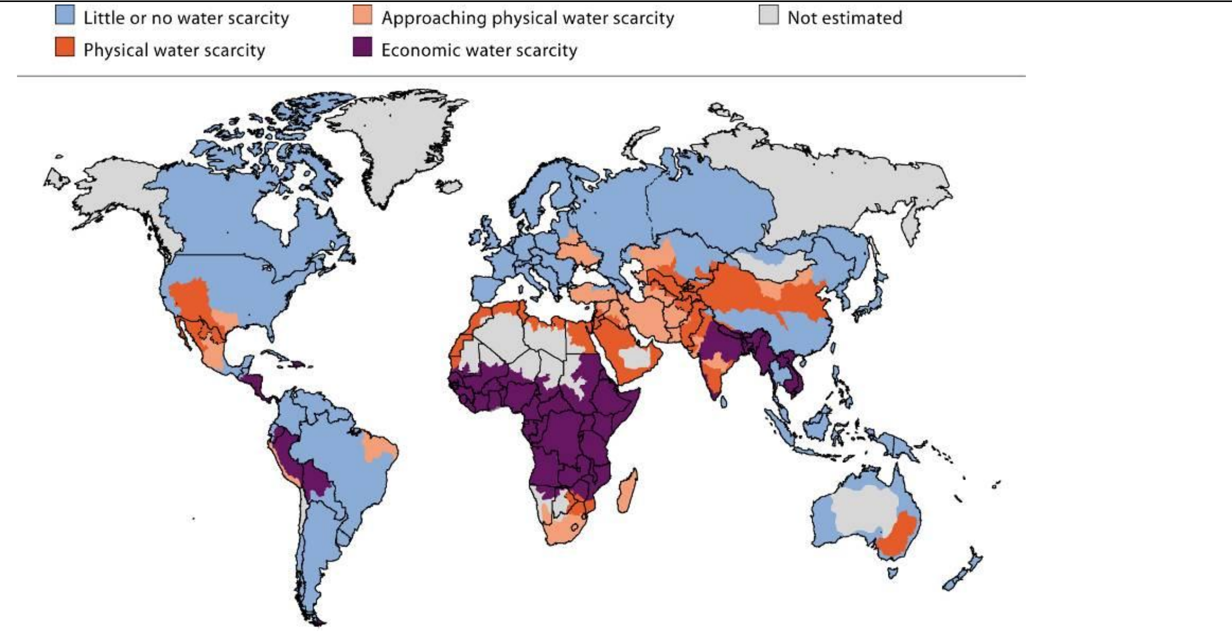
Globally, agriculture uses 70% of the world's extracted freshwater. In some developing countries the figure is as high as 90%. Already, several river basins have become essentially 'closed' – that is, all the water is being used and little or no water flows to the ocean. When this happens, ecosystem services, such as biodiversity and water quality, are compromised.

Water scarcity can be physical or economic (see Figure 1.4), and the types of solutions required to address each form of scarcity are quite different. Scarcer water and more nutrient-depleted soils, combined with rising populations, higher energy prices and other drivers, will contribute to rising food prices. Food crises and sudden spikes in food prices will become increasingly frequent in future, thus threatening the food security status of millions of poor households.

By 2025 it is estimated that water scarcity will affect the livelihoods of more than 1.8 billion poor people (Nelleman et al., 2009; WHO, 2007). The 2009 FAO Expert Panel on Food Security predicted that we must increase food production by 70% to meet demand in 2050 (Bruinsma, 2009). Achieving this will require more water, more land and more fertilizer, as well as the continued provision of a wide range of ecosystem services that underpin productive agriculture. Forecasts made in the Comprehensive Assessment of Water Management in Agriculture (CA, 2007) suggest that water demand from agriculture could double by 2050. Water demand in

India could exceed supply by 50% in 2050, with increasing demands for food, biofuels, and other uses (Mckinsey, 2009; 2030 WRG, 2009).

Figure 1.4. A water-scarce world (CA 2007)



One-third of the world's population grapples with water scarcity:

- *Physical water scarcity*: water resource development is approaching or has exceeded sustainable limits – 1.2 billion people.
- *Economic water scarcity*: lack of water access in spite of sufficient water availability due to financial or human capacity constraints – 1.6 billion people.

Variability in water supply is already the greatest threat to production in many areas. Climate change predictions (Bates et al., 2008) for many tropical countries indicate that higher temperatures, increased evaporation and greater variability of rainfall will present new challenges and increase the complexity of management in both irrigated and rainfed agricultural systems. It will not only be the absolute changes in temperature and rainfall that will make agriculture more risky and the poor more vulnerable, but also the increased variability, which will require innovative adaptation strategies.

Coupled with the issues of water scarcity and supply variability is a third critical issue: equitable access to water. Lack of access is often a fundamental constraint to improving people's livelihoods. Although the relationship between poverty, livelihoods and access to water is complex, Lawrence et al. (2002) have shown that access to water and the level of development can be strongly linked.

In summary, as competition for water resources from cities, industry and the environment increases, agriculture faces the paradox of having to produce much more food using no more – or even less – water than it does at present. Solving this paradox presents a major challenge for CRP5 researchers.

1.4.2. Land degradation

Many forms of land degradation are found in the agricultural areas of both industrialized and developing countries: soil salinization, organic matter and carbon depletion, erosion, and nutrient exhaustion. The Global Assessment of Human-Induced Soil Degradation (GLASOD) was the first attempt to estimate the extent of soil degradation globally (Oldeman et al., 1991). It remains the main source of land degradation data, although new initiatives are under way (Sanchez, 2009; Vlek, 2010; Winslow et al., 2011).

According to GLASOD, degradation of croplands is most extensive in Africa, affecting almost two thirds of cropland areas, compared with just over half in Latin America and more than a third in Asia (CA, 2007). About 1 billion hectares of the world's agricultural land have been degraded by deforestation and inappropriate agricultural practices (Pinstrup Andersen and Pandya-Lorch, 1998). The Millennium Ecosystem Assessment (MA 2005) estimated that 10–20% of the world's drylands suffer from one or more forms of land degradation, but reliable data are limited. Dryland degradation is also responsible for a global decline in both the actual and potential ability of the earth to produce organic matter (Zika and Erb, 2009). Numerous studies (see Appendix 1c) have demonstrated links involving soil nutrient and structural decline, acidification, and low and declining crop and pasture yields.

Additionally, urbanization and industrialization consume increasing areas of often high-quality agricultural land every year. The soils in many areas of sub-Saharan Africa are old and intrinsically lower in nutrients than the relatively young and extensive alluvial soils that supported the Green Revolution in Asia (van der Zaag, 2010). Making the situation worse, productivity has declined significantly (up to 40%) in several sub-Saharan countries because of land degradation and nutrient exhaustion (Bai et al., 2008; Bai and Dent, 2006). The persistently high population growth rates in many African countries combined with the small proportion (only around one sixth) of land area in Africa with high agricultural potential (Eswaran, et al., 1997) will exacerbate these issues.

As agriculture expands and intensifies, we must end the persistent degradation of farmland that has reduced productivity and impaired the livelihoods of many poor households. Particularly in Africa, many smallholder farmers have not replaced the nutrients taken up from soils by crops each season. As a result, soil nutrients have been depleted across large areas of farmland, slashing the productive potential of crop and livestock agriculture. We must break the downward spiral of declining productivity by providing farmers with affordable access to plant nutrients, along with the technical assistance needed to apply them correctly.

Later in this proposal we describe opportunities to reverse land and water degradation and minimize environmental pollution through ecologically sound integrated land and water management practices, including recovering and reusing waste materials.

1.4.3. Supporting ecosystems

Ecosystems have sometimes been described as life support for the planet. Agricultural ecosystems have replaced natural ecosystems across much of the globe. Well managed agricultural systems improve soil fertility, encourage pollination, suppress pests and diseases, maintain healthy wetlands, provide clean water for healthy communities, and can enhance

biodiversity. By contrast, efforts to intensify agriculture, with too little concern for the environment, can impair supporting ecosystems.

The intensification of agriculture since the Green Revolution has seen the area under irrigation nearly double, and the use of nitrogen and phosphate fertilizers increase by more than seven times and three times, respectively (Green et al., 2005). Ecosystem services – which were dependent on adequate water, healthy soils and healthy biodiversity – have been replaced by external inputs that have damaged the agro-ecosystem.

Agricultural run-off has led to significant sedimentation, eutrophication, and algal blooms in numerous rivers, causing harm to water quality, aquatic habitat and fisheries. Water is used excessively, at the expense of the environment, particularly in closed river basins (Smakhtin et al., 2004). Prominent examples include the Murray–Darling River basin in Australia, the Krishna in India, and the Colorado in the United States and Mexico, where in many years nearly all the annual water supply is fully allocated to users, such that little or no water reaches the ocean. As a result, water quality is impaired by high levels of salinity and pollutants, and biodiversity is reduced.

With our increased knowledge has come a growing awareness that thresholds have been reached or exceeded for rivers, groundwater and soil resources in many parts of the world (Rockström et al., 2009). There is also a growing realization that we can no longer view water, land and the biodiversity that ensures ecosystem function as inexhaustible and free inputs to a global food production system. We can no longer assume that the environment will continue to provide the services that support agriculture. We cannot continue to pursue a vision of agricultural productivity based on yields at the expense of equity, resilience and sustainability, but must instead broaden the range of benefits to society as a whole.

CRP5 researchers will consider the individual issues of water scarcity, land degradation, biological diversity loss and ecosystem deterioration in an integrated manner designed to generate sustainable improvements in food security, livelihoods and the environment. This approach will contribute to global discussions and decision-making regarding agricultural development. Examples of key issues include the question of land conservation versus land transformation (Fischer et al., 2008); the role of agriculture in crossing critical environmental thresholds (Rockström et al., 2009); and the potential of sustainable, biodiverse systems and multifunctional landscapes to sustain ecosystem services and feed the planet while providing sustained livelihood options for rural populations (Pretty et al., 2006; Pretty et al., 2011; Scherr and McNeely, 2009).

1.5. CRP5 harnesses the power of integration

"It is not an eye-opening statement to suggest that natural resource management increasingly occurs in turbulent, contentious settings. These settings are often typified by contested or ambiguous goals and lack of scientific agreement on cause–effect relationships." – McCool and Guthrie, 2001.

The above quote is apposite, in part, because NRM work in agriculture is often piecemeal and practiced only at the field and farm scales. CRP5 considers a more systematic approach that takes landscapes and river basins into account. There are a few examples of how the impacts of agriculture on natural resources and the environment have been managed at these scales. These include the success of the Murray–Darling Basin Commission's Salinity and Drainage Strategy, which used land and groundwater management strategies to maintain low salinity levels in the Murray River in Australia; the LandCare movement, again initiated in Australia; and South Africa's Water Policy.

The Challenge Program on Water and Food (CPWF) also has succeeded in bringing together researchers, policymakers, funders and the community to solve problems at the basin and sub-basin scales. These successes offer a guide to what CRP5 can achieve, given its more integrative nature and broader geographic coverage.

These examples succeeded because they looked at big-picture issues, used scientific evidence backed up by policy development to initiate change, and gained a degree of bipartisan political support. They indicate that if CRP5 is to succeed, it must catalyze sound land and water management practices – through government- and private-sector policies and strategies – in the regions in which it will operate. Furthermore, CRP5 must look at agriculture and NRM from an integrative perspective, which it has been designed to do. Part of this will be to see agriculture as part of the solution to environmental problems as opposed to the cause.

Above all else, CRP5 will bring critical mass and diverse skills to solve key problems via an integrated R&D value chain including farmers, environmental managers and policymakers

Currently, there are major gaps in NRM R&D programs in many countries. Institutionally, resource sectors are separated and few pay much attention to issues of impending scarcity, degradation and environmental management. Gender, age and caste/class inequities in NRM are widespread, and formal sectors often lack the capacity to bring in local-level knowledge and expertise. Specific examples of where CRP5 will address these gaps are given in Box 1.3.

We will also build a system of delivery via NARES, NGOs, government agencies and the private sector that few, if any, alternative suppliers can emulate. The CGIAR centers bring strength in physical and social sciences and agriculture on the scale necessary to address local, national, regional and global problems. To fulfill CRP5's promise, the CGIAR needs new partners and new forms of partner networks to promote uptake and to expand its development work and capacity building.

Research links involving universities, national research institutes and global organizations (e.g. UN and World Bank) are poorly coordinated, and there are strong demands from the NGO community, the private sector and governments for credible scientific information and policy advice. Thus, the CGIAR and its partners have the opportunity, via the integration of CRP5's NRM work, to lead international efforts to balance agricultural productivity objectives with environmental sustainability. This will happen through the nested regional-, basin- and issue-focused strategy detailed in the Conceptual Framework (Chapter 2) and subsequent sections.

Box 1.3. How CRP5 will improve natural resource management and the environment

- Involving, from the outset, key stakeholders via participation in research and development
- Achieving critical mass among the CGIAR and its partners to solve key problems
- Integrating biophysical solutions and socioeconomic drivers to develop a holistic view of possible beneficial changes
- Taking an evidence-based approach based on a logical pathway via hypotheses and methodologies to develop solutions and catalyze change at policy level
- Adopting an integrated landscape/basin approach, as opposed to focusing on single issues
- Viewing agriculture as part of the solution not the cause of the problem
- Harnessing the private sector and NGOs to help deliver solutions
- Using information systems and technology to ensure the message gets to farmers and land and water managers
- Being clear about the development outcomes we wish to achieve and using adaptive management approaches to achieve them
- Developing appropriate partnerships at science, policy and implementation levels, and clearly defining responsibilities and accountabilities

1.6. CRP5's comparative advantage

CRP5's international focus will assist the development of strong networks of ARIs, CGIAR centers, private-sector partners, NARES and other relevant government agencies. Many alternative suppliers conduct NRM research (e.g. universities, foundations, international NGOs, multinational corporations and think tanks), but few can bring together partnerships at the scale or scope that CRP5 can accomplish. Furthermore, few aim to transfer lessons learned in one part of the world to another, and few are dedicated to the creation of global public goods. Although there are other groups and universities working in complementary areas, these are usually project- or location-based. However, by developing strategic partnerships, we will access the high-quality work of these suppliers.

CRP5 also complements the NRM work of national researchers by exchanging lessons learned and bringing in ideas from the global community. The private sector, although showing increasing concern about the environment and solving problems related to their particular industry, generally does not offer international public goods. Our role will be to build private-sector partnerships where there is likely to be a market-based solution to a problem (for example, we are partnering with Jain Irrigation in South Asia to overcome technical issues that are limiting adoption of high-efficiency irrigation).

Lastly, CRP5 intends to build on the successes of its partners to deliver innovative information products to users of appropriate technology. Highlights of this new approach will include: a partnership with FAO to link and improve NRM databases and target information to their network; delivering NRM information directly to farmers by mobile phones (as being developed by IWMI and the International Fund for Agricultural Development); and further developing products that build on the successful African Soil Mapping technology of the World Agroforestry Centre (ICRAF) – including improved soil water and drought forecasting tools, flood prediction information, and population vulnerability mapping.

2. A truly interdisciplinary research program

The research questions we have posed are substantial and comprehensive. We seek a better understanding of interactions involving land, water and ecosystems in agricultural settings, with the goal of increasing productivity and enhancing ecosystem services. This work will require substantial interdisciplinary collaboration, involving biophysical and social scientists. It will also require new ways of developing and delivering results that go beyond traditional research programs. In addition, we must consider the off-farm, basin-level and longer-term implications of agricultural practices. This larger-scale approach, unique to CRP5, will increase the chance of our results and recommendations achieving sustainable improvements in agriculture and ecosystems.

We have crafted a set of five SRPs (described in detail in chapters 4–8; see Box 2.1 for terminology) that encompass our primary research questions, and describe where and how technical and policy interventions will be most likely to achieve the productivity gains and ecosystem enhancements that constitute our vision of success. We have also developed a system for delivering those results that allows learning, focuses on core issues of poverty alleviation, and holds us accountable for results we can monitor. Finally, we have developed a framework and process for ensuring that the results and insights from each research portfolio feed back into our broader program and build synergies for achieving our overall goal.

Box 2.1. Notes on terminology

Regions: CRP5 works in these regions: Latin America; East, West and Southern Africa; the Middle East and North Africa; and Asia.

Research sites and scales: Research takes place at specific geographic locations within regions called research sites. Research at a site might address issues at one or more scales (e.g. farm, watershed, landscape, basin, country and region) and investigate implications across scales. For example, research on groundwater recharge at a site might address local issues defined by the extent of the aquifer (a landscape), but have implications for the basin (upstream or downstream trade-offs), the country (food security), and the region (transboundary conflict resolution).

Strategic Research Portfolios (SRPs): A research portfolio describes a set of investments in research aimed at tackling challenges related to irrigation, rainfed agriculture, pastoral systems, groundwater, resource recovery, river basin management, ecosystems, the social and cultural practices that lead to gender and other forms of inequity, information, and governance. Portfolios are 'strategic' because their five research domains were identified by partners and other stakeholders as offering the most promising pathways to achieving development goals.

2.1. Establishing priorities – creating research portfolios

While the need to address global issues regarding water land and ecosystems is clear, the scope and nature of the issues require that we organize our research program into easily managed components, each with its own set of clear priorities. To this end, we engaged in a three-fold process of regional consulting, global visioning and strategic reasoning (described below).

2.1.1. Regional consulting

We conducted a series of regional workshops and e-consultations involving hundreds of natural resource specialists, investors and farmer representatives (see Appendix 2b). Participants described the need for new research regarding water, land and ecosystems, both in general and within their regional contexts. Participants brought attention also to pressing and long-term issues, and described in detail the agronomic, hydrologic and socioeconomic aspects of each issue.

2.1.2. Global visioning

We placed the regional needs in global perspective, considering:

- the scope for direct and indirect poverty impacts
- potential positive impacts on global food systems, agricultural prices and ecosystem services
- the ability to scale solutions up or out.

2.1.3. Strategic reasoning

We considered whether the problems fit within the mandate of the CGIAR, and whether solutions would contribute to achieving the CRP5 vision of success. In particular, we considered:

- the need to enhance global knowledge, rather than closing site-specific knowledge gaps
- the potential for insights gained to be applicable beyond a given region or outside the scope of a single problem
- the opportunity to develop international public goods from the proposed research
- the need to bring together a wide range of national and international partners who can help cross the divide between agriculture and environment in conducting the research.

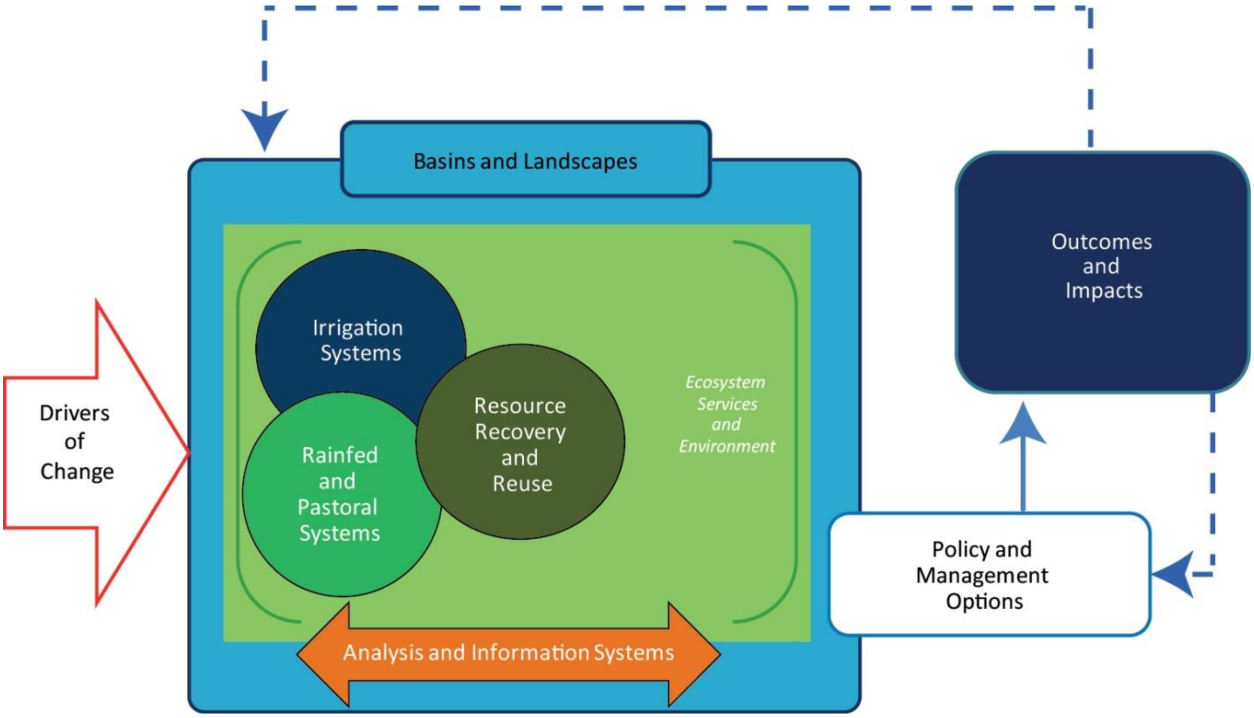
Each part of the process was helpful in formulating a conceptual framework for the research we will conduct in CRP5, crafting a practical set of SRPs, and determining the geographic scope of the research program. Input received from reviewers of initial drafts of our proposal has also been helpful in refining the scope and nature of our research program.

2.2. Conceptual framework

Agriculture and ecosystem services are influenced by external drivers that exert pressure on production systems that, in turn, affect the natural resource base and environment (see Figure 2.1 and Box 2.2). Currently, many agricultural practices contribute to land degradation and loss of ecosystem services, resulting in lower productivity and less resilience, equity and food and livelihood security. These practices are driven by many factors within and outside the agricultural system, including policies, information and knowledge asymmetries, and energy flows. Scarcity, degradation and other negative outcomes of inappropriate agricultural management practices are in themselves major drivers. Feedback loops exist whereby water scarcity, for example, triggers policy change and infrastructure development, and reduced productivity alters farming practices. Often the feedback loops are negative, resulting in increased degradation and downward spirals. Natural systems have both resilience and thresholds that must be understood and considered when making decisions.

However, a key entry point for CRP5 is that we can influence our impact on natural resources and ecosystems by modifying the governance and management of agriculture. A major question is whether we are able to measure changes to ecosystem services and whether we can use the nature of those changes to further influence governance and management. If changes can be observed and measured at basin and landscape scales in terms of processes (e.g. water flow, erosion rates and vegetation change), we can use this information to provide policy advice and further adapt management practices. Given that different management practices may act independently, we also need to determine the cumulative impacts of different management practices via modeling and mapping tools. Hence the need for a strong analytical and information base to support the CRP5 research program.

Figure 2.1. The conceptual framework for CRP5



Our view is that we can manage rainfed and irrigated systems better, to enhance interactions with the environment. Similarly, we can recover and reuse nutrients from wastes to improve fertility and minimize pollution. Consequently, these three areas – irrigation systems, rainfed systems, and resource recovery and reuse – are important research foci for CRP5.

We view the relationships involving drivers and responses of the production system and its underpinning natural resources through a nested approach, which includes fields, basins, and regions. Our research will complement the plot-scale work in other CRPs (e.g. conservation tillage trials). We will extrapolate plot-scale results across larger spatial units.

With regard to system dynamics, our basic analytical framework is a river basin or landscape unit. Using basins enables us to quantify water and nutrient flows and uses within the system, and thus we can examine upstream–downstream environmental changes and socioeconomic

trade-offs. We will use basic tools of water accounting and new land health surveillance tools to quantify the impacts of agriculture on the environment and vice versa.

Box 2.2. Factors influencing NRM and agricultural production

- External drivers such as climate change processes, existing agricultural and natural resource policies, trends in trade, and socioeconomic and cultural contexts.
- Actions that stem from our research, such as the use of new technologies; policy, governance and institutional reform; and uptake of integrated management strategies.
- Consequences of the above actions for, e.g. equity, environment and ecosystem services.
- Feedback, which involves understanding consequences and drivers, to help to redesign actions.

Agricultural and natural ecosystems function within basins and landscapes. Where ecosystems occur across basins or landscapes, we will use models to partition the area into similar environments and thus consider how the overall landscape pattern influences basin-level responses. Given that ecosystem work will cut across landscapes and themes, we have developed guiding principles for ecosystem services research in CRP5 (Box 2.3).

Box 2.3. Guiding principles for cross-cutting ecosystems work in CRP5

- Examine supporting, regulating and provisioning services, including evaluating on- and off-site effects of farming systems and management practices on ecosystem services.
- Work at landscape scales, incorporating social and biophysical functions and interactions, such as analyzing how the interaction of diverse land uses, social networks and institutions across landscapes influence the ecosystem services that sustain agriculture and ecosystems.
- Examine how ecosystem services help alleviate poverty and vulnerability, including understanding the scales at which ecosystems provide services to people.
- Examine transformation and change by evaluating trajectories, tipping points and thresholds in agricultural landscapes.

Sometimes a basin approach will not be necessary; for example, when change (e.g. biomass production) can be detected at landscape level and within administrative and regional or country boundaries, although such changes may affect the water balance of the landscape and associated basins. However, we will also have the option of using analytical approaches that enable the intersection of administrative and basin boundaries to differentiate approaches and policies across borders. We believe that this spatial approach combined with the differentiation of management practices that influence natural resources and ecosystems, and the integration of this change across landscapes and basins, will be extremely effective in helping us scale up outputs.

At the broadest level we focus on major regions. Where possible, broader agroecological characterization and development of information and other products (e.g. international public goods on nutrient cycling, soil fertility and water scarcity) will be targeted at these regions, and tailored to the different environments within them.

2.3. Five Strategic Research Portfolios

The defining feature of our research program is a set of five SRPs that resulted reflect the input of many scholars and practitioners, careful consideration of regional and global perspectives, and the conceptual framework. The five portfolios are:

1. Irrigated Systems
2. Rainfed Systems
3. Resource Recovery and Reuse
4. River Basins
5. Information Systems

While seemingly distinct, we view the five portfolios as comprising an exciting opportunity to conduct research across a wide range of critical topics within a single research program. CRP5 researchers will work collaboratively within and across the portfolios through well-defined processes as they seek answers to research questions that will enhance global knowledge regarding land, water, and ecosystems. We describe each portfolio below.

SRP1: Irrigated Systems

The first of our five SRPs targets irrigation. As noted above, 40% of the world's food is produced on the 20% of farm land under irrigation. Irrigation has improved livelihoods and enhanced food security for millions of rural and urban households. It has reduced poverty, and is expected to play an important role in climate change adaptation. However, irrigation has both positive and negative impacts on ecosystems. Gaining a better understanding of those impacts will enable us to determine why the rates of increase in productivity on irrigated lands are stagnant or declining in several important regions, such as the Indo-Gangetic plains. We will also improve understanding of constraints and opportunities for extending irrigation across Africa, and we will analyze issues relating to the use of surface water and groundwater, individually and in combination.

CRP5 researchers will examine opportunities to revitalize existing irrigation systems and invest in new systems to increase agricultural production and improve livelihoods. We will determine how to expand and improve irrigation with minimal impacts on supporting ecosystems. Water withdrawals from many important aquifers exceed the natural rates of recharge, making irrigation unsustainable. In areas where millions of smallholders depend on irrigation for their livelihoods, the potential impacts of losing access to irrigation water are enormous. We must develop strategies that restore sustainable rates of water withdrawals, while ensuring that all households can achieve and maintain food security.

Examples of the research we will conduct in this SRP include the following:

- Identify and characterize opportunities and options to develop irrigation in Africa, with the aim of increasing crop and livestock production;
- Work with partners to further experiment with new models for managing large pubic irrigation systems in Asia;
- Examine ways of improving groundwater management in South and Central Asia, where persistent overdraft of aquifers threatens agricultural sustainability.

SRP2: Rainfed Systems

Our second SRP targets the 80% of the world's farmland that is largely rainfed. Though many farmers in rainfed areas capture and store water for use as supplemental irrigation, millions more are entirely dependent on rainfall. The inherent uncertainty and extensive poverty that characterize rainfed systems generate research questions that are quite different from those pertaining to irrigated agriculture. We need to better understand the risks that households face in rainfed settings. We must explore the reasons why many methods for enhancing soil and water management are not adopted, while learning more about livestock production in water-scarce environments. Much of humanity earns its living in rainfed crop and livestock systems; this SRP will provide insight into issues that affect millions of households every day.

In many areas, increasing populations have placed substantial pressure on rainfed cropland and on the land and water resources used by livestock. As a result, the land and water resources in many areas are degraded and unproductive. Soils have inadequate amounts of essential nutrients and organic matter, and ecosystems have lost a portion of their inherent biodiversity. CRP5 researchers will determine ways to restore degraded resources using multifunctional landscape management approaches, and will develop integrated soil and water management techniques. We will endeavor to improve soil fertility and motivate better land and water management, with the goal of unlocking the inherent potential of rainfed agriculture while at the same time reversing the trend of ecosystem degradation.

In pastoral systems, extensive land degradation and the loss of access to water and land resources threaten the livelihoods of millions of pastoralists, leading to conflicts in some areas. CRP5 researchers will determine the changes in land and water management and the complementary policies needed to support pastoral livelihoods.

Examples of the research we will conduct in this SRP include the following:

- Develop recommendations for improving and extending water harvesting technology throughout rainfed regions of sub-Saharan Africa;
- Examine the financial and infrastructural constraints that limit farm-level access to commercial fertilizer;
- Study interactions involving crop and livestock production in regions with scarce water supplies, with the goal of improving productivity and enhancing the livelihood status of farmers and pastoralists.

We will examine how individual management changes at farm level affect landscape and basin processes and thus ecosystem services.

SRP3: Resource Recovery and Reuse

Land degradation and nutrient depletion characterize large areas of agricultural production, particularly in sub-Saharan Africa. Many farmers in Africa are unable to afford fertilizer, in part because the cost of transportation from ports or production centers to distant farms is high. Yet both human and animal wastes contain substantial amounts of nutrients that can be used in agriculture, such as nitrogen and phosphorus. Such use is very compelling in regions where the price and availability of commercial fertilizers do not match farm-level demands.

Enhanced recovery of water, nutrients and organic matter from otherwise wasted resources for use in agriculture will serve two critically important goals, as we endeavor to feed the world in 2050. First, more nutrients and water will be available for use in agriculture even as the natural stocks of nutrients, such as phosphorus, become more expensive to mine. Second, opportunities for generating revenue will support the provision of sanitation services.

We will determine through a business approach how to maximize the untapped potential for recovering water and essential nutrients. At the same time we will promote safer and healthier practices when reusing waste materials on farms and when processing crops for consumption in local markets. We will also examine affordable measures for improving land, water and environmental quality in areas where reuse occurs. Critically, we will contribute to notable gains in food security through the safe and effective recovery of nutrients from solid and liquid domestic and agro-industrial wastes.

CRP5 will explore scalable business models for blending compost with fertilizer, and developing alternative fertilizers from human and livestock waste as a byproduct of biogas production. Engaging the private sector might be the most effective approach to increasing the coverage of sanitation services and closing the nutrient cycle in agriculture by recovering and reusing elements such as nitrogen and phosphorus. We will also identify opportunities to develop scientific and policy recommendations to promote the safe reuse of wastewater and sludge by smallholder farmers in peri-urban areas (i.e., at the edges of cities and towns) to alleviate water scarcity and help restore nutrient losses on agricultural lands.

SRP4: River Basins

River basins will be used as a unifying unit of analysis to assess the impact of agricultural management on many ecosystem services given that hydrological processes naturally connect all water and land users. This connection greatly complicates decision-making on water, land and ecosystem issues, as decisions made in one location can have substantial and often unrecognized impacts in others. Salinization in the lower Indus, for example, is partly the result of farmer choices further upstream. In the Mekong, hydropower dam construction and monoculture plantation may have profound impacts on downstream flow. Countries in the lower Nile basin are concerned that their upstream neighbors may overuse water. Hydropower production and agricultural water use are in direct competition in the Aral Sea basins of Central Asia.

The interconnection in river basins also brings advantages. Cooperative development and use of water resources can generate benefits greater than those achieved through individual or sectoral actions. The opportunity for cooperation on water use, whether between two farmers or two countries, can provide a basis for even greater cooperation on other issues.

Making wise choices on water use, promoting cooperation and avoiding conflict require an understanding of how the physical unit of the basin intersects with the social and political spheres in which decisions are made and people organize their lives. In the richest countries this is not easy. In many of our target locations it can be even more complicated. CRP5 researchers will examine issues pertaining to competition for water, benefit-sharing

mechanisms and other forms of cooperation in river basins, where the sum of competing water demands is greater than available supplies.

Our research will produce both better and cheaper information sources for decision-making and, as importantly, on how cooperative solutions can be put into practice. Researchers will also develop recommendations for improving the allocation and management of water within river basins, with particular emphasis on key policy issues, such as efforts to improve livelihoods, increase drought resilience and reduce the potential damage from floods. While conducting this research, we will focus also on the implications of river basin policies and water allocations for people, livelihoods and ecosystems.

As an example of the research we will conduct in this SRP, we will demonstrate the potential benefits of collaborative investments in water storage and distribution networks, and cooperative management of water releases, in Central Asia.

SRP5: Information Systems

We complete our set of five SRPs with a portfolio designed to address a critical issue that can either constrain or enhance any research effort – the availability of accurate, reliable information. Our Information Systems SRP reflects the pressing need for much better data on hydrology, water management and agriculture. In many countries, data collection and reporting efforts are inadequate to support high-quality analysis of important research questions. These activities must be enhanced, taking advantage of modern methods such as remote sensing. Inadequate national data also constrain analysis of international and transboundary issues.

We will establish data collection and reporting systems that will provide the information needed to improve national and international research programs. We will work closely with national partners to design systems that can be managed and sustained within countries, and to build institutional capacity.

CRP5 researchers will work with NARES partners, universities and others to develop and implement global and regional agro-ecological information and assessment tools and make these available through user-friendly interfaces to stakeholders, including other SRPs in CRP5 and other CRPs. We will deploy novel spatio-temporal surveillance methods and standards to facilitate better, evidence-based planning and evaluation of agricultural interventions at multiple scales. Emphasis will be on strengthening stakeholder capacity in the development of information and surveillance systems in data-sparse regions.

We will endeavor to develop the highest-quality data collection protocols, while acknowledging the incremental costs and benefits, and the likelihood that new data collection activities can be sustained. It will not be sufficient to merely develop and implement new information systems – we must also ensure that national partners have the institutional capacity and legislative funding authority to maintain data-gathering activities. To this end, we will examine also the institutional and financial aspects of sustainable information systems.

As an example of the research we will conduct in this SRP, we will develop ways for countries participating in the Mekong River Commission to improve cooperation in collecting and reporting hydrologic data.

2.4. Cross-cutting themes

In addition to the five SRPs, we have established two cross-cutting themes that will influence and enhance our research: 1) Ecosystem Services, and 2) Institutions and Governance. Within each SRP, we will promote ecosystem resilience and work to minimize harmful impacts on ecosystem services. In addition we will determine methods of enhancing ecosystem services and providing farmers and pastoralists with production systems that can better adapt to environmental change. We will also seek to increase the value placed on ecosystem services. With regard to institutions and governance, we will examine measures for building capacity and enhancing policy and institutional effectiveness across the SRPs.

To systematize and institutionalize this approach, we will establish working groups on ecosystems (Box 2.3 on page 27) and institutions and governance (Box 2.4) to ensure that these cross-cutting themes are highlighted in research planning and reflected in our impact pathways. This work will be established and overseen by the Strategic Planning and Management Committee.

Box 2.4. Guiding principles for cross-cutting governance and institutions work in CRP5

- Governance is the process for joint decision-making. Institutions are the systems, mechanisms and traditions through which governance is implemented. We recognize the great difficulties faced around the world in designing governance and institutions to equitably and efficiently manage water, land and ecosystems. We thus know that governance and institutional issues, and how they relate to both poverty and productivity, must be at the core of our research.
- We will ask how current governance and institutions influence the way water, land and ecosystems are used and affected by agriculture
- We will ask how changes in governance or institutions may bring about positive impacts on agricultural productivity and resource sustainability and equity, and how changes may facilitate the technical and economic interventions we develop. We will not forget that existing institutions and bureaucracies are part of any change process.
- We will consider how governance and institutions can improve livelihood and poverty outcomes at different scales.
- We will learn from successes and failures around the world, but recognize that governance and institutions operate within larger social, environmental and political contexts and that successful interventions in one country or region cannot simply be transplanted to another.

2.5. Fertile fields, not isolated silos

We will work intently to ensure that the five SRPs operate as fertile fields of innovative, collaborative research, rather than silos of limited inquiry involving only one or two scholarly disciplines. We recognize that making such a statement is much easier than implementing the plan, but we have given substantial thought to this endeavor and offer the following perspective.

We will foster close collaboration between biophysical and social scientists within each of the five SRPs and also across selected combinations. For example, it is easy to imagine the need for hydrologists, agronomists and economists to together explore measures for reducing groundwater overdraft on the Indo-Gangetic plains. Political scientists and social scientists will also have important roles in seeking viable solutions to such problems. Similar collaborations will be important in examining opportunities for extending irrigation across Africa or improving rainfed systems in South and Southeast Asia.

The necessity of collaboration is equally evident in the Resource Recovery and Reuse SRP. Water quality specialists, agronomists, economists and business specialists must join together to develop viable business models for expanding sanitation services and promoting the reuse of plant nutrients in waste materials. Our work in developing data collection and reporting protocols will also be best informed by collaboration involving biophysical and social scientists.

The structure of CRP5, which involves a wealth of CGIAR centers and national partners, will also enable exciting interaction and collaboration across SRPs. We see great potential for sharing research ideas, data and implications across the portfolios. For example, researchers working to improve crop and livestock production in rainfed settings will gain value by interacting with researchers developing business models for resource recovery and reuse, which will likely benefit many rainfall-dependent farmers. Thus the interaction will enhance the efforts of researchers engaged in both the Resource Recovery and Reuse and Rainfed Systems SRPs.

Another example of cross-SRP collaboration will involve researchers in the Irrigated Systems and River Basins SRPs. Both groups will benefit from exchanging information on strategies for improving water allocation and use along rivers that cross international borders. The same is true for aquifers that underlie more than one country. Researchers in the Rainfed Systems and River Basins SRPs also will gain from collaboration, as many livestock herders move their animals across international borders and even across river basin boundaries.

Collaboration across SRPs will enhance our research in ways we cannot fully predict at the outset. Often, the most meaningful insights from collaborative research occur serendipitously, while colleagues are engaging in fieldwork together or reviewing information compiled by research partners. The best way to increase the likelihood of such unexpected benefits is to establish a research framework in which interdisciplinary specialists will have numerous and continuous opportunities to collaborate. By design, CRP5 provides precisely such a framework. Another key area where interdisciplinary specialization is given priority is on gender and equity issues. Gender equity has long been cited as an important indicator of the success of development interventions in poor agricultural communities. The core of our mandate is poverty reduction and we know that a pro-poor perspective takes into account social differentiation within communities. We also know that gender and equity issues in research often receive more consideration than action. CRP5 takes seriously the issue of gender and equity in the management of resources for agriculture. CRP5 incorporates a separate strategy to mainstream gender and equity issues across SRPs. Within SRPs we focus on specific issues that are strongly influenced by gender, such as the ownership of assets, access to markets and information, and vulnerability to risks and shocks.

We hold no illusions of the challenges and costs of engaging in truly interdisciplinary research. Yet we are eager to move forward in the collaborative spirit that has produced some of the CGIAR's best research in years past. We are ready to collaborate effectively, within and across the many centers participating in this research program, as we endeavor to enhance global understanding of water, land and ecosystems.

2.6. Research alone is not sufficient

The questions we must answer are of course the core reasons for the program. However, our goal is not simply to do research, but also to improve *how* we do research. We must aim to improve the cost effectiveness of producing results on the one hand, and to increase the value of those results through more effective pathways to impact on the other. Our approach is thus defined not only by the questions we address, but the way in which we address them. This involves 1) embracing the spirit of the CGIAR reform, 2) keeping partnership at the center, focusing on capacity, 3) keeping monitoring and evaluation as a cornerstone, 4) embracing capacity building, and 5) understanding that communication and uptake defines success.

Embracing the spirit of the reform*:* Work on water, land and ecosystems now occurs across the CGIAR. To rationalize that work, almost all centers have joined CRP5. This CRP seeks to gather the synergies from the existing skills, gain economies of scale, and focus our efforts to solve problems. We seek this collaboration not only for that reason, but also because we are running this CRP in the spirit of CGIAR reform.

Partners are key: CRP5's partners constitute an unconventional mix, ranging from traditional partners from agriculture such as NARES and ARIs, to strong international and local environmental NGOs. To capitalize and draw on the wide range of skills and capacities within our network, we have designed a *partner strategy* to engage our partners according to their specific skills and reach, and their proximity to communities and issues on the ground. Our partners, therefore, are the chief vehicles through which CRP5 interacts and engages with people and their day-to-day realities.

Monitoring and evaluation and impact assessment is a cornerstone: We understand the difficulties in evaluating NRM programs and impacts. CRP5 endeavors to use its *strategy for monitoring and evaluation and impact assessment* as the basis for continually improving and refining the program's research agenda, process of engagement and uptake strategies.

Good capacity building: The *capacity building strategy* of the program explicitly guides learning within and through the research agenda, however it fits within the ethos of the larger program. The strategy looks at enhancing the capabilities of researchers, partners and stakeholders through research projects, improving technical skills, building learning alliances and networks, and helping to build the institutional capacity of research management organizations. CRP5 will facilitate greater investment in capacity building activities ranging from training and scholarships to mentoring, driven by the demand and needs of stakeholders.

Communication and uptake is essential: The CGIAR has long been a source for valuable international public goods in NRM. Much of the impact of this work is attributed to clear

strategies that began with problem-focused research. It went beyond just making information and solutions available in the public domain by engaging with stakeholders or 'change agents' who could shape and affect policy change. CRP5's *marketing, communication and knowledge strategy* is the mechanism through which project and program results are communicated to its stakeholders and the general public. The strategy ensures that key messages that emerge out of projects are developed through collaborative processes between researchers, partners and other stakeholders. In linking with uptake strategies, information products and lessons learnt from SRP initiatives will not be made available only as international public goods, but key messages will be assimilated into plans and campaigns to influence policy and global agendas.

2.7. Where CRP5 will work

During the regional workshops we considered which regions and basins should be targeted, based on significance of the problems identified, logistics of access to specific regions and our capability to mount an effective program in such regions. Given these considerations, we have chosen to begin working in regions focused around eight sets of large river basins:

- **Southeast Asia** (Mekong Basin)
- **South Asia** (Ganges and Indus)
- **Central Asia** (Aral Sea)
- **Middle East** (Tigris and Euphrates)
- **East Africa** (Nile)
- **West Africa** (Volta and Niger)
- **Southern Africa** (Limpopo and Zambezi)
- **Latin America** (Andes Basins)

Each basin contains a mixture of agro-ecological zones, urban and rural landscapes, and social, economic and political entities. In each, the natural resource base supporting agriculture and livelihoods is under stress. By working in these basins, we will capture the regional dimension of interlinked issues, such as the development of hydropower and its impact on riparian countries. In addition, the Africa Soil Information Service (a component of the Information Systems SRP) will provide a focus for improving soil resource management in sub-Saharan Africa because of the imperative to increase food production in this region. Our long-term target is to have a positive impact on the livelihoods and food security of 50–60% of the agricultural population residing within these basins (Table 2.1). Details of the basins and key issues are described in section 2.5.

Table 2.1. Potential beneficiaries (in millions) of CRP5 R&D outcomes by river basins.

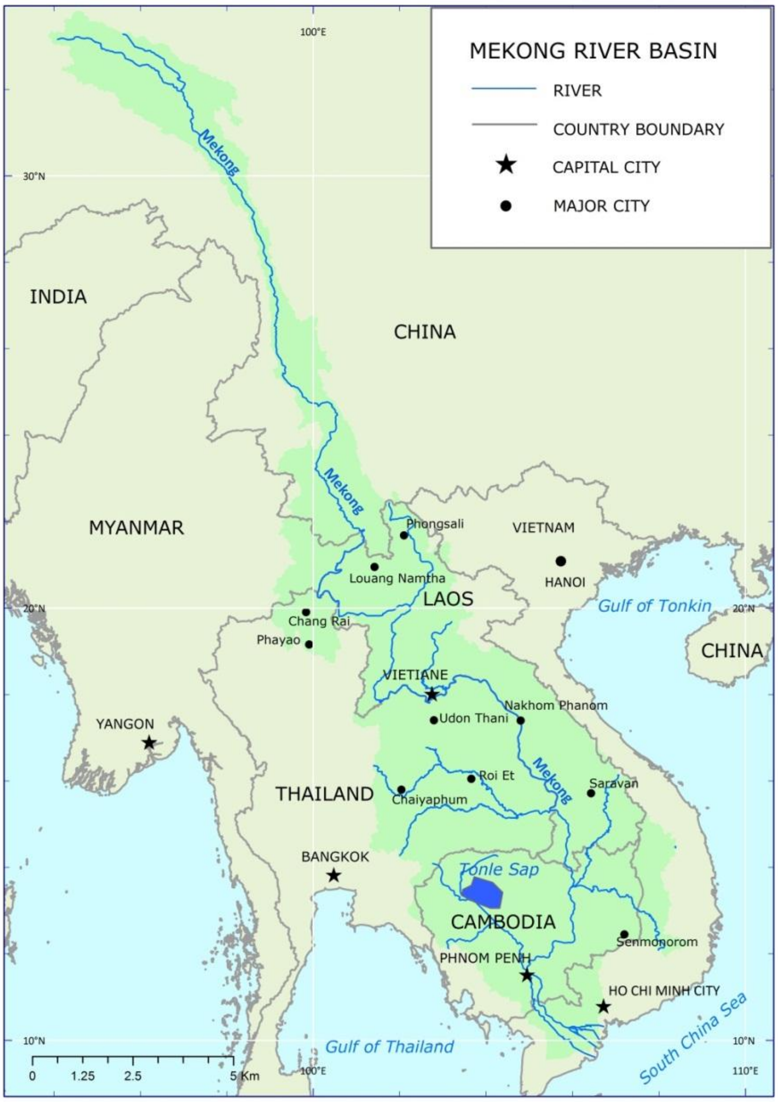
Region	**Basin population**	**Rural population**	**Agricultural population**	**Expected numbers benefited by CRP5**
East Africa (Nile)	200	128	102	61
West Africa (Volta and Niger)	126	80	80	48
Southern Africa (Limpopo and Zambezi)	45	24	23	12
Central Asia (Amu Darya and Syr Darya)	42	24	9	5
Middle East (Tigris and Euphrates),	45	30	25	12
South Asia (Indus and Ganges)	400	280	196	118
Southeast Asia (Mekong)	70	46	42	25
Latin America (Andes)	92	28	24	14

Source: these figures were compiled from FAO Aquastat and personal communication from partner organizations.

2.8. CRP5 basins and key issues

1. Mekong

Cambodia, China, Laos, Myanmar, Thailand, Vietnam



Potential impacts

- Basin population: 70 million
- Rural population: 46 million
- Agricultural population: 42 million

We expect to improve the livelihoods of 60% of the agricultural population.

Issues motivating CRP5 research

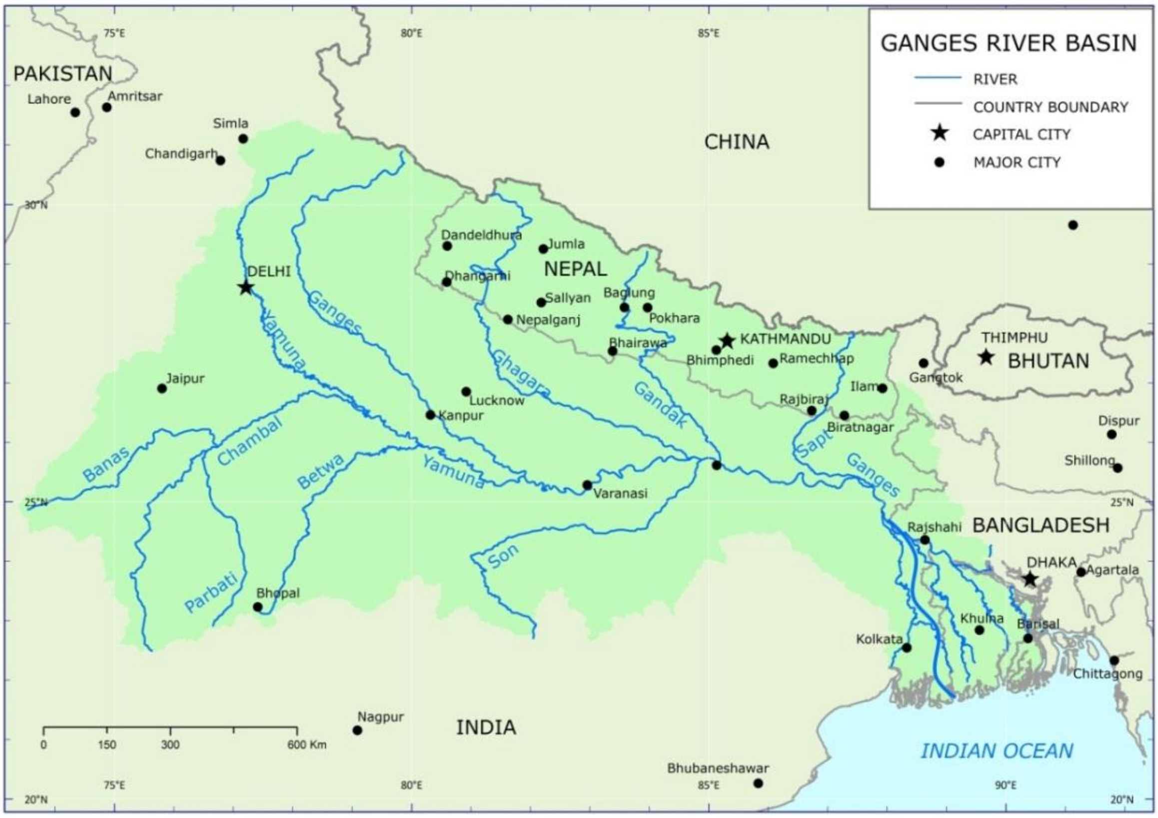
- Insecure property rights and inadequate access to natural resources contribute to the region's substantial poverty.
- Important fisheries are under pressure from hydropower development.
- Governments in the region are focused on economic development, yet there is inadequate cooperation and too little sharing of information along the Mekong River system.
- Agricultural productivity is low, particularly in northeast Thailand and Cambodia.

CRP5 research activities

- Develop policy recommendations for managing the expansion of hydropower production in a manner that protects and enhances the livelihoods of smallholder households located in or near hydropower watersheds.
- Develop a set of field-tested practices that demonstrate how to enhance the productivity of seasonal floodwaters to benefit the poor.
- Study informal and formal business models for the recovery of nutrients from domestic and agro-industrial waste for replication and application in other regions.
- Assess the extent, status and trends of terrestrial ecosystem degradation that are leading to low agricultural productivity
- Design and test location-based adaptive strategies for improved NRM.

2. Ganges

Bangladesh, India, Nepal



Potential impacts
• Basin population: 400 million • Rural population: 280 million • Agricultural population: 196 million
We expect to improve the livelihoods of 60% of the agricultural population.

Issues motivating CRP5 Research

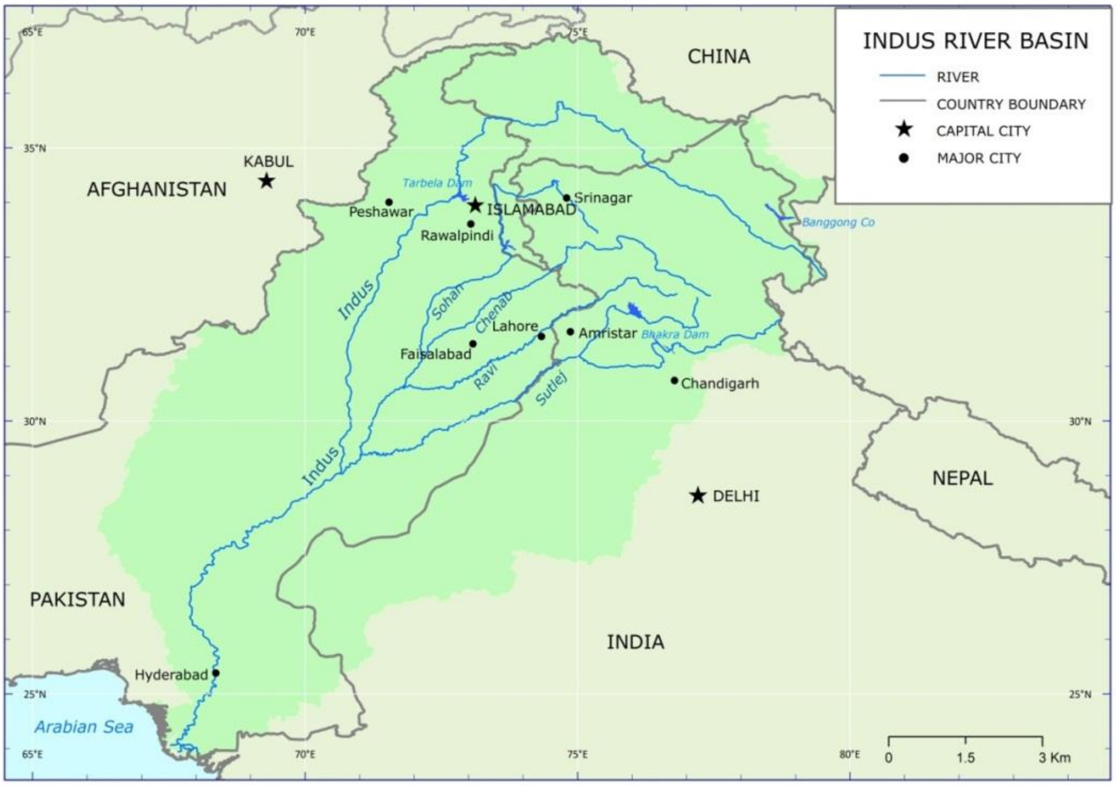
- The Ganges basin is the most densely populated in the world with a population of about 400 million people. About 85% are poor and dependent on agriculture-based livelihoods.
- Shallow groundwater use is anarchic and widespread. Arsenic poisoning is a serious health problem affecting large numbers of the poor towards the eastern part of the basin.
- Floods in the Ganges delta affect Bangladesh in particular. Saltwater intrusion into upstream areas in Bangladesh affects agriculture and drinking water sources.
- The Ganges is one of the most polluted rivers in the world and downstream siltation caused by unsustainable land management on steep slopes upstream.
- In India, more than two thirds of farmers purchase agricultural groundwater through informal markets. Of the rest, 20% have their own pumps and 6% use canal water. In Nepal, most farmers depend on a single source of water, either from canals or groundwater.

CRP5 research activities

- Assess the extent, status and trends of land degradation to pinpoint sources of erosion and siltation in the basin, and design and test appropriate interventions.
- Develop better policy recommendations for modifying or eliminating the electricity subsidies that encourage excessive pumping of groundwater.
- Promote a better understanding of the role of energy policies (on rural electrification, renewable energy and diesel subsidies) in encouraging or impeding groundwater development.
- Examine opportunities for improving river water quality and the production of safe crops for consumers in close collaboration with the World Health Organization (WHO).
- Study the potential implications of water quality programs that will reduce the volume of irrigation water available to farmers along the downstream reaches of rivers that flow through or near urban centers.
- Examine opportunities for India and Bangladesh to cooperate in improving water quality in the Ganges River and managing the volume of water discharged from India to Bangladesh.
- Study informal and formal enterprises engaged in resource recovery from waste for the benefit of agriculture.

3. Indus

India, Pakistan



Potential impacts
• Basin population: 200 million • Rural population: 168 million • Agricultural population: 114 million We expect to improve the livelihoods of 50% of the agricultural population and help Pakistan become a food supplier to the world.

Issues motivating CRP5 Research

- The Indus irrigation systems have the potential to be global agricultural engines.
- Rural poverty is endemic, particularly in Pakistan.
- There is vast potential to increase yields and produce more food with less water.
- Intensive irrigation has contributed to some of the world's most extensive salinity and waterlogging.
- In recent years damage from flooding has been substantial.

CRP5 research activities

- Establish a land health surveillance system to map and monitor salinity and waterlogging problems, and guide the design of land reclamation programs.
- Determine strategies for optimizing the collection and reuse of agricultural drainage water, while providing relief from saline high-water tables.
- Examine opportunities for reclaiming land and improving water quality in degraded areas, where reclamation would increase agricultural production and enhance livelihoods.
- Examine opportunities for constructing new water storage and transport facilities to provide better flood control, while increasing irrigation potential.

4. Amu Darya and Syr Darya

Afghanistan, Kazakhstan, Kyrgyzstan, Tajikistan, Turkmenistan, Uzbekistan

Potential impacts
• Basin population: 42 million • Rural population: 24 million • Agricultural population: 9 million
We expect to improve the livelihoods of 60% of the agricultural population.

Issues motivating CRP5 Research

- The breakup of the Soviet Union created fundamental challenges for agricultural water management that have yet to be resolved.
- Farm-level returns in agriculture are small because of inadequate market development and government policies that create disincentives for optimizing the use of farm inputs.
- Waterlogging and salinization reduce agricultural productivity in the region, particularly in lower reaches of the two rivers.

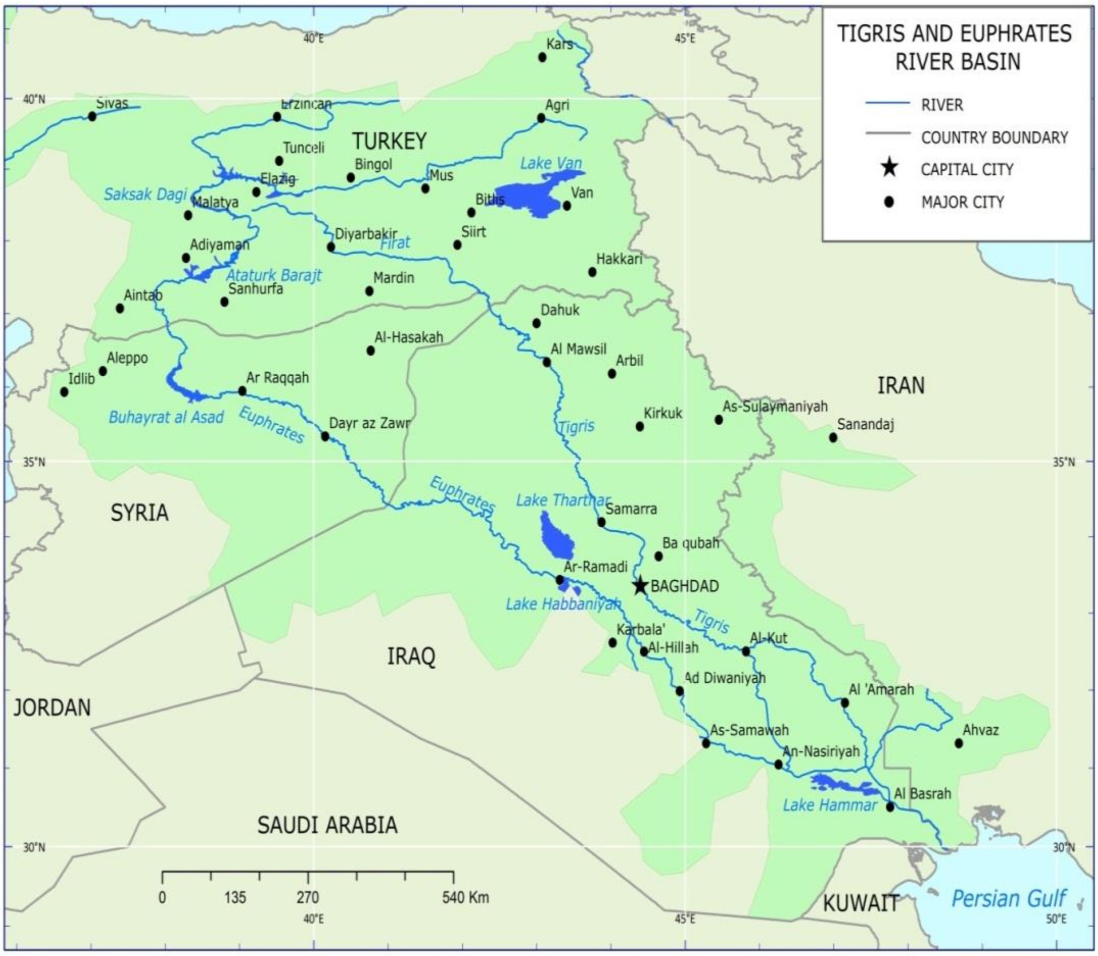
- Drinking water quality is degraded by salt and pesticide residues in lower reaches of the Amu Darya and Syr Darya.

CRP5 research activities

- Assess the extent, status and trends of unsustainable soil management and design preventive and rehabilitation strategies.
- Look at new models for governing a complex transboundary system and work with governments to implement viable approaches.
- Improve farm-level access to modern inputs, such as fertilizer, pesticides, tractors and other machinery used in cultivation and harvest.
- Examine strategies to benefit-sharing that leads to improved transborder management of water.
- Examine ways to boost farm-level incomes, with the dual objective of improving livelihoods and providing incentives for farmers to invest in the fixed and variable inputs that improve long-term productivity.
- Examine business options to make marginal quality water, including irrigation return flows, a valuable asset.

5. Tigris and Euphrates

Iraq, Syria, Turkey



Potential impacts
• Basin population: 45 million • Rural population: 30 million • Agricultural population: 25 million
We expect to improve the livelihoods of 60% of the agricultural population.

Issues motivating CRP5 research

- Agricultural policy has contributed to problems of desertification, driven by unsustainable dryland cropping and rangeland management, and to soil salinity as a result of unsustainable irrigation.
- The basin has a history of water disputes owing to the development of dams and hydropower plants along the Euphrates River, which rises in Turkey, and flows through Syria and Iraq.

- Information and data on annual flows, precipitation, evapotranspiration, salinity and other features are not shared and are often disputed.

CRP5 research activities

- Assess the extent, status and trends of terrestrial ecosystem degradation and design and test location-based adaptive strategies for improved management.
- Examine opportunities for increasing the sum of net benefits from water allocation and use along the Tigris and Euphrates, through international cooperation involving Turkey, Syria, Iraq and Iran.
- Study ways to increase the production of cereals and legumes, and improve the health and productivity of livestock in rainfed areas.
- Look at business options to make marginal quality water, including irrigation return flows, a valuable asset.
- Land health surveillance will focus on monitoring vegetation cover in agricultural areas and soil salinity in irrigated areas as a basis for designing interventions and assessing impacts.

6. Nile

Burundi, Democratic Republic of the Congo, Egypt, Eritrea, Ethiopia, Kenya, Rwanda, South Sudan, Sudan, Tanzania, Uganda

Potential impacts

- Basin population: 200 million
- Rural population: 128 million
- Agricultural population: 102 million

We expect to improve the livelihoods of 60% of the agricultural population.

Issues motivating CRP5 research

- Most of the poor live in rural areas (except in Egypt) and most make their living in agriculture.
- Egypt and Ethiopia have large populations and are growing at notable rates. Ethiopia's plans to develop hydropower and irrigation tend to meet resistance from Egypt.
- Unsustainable agricultural practices have inflicted upon Ethiopia some of the most severe land degradation problems in the world.
- Accelerated soil erosion from agricultural land poses a threat to the health of Lake Victoria.

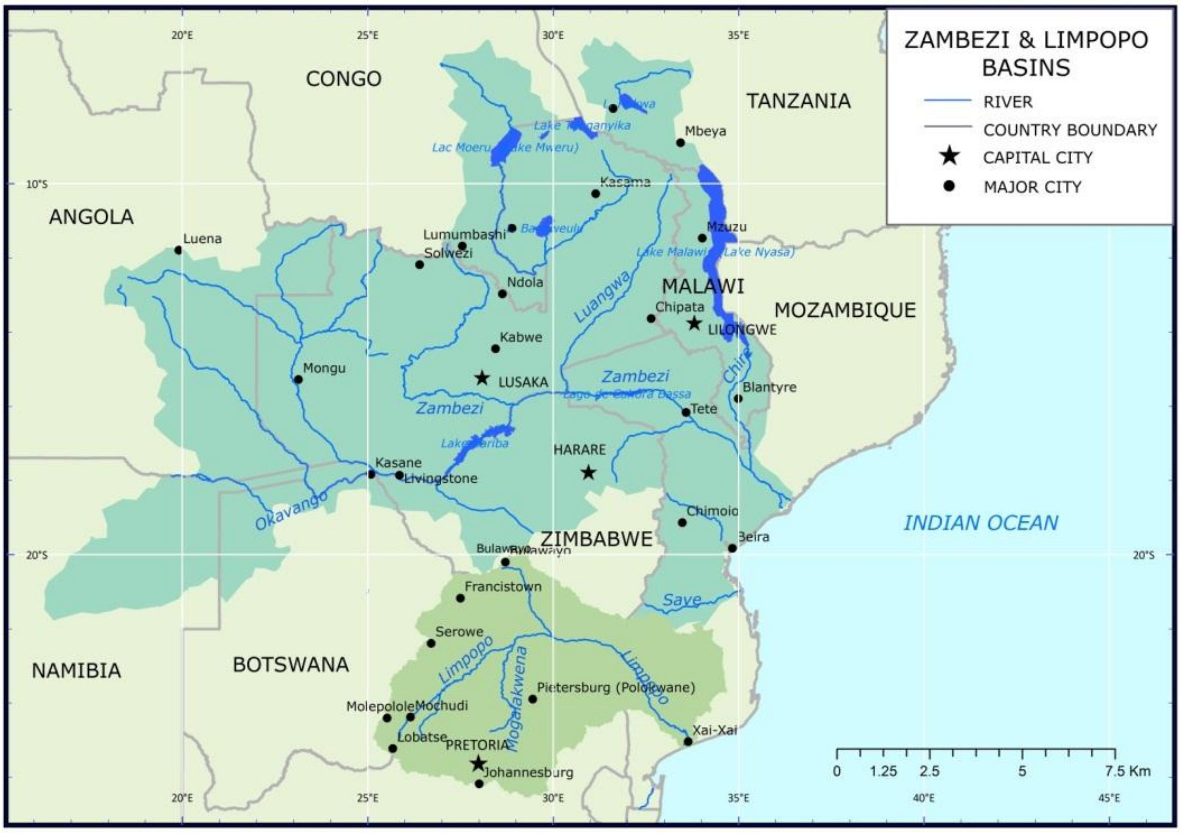
- There is substantial poverty in Sudan, despite notable agricultural potential, particularly in the Gezira region. There is very little information on the current state of land resources to guide development in South Sudan.

CRP5 research activities

- Examine opportunities for improving agricultural productivity in irrigated areas of the Nile Valley and Delta, given the likelihood of increasing pressure on water supplies in the region.
- Develop recommendations for investing in new irrigation schemes in Ethiopia and Sudan, while cognizant of international discourse regarding new water development in the Nile Basin.
- Develop strong technical capacity in the Nile countries in surface and groundwater resources assessment and management.
- Develop options for recovering water and nutrients from marginal quality water and other waste resources for agriculture and aquaculture.
- Establish a basin-wide land health surveillance system to provide a baseline on ecosystem services, a basis for prioritizing interventions, and mechanism for monitoring impacts. Ground sampling through sentinel sites will be a high priority in Ethiopia, Kenya, Uganda, Rwanda and South Sudan.

7. Limpopo and Zambezi

Angola, Botswana, Malawi, Mozambique, Namibia, South Africa, Tanzania, Zambia, Zimbabwe



Potential impacts

- Basin population: 45 million
- Rural population: 24 million
- Agricultural population: 23 million

We expect to improve the livelihoods of 60% of the agricultural population.

Issues motivating CRP5 research

Zambezi

- Over 31 million people reside within the boundaries of the Zambezi. Three countries – Malawi, Zambia and Zimbabwe – account for 86% of the cultivated land in the basin. Between 60% and 80% of the population in rural areas is poor.
- Rainfall is erratic and sometimes low. Almost 90 % of the streamflow in the basin occurs in the wet season.
- Extensive floodplain and wetland areas provide economic and social value to agriculture, fisheries, wildlife and tourism. Flood control in the estuary and delta areas is an important for sustainable livelihoods and ecosystems.

- In the Zambezi, although there is great potential to expand irrigation in the basin, lack of infrastructure for storage, diversion and delivery of water is a major constraint.

Limpopo

- Insecure tenure rights are a major obstacle to smallholder farmers improving their agriculture-based livelihoods in the semi-arid environment of the Limpopo basin.
- Over 14 million people live within the basin; around 1 million of these receive food aid.
- Heavy but unreliable rainfall, a characteristic of the climate in this region, seriously compromises food security.
- More than half the population falls below the poverty line and poverty is higher among female-headed households.

CRP5 research activities

- Characterize the binding constraints to improvements in agricultural productivity and sustainable ecosystem management, by agro-ecological zone, within the basin.
- Identify interventions to overcome the binding constraints in a manner that provides long-term gains in crop yields and livestock health and productivity.
- Describe and test affordable strategies for improving the management of land, water and nutrients in rainfed areas.
- Identify opportunities for investments in new irrigation potential, in both formal and informal settings.
- Examine opportunities for constructing new water storage facilities and water transport facilities to provide better flood control, while increasing irrigation potential.
- Study the potential gains from investments in hydropower generation, with particular emphasis on how a portion of the gains might be invested to increase agricultural productivity and improve livelihoods.

8. Volta and Niger

Benin, Burkina Faso, Ghana, Guinea, Mali, Niger, Nigeria

Potential impacts
• Basin population: 126 million • Rural population: 80 million • Agricultural population: 80 million
We expect to improve the livelihoods of 60% of the agricultural population.

Issues motivating CRP5 research

Volta

- Much of the population is very poor, has inadequate access to water supplies, and suffers from water-related diseases such as malaria, schistosomiasis and guinea worm.
- Poverty is caused by low agricultural productivity, limited access to markets, unstable prices and insecure land tenure.
- The scarcity of productive assets limits expansion of agriculture. Increasing demand for land will accelerate land degradation without preventive intervention.
- Rainfall is sparse and variable in much of the basin, thus limiting the productivity of rainfed agriculture.

Niger

- Much of the population suffers from extreme, chronic poverty and is vulnerable to droughts and malnutrition.
- Child mortality (deaths under the age of 5) is the highest in the region. Many deaths are due to malaria and diarrheal diseases.
- Agriculture and irrigation are not well developed. Most agriculture is for subsistence, and production is itinerant.
- Several dams are planned, generating potential conflicts between water users in several sectors: hydropower, irrigation, fisheries and ecosystems.

CRP5 research activities

- Identify and characterize opportunities to develop irrigation, with the aim of increasing crop and livestock production.
- Develop recommendations for improving and extending water-harvesting technology throughout rainfed areas of the basin.
- Explore opportunities for developing alternative energy sources (using byproducts and residues of crop and livestock production and processing) that could reduce the demand for forest products and thus reduce the rate of deforestation.
- Develop scientific and policy recommendations to promote the safe reuse of wastewater and sludge (which is common among smallholder farmers in peri-urban areas) to reduce water stress and help meet fertilizer needs.
- Describe opportunities to enhance cooperation in collecting and reporting hydrologic data, and demonstrate the benefits of collaborative investments in water storage and management facilities.
- Link with CRP4 (Agriculture for Improved Nutrition and Health) to ensure that any water related intervention is not increasing the risk of vector-borne diseases.
- Link with CRP1 (Integrated Agricultural Systems) to test the adoption and ensure the application of any recommended technology or change of practice at the household or farm level.
- Map areas vulnerable to land degradation and identify the main drivers as a basis for designing and testing preventive and rehabilitative intervention strategies.

9. Andes

Columbia, Ecuador, Peru

Potential impacts

- Basin population: 92 million
- Rural population: 28 million
- Agricultural population: 24 million

We expect to improve the livelihoods of 60% of the agricultural population.

Issues motivating CRP5 research

- Around 42 million people in Colombia, Ecuador, Peru and Bolivia are poor and depend on rural livelihoods.
- Water supply and availability vary considerably across the Andes, where rainfall gradients are quite large. Ecosystem degradation and climate change are primary concerns regarding water supply, while issues regarding water demands are gaining importance. Access to water in rural areas is limited and quality is often poor. Deforestation, unsustainable cultivation of slopes, and abandonment of land have accelerated soil erosion.
- The high mountain environment, with populations at both high and low altitudes, creates opportunities for benefit sharing between upstream and downstream stakeholders.
- Agriculture on steep lands is not very productive, yet reduces water quality, thus affecting communities downstream.

CRP5 research activities

- Improve the characterization of water supply from ecosystems.
- Fill rainfall gaps using remotely sensed data, especially at high altitudes, thus improving the knowledge of hydrological regulation processes and how they are degraded by land conversion.
- Jointly analyze water supply and uses at different spatial and temporal scales, including future scenarios. This also feeds into and CRP7 (Climate Change, Agriculture and Food Security).
- Assess the extent, status and trends of land-use change and unsustainable land-management practices as a basis for designing and testing interventions.
- Research benefit-sharing mechanisms that can help alleviate poverty by conserving fragile upland areas, reducing sediment flow and improving water availability. This work will provide valuable knowledge to other basins around the world.
- Examine agricultural practices at higher altitudes and on steep, sloping lands to determine their impacts on hydrological regulation processes, and develop interventions that can improve these processes.

2.9. Integration of CRP5 with other CRPs

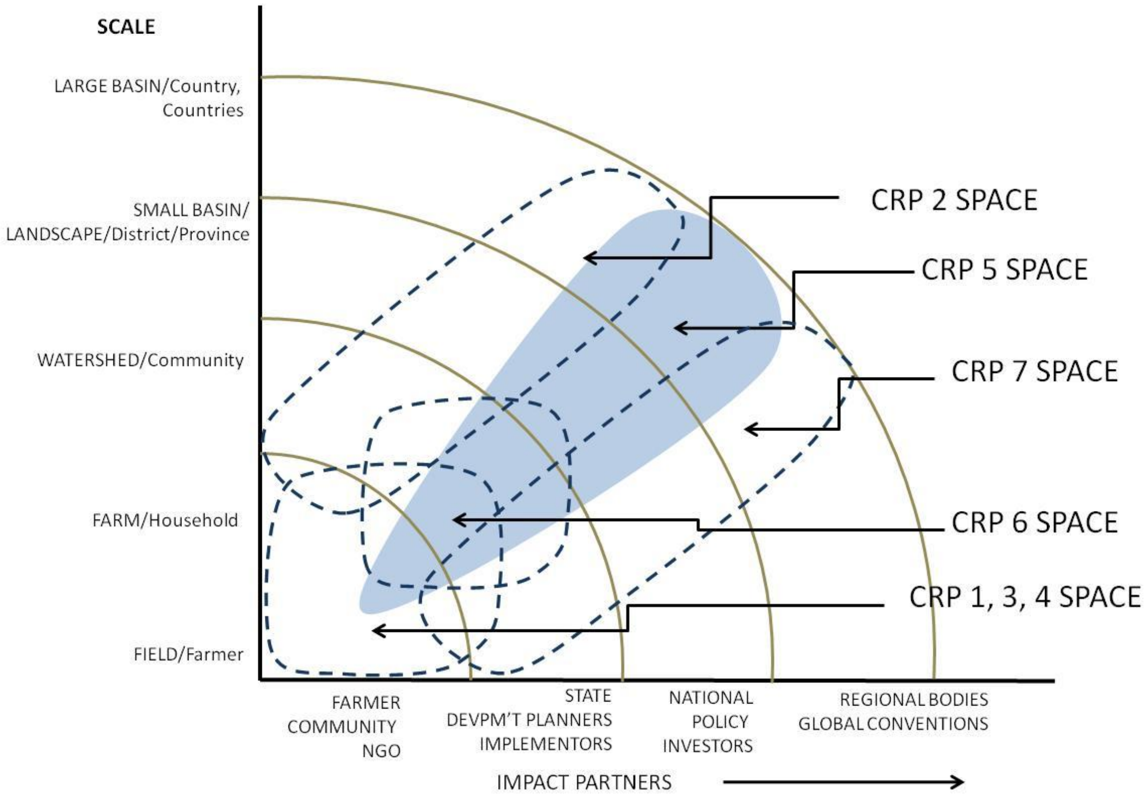
While other CRPs will conduct research at the commodity, field and farm levels, CRP5 researchers will work primarily at larger scales (landscapes and basins), with an emphasis on interventions that affect environmental quality and the natural resource base. We will also endeavor to understand what is happening at plot and farm, so as to predict the consequences of actions and interventions, and thus scale up results to the landscape and basin scales. The relationship between CRP5 and other CRPs is shown in Figure 2.2.

CRP5 researchers therefore have a unique opportunity to integrate the program's work at basin and landscape level, and also to investigate the spatial consequences of more site-specific work being undertaken in other CRPs. The nested strategy adopted in the conceptual framework will facilitate this. We will seek to work in locations where other CRPs are undertaking crop and field management trials. For example, drought-tolerant crop varieties may have beneficial impacts on the hydrological cycle. Conservation tillage can increase groundwater recharge while reducing runoff and erosion. Improved management of water in rainfed fields may increase crop production but reduce water flow in wetlands and streams, thus affecting biodiversity. To improve long-term analysis, we will work with researchers in other CRPs to select sentinel monitoring sites that monitor crop cover, soil properties and other factors.

To facilitate modeling of water flow, we will also work to improve the understanding of hydrological processes in key basins. Given that rainfed systems often coexist with irrigated systems, our work will view the landscape as a mosaic of interacting land uses in which changes in the management of one form of land use may affect another use or the environment. This is important for assigning water allocations and developing water sharing plans. We will cooperate with CRP2 in this area, with respect to policy changes needed to facilitate better

water governance. Such work will also be strongly linked with climate change predictions being developed in CRP7.

Figure 2.2. How CRP5 integrates with and complements the other CRPs



3. From research to impacts

A major challenge for CRP5 is to translate rigorous research into robust development outcomes that contribute to poverty reduction and food security while ensuring environmental sustainability.

Although the ultimate impacts of our research will depend upon a combination of political will, transparent systems of governance, and technical, financial and managerial capacity, there are many ways we can work to ensure that our technical and policy recommendations are implemented. Primarily, CRP5 researchers must work closely with strategic partners to ensure policy and management change. Poor and vulnerable groups have little choice when it comes to practices that degrade land, water and ecosystems. Consequently, we must give equal focus to the socioeconomic factors that overcome this lack of choice, including social support systems, in addition to proposing technical solutions.

A central feature of our approach will be to ensure that the exclusion of women and youth from decision-making processes in agriculture and NRM and the benefits derived is addressed more directly. We have therefore given considerable attention to what we term ‘theories of change’ and Impact Pathways, as described subsequently (see Box 3.1 for terminology). This chapter also examines how CRP5 will prioritize its work.

Box 3.1. Terminology

Theory of change: A theory of change describes how a project or program worked, or is expected to work (Weiss, 1995). In our case it explains how we speculate that CRP5 research will bring about developmental outcomes. Theories of change can be expressed in different ways (e.g. as logic models, LogFrames and impact pathways), and at several scales (e.g. project, SRP and Program).

Lever of change: an opportunity for research to lever developmental change together with a description of the strategy and tactics by which the opportunity might be realized.

Impact pathway: The research-to-development continuum; the connections between organizations that turn research into developmental outcomes and provide feedback on what is needed, working and not working.

Next users: the people and organizations that co-develop and use research knowledge for the benefit of the end users.

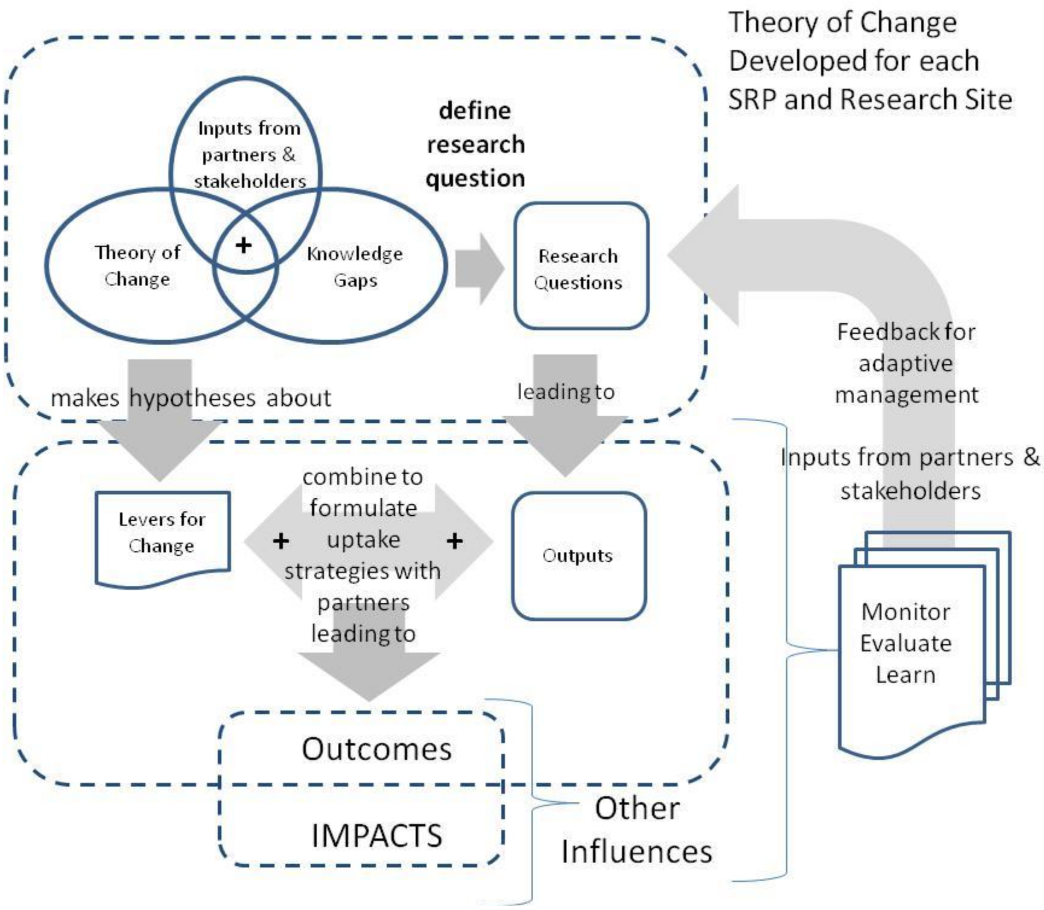
End users: our ultimate beneficiaries – the rural and urban poor whom the CGIAR seeks to benefit.

3.1. Theories of change

A generic theory of change (see Figure 3.1) was used to formulate the CRP5 SRPs. CRP5’s theory of change describes the levers we can pull to bring about the changes we believe will foster sustainable agriculture and healthy environments, and alleviate poverty. Creating impact means changing behavior, be that policy change or farmer adoption. Hence our theories of

change describe how co-developing and communicating research outputs with partners will contribute to behavior change of key actors.

Figure 3.1. Generic theory of change underpinning CRP5 design



Taking a theory-of-change approach implies that, although outcomes and impact are beyond a researcher's direct control, researchers share a responsibility to strive towards developmental change by linking and collaborating with others.

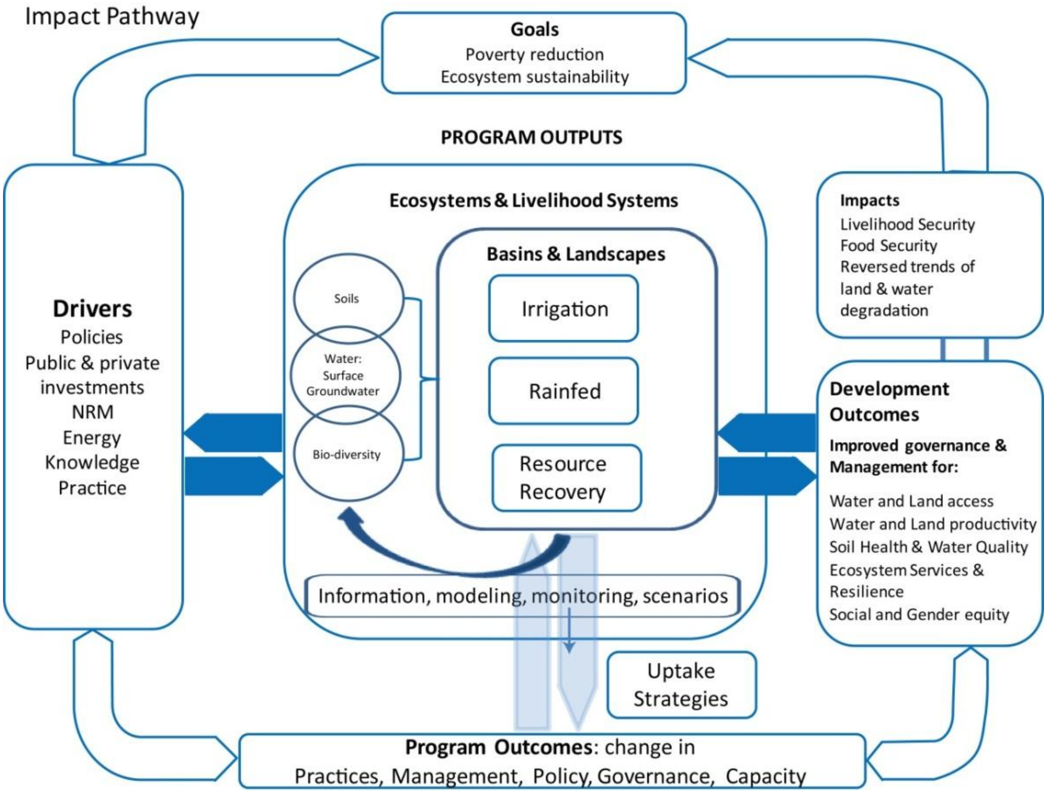
In the process of conceptualizing theories of change and formulating uptake strategies, we consult with our partners and stakeholders and scan the wider environment to see what other influences may help or hinder our efforts. The monitoring, evaluation and learning process, which includes inputs from partners and stakeholders, provides the feedback we need for adaptive management, i.e. reformulating our theories of change, redefining knowledge gaps and formulating new research questions.

Each SRP has a unique theory of change, as will each project. Aligning theories at each level will contribute to greater impact on a wider scale. Regional uptake strategies will be developed using a similar process.

3.1.1. Program-level theory of change

The CRP5 theory of change (Figure 3.2) is derived from the conceptual framework (Figure 2.1) and the generic theory of change (Figure 3.1). Figure 3.2 is a generalized depiction of how we foresee pathways to impact.

Figure 3.2. The theory of change for CRP5.



The process of achieving impact is nonlinear, dynamic and recursive and is driven by continuous engagement with the people, organizations and institutions that make decisions from farm to national and international scales (Douthwaite, 2002 and Douthwaite et al, 2003). We recognize that behaviors, goals and impacts are influenced by many factors outside the program and we must be aware of these. These are the drivers of change (left-hand side of Figure 3.2) which will be studied through scenario and other analyses at the global scale and at the research sites. Drivers can also be levers of change, such as policy and investments.

Development outcomes (right-hand side of Figure 3.2) are improvements in NRM resulting in changes to access, better productivity, improved soil health and water quality, better ecosystem resilience, and equity in benefit sharing – as indicated by CRP5's objective statements (see Chapter 1). The program is *engaged* in these outcomes, but there are many other strong influencing factors. CRP5, working with others can, in certain settings, influence governance, management, policy and practices that lead to development outcomes. In addition, we generate knowledge and build capacity to facilitate change.

At the center of the Figure 3.2 is the natural resource base – the basic building blocks of soil, water and ecosystems. People change and manage these resources to produce food, fiber, fuel, medicine and cultural artifacts in a range of different agricultural systems (e.g. in irrigated or rainfed systems). Resources and farming systems are situated within basins and landscapes, and interact with multiple natural and human-engineered ecosystems. CRP5 encompasses and works within and among these various components, and will generate a range of outputs through its SRPs and several integrated outputs considering basins and landscapes, ecosystems, and means of recovering resources. CRP5 will pay particular attention to disseminating the information generated from its work to help foster change.

We recognize that this is a complex and nonlinear process with hard-to-predict feedback loops in which a change in one part of the pathway influences another part. Hence, monitoring, evaluation, feedback and learning are critical to testing the theories of change at project, regional, SRP and program levels. The Monitoring, Evaluation and Impact Assessment unit of the CRP Management Committee will develop a set of indicators during the inception phase.

As will be described later, one focus of CRP5's partnership strategy will be to engage with outreach partners, many of whom are concerned with the development and implementation of global conventions. For example, at the international level CRP5 addresses the Millennium Development Goals of reducing poverty and achieving food and water security; the United Nations (UN) conventions on desertification and land degradation (the UN Convention to Combat Desertification), biodiversity (the UN Convention on Biodiversity), climate change (the UN Framework Convention on Climate Change); and the Ramsar Convention on Wetlands; as well as the food security, environmental and development priorities of numerous intergovernmental organizations, international donors, development banks and sections of the business community.

3.2. Uptake strategies

Uptake strategies specific to each output are required to move research to outcomes. An uptake strategy combines a set of levers to affect change. There is an existing set of levers we know and employ with some success. Capacity building and policy change are two such examples. At the outset, SRP partners will decide on what combination of levers offers the best pathway to change, and then modify their theory of change on the basis of feedback in a process of adaptive management and learning selection. Some of these levers are outlined below with example uptake strategies (Table 3.1). Each SRP outlines a combination of levers specific to the problem set it addresses. As we learn, new levers and impact pathways will emerge. Monitoring, evaluation and learning have a central role to play in this adaptive learning process.

Table 3.1. Levers of change and related uptake strategies

Levers of change	**Uptake strategies**
Working with men and women in farming communities	Include farmers in learning alliances; learn from famers; let farmers test, innovate, lead.
Building capacity and leadership	Design and conduct training and professional development programs that change people's knowledge, attitudes and skills and lead to new behaviors; work with schools (teachers and students) and youth groups; focus on building leadership capacity among women.
Changes in policy and incentive structures	Sit at the table with policymakers; include them in the research from the earliest appropriate stage; make them partners in changing policy and incentive structures; include women at the table.
Working with the private sector	Provide scientific support for the development of investment packages that support sustainable, pro-poor agriculture. Co-develop new and low cost technology that can benefit resource-poor land users.
Developing market chains (link with CRP2)	We have separated this from 'working with the private sector' because a number of International NGOs and civil-society organizations are equally good at this.
Consumer power	In some countries, consumers can wield significant power through their purchase decisions and through demands for accountability from government, the private sector and primary producers.
Working with strategic partners outside the water, land and environment sectors	Look outside for levers on relationships and policies such as the one between energy pricing and groundwater pumping; use one to control and influence the other.
Using new developments in social network theory to map, measure and manage partnership networks	Adjust the size and shape of networks, change the patterns of interaction within the network to stimulate new ideas and learning; recognize that women and men have separate networks and ensure that both are included.
More coordinated joint effort (interactions with donors, joint publications, conferences, capacity-building initiatives, etc.)	Set up management structures within the CRP to ensure coordinated action; manage networks more effectively.
Better use of the media, public relations and behavior change communication.	Explore innovative ways of performing research and data collection; use coordinated media campaigns for information dissemination, advocacy, focusing public opinion.
Franchising data gathering and information services.	Work with development partners on sustainable business models for gathering data on ecosystem health and providing information and advisory services.
Global fora	Position CRP5 as an agenda-setting body linked to international policy through supplying concrete examples to the global policy dialogue; publish, promote NRM; provide sound data on ecosystems problems, risks and intervention opportunities.

3.3. Moving to implementation

Outlined below is a process to ensure that the CRP5 research program is truly coherent; i.e. that the output of one project or activity is viewed as an input to another. This process is noted in the work plan under the heading *Develop regional program plans*.

1. Based on existing experience, develop initial problem sets (for regions, basins, sub-basins and ecosystems).
2. Design and implement a process of defining and prioritizing a more complete set of regional problem sets – including consultation workshops and synthesis of information.
3. For each regional problem set:
    - develop a coherent program based on the theory-of-change logic and SRP logic presented here;
    - use SRPs to integrate across regions;
    - include an exit strategy for each research site;
    - set budget goals for regional programs and projects, consider existing or ongoing projects and design new ones, and determine which budgets must be increased and which must be reduced.

We recognize also the need to move efficiently and appropriately from a focus on current research programs to future research activities corresponding to the CRP5 theory of change. As we accomplish the transition from current to future work, we will prioritize our activities in two ways:

1. During an implementation phase of approximately 6 months, we will:
    a. Consider how to improve integration of water, soil and ecosystem work in specific environments.
    b. Provide more detail of specific deliverables at the basin and regional level.
    c. Consider improved ways of delivering natural resource and environmental data to users through the Information Systems SRP and the linkage with FAO and other key partners such as the International Soil Reference and Information Centre (ISRIC), with a particular emphasis on international public goods.
    d. Develop theories of change with the key stakeholders and change agents (implementing partners) at the specified field sites to ensure ownership of program outputs and their translation into impact.
    e. Consider beneficial interactions with CRPs 1.1, 1.2, 1.3 (on integrated agricultural systems), 3 (wheat, maize and rice), 6 (forests, trees and agroforestry) and 7 (climate change and food security), with respect to common regional approaches, field site complementarity and selection of sentinel sites.
    f. Develop indicators required by a Performance Indicators Matrix and commence the development of detailed, rolling annual work plans that will be the basis of contracts between partners and performance monitoring.
    g. Commission several studies of potential impact within SRPs to facilitate further prioritization.

2. We will assist the Steering Committee in developing a formal process for prioritizing new proposals. Our aim will be to commission several consultants with in-depth experience of prioritization processes to provide options for the Steering Committee to consider for the Program as a whole. We expect the criteria used will be related to:

a. Potential impact in terms of people and environment
b. Our ability to capture the benefits of the R&D through effective uptake strategies
c. Science quality
d. Capacity of partners to deliver.

These two strategies will enable us to maintain focus, while terminating non-performing or completed projects. In addition, we will have the flexibility to consider new research activities motivated by changes in the external drivers affecting agriculture, natural resources and environmental management. An annual Workplan for CRP5 is presented in Appendix 4.

The Program Steering Committee (see Chapter 13) will lead the process of ongoing prioritization of activities within the SRPs and will set strategic directions.

4. Strategic Research Portfolio: Irrigated Systems

Our vision: a revitalized Asia, a vibrant Africa, and a food-secure world

We envision a world in which public irrigation systems in Asia return to their productive potential while adapting to climate change and to increasing demands on water. A world in which men and women farmers in Africa are finally able to take full advantage of their abundant water resources. A world in which irrigation lifts millions more farm families out of poverty, while helping them adapt to the vagaries of climate and ensuring their, and our, food and nutritional security. We envision a world in which the remarkable social and productive benefits of irrigation are not offset by harmful impacts on the environment, but rather are enhanced by investments and policies that promote sustainable practices and protect supporting ecosystem services.

4.1. The compelling need for this research

The need to increase global food prodution at reasonable cost was clear long before the most recent food crisis. Irrigation has long been the cornerstone of global food production, owing to its direct and indirect impacts on crop yields. Irrigation gives farmers the assurance they need to plant new varieties and invest in their soils. Investments in large- and small-scale irrigation represent one of the most effective poverty reduction strategies of the 20th century, and still offer great potential across large areas of Asia and Africa. Irrigation, and the water storage systems that support it, have stabilized village, regional and national economies against rainfall variability, thus enhancing capital accumulation and economic growth. This aspect of irrigation's value to society will become even larger as households and countries across the globe adapt to the increasing variability in water supplies that will come with not only climate change but also with increasing competition from other water users.

Given irrigation's past contributions and the outlook for even greater value, one might expect irrigation systems to be among the world's prized and highly managed capital assets. Yet many irrigation systems are under financial and political pressure, with invidious political economies trapping many public systems in build–neglect–repair cycles even as demands on those systems and competition from other water users increases. Groundwater overdraft is increasingly dire in some regions, threatening the livelihoods of millions of smallholder households. Some of our most productive irrigated areas now suffer from salinization and waterlogging due to poor planning, inadequate investments and our failure to address important externalities (unintended costs or benefits that result from industrial or commercial activity, and which are not reflected in the cost of the goods or services involved). We have known of these problems now for decades, yet our scientific understanding has not translated into the right policy choices. We must continue exploring scientific frontiers while extending our knowledge more effectively into the policy realm.

To achieve our vision of a revitalized Asia, a vibrant Africa and a food-secure world within 10 years, we must conduct the research needed to answer several pressing questions regarding the science and policy of irrigation. We must determine why productivity in many public surface irrigation systems – which delivered unprecedented increases in crop yields during the 1970s

and 1980s – has remained static or even declined, while performance in other systems remains strong. We must find the right mix of investments, incentives and capacity building to spur the development of irrigation in Africa, to the benefit of millions of men and women smallholder families who currently rely on rainfall. We must learn how to improve the combined use of groundwater and surface water in practice rather than theory, with a view toward enhancing production and improving ecosystem management. We must improve groundwater governance to ensure that aquifers are managed in a sustainable fashion.

4.2. The scope and depth of the opportunity

Irrigation powers the global food system. It is also a remarkable source of livelihoods and provides food and nutritional security for much of humanity.

Irrigation takes place on 20% of the world's cultivated areas, which generate 40% of global food production (FAO, 2006), and enhances directly the lives of more than one billion poor people in rural Asia, Africa and Latin America (CA, 2007). Well-managed irrigation systems in the developing world have been a powerful force for poverty alleviation within and outside agriculture (Faures et al., 2007). Access to reliable irrigation stabilizes and improves crop yields, makes multiple cropping possible, enables small-holders to adopt high-value crops, provides year-round farm employment to the rural landless, and shields farmers from rainfall variability. Developing irrigation produces and supports strong forward and backward linkages, boosting income and generating employment in farm input supply, agro-processing and marketing businesses in rural areas. Small and large reservoirs near settlements promote multiple uses of water for livelihood enhancement.

The social benefits of irrigation extend beyond the borders of irrigation schemes. The increases in production reduce national and global food prices, and provide the basis for a reliable value chain for higher-value crops and enhanced livelihood opportunities. Irrigation also reduces variability in production due to uncertain rainfall and the impacts of climate change, thus enhancing national and global economic performance.

Irrigation is also the largest water diverter in the global hydrologic cycle, accounting for more than 70% of annual water withdrawals, thus generating impacts on landscapes, ecosystems, soils and biodiversity. The off-farm effects of developing irrigation are both negative and positive. Through research, we can learn much more about minimizing the negative impacts and enhancing ecosystem services, while increasing food production and enlarging the social benefits made possible by investments in irrigation.

Much of Asia has developed most of its surface irrigation potential. Within Asia, we must determine how to restore productivity increases in irrigated areas, while improving groundwater management where overdraft threatens the sustainability of irrigated agriculture and the livelihoods it supports.

While the irrigation revolution has improved the lives of millions of Asia's poor, it has so far eluded millions of African smallholder farmers and pastoralists (Ngigi, 2009). Despite substantial water endowments, sub-Saharan Africa irrigates only 7 million of its 39 million

hectares of irrigable land. Most of the continent's irrigation investments are found in just three countries – Madagascar, South Africa and Sudan – and most are on commercial farms. Scientific and policy research are needed to develop practices and strategies to extend irrigation's benefits across Africa. At the same time, we must help sustainably unlock the potential of groundwater where it has yet to be developed, including in sub-Saharan Africa, portions of eastern India and Southeast Asia.

With good science and appropriate policies, we can restore irrigation's prominence as a primary source of livelihoods for much of humanity. The right mix of investments, management regimes and institutional capacity will generate irrigation systems that reduce both rural and urban poverty and reduce or reverse degradation. They will achive this by providing livelihood opportunities for men and women, enhancing food supplies and moderating food prices. Through research, we can determine how to best revitalize existing irrigation schemes and create the conditions for investments in new schemes that will extend benefits across large areas of arable land, and into the households of millions of farm families.

4.3. A compelling role for the CGIAR

Millions of smallholder households across South Asia have achieved food and nutritional security, owing in part to research conducted by CGIAR Centers. Households in rural areas have benefitted directly through higher productivity made possible by improvements in crop genetics, agronomy and animal husbandry. Urban households have benefitted also, through better access to affordable food and nutrition. The substantial increases in agricultural production and the consequent improvements in livelihoods attributed to the Green Revolution of the 1960s and 1970s provide durable and compelling evidence of the potential role of the CGIAR in solving globally pressing issues.

The primary scientific advance at the core of the Green Revolution was the discovery of new crop varieties with much larger grain-to-biomass ratios. Farmers could produce more harvestable grain per hectare, and crop yields were no longer decimated by the lodging (toppling) of top-heavy plants in advance of harvest. The gains in output were extraordinary, enabling India to produce sufficient food for its increasing population and eventually become a grain exporter. Plant geneticists deserve much of the credit for the success of the Green Revolution, yet they had a strong supporting cast.

Improvements in plant genetics would not have been sufficient to generate the much-needed gains in agricultural output. The new crop varieties required more water and more fertilizer to achieve their yield potential. National and state governments provided fertilizer subsidies and invested in large-scale irrigation systems in some areas, such as the Indian states of Punjab and Haryana. Surface water in large-scale irrigation schemes was provided at low cost, while farmers pumping groundwater were given free electricity. The goal of such subsidies was to stimulate irrigation, in the interest of increasing agricultural output as quickly as possible. The goal was achieved with remarkable success.

Since the 1980s, CGIAR researchers have continued exploring the frontiers of land, water and plant relationships, while building on fruitful collaborations with scientists in national research

centers. We have learned much about the problems of groundwater overdraft in portions of India, China and elsewhere, and we have gained a better understanding of the decoupling of public and farm-level objectives regarding irrigation. We have studied the impacts of advances in technology on farm-level irrigation strategies and we have examined the implications of inappropriate policies on farm-level water withdrawals. We have also improved understanding of interactions involving irrigation, the environment and human wellbeing, and the impacts of irrigation on livelihoods and food security in developing countries.

Throughout this half-century of outstanding contributions to agricultural science, the CGIAR has established strong networks of physical and social scientists in national and international research centers around the world working on irrigation. Those networks, and the accumulated human capital within the CGIAR, provide an excellent platform for launching the next wave of research regarding viable, sustainable irrigation.

4.4. Building on a solid research foundation

Investments in large, public irrigation systems increased steadily during the 1970s and 1980s. Yet their poor performance and environmental impacts motivated researchers to examine many important questions, beginning in the 1990s. Through that research, we have learned that irrigation systems differ greatly in the values they create per unit of water transpired by plants (Sakthivadivel et al., 1999), and have developed our knowledge of the characteristics of high-performance systems (Keller and Keller, 1995).

In Southeast Asia – especially in Malaysia, Indonesia and Thailand – there are interesting examples of management improvements in rice irrigation systems. In China, public agencies motivate better performance of irrigation personnel and contractors by providing financial incentives (Wang et al., 2010). We are aware also of interesting innovations for saving water in rice irrigation that have additional benefits for ecosystem services (Barker et al., 2010). Although farmers in some community-level irrigation schemes, such as those involving tanks and small reservoirs, are dissatisfied with the service they receive, the systems perform well owing to farmer initiatives and investments.

Because farmers along many canal systems pay subsidized irrigation charges, managers have little motivation to improve service, and farmers have no moral basis for complaint. Many analysts argued during the 1970s that charging volumetric water fees would improve irrigation performance, but installing tamper-proof measurement devices at water delivery points has proven a major challenge (Carruthers and Stoner, 1981). While some have argued that volumetric pricing is needed to improve the management practices of farmers and irrigation managers, others say that effective rates would be too high to be politically feasible (Perry, 2001). Organizing farmers for local water management has been an imperfect process (Shah et al., 2002; Mukherji et al., 2009A), but we we do not yet know if the failure is one of concept (Suhardiman, 2008; Hunt, 1989) or the concept's implementation (FAO, 2007).

We have developed substantial understanding of the problems and potential solutions pertaining to groundwater, including its impact on different groups of farmers such as the landless and landed and by gender (Shah, 2009; Mukherji et al., 2009B; Giordano and Villholth,

2007; Llamas and Custodio, 2003). All-encompassing groundwater laws consistently fail, but when they have well-defined objectives, such as postponing the sowing date of paddy through regulation, as in the Indian Punjab, they can succeed (Sharma and Ambili, 2009). Rationing electricity supply reduces groundwater overdraft; while subsidized electricity without rationing encourages farmers to use groundwater more intensively and also to sell water to their neighbours (Shah, 1993; Mukherji, 2004). Farmers resist any attempts to curtail their access to groundwater, and they can form formidable lobby groups in opposition. However, they are enthusiastic about supply augmentation strategies, and they are willing to come together for collective action involving managed aquifer recharge.

Groundwater management takes place on farm fields, in the absence of any formal groundwater governance structure. Where farmers are given the chance to understand the nature and constraints of aquifer systems, they can come together to make sensible planning decisions that best use available water within its limits. Successful examples include the Andhra Pradesh Farmer Managed Groundwater Systems Project (World Bank, 2010) and community-based participatory approaches, such as the community management of groundwater program in southern India, developed by FAO and local NGOs (Rama Mohan, 2009; FAO, 2008; Garduno et al., 2009).

Sub-Saharan Africa offers substantial potential for small- and large-scale systems (CA, 2007), but previous public investment in the region has provided much less benefit and at much higher cost than anticipated (Inocencio, et al 2007). New investors recognize the potential returns to investment in Africa but do not necessarily leverage those investments for poverty reduction.

4.5. Our Theory of Change for irrigation

We aim to better understand how irrigation can contribute once again to the large-scale alleviation of poverty among smallholder farmers and improve global food security with enhanced ecosystem services. To achieve our vision of revitalized irrigation in Asia and a vibrant irrigation sector in Africa, we must conduct good science, improve knowledge and understanding of new issues, and influence debates on issues that have reduced public investment in irrigation in recent years.

Public investments in irrigation systems are profoundly political. The political needs of a diverse range of interest groups shape decisions on the funding of new projects, selection of existing projects for renovation, reform of institutions and bureaucracies, or how limited water supplies will be allocated across sectors and between competing users. Engaging key regional political influences, whether groups or individuals, is imperative to bringing about real change in policy that can make the most of technology and resources.

Three important problems resulting from the current political economy of irrigation include inadequate incentives for staff to deliver high-quality service, a lack of moral imperative for famers to demand higher quality, and inadequate capacity (including resources) to improve system performance. Change is hampered by the quality of information and available knowledge of previous investments in irrigation and present irrigation management. Lack of high-quality information at the relevant scales prevents evaluation of current performance and

development of effective strategies and decisions for improving irrigation service and ensuring the sustainability of new investment. The result is that irrigation systems perform below potential, in agricultural productivity as well as in the provision of ecosystem services; the sustainability of agricultural activities is not assured and negative externalities increase; and new investments often prove unsuccessful.

4.6. What needs to happen for irrigation management to improve?

We believe actions in four critical areas are necessary for change to take place in the political economy of irrigation management. These form the main thrust of interventions within our research program:

1. **Acknowledging and engaging key political influences in irrigation management**
   As we devise our plans for research projects, politicians and representatives of key interest groups, including the vulnerable and marginalized, will be engaged as members of our research teams to bring on board key influencers in irrigation management and give a platform for implementation.

2. **Reversing perverse incentives**
   As we endeavour to achieve our vision of vibrant irrigation sectors, we must first recommend removal of the perverse incentives that have hindered irrigation performance for many years, in and outside the sector.

3. **Building institutional capacity**
   As we develop new options for managing irrigation, we will encourage appropriate ministries and other relevant leaders to develop and apply the capacity needed to implement our recommendations. This includes financial capacity.

4. **Develop high-quality information**
   As we develop new knowledge of surface water and groundwater systems, we will also recommend new procedures for collecting, evaluating and sharing information describing irrigation investments, management and governance, and the status of water resources.

We are aware that this Theory of Change will not produce immediate gains in agricultural output or environmental protection. Our goal is to foster change by bolstering and improving the process by which decisions are made within irrigation and other related bureaucracies and organizations through collaboration with partners on the research programs and a culture of learning. Our vision cannot be achieved without a deep and meaningful engagement with partners at all levels and a sense of shared ownership of demonstrated impacts.

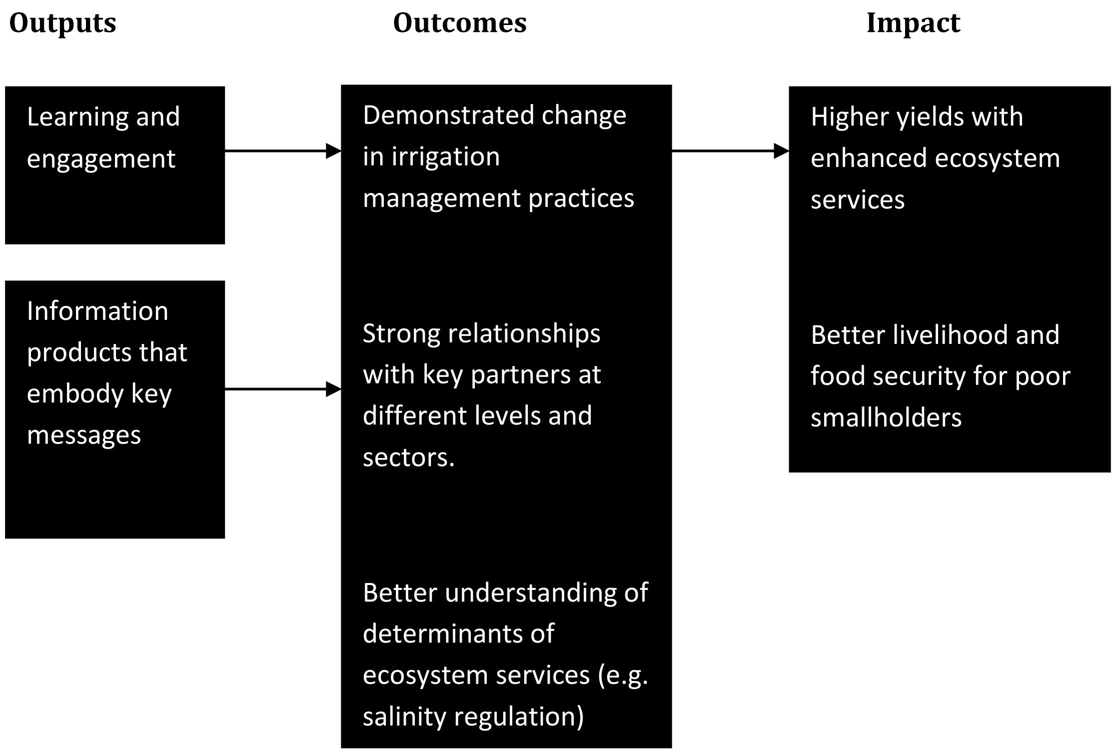
4.7. Our impact pathway

Our approach will be based on two pathways to impact (Figure 4.1):

1. **Learning and engagement**
   The research program will take on a learning approach that begins with the creation of inclusive diverse teams that develop tools, technology, expertise, guidelines and investment plans that emerge as research outputs.

2. **Information products that embody key messages**
   The creation of knowledge products of high scientific value with clear messages will help pull the levers required for desired change. The knowledge we develop and the information we make available will inform politicians and public agency personnel of the current gaps between existing irrigation practices and those that would, with appropriate investment, generate greater benefits across the range of stakeholder groups. Public officials and other decision-makers can then determine the interventions required to improve agricultural performance, while also achieving socioeconomic objectives and protecting ecosystems.

Figure 4.1. Pathways to impact in irrigated systems



The process by which outcomes will be achieved will require deep engagement with partners directly associated with irrigation management at local, regional and international scales, but also with sectors that are closely connected with and strongly influence irrigation policy. To develop and popularize adaptive management practices, we will actively engage with irrigation managers, local researchers, NGOs, ARIs, international organizations (such as the FAO, World Bank, and African and Asian Development Banks), and the private sector in a protocol involving

five distinct sets of activities in each basin for each identified problem area in which we work (see section 4.9).

4.8. Our links with other SRPs and CRPs

Our focus on irrigation complements most closely the SRP on river basins and will add value to the global irrigation assessment described in the information systems SRP. Our work will also contribute to CRP5 research on markets and policies, and will benefit from ther program's work on the overall agricultural policy environment. We will also draw from and contribute to CRP7 (Climate Change, Agriculture and Food Security), as irrigation is fundamentally about adapting to variability.

4.9. Five years and five problem sets

During the next five years we will focus our research on five problem sets corresponding to globally pressing issues regarding irrigation. We have chosen these sets in discussion with national and international researchers who share our concern for the urgent need to revitalize irrigation in Asia and expand irrigation in Africa. We are aware of the notable challenges involved in this endeavour and we are ready to engage in the collaborative research that will help determine the best ways forward in promoting new and effective investments in irrigation.

4.9.1. Problem Set 1: Revitalising Asia's public irrigation systems

Synsopsis: *New research on public surface irrigation systems has vast potential to deliver better service to men and women farmers, thus generating higher yields and improving household food and nutritional security across large areas of South Asia.*

The initial success of large-scale irrigation in Asia has given way in recent decades to declining growth rates in crop yields and the development of large areas in which increasing soil salinity, waterlogging and groundwater overdraft threaten productivity. Due partly to the persistent use of subsidies implemented during the Green Revolution, moribund public agencies, and also to the externalities inherent in large-scale irrigation schemes, these problems have reduced irrigation's appeal as a source of future growth in agricultural output. Yet these problems can be solved through new research that addresses the proximate causes of salinity, waterlogging and declining rates of growth in crop yields, thus enhancing a broader range of ecosystem services.

We will begin with new research on the benchmarking of performance in large-scale irrigation systems. Benchmarking provides the information needed by system operators and agency personnel to evaluate performance, in comparison with national and international standards. Such evaluation is essential in developing new strategies for targeting public investments in the repair, reform and revitalization of irrigation schemes. It is equally important in determining the design criteria for new investments in irrigation, and evaluating the implications of policies that influence the practices of irrigation managers and water users. The information we develop will represent the classic case of an international public good, given the widespread interest in revitalizing irrigation in many countries and expanding irrigated areas across Africa.

We envision conducting benchmark analyses for 30 major irrigation schemes in Asia and Africa, in close collaboration with research partners in FAO and national research centers. As we conduct this research, we will examine also the potential for implementing new technologies, governance structures, management practices and agronomic innovations to improve agricultural productivity and regulate ecosystem services in large-scale irrigation schemes.

Working with national partners, we will establish pilot studies of selected innovations and evaluate the outcomes in terms of agricultural output, income generation, and impact by gender, class and livelihood status. We will engage in these efforts in public irrigation schemes within the Indus, Mekong, Amu Darya and Syr Darya river basins.

Our impact pathway for this problem set (Table 4.1) will involve the use of several levers of change that will improve the performance of large-scale irrigation systems. These include:

1. improving main system management and preparing formal service contracts with water-user associations;
2. rating the performance of distributaries and branch canals, with third party verification;
3. promoting mobile phone use to transmit real-time data describing canal flows, irrigation scheduling and farm-level implications.

Table 4.1. Impact Pathway: revitalizing Asia’s public irrigation systems

Issue	Levers of change	Research outputs	Outcomes	Potential impact	Contribution to SRF outcomes
Built during colonial times and in the early years of independence of Asian countries, large-scale public irrigation systems played a catalytic role in bringing about the Green Revolution in Asia. However, many of these irrigation systems are now in a state of disarray and need urgent reforms. This assumes even greater significance in view of increasing food prices in recent years.	National governments to instigate institutional policies and investment plans for revitalizing and reforming Asia’s irrigation in partnership with international donors and national irrigation agencies.	• Methodology for benchmarking irrigation performance across systems so that performance can be measured and compared • 30 public irrigation schemes benchmarked world wide • Recommendations for technical reforms through adapting global best practices to local contexts • Recommendations for institutional reforms after studying global best practices and suitably modifying them for local conditions • Undertake rigorous impact evaluation in close collaboration with an implementing agency responsible for either technical or institutional reform or both.	• National governments adopt research findings through policy and action recommendations, and direct irrigation agencies to implement them • National governments chart out clear-cut irrigation development strategies • Both traditional and non-traditional donors invest in modernizing and reforming irrigation bureaucracy in Asia • Irrigation agencies implement new solutions and strategies.	• Large public irrigation systems reclaim their lost glory and once again become magnets of rural prosperity • In the medium to long run, food prices fall • National food security is improved.	• Significant contribution to SRF goals on food security, livelihoods and environmental sustainability • Improved smallholder income helps diversification of diet and helps prevent malnutrition.

4.9.2. Problem Set 2: Ensuring the success of irrigation in Africa

Synsopsis: *Investments in smallholder irrigation must achieve their potential to stimulate significant agricultural growth, ensure food security and reduce persistent poverty in sub-Saharan Africa*.

An estimated 70% of the 400 million poor residents of sub-Saharan Africa live in rural areas and earn their livelihoods by raising crops and livestock. The Comprehensive Africa Agriculture Development Programme (CAADP), prepared in 2002 under the New Partnership for Africa's Development (NEPAD), adopted land and water management as the first of its four pillars for priority investments. Pillar 1 aims to extend the area under sustainable land management and reliable water control systems to 20 million hectares by 2015, up from its current 7 million hectares. In response, several countries (Ethiopia, Ghana, Kenya, Malawi, Mozambique, Nigeria and Tanzania) have expressed a renewed interest in irrigation. Our research will support this exciting development.

We will endeavour to provide the scientific knowledge, policy tools and investment recommendations that will help interested governments develop or expand irrigation. We will work closely with national partners, the private sector, NGOs and financial institutions to promote profitable, sustainable smallholder irrigation in sub-Saharan Africa that provides benefit to both men and women farmers as well as others along the value chain.

During the first five years of our research, we will focus on the Nile, Volta and Limpopo River basins. Working closely with our partners in each basin, we will:

1. assess irrigation potential;
2. evaluate alternative technologies and institutions;
3. analyse socially differentiated irrigation impacts on food and livelihood security, and on ecosystem services;
4. define and recommend high-impact investment options;
5. assist in building capacity for effective management of local irrigation.

We will also evaluate potential opportunities and implications regarding the large-scale acquisition of land by foreign investors. We will examine, in particular, the potential impacts on smallholder access to land and water resources, and their opportunities for engaging in sustainable livelihood activities.

Our impact pathway for this problem set (Table 4.2) will involve the use of several levers of change, including:

1. improving support for irrigation service providers;
2. increasing the efficiency of manual pumps;
3. promoting multiple-use systems for water collected in small reservoirs.

These efforts will increase agricultural productivity and enhance livelihoods in smallholder households.

Table 4.2. Impact Pathway: Ensuring the success of irrigation in Africa

Issue	Levers of change	Research outputs	Outcomes	Potential impact	Contribution to SRF outcomes
In sub-Saharan Africa as a whole, less than 5% of the cultivated area is irrigated. But irrigation holds significant potential for agricultural growth, food security and poverty reduction in the region. The Comprehensive Africa Agriculture Development Programme (CAADP), prepared in 2002 under the New Partnership for Africa's Development, adopted land and water management as the first of its four pillars for priority investment. This research will develop a menu of investable options for irrigation development in sub-Saharan Africa.	CAADP must act to encourage national governments to implement institutional policies and investment plans for irrigation development in partnership with the international donors, NARES and local NGOs.	• Economic and environmental analyses of costs and benefits of irrigation development on men and women farmers in sub-Saharan Africa • Identification, documentation of different irrigation systems in sub-Saharan Africa, and the advantages and disadvantages of each • Based on the above two outputs, develop a menu of investable options for irrigation development in sub-Saharan Africa • In close collaboration with an implementing agency, conduct rigorous impact evaluation of 5–10 irrigation projects in sub-Saharan Africa.	• CAADP adopts research findings in policy and action recommendations • The Alliance for a Green Revolution in Africa adopts research findings on irrigation in its implementation activities • National governments chart out clear-cut irrigation development strategies • Both traditional and non-traditional donors invest in irrigation • Various types of irrigation infrastructure – large, small, formal and informal – emerge in Africa.	• Livelihoods of men and women farmers improved because of higher yields, lower yield variability and higher incomes • National food security is improved and countries reduce their dependence on foreign food aid.	• Significant contribution to SRF goals on food security, livelihoods and environmental sustainability • Improved smallholder income helps diversification of diet and helps prevent malnutrition.

4.9.3. Problem Set 3: Managing Groundwater overdraft in South Asia, with a focus on energy–irrigation interactions

Synsopsis: *Innovative policies are needed to achieve wise management of groundwater in India and Pakistan, where subsidized electricity motivates excessive withdrawals. The politics of this problem are complicated, but the potential long-term gains to smallholder households will exceed the near-term costs of eliminating the electricity subsidy.*

Providing subsidized electricity to promote groundwater pumping made good sense in the 1960s and 1970s, when the goal was to expand irrigation and increase agricultural output very quickly, to feed a rapidly increasing population. The subsidies, in conjunction with other policy interventions and cost-reducing improvements in technology, spurred an unexpected boom in groundwater irrigation. Groundwater withdrawals increased from about 15 billion cubic meters per year in 1960 to 400 billion cubic meters in 2000. Millions of farmers across India have installed tubewells and fitted them with inexpensive pumps, thus providing access to groundwater, which farmers can extract and apply on their own, with no oversight or scheduling required by a water management agency or a public irrigation scheme.

The public sector in India has paid a high price in retaining the subsidy program, as the total cost has increased to a notable proportion of the country's agricultural output, and electricity boards are unable to provide sufficient power to fuel the demands of non-agricultural growth. If the subsidies had been ended, groundwater pumping might have stabilized at sustainable levels. Instead, excessive withdrawals increased pumping depths in many areas, thus increasing the per-unit cost of pumping groundwater. This increasing cost places an even larger strain on electricity boards, as they must provide additional energy, yet they receive no additional revenue from farmers.

In many areas of South Asia, such as in western and southern India and in Pakistan's Baluchistan Province, continued electricity subsidies have led to severe groundwater overdraft. Public agencies are caught between the competing objectives of restoring financial solvency to the state electricity boards and keeping farmers happy by continuing the subsidy programs. Unable to resolve this conundrum, excessive pumping continues, at increasing cost to society.

Our goal in this Problem Set is to determine practical measures, involving both technologies and policies, that can be implemented to achieve sustainable groundwater management without disrupting smallholder livelihoods or reducing agricultural output. We also wish to restore the financial solvency of state electricity boards by developing viable revenue collection programs. This is a tall order, given the long history of electricity subsidies in the region, the current farm-level dependency on low-cost groundwater irrigation, and the apparent political infeasibility of any increase in the price of electricity. Yet the potential gains from successful research and policy implementation are substantial, as the current program of excessive groundwater overdraft is inherently unsustainable. Millions of smallholder households will suffer livelihood disruption if they no longer have access to groundwater.

In conducting this research, we will work closely with the groundwater departments and electricity utilities in Baluchistan and Khyber Pakhtunkhwa Provinces in Pakistan and in the

Indian states of Punjab, Haryana, Gujarat, Rajasthan, Madhya Pradesh, Andhra Pradesh, Karnataka and Tamil Nadu. Taken together, these regions account for more than 80% of the area in South Asia in which groundwater overdraft is occurring.

Our impact pathway for this problem set (Table 4.3) will involve the use of several levers of change, including:

1. rationing farm power supply in terms of voltage and hours of use;
2. motivating farmers to use less energy;
3. organizing farmers for local groundwater monitoring and management.

These efforts will enhance understanding of the impacts of energy pricing policies on groundwater pumping, and measures to reduce pumping rates in regions where millions of smallholders obtain groundwater using tubewells and small pumps.

Table 4.3 Impact Pathway: Managing Groundwater overdraft in South Asia, with a focus on energy-irrigation interactions

Issue	**Levers of change**	**Research outputs**	**Outcomes**	**Potential impact**	**Contribution to SRF outcomes**
Groundwater overexploitation is a major water management challenge across much of South Asia. The driver for overexploitation is often subsidized electricity that allows farmers to pump to the bottom of the aquifer. The solution must also come from the energy sector. Energy policies must be moulded so that farmers and electricity utilities are offered incentives to avoid overexploiting groundwater.	National governments to implement institutional policies and investment plans for reforming the electricity sector in partnership with the international donors and national irrigation agencies, with special reference to agricultural electricity supply.	• Documentation and understanding of electricity policies and their impact on groundwater extraction in affected Indian states and in Pakistan and Bangladesh • Concrete and achievable suggestions for implementing electricity policies that positively influence farmers' and utility managers' behavior • In close collaboration with an electricity utility, undertake a rigorous impact evaluation of changes in electricity policy on farmers' groundwater use • Based on policy lessons in South Asia, draw future policy guidelines for Central Asia, Southeast Asia and sub-Saharan Africa, which may face similar issues of groundwater overexploitation.	• National governments and their respective planning commissions adopt suitable energy policies • Both traditional and non-traditional donors invest in modernizing the energy sector and and reforming electricity bureaucracy in India • Electricity utilties implement new solutions and strategies.	• In areas of severe groundwater overexploitation, the rate of exploitation is arrested • Groundwater levels recover in the medium to long run • Negative externalities, such as fluoride contamination of groundwater, are minimized • Food production becomes sustainable.	Significant contribution to SRF goals on food security, livelihoods and environmental sustainability.

4.9.4. Problem Set 4: Revving up the Ganges Water Machine

Synsopsis: *In the Ganga–Meghna–Brahmaputra basin, South Asia's 'poverty square', rapid groundwater development made possible by new research can alleviate agrarian poverty*.

Current poverty levels in Eastern Uttar Pradesh, Bihar, West Bengal, Assam, the Nepal terai and Bangladesh are similar to those in sub-Saharan Africa. Household incomes are low, food security is not assured, and devastating floods occur too often, with particularly severe impacts on the poor. The floods are caused primarily by excessive rainfall, but the impacts can be reduced through wiser groundwater management that enhances the regulating services of the basin's natural and agricultural ecosystems.

Annual rainfall in the region ranges from 1500 mm to 2500 mm per year. Substantial rainfall and deep alluvial aquifers with high rates of natural recharge provide the region with substantial water resource potential. Scientists studying the interactions of rainfall and groundwater in the region in the 1970s assigned the title of 'Ganges Water Machine,' as they described how those interactions contribute to the intensity of flooding in the region. When aquifers are fully recharged, heavy rainfall cannot be absorbed, and thus runs off the surface, causing major floods. If aquifers can be managed to provide storage capacity in advance of the monsoon season, the severity of floods might be reduced, thus enhancing regulating ecosystem services at basin scale. The 1970s studies also suggested that groundwater development could enhance agricultural productivity in winter and summer, thus reducing poverty in the region.

We will examine the veracity of the Ganges Water Machine hypothesis. In addition, we will study a range of policy alternatives, including energy and food procurement and pricing policies, that influence groundwater use in the region. We will develop policy, institutional and technological options to support sustainable intensification of the region's groundwater-irrigated agriculture. Our results will enhance agricultural productivity for up to 20 million men and women farmers, and thus transform this poverty square into the granary of South Asia.

Our impact pathway for this problem set (Table 4.4) will involve the use of several levers of change, including:

1. promoting the use of containerized natural gas for irrigation pumps in the Ganges River basin;
2. leasing power lines to irrigation service providers;
3. providing electricity more widely, while charging appropriate tariffs.

These efforts will enable agricultural expansion in regions where groundwater resources are substantial and largely untapped.

Table 4.4 Revving up the Ganges Water Machine

Issue	Levers of change	Research outputs	Outcomes	Potential impact	Contribution to SRF outcomes
Inadequate policies and irrigation infrastructure in the eastern Ganges region hinders food production and livelihoods. Opportunities may arise from more dam building for hydropower in the region, but groundwater could supply most of the irrigation water requirement. Groundwater irrigation is already extensive in most parts of eastern Ganges. The problem is not so much of expanding irrigation, but of making it economic for farmers to grow water-intensive and remunerative crops. Groundwater is the main source of irrigation in this region, but a lack of electricity means that farmers use diesel. Because diesel is expensive, they under-irrigate or grow lower-value crops that need less irrigation.	There is potential to intensify cropping systems by growing three water-intensive crops per year. This will need the development of a coalition of researchers, Indian Federal and State Finance and Irrigation Ministries, the Planning Commission, and investors to facilitate policy change and on-ground action via technical assistance, grants and incentives for poor farmers	• Analysis of actual/potential water productivity increases from more efficient irrigation at regional scale • Analysis of the sustainable yield of shallow groundwater and modeling the flood-reduction potential of increased groundwater use – i.e. a rigorous test of the Ganges Water Machine hypothesis. • Analysis of the role of energy policies in encouraging or impeding groundwater development • Analysis of the roles of India's and Bangladesh's food and food procurement policies and the way they affect farmers' incentives in the eastern Ganges basin • Understanding of how informal groundwater markets help benefit-sharing of irrigation among small and marginal farmers. • New models for combined use of surface water and groundwater • Assessments of environmental flow impacts from increased groundwater use on rivers, wetlands and floods • Development with private sector of improved irrigation technologies	• The respective government agencies and donors adopt key policy recommendations to bring about intensive groundwater development in the eastern Ganges basin • Men and women farmers invest in shallow groundwater extraction through appropriate electrification • Business opportunities created in irrigation sector • New models implemented for management of sustainable yield that consider men and women users and the environment.	• Improved land and water productivity for up to 20 million farmers • Less reliance on food supplies from western India. • Insurance against poor monsoon rains via better groundwater access • Potential environmental benefits because of less pressure for dam building • More sustainable use of groundwater harmonized with other environmental requirements.	Significant contribution to SRF goals on food security, livelihoods and environmental sustainability

4.9.5. Problem Set 5: Reducing salinity, at last, along the Indus and in Central Asia

Synsopsis: *Research can pave the way for achieving stable groundwater levels in irrigated areas of the Indus and Aral Sea basins, while limiting secondary salinization, minimizing waterlogging and reducing farm-level irrigation costs.*

Secondary salinization arising from irrigation with poor-quality groundwater is a major threat to irrigated agriculture in South and Central Asia. The Lower Indus basin is particularly affected by increasing soil salinity, especially in Sind, where 56% of irrigated land is affected. The primary source of the problem is the presence of marine salts and poor natural drainage. Yet irrigating with poor-quality groundwater, in the absence of sufficient surface water supplies, exacerbates the problem. Leaching opportunities are limited, given the development of highly saline shallow groundwater. Salinity and waterlogging have hampered Pakistan's agricultural output for decades, and the problems remain substantial today. The outlook for future food security will not be clear until these problems are solved.

Many farmers in the Indus Basin practice the combined use of surface water and groundwater in the head and tail portions of canal command areas. The head-end farmers divert excessive volumes of canal water, leaving less water for mid-reach and tail-end farmers. This spatial inequity in canal water supplies often results in head-end areas with waterlogged soils and tail-end areas with increasingly saline soils. Moreover, groundwater levels decline in large portions of mid-reach and tail-end areas, while they rise in head-end areas. These classic problems of hydrologic interactions involving head-end and tail-end irrigators are found across large areas of South and Central Asia.

We will address the persistent challenge of stabilizing groundwater levels throughout canal command areas, while minimizing waterlogging and salinization, and ending groundwater overdraft. We will examine groundwater management strategies across the spectrum of centralized management, atomistic pumping and combined use. We will conduct technical studies, collect field data, and construct analytical models for use in studying a wide range of management and policy options. We will also examine the important roles of institutions and alternative forms of governance with regard to surface water and groundwater resources and the way that change affects both men and women farmers.

Our impact pathway for this problem set (Table 4.5) will involve the use of several levers of change, including:

1. operating canals to increase groundwater use at head-end reaches, while increasing surface water use at tail-end reaches;
2. building clusters of on-farm evaporation ponds for local salinity management;
3. promoting deficit irrigation in areas with saline, shallow groundwater.

These efforts will improve farm-level and regional salt management, such that crop yields can be sustainably increased.

Table 4.5 Impact Pathway: Reducing salinity, at last, along the Indus and Ganges and in Central Asia

Issue	Levers of change	Research outputs	Outcomes	Potential impact	Contribution to SRF outcomes
Secondary salinization arising from irrigation with poor-quality groundwater is a major threat to irrigated agriculture in South and Central Asia. The Lower Indus basin is particularly affected by growing soil salinity Presence of marine salts and poor natural drainage are basic reasons; but irrigating with poor-quality groundwater, for want of sufficient surface water supplies, exacerbates the problem.	National governments and irrigation agencies adopt appropriate policies and donors support them in implementing those policies.	• Tested and implementable strategies stabilizing groundwater levels throughout the canal command to minimize water logging, salinization, groundwater depletion and soaring pumping costs • On-farm irrigation practices for minimizing the impact of saline groundwater use • Modeling of conjunctive use of marginal-quality groundwater with fresh surface water • Clear understanding of governance challenges involved in managing marginal-quality groundwater, and ways and means of overcoming the problem through both technical and institutional solutions.	• Planned and well-coordinated combined use of marginal-quality groundwater with surface water for improving overall productivity of irrigation systems • Rehabilitation of land left unusable because of soil salinity problems.	• Increase in irrigated area and crop productivity by sustainably using land that has been declared unfit for cultivation necause of high salinity • Long-term food security in the Indus and Central Asian river basins • Minimize loss in biodiversity by reclaiming saline lands.	Significant contribution to SRF goals on food security, livelihoods and environmental sustainability.

4.10. What we will achieve in the second five years

During the second five years of our research, we will focus more intently on the questions we have identified as most pertinent for further enhancing livelihoods through wise investments in irrigation. We will extend our analysis of selected components of the original five Problem Sets, while possibly defining new Problem Sets that gain our attention as we conduct our research. We envision also the development of pilot studies in which we evaluate with national partners some of the technical and policy recommendations that arise during the first five years. We will continue evaluating the uptake and impacts of our research, and we will set in place appropriate methods for assessing the outcomes.

4.11. Partnership strategy

The approach that we will take with respect to partnerships will be to work with government irrigation and related agencies (e.g. energy utilities) in terms of problem definition and identification of potential policy and management solutions. Research will then be conducted with core partners using hypotheses to test the efficacy of proposed solutions. Successful solutions will be implemented by business partners and irrigation management agencies.

Outreach will be conducted with partners such as FAO and the UNESCO-IHE Institute for Water Education, and via linkages with the relevant development banks including AfDB, ADB and the World Bank. For example, in Pakistan we will work with the Punjab Irrigation Department to define improved canal management strategies, test these in the field with research partners including the Pakistan Council of Research in Water Resources, and provide relevant information back to the irrigation agencies to implement management reform to reduce salinity risk.

With respect to the problem set on *Ensuring the success of irrigation in Africa*, the research will be conducted with numerous in-country irrigation agencies. Economic assessments of feasibility of new developments will be conducted using linkages with CRP2 (Policies, institutions, and markets to strengthen assets and agricultural incomes for the poor) and the key outreach partner will be the CAADP.

Work on groundwater overdraft and enery interactions in Asia will engage energy utilities and the business sector, including Jain Irrigation Systems Ltd, to examine potential efficiencies of sprinkler and drip systems. This work may also involve linkages with Wageningen University and Waterwatch Remote Sensing Services to examine water productivity issues.

The partnership strategy of the Irrigated Systems SRP is further detailed in Table 4.6.

Table 4.6. CRP5's partnership strategy for the Irrigated Systems SRP

Region/Basin	Core Research	Implementation	Outreach
Indus	Wageningen University and Research Center	Provincial Irrigation and Drainage Authorities Pakistan Council of Research in Water Resources, Islamabad; Central Soil Salinity Research Institute, Karnal Pakistan; Punjab Irrigation Department, Chandigarh	ADB
Ganges	PRADAN; Water Nepal; Delhi School of Economics; BRAC[1], Dhaka; BADC[2], Dhaka; IDE, Nepal; LILI[3] Project of Helvetas; WaterWatch Remote Sensing Services	CGWB, India; Planning Commission, GoI; BWDB, Dhaka[4]; LGED[5], Dhaka; Department of Irrigation, GoN; Electricity Utilities in basin states; Jain irrigation	FAO; GEF Groundwater Governance Project; MetaMeta; SEED; Tata Trusts, Mumbai;, Jalgaon, Waterwatch Remote Sensing Services
Mekong	Centre d'Etude et de Development Agricole Cambodgien (CEDAC), Cambodia ; Stockholm Environment Institute (SEI)	Institute of Water Resources Planning (IWRP), Hanoi; Lao PDR and Cambodian Governmnet Irrigation Agencies	FAO
Amu Darya and Syr Darya	Danish Hydraulics Institute (DHI), CSIRO (Australia): SANIIRI, Tashkent; Tajik Research Institute for Irrigation; Kyrgiz National Irrigation Research Institute ; Kazakh National Irrigation Research Institute	Ministry of Agriculture and Water Resources, Uzbekistan; Ministry of Melioration and Water Resources, Tajikistan; Committee of Water Resources of Kyrgyz Republic;	FAO, ADB
Nile	Ethiopian Institute for Agricultural Research; Ethiopian Development Research Institute; Colorado State University; USGS; US Salinity Laboratory ZEF;	Ministry of Agriculture; Ministry of Water and Mines; Jain Irrigation	UNESCO-IHE,;FAO, World Bank, AfDB; MIDROC Ethiopia[6]
Volta	Water Research Institute, Ghana; Kwame Nkrumah University; SARI[7]; 2iE Institut International de l'Ingénierie de l'Eau et de l'Environnement; l'institut de l'environnement et de recherches agricoles (INERA); CIRAD (France)	Ghana Irrigation Development Agency (GIDA); Volta Basin Authority (VBA); Direction des Aménagements et de l'Irrigation (DADI) ; Direction Générale des Ressources en Eau(DIRE)	UNESCO-IHE, AfDB

[1] Bangadesh Rural Advancement Committee
[2] Bangladesh Agricultural Development Council
[3] Local Infrastructure for Livelihood Improvement Project
[4] Bangladesh Water Development Board, Dhaka
[5] Local Government Engineering Department, Dhaka
[6] Mohamed International Development and Research Organization Companies
[7] Savannah Agricultural Research Institute

5. Strategic Research Portfolio: Rainfed Systems

Our vision: farmers and pastoralists thrive in highly productive rainfed areas, supported by vibrant ecosystems

We endeavor to change the future of crop and livestock production on rainfed landscapes across Africa and Asia. We will conduct research to support interventions that will increase productivity of men and women farmers, while reducing or reversing the overgrazing, soil nutrient mining and land degradation that have deepened the poverty of millions of smallholder households. We will enhance understanding of soil, water, nutrient and carbon management in the rainfed and pastoral settings in which so many farmers struggle to grow crops and raise livestock with minimal inputs, inadequate finance and too little certainty of success each season. We will reduce the risk of failure, thus improving livelihood status and enhancing food security for the millions of men, women and children who till the earth and raise their animals in precarious rainfed areas.

5.1. The compelling need for this research

Most of the world's approximately 1 billion million poor (based on the $1.25/day threshold)live in the developing countries of Asia and Africa, and many earn their living in rainfed agriculture. Uncertainty regarding rainfall, persistent water scarcity and extensive areas of degraded landscapes characterize many of the rainfed settings in which farmers and pastoralists attempt to sustain their livelihoods. It is difficult to imagine how families can generate sufficient income to achieve and maintain food security in such conditions, yet millions of households face precisely that task. And millions are not successful.

Extensive poverty, food insecurity, and malnutrition are found throughout rainfed settings in which many households are unable to produce the food or generate the income that would enable them to cope successfully with the uncertainty that defines their environment. Most households have no savings account, other than the market value of their livestock. Lacking financial resilience, farmers cannot take the risk of applying the fertilizer that might enable them to obtain higher yields. If rains do not arrive on time, farmers will lose all the money they have spent on seeds, fertilizer, and other inputs. Lacking secure land tenure, farmers will not invest in efforts to restore soil nutrients and organic matter, or to reduce soil erosion.

Farmers and pastoralists in rainfed settings face challenges and constraints that would overwhelm most people if placed in such conditions. Yet they work as best they can to generate livelihoods and achieve food and nutritional security for their households.

Over time, as population has increased in rainfed areas, the pressures exerted on supporting ecosystems have also increased. Thus we see extended areas in which soil nutrients are depleted, vegetation cover and biodiversity are declining, and land is degraded by soil erosion and overgrazing. We see increasing competition for limited

land and water resources, and we note the constant or declining rates of growth in crop and livestock yields. It is time to reverse these trends, before the challenges and constraints overwhelm even the most resilient and successful households. It is time for the research we propose in this Rainfed Systems SRP.

5.2. The scope and depth of the opportunity

Globally, there are 15 million km² of rainfed cropland and 33 million km² of grazing lands (Table 5.1). Rainfed areas account for 80% of global agricultural area, while generating an estimated 60% to 70% of world food production (CA, 2007). Millions of smallholder households cultivate crops and raise livestock in rainfed areas, where increasing water scarcity and impending climate change are bringing new stresses to environments already challenged by overgrazing and the mining of soil nutrients (Wani et al., 2009; Rockström et al., 2010). Depleted soils produce low yields, thus creating a vicious circle in which reductions in farm income further constrain farm-level ability to afford critical inputs. We endeavor in this research to replace this vicious circle with a virtuous one in which productivity is restored through greater use of plant nutrients and improvements in soil management practices, thus enabling farmers to afford additional investments that will enhance crop yields and protect the environment.

Table 5.1. Rainfed and irrigated agriculture on three continents and globally (million km²)

Land use	Africa		Asia		South America		World	
	km²	%	km²	%	km²	%	km²	%
Rainfed agriculture	11.5	*39*	14.1	*46*	5.7	*32*	45.8	*35*
Arable and permanent crops	2.5	*8*	5.4	*17*	1.3	*7*	15.3	*12*
Permanent grazing lands	9.1	*31*	10.9	*35*	4.5	*26*	33.6	*26*
Irrigated agriculture	0.1	*0*	2.2	*7*	0.1	*1*	3.1	*2*
Total	**29.6**		**30.9**		**17.6**		**130.0**	

Data from the Food and Agriculture Organization, FAOSTAT, 2008.

Poverty, food security, human health and water stress are correlated (Falkenmark, 1986; Goklany, 2009; Oluoko-Odingo, 2011). In a study of household data from 367 sub-national units in Africa, de Sherbinin (2011) finds that after controlling for income, three variables are significantly correlated with child malnutrition: drought prevalence, the proportion of households without piped water, and the prevalence of diarrheal disease. The proportion of underweight children exceeds 30% in most sub-national units across the African Sahel. The UN Millennium Development Project has identified several 'hot spot' countries where malnourishment is prevalent (Eriksen et al., 2011). Many of these countries are characterized by semi-arid and dry, sub-humid hydro-climates. These include the savannahs and steppe ecosystems, where most food is produced in rainfed settings and where water scarcity constrains crop production (Rockström et al., 2005).

If we wish to improve child nutrition and enhance food security more broadly, we must manage land and water wisely in rainfed areas, while increasing the output of farmers and pastoralists. Crop production and animal husbandry provide local sources of food

and, more importantly, they generate the income needed by smallholder households to purchase food in local markets. There is no better way to reduce poverty and enhance food security in the world's rainfed areas than to help smallholder families increase crop and livestock productivity in sustainable fashion.

The potential for improving productivity seems evident, given current gaps between actual and potential yields. The average grain yield in sub-Saharan Africa is about 1 ton per hectare, while average yields elsewhere range from 2 to 10 tons per hectare (CA, 2007). These gaps are due to a combination of factors involving soil and water management. In the Rainfed Systems SRP, we will examine the impacts of land degradation, soil nutrient mining, water scarcity and reduced biodiversity. We will examine also the roles of biodiversity and ecosystem services in supporting crop and livestock production. And we will develop interventions that enable smallholder households to achieve the gains in productivity they need, while also beginning to rebuild soil nutrient and carbon stocks and restoring degraded lands.

There is scope, as well, for increasing the extent of rainfed agriculture in sub-Saharan Africa, particularly in countries such as Angola, the Democratic Republic of Congo, Sudan and Zambia (McKinsey, 2009). However, history has shown that land-use conversion can lead to severe resource degradation. We must study ways of expanding agriculture in rainfed areas, while not harming the supporting ecosystems. We must also learn how to increase cropping intensity in rainfed areas, where household access to fertilizer and other essential inputs currently is inadequate. We will examine both the biophysical aspects of increasing crop and livestock productivity in rainfed areas, and the policies needed to enhance farm-level access to inputs, finance and markets.

5.3. Research, investments and better management are needed

Several authors have argued that investments in agriculture will enhance food security and lift farmers and pastoralists out of poverty only if the programs focus on increasing smallholder production of staple crops and livestock products (Nin-Pratt et al., 2009). Such efforts will produce sustainable outcomes only if other security needs and risks are addressed at the same time. Intensification of agriculture, without sufficient concern for supporting and regulating ecosystem services, can result in land degradation, wind and water erosion, and the loss of biodiversity.

The low, average cereal yields observed in sub-Saharan Africa mask considerable variation across regions and countries. Maize yields obtained by the highest quintile of farm households can be 20 times those of the lowest quintile, within a single district of Kenya, Mozambique or Zambia (Jayne et al., 2010). The variation is due to differences in cultural practices, soil fertility, input use, water management and other characteristics of production that differ substantially among smallholder farmers (Vanlauwe et al., 2006; Tittonell et al., 2008; Okumu et al., 2011).

The variation implies that our science and our solutions must address spatial differences in biophysical parameters and administrative differences in the institutions that

influence farm-level and household decisions. A generic approach to stimulating adoption of alternative management options will not be sufficient. For farmers, the opportunity to move out of poverty is not associated with a single production factor, but rather with a system that involves crop choices, land and water management, storage and transport, and access to markets. Farmers also consider the policy environment in which they operate. Thus, to reduce poverty, we must: 1) provide men and women farmers with better knowledge and technical information; 2) motivate them to adopt technologies that increase productivity; and 3) implement the policies and institutions that improve their representation and access and enable them to succeed.

While embarking on this research program, we will give due attention to emerging issues and opportunities pertaining to agriculture and livelihoods in rainfed areas. For example, we will study the interface between intensification and ecosystem services, and explore the ways in which biodiversity contributes to sustaining rainfed production systems for men and women farmers. We will examine the debate regarding whether or not selected lands should be set aside from agriculture to preserve biodiversity, or whether some forms of farming can enhance biodiversity (Ewers, et al., 2009; Perfecto and Vandermeer, 2010; Phalan et al., 2011).

We will also examine the potential impacts of international investments in farmland, known by some as 'land grabbing,' on land and water resources in rainfed areas (Robertson and Pinstrup-Andersen, 2010; Borras et al., 2011). More importantly, we will also examine the potential impacts on the livelihoods of smallholder households, such as the impacts on women and youth, that are displaced from their land and lose access to water and other resources when international investors develop large areas of land in developing countries (Chaudhuri and Banerjee, 2010; Li, 2011).

5.4. A compelling role for the CGIAR

As we implement this SRP, we will build upon previous work of the Tropical Soils and Biology and Fertility unit of the International Center for Tropical Agriculture (CIAT), ICRISAT, and the recommendations of the Comprehensive Assessment of Water Management in Agriculture (CA, 2007). The 700 researchers engaged in the Assessment concluded that large gains in productivity and notable improvements in livelihoods could be achieved in rainfed areas if we engage in collaborative, interdisciplinary research involving soils, nutrients, water and the roles of ecosystems in supporting crop and livestock agriculture. This is precisely the program we propose.

The new CGIAR, with its wealth of experience in agriculture and NRM, is uniquely prepared to conduct interdisciplinary research regarding the science and policy dimensions of efforts to increase crop and livestock productivity in rainfed areas, while protecting ecosystems. The new collaborations we form in this SRP will strengthen research linkages between biophysical and social scientists, and spur innovative thinking about agriculture in rainfed settings. For example, we will enhance our research output by joining together specialists on water harvesting and researchers who study supplemental irrigation. Such partnerships will be enhanced further by involving

soil scientists, agronomists, agroforestry experts, and livestock specialists. With the inclusion of scientists who study biodiversity and ecosystem resilience, we will have assembled world-class teams ready to conduct the interdisciplinary analyses that are needed to realize our vision of thriving farmers and pastoralists, supported by vibrant natural and agricultural ecosystems.

5.5. Building on a solid research foundation

Many researchers in CGIAR centers already have substantial knowledge of and insight into the challenges facing farmers and pastoralists in rainfed areas. Many have also studied NRM and ecosystem science in such settings. The existing literature provides a helpful understanding of four subject areas that will be central in our research effort: improving soil fertility, improving water management, enhancing pastoral systems, and valuing ecosystem services. We describe each of these in turn.

5.5.1. Improving soil fertility

Many researchers have examined issues pertaining to soil fertility in rainfed areas, particularly in sub-Saharan Africa, and also in South Asia (Sahrawat et al., 2009). Their results point to starting points for our research, and the range of issues we must consider to ensure that our research questions and approaches are appropriate. Among the many issues and interventions examined in previous studies, we highlight just a few that we find particularly relevant.

Vanlauwe et al. (2010) advocate integrated soil fertility management (ISFM) in smallholder African farming conditions. ISFM is defined as a set of soil fertility management practices that necessarily include the use of fertilizer, organic inputs and improved germplasm (e.g. seeds), combined with the knowledge of how to adapt these practices to local conditions. The goal of ISFM is to improve productivity by maximizing the agronomic use efficiency of applied nutrients.

Kibblewhite et al. (2008) describe the importance of soils in the provision of ecosystem services in agricultural and non-agricultural settings. Nutrients, water, organic carbon and biota are important components of those services, which include nutrient cycling, carbon transformation, soil structure maintenance and regulation of biological populations. ISFM involves managing soils in a manner that recognizes the important roles of these ecosystem services.

Tabo et al. (2006) and Twomlow et al. (2010) examine the potential productivity gains from micro-dosing of fertilizer (an ISFM technique), in conjunction with water harvesting, in sub-Saharan Africa. The authors recommend wider adoption of micro-dosing in other challenging environments. Reij and Thiombiano (2003) also examine the potential gains of managing soil fertility and water within a single perspective, rather than separately.

Haggblade and Tembo (2003) examine conservation agriculture, in which cultural practices match smallholder needs and capacities. Adoption of conservation agriculture

has been limited in sub-Saharan Africa, and new research is needed to determine the conditions required for successful implementation. Sanginga et al. (1997) promote soybean–maize cropping systems that provide farmers with dual sets of benefits involving crop rotation and market entry. Several authors have examined measures for improving soil conditions through maize–legume intercropping, and by replacing slash-and-burn agriculture with slash-and-mulch systems on hillsides in Central America (Ayarza and Wélchez, 2004; Castro et al., 2009; CIAT, 2009).

5.5.2. Improving water management

Oweis and Hachum (2006) examine the combined management of rainfall and irrigation water in settings where deficit irrigation can enhance productivity. The authors note the importance of considering also the roles of plant nutrients and cultivars. They show that crop yields can be increased substantially in some settings when applying as little as 100 mm to 300 mm of water to alleviate stress during dry spells.

Supplemental irrigation has enabled farmers in Morocco, Syria and Tunisia to plant responsive wheat varieties and apply more inputs, thus enabling them to achieve yields of 5–6 tons per hectare in rainfed settings (Ben Mechlia and Masmoudi, 2003). By combining farm water harvesting with supplemental irrigation, the farmers also reduced erosion. In Inner Mongolia and Gansu Province, China, farmers doubled their yields of potatoes by changing from conventional, supplemental irrigation to partial root-zone drying (Xie et al., 2011). Water harvesting and water storage (in the soil, in ponds and reservoirs, or in aquifers, through groundwater recharge) can help farmers adapt to climate change (Oweis and Hachum, 2006).

Several authors have engaged in research at the watershed scale, often examining both biophysical and economic dimensions of agricultural and natural resource issues. For example, some have examined measures to achieve desired changes in watersheds, including traditional policy and land reform instruments, market-based incentives, and benefit-sharing mechanisms (Wunder, 2005, Wani et al., 2008). Several interventions in benchmark watersheds in China, India, Syria, Thailand and Vietnam have demonstrated the possibility of providing tangible economic benefits to small and marginal farmers, who are mostly women, through enhanced rainwater-use efficiency and targeted income-generating activities (Wani et al., 2008,).

5.5.3. Enhancing pastoral systems

Existing research is helpful in understanding critical aspects of rangeland productivity, water management, land degradation, and the role of ecosystems in supporting crop and livestock production in rainfed areas. Yet knowledge gaps exist, as pastoral systems have long occupied the margins of mainstream agricultural research.

Pastoral systems are highly dynamic and undergo rapid change in response to many factors, such as loss of access to water and land resources, in addition to climate variability (Campbell et al., 2006; Hobbs et al., 2008; WISP, 2008). Pastoralists cope by diversifying into non-livestock related activities to secure their household incomes (Little et al., 2008), a strategy that is debated in light of further loss of land and water

resources, climate change, and low investment in pastoral areas (Hobbs et al., 2008; Devereux and Scoones, 2006; Birch and Grahn, 2007). However, there is no understanding of the implications of these drivers of change on the ability of rangelands to support pastoral and new livelihood activities (Sanford and Scoones, 2006).

Access to land and water resources over wide stretches of land is critical to the maintenance of pastoral livelihoods and the survival of their communities (Niamir-Fuller 1998; Butt et al., 2009). Pastoralist access to critical zones better endowed with water resources, such as river valleys and highlands, is increasingly threatened by encroachment of agriculture, including irrigated and rainfed farming, and the establishment of conservation areas (Angassa and Oba, 2008; Lamprey and Reid, 2004). Resolution of these competing claims requires careful planning and policy negotiation at local, national and regional levels. Yet technical and policy interventions at any level meet constraints at up and down existing administrative hierarchies (Lamprey and Reid, 2004).

Debate remains over the extent to which rangelands are degraded and what scope there is for restoration. Restoration of degraded rangelands and sustainable improvements in their productivity will not succeed without community involvement (WISP, 2008; Mortimore 2009), as pastoral systems are dynamic and locally specific. Local communities know their needs best (Desta and Coppock, 2004), as herders have a deep understanding of the rangeland systems they have used for generations (Oba and Kaitira, 2004). Participatory land-use planning with herders is a potentially viable, yet little explored, approach to successful rangeland restoration and management (Reid et al., 2000; Reid et al., 2009).

Opportunities for generating greater social benefits are highly context-specific and are a function of variability in herd size, environment, market access, range condition, attitudes towards risk, property rights regimes, and the ability to move to different grazing areas (Baker and Hoffman, 2006; Campbell et al., 2006; Sanford and Scoones, 2006; Butt et al., 2009). Pastoralism is a complex socioecological system (Cioffi-Revilla, 2010), and complexity must be considered when exploring livelihood-enhancing solutions.

5.5.4. Valuing ecosystem services

Several researchers in the CGIAR have advanced understanding of the value of ecosystem services in supporting agricultural production, improving smallholder livelihoods and achieving sustainability (Frison et al., 2011). Researchers have also examined the role of biodiversity in the control of pests and diseases, and the importance of within-crop diversity to smallholder farmers (Jarvis et al., 2007, 2008). Smale (2008) and Drucker (2007, 2010) have investigated the economics of biodiversity maintenance in crop and livestock production. Others have examined the role of biodiversity in improving sustainability and enhancing resilience, while also considering the policies that might be helpful in ensuring that biodiversity is maintained in agricultural settings (Jackson et al., 2010; Halewood, 2011).

5.6. Our Theory of Change for rainfed systems

Men and women farmers will not invest in managing natural resources or protecting ecosystems unless they see a clear financial gain within a reasonable timeframe, and they are assured that the gain will be theirs to receive. Thus, we must determine the right mix of policies, incentives, and the assignments of property rights to land and water if we wish to motivate farm-level investments in desirable production practices. We must also reduce the farm-level costs and risks associated with technology adoption and the use of fertilizer and other costly inputs in rainfed settings. And we must develop mechanisms that enhance interactions involving different groups of farmers, government agencies and research partners.

Land and water resources are becoming scarcer, owing partly to increasing demands for food, feed and biofuels. New legislation and enforcement will be needed in some countries to ensure that smallholder farmers retain access to the resources they need to support their livelihood activities. Such efforts should include consideration of incentives to encourage farm-level and regional investments that will enhance the protection of supporting ecosystems.

Substantial investments are needed to reverse land degradation and begin rebuilding soil nutrient and carbon stocks in rainfed areas, particularly in sub-Saharan Africa and South Asia. At the same time, the cost of inaction is substantial. The opportunity costs of the agricultural and livelihood benefits foregone, as land degradation takes its toll on crop and livestock productivity, likely are much larger than the cost of restoring degraded lands. And that cost can be shared among partners engaged in the restoration effort, such as governments, international donors, and nonNGOs that promote sustainable improvements in livelihoods in challenging environments.

In preparing this Theory of Change, we have identified four levers pertaining to the scientific and policy issues we will address and the countries in which we will work:

1. **Recommending policies**
   Based on the results of our scientific studies, we will develop policy recommendations to enhance livelihoods of both men and women through wiser management of land and water resources in rainfed areas. We will engage in formative discussions with community representatives, donors and public officials across the regions in which we work. In Africa, we will build strong links within the CAADP process and other regional policy and investment initiatives.

2. **Supporting development**
   We will work with development partners to identify contextual barriers to change, to enhance the planning and effectiveness of programs and promote the adoption of specific interventions. We will provide data and analysis that allow prediction of the on-farm and off-site impacts of large-scale technical, financial and policy interventions. We will develop watershed models and monitoring programs to enhance understanding of sustainable resource management.

3. **Promoting participation**
   We will promote participatory approaches to planning, monitoring and evaluation, in which men and women farmers engage with local development partners as they improve their agronomic practices. This will increase the attention given to individual and community values, while also empowering households to negotiate institutional arrangements with relevant authorities.

5.7. Our links with other SRPs and CRPs

Within CRP5, we will interact most closely with researchers in the Basins and Information Systems SRPs. Regarding other CRPs, we will interact most closely with CRP1.1 (Integrated agricultural production systems for dry areas), CRP1.2 (Integrated systems for the humid tropics), CRP2 (Policies, institutions, and markets to strengthen assets and agricultural incomes for the poor), and CRP7 (Climate Change, Agriculture and Food Security). We will add value to the information developed in CRP1.1 and CRP1.2 at the farm and field levels, by incorporating those results in our research at watershed and landscape scales. The farm and field results will be helpful as we examine opportunities to improve land use planning and we craft public policies that provide incentives for managing natural and agricultural ecosystems in sustainable ways.

We will also incorporate the results of CRP2, regarding institutions, policy, and gender. Recommendations regarding market incentives and institutional change will be particularly relevant to our work on efforts to intensify agriculture in rainfed areas. In return, the information we develop on land degradation, and the constraints and opportunities pertaining to agricultural intensification, will contribute to the policy analysis conducted in CRP2. We will integrate the outputs of CRP5 with those of CRP3 (on wheat; maize; rice; roots, tubers and bananas; grain legumes; dryland cereals; and livestock and fish), to enhance adoption of management practices that will increase productivity.

The results produced in CRP7 will also be helpful as we construct scenarios depicting alternative land and water management interventions in rainfed areas of Asia and Africa. We must consider the potential impacts of impending climate change on hydrology and crop production in rainfed areas, as we conduct our research. The insight we gain regarding restoration of degraded landscapes, the improvement of pastoral systems, and the rebuilding of soil carbon stocks will serve as inputs to CRP7 research on mitigation and adaptation to climate change.

We will also interact with the CRP researchers who are developing crop varieties that are better adapted to variations in natural resource conditions. We envision constructing scenarios that include combinations of improvements in NRM and the availability of new crop varieties better suited for future conditions.

5.8. Research partners

Perhaps one of the greatest assets of the Rainfed Systems SRP will be our ability to work outside the silos that have traditionally limited the added value of research on soils, water and nutrient management. Indeed, we will form truly interdisciplinary research teams involving traditional partners (NARES, ARIs and CGIAR centers) and others involved in agriculture and NRM and with close links with communities. We will also develop close links with pertinent UN agencies in an ongoing effort to generate and extend the discussion of international public goods. During the inception phase we will define precise roles for existing and new partners with respect to each of the problem sets. We envision four types of partnerships as we engage in this research: 1) core research; 2) implementation; 3) influence and outreach partners; and 4) international conventions. Table 5.1 provides examples of the organizations likely to be involved.

International conventions

In addition to developing research partnerships, such as those described above, we will develop strong links with selected international conventions. Given our focus on land degradation and our interest in determining options for balancing the development of diverse ecosystems, including wetlands and the dry margins between agricultural and pastoral systems, we envision helpful alliances with the UN conventions to combat desertification (UN Convention to Combat Desertification; UNCCD), promote biological diversity (UN Convention on Biodiversity; UNCBD), and protect wetlands (Ramsar Convention on Wetlands). IWMI's current partnership with Ramsar will serve as a helpful guide in establishing new relationships. As an International Organization Partner (IOP) of Ramsar, IWMI scientists participate in the Science and Technical Review Panel, actively contributing to expert working groups addressing the issues of: 1) wetlands and poverty alleviation; 2) wetlands and agriculture; 3) wetlands inventory and assessment; and 4) wetlands and climate change.

5.9. Where we will work

We will work in selected regions of Africa, Asia and Latin America, conducting research to generate international public goods regarding pressing issues in rainfed areas. We provide a few examples of the issues we will address, by region and farming system.

- In ***sub-Saharan Africa and South Asia*** we will examine measures to restore degraded landscapes and improve soil health by rebuilding nutrient stocks and improving water management.

- In ***East and West Africa and South Asia*** we will examine the balance between efforts to improve livelihoods and efforts to enhance ecosystem services.

- Also in ***East and West Africa*** we will determine how better land-use planning that supports mobility and provides access to dry-season grazing areas can reduce conflicts over competing land uses, while improving livelihoods in crop and pastoral systems.

- In ***Latin America and Southeast Asia*** we will examine ways to intensify production in rainfed rice systems and mixed upland cropping systems, while maintaining critical ecosystem services such as flood regulation, soil retention, and pest and disease control. We will also examine ways of intensifying agricultural production, while retaining biodiversity in the transition zones between forests and intensive cropping areas.

- In ***Central and West Asia and North Africa***, we will examine the potential for intensifying agriculture in favorable rainfed settings and enhancing the resilience of farming communities in less favorable settings, while increasing our understanding of the consequences of intensification on ecosystems.

Table 5.1. CRP5's likely partners on the Rainfed Systems SRP

Region/Basin	Core Research	Implementation	Outreach
Southern Africa (Limpopo – Zambezi)	American University of Beirut; Univ. of Natural Resources and Applied Life Sciences (BOKU); Swedish University of Agricultural Sciences (SLU); Wageningen University and Research Centre (WUR); Univ. of Free State (UFS), RSA; Univ. of Zimbabwe (UZ); Bunda College of Agriculture – University of Malawi; University of Bonn;	Catholic Relief Services (CRS); WorldVision; Cooperative for Assistance and Relief Everywhere (CARE); International Fertilizer Development Centre (IFDC); International Plant Nutrition Institute (IPNI)	IUCN; World Resource Institute (WRI); Convention on Biological Diversity (CBD); UN Framework Convention on Climate Change; African Ecosystem Research Network (CAS-UNEP)
Western Africa (Volta and Niger)	The International Institute for Geo-Information Science and Earth Observation (ITC); Colorado State University (CSU); University of Colorado; Wageningen University and Research Centre (WUR); Institute for Agricultural Research (IAR), Nigeria;	Institute d'Economie Rural IER); Institute National de la Recherche Agronomique de Niger (INRAN), Niger; Institute de l'Environnement et de Rescherche Agricoles (INERA), Burkina Faso; Vétérinaires Sans Frontières (VSF); SOS Sahel;	IUCN; World Resource Institute (WRI); UN Convention to Combat Desertification (UNCCD), Convention on Biological Diversity (CBD); UN Framework Convention on Climate Change; African Ecosystem Research Network (CAS-UNEP); Animal Production Researching Department (UNEP-DIPA); FAO Livestock Emergency Units World Initiative for Sustainable Pastoralism under IUCN (IUCN-WISP);
East Africa (Nile)	International Fertilizer Development Center (IFDC); Univ. of Natural Resources and Applied Life Sciences (BOKU); Catholic University of Leuven, Belgium; Swedish University of Agricultural Sciences (SLU); Wageningen University and Research Centre; National Resource Conservation Service (NRCS); Colorado State University (CSU); University of Colorado; UC Davis; Makerere University Kampala (MUK), Uganda; Addis Ababa University (AAU); Univ. of Nairobi (UON); Moi University, Kenya; Kenyatta University, Kenya; Sokoine Univ. of Agriculture (SUA), Tanzania;	Catholic Relief Services (CRS); Selian Agricultural Research Institute (SARI), Tanzania; Mlingano Agricultural Research Institute (MARI), Tanzania; Ayole Agricultrual Research institute (AARI), Tanzania; Ethiopia Institute of Agriculture Research (EIAR); Amhara Regional Agricultural Research Institute (ARARI), Ethiopia; Kenya Agricultural Research Institute; Institute des Sciences Agronomique du Rwanda (Rwanda	IUCN; World Resource Institute (WRI); Conservation International (CI); UN Convention to Combat Desertification UNCCD), Convention on Biological Diversity (CBD); UN Framework Convention on Climate Change; African Ecosystem Research Network (CAS-UNEP); Animal Production Researching Department (UNEP-DIPA); FAO

		Agricultural Research Institute) (ISAR); UCB, DR Congo; Cooperative for Assistance and Relief Everywhere (CARE); Grameen Foundation; International Plant Nutrition Institute (IPNI)	Livestock Emergency Units; World Initiative for Sustainable Pastoralism under IUCN (IUCN-WISP);
South Asia (Indus and Ganges)	State Agricultural Universities, India; Jawaharlal Nehru University (JNU); Univ. of Agricultural Sciences Bangalore (UAS)	Indian Council of Agricultural Research (ICAR); Bharatiya Agro Industries Foundation, India; Watershed Organization Trust, India ; SevaMandir, India; SM Sehgal Foundation, India; Aga Khan Foundation	
Middle East (Tigris and Euphrates)		General Commission for Scientific Agricultural research (GCSAR), Syria; Education and Extension Organization (AREEO), Iran; General Commission for Scientific Agricultural research (GCSAR), Syria; National Center for Agricultural Research and Extension (NCARE), Ministry of Agriculture, Jordan;	
Southeast Asia (Mekong) (more for CIP than CIAT)	Chinese Academy of Agricultural Sciences (CAAS); Guizhou Academy of Agricultural Sciences (GAAS)		
Southeast Asia (Mekong) (For CIAT)	Chinese Academy of Tropical Agricultural Sciences (CATAS); Chinese Academy of Agricultural Sciences (CAAS); Chinese Academy of Sciences (CAS);Guangxi Subtropical Crops Research Institute (GSCRI); Yunnan Academy of Agricultural Sciences (YAAS) Guangxi Academy of Agricultural Sciences (GAAS); Vietnam Academy of Agricultural Sciences (VAAS) and constituent institutes; Tay Nguyen University (TNU); Thai Nguyen University of Agriculture and Forestry (TNUAF); Nong Lam University (NLU); Hue University of Agriculture and Forestry (HUAF); Royal University of Agriculture (RUA) of Cambodia, Cambodian Agricultural Research and	Ministry of Agriculture and Rural Development (MARD) of Vietnam plus Provincial and District authorities; Ministry of Agriculture and Forestry (MAF) and Provincial and District Agriculture and Forestry Offices (P/DAFO); National Agriculture and Forestry Extension Service (NAFES); Thai Tapioca Development Institute (TTDI); Thai Department of Agricultural Extension (DOAE); Northern Agriculture and Forestry College (NAFC) in	ADB and IFAD Loan/Investment projects; CARE; Catholic Relief Service (CRS); Oxfam; World Vision (WV); Christian Reformed World Relief Committee (CRWRC); Adventist Development and Relief Agency (ADRA); and other NGOs and Development Projects

	Development Institute (CARDI); Kasetsart University Thailand (KU); Khon Kaen University (KKU); Chiang Mai University (CMU); Thai Department of Agriculture (DOA); Yezin Agriculture University (YAU), Burma; Department of Agricultural Research (DAR) Burma; National Agriculture and Forestry Research Institute (NAFRI); National University of Laos (NUOL); Commonwealth Scientific and Industrial Research Organisation-Australian Animal Health Laboratory (CSIRO-AAHL); University of Queensland (UQ); University of New England (UNE); Charles Sturt University (CSU); Japan International Research Center for Agricultural Science (JIRCAS); Institut de Recherche pour le Développement (IRD); Centre de coopération Internationale en Recherche Agronomique pour le Développement (CIRAD);	Luang Prabang; Battambang University (BBU); General Directorate of Agriculture (GDA) Cambodia; Provincial Departments of Agriculture in Cambodia; SNV; Helvetas; Gesellschaft für Internationale Zusammenarbeit (GIZ)	
Central Asia (Amu Darya and Syr Darya)		SENNIRI, Uzbekistan;	IUCN
Latin America and Caribbean (Andes basin, South America savannas and Central America hillsides)	Instituto de Ecologia (IoE), Mexico; Tropical Agronomic Centre for Research and Higher Education (CATIE), Costa Rica; Museu Paraense Emilio Goeldi (MPEG); EMBRAPA Amazonia Oriental; Universidad Federal do Para (UFPA), Universidad de la Amazonia (Florencia), Universidad Tecnologica Pereira (UTC), Université Antilles Guyane, INRA Guadeloupe, National University of Agriculture (UNA), Nicaragua; National School of Forest Sciences (ESNACIFOR), Honduras; National University of Colombia (UNAL), Colombia; University of Western Australia (UWA), Australia; Swiss Federal Institute of Technology – Zurich (ETH Switzerland); University of California, Davis; Japan International Research Center for Agricultural Sciences (JIRCAS), Japan; International Maize and Wheat Improvement Center (CIMMYT); Cornell University; Integrated Management of Soil Consortium in Central America (MIS)	Nicaraguan Institute for Agricultural Technology (INTA/CENIA), Nicaragua; Direction of Science and Farming Technology (DICTA), Honduras; Ministry of Agriculture and Rural Development (MADR) Colombia; Colombian Coorporation for Agricultural Research (CORPOICA); Consortium for the Sustainable Development of the Andean Eco-region (CONDESAN), Peru	IUCN; Food and Agriculture Organization of the United Nations (FAO), Central America

5.10. Five years and five problem sets

We have selected five Problem Sets that will determine our research foci during the next five years, as outlined in sections 5.10.1–5.10.5.

5.10.1. Problem Set 1: Recapitalizing African soils and reducing land degradation

The soils in rainfed agricultural systems provide important ecosystem services that underpin agricultural production. They store and cycle water and nutrients that are critical in the production of crops and forages for livestock. Soils harbor organisms that fix nitrogen and make other nutrients available for crops. They have a role also in the transformation of carbon, which maintains soil structure and fertility. Despite the critically important role of soils, farmland and grazing areas have been degraded over time, and nutrients have been mined, rather than replenished each season.

Land degradation is caused largely by unsustainable land management practices that result in the loss of nutrients due to erosion and soil nutrient mining, loss of soil carbon and the associated loss of soil biota. On severely degraded lands, applications of nitrogen, phosphorus and potassium have limited effects on crop yields. Thus, even if farmers on such lands could afford supplemental fertilizer, the additional nutrients would not necessarily increase their net returns.

We will examine technical interventions and policy options for restoring nutrient balances in African soils and reducing land degradation. We will consider the implications of population pressure, the roles of input and output prices, and the lack of information available to men and women farmers and pastoralists regarding soil constraints, nutrient balances and land degradation. We will consider also the potential role of carbon sequestration programs, which may enhance soil fertility and soil moisture status (World Bank, 2010). We will determine if carbon credits and other payment for environmental service programs might be helpful in motivating farmers to restore the carbon, nutrient and water cycles of degraded soils (Thomas, 2008; Ferraro, 2009; Jack, 2009; Swallow et al., 2010).

We will develop methods for identifying nutrient limitations cheaply and efficiently at a given location, to reduce the risk of large financial losses when applying fertilizer. We will also examine opportunities for increasing biomass production at the farm level and across agricultural and pastoral landscapes, thus providing greater opportunities for restoring soil organic matter.

Guiding hypothesis
We can restore agricultural productivity on degraded lands within 5 to 10 years by providing farmers with affordable access to fertilizer and helping them to implement practices that restore desirable levels of carbon, phosphorus, nitrogen, and limiting meso- and micro-nutrients in soils, while minimizing the impact on supporting ecosystems.

Examples of research questions

1. What are the best ways to replenish carbon, phosphorus, nitrogen and potassium in depleted soils?
2. What are the implications of meso- and micro-nutrient deficiencies, and how can these be identified and ameliorated?
3. How can we identify and ameliorate soils that are not responsive to simple fertilizer packages?
4. What opportunities exist for developing organic and bio-fertilizers?
5. What is the potential for developing biological forms of nitrogen fixation?
6. What is the potential for biochar production in rainfed areas?
7. Which restoration techniques are available, and which are most appropriate?
8. What production methods are most appropriate for use on restored lands?
9. What incentives would increase the likelihood of adoption by poor men and women farmers?
10. What policy constraints discourage adoption, and how might those be resolved?
11. What is the carbon sequestering potential in rainfed areas, what is the feasibility of implementing carbon credit programs across extensive landscapes, and how might farm households benefit?

The impact pathway for this Problem Set is further detailed in Table 5.2.

Table 5.2. Impact Pathway: Recapitalizing African soils and reducing land degradation

Issues	Levers of change	Research outputs	Outcomes	Potential impact	Contribution to SRF outcomes
Poor soils that show no significant response to application of macro-nutrients are a pervasive problem, and require a dedicated effort to restore soil fertility. Degradation is the result of unsustainable land management in combination with vulnerable soils or soils of low inherent soil fertility. This leads to loss of soil carbon and degradation of soil structure, with consequences for available soil water and the biological activity that underpins agricultural production. Solutions must combine integrated soil fertility management (ISFM) with soil conservation measures, land-use options and land-use planning options for area-wide intervention.	• Information on land degradation status and associated costs raises awareness of associated problems and increases preparedness • Effective linkages with international initiatives such as UNCCD and CAADP • Information on local variation in land degradation and soil productivity to target investments • Benefits from carbon sequestration in agricultural lands to be generated through carbon credits • Documentation of sustainable land management practices with associated costs and predicted benefits.	• Assessment of land degradation status and analyses of soil and land health problems at various scales; identification of areas available for expansion of agricultural land through restoration of degraded areas and through land conversion. • Review and evaluation of integrated solutions to restoring degraded soils, including soil conservation, ISFM and water-conservation technologies • Improved pastures and agroforestry systems • Tools for land-use planning and area-wide approaches to restore degraded agricultural landscapes • Evaluation of local organizational structures for rehabilitation of degraded landscapes • Evaluation of policies and national action plans to address desertification, land degradation and drought.	• Increased awareness of severity and acuteness of land degradation will generate policy support and secure investments in combating land degradation and restoring degraded lands • Detailed information on land degradation status and identification of effective management practices will result in more effective interventions • Proper incentive structures and proven management practices will enhance adoption by farmers of practices for restoring soil fertility • Adoption of effective management will restore soil fertility over time and increase the area of productive soils.	• Soil resource base expanded and improved, improving the livelihoods of up to 5 million households in rural areas • Increased production providing food security and income opportunities for an estimated 5 million households • Reduced vulnerability and increased resilience of an estimated 1 million rural households.	Sustainable management of natural resources; food security.

5.10.2. Problem Set 2: Revitalizing productivity on responsive soils

Not all soils in rainfed areas are degraded. Many soils have the potential to support good yields, but farmers lack the inputs and information needed to realize that potential. We consider such soils to be responsive, as they will produce good yields if farmers apply the right inputs and manage their fields appropriately, and if adequate rainfall arrives with good timing. To be sure, there are many uncertainties in rainfed areas that even the best soils cannot overcome. Yet in this Problem Set we emphasize and develop the potential of responsive soils, and demonstrate the improvements in crop and livestock production made possible by providing men and women farmers with the inputs and information they need to generate better yields. If successful, the gains in aggregate productivity across large areas of Asia and Africa will be substantial.

Our research in this Problem Set will involve combinations of agronomic, hydrologic and economic analysis. We will begin by locating responsive soils, using the Africa Soils Information Service. We will then examine methods of increasing fertilizer use on responsive soils, while acknowledging the costs and inherent risks involved for farmers, with a particular focus on understanding gender-based constraints. We will also study potential changes in crop choices and will develop recommendations regarding cropping patterns, plant nutrients and water requirements for use on responsive soils. , To support higher productivity, we will examine the potential for improving water-harvesting activities in rainfed areas. We will also propose enhancements in farm-level access to input and output markets, and improvements in land-tenure regimes, so that both men and women farmers will have the necessary incentives and opportunities to invest in revitalizing the productivity of responsive soils.

Guiding hypothesis

Substantial gains in farm-level productivity and the aggregate output of crop and livestock products can be achieved by providing men and women farmers and pastoralists with the information and inputs needed to revitalize the productivity of responsive soils in rainfed areas.

Examples of research questions

1. What is the current extent of responsive soils in selected rainfed areas of Asia, Africa and Latin America?
2. What are the binding constraints that limit crop and livestock productivity?
3. How can those binding constraints be relaxed, while also enhancing the ecosystem services that support agricultural production?
4. What investments and policy alternatives would be helpful in supporting widespread improvements in access by men and women farmers to input and output markets, in the interest of promoting greater use of fertilizer and providing opportunities to receive higher prices for crop and livestock products?

The impact pathway for this Problem Set is further detailed in Table 5.3.

Table 5.3. Impact Pathway: Impact Pathway: Revitalizing Productivity on Responsive Soils

Issue	**Levers of change**	**Research outputs**	**Outcomes**	**Potential impact**	**Contribution to SRF outcomes**
Many soils, including those with high potential, produce small yields because farmers lack information, knowledge and skills, and they have limited access to input and output markets. Many soils are constrained by nutrient limitations but would respond to nutrient application. If these soils can be identified and managed appropriately, significant increases in yield are possible without environmental degradation.	• Providing information and knowledge on integrated soil fertility management (ISFM) to help farmers achieve realistic production targets • Training to improve farmer skills to implement ISFM • Risk insurance mechanisms to provide incentives for investment in production-enhancing technologies • Establishing farmer organizations to improve access to markets, land and water resources, and better linking of local enterprises • Working with CAADP to encourage policies to support these actions.	• Assessment of local variation in yields, yield potential, local land and soil health status, risk of drought, erosion risk, agronomic practices, and socioeconomic characteristics • Analyses of yield gaps and diagnoses of production constraints; responses to nutrient application, drivers of change; resource-use efficiency at different scales; analyses of local policies and incentives, institutions and farmer organizations • Review of ISFM options and technologies to improve nutrient availability and plant uptake, and to improve soil fertility; land-use options for cereal-legume intercropping and rotations, crop-livestock systems and area-wide integration of enterprises • Decision support tools for development practitioners and farmers • Monitoring-and-evaluation tools for farm performance, resource-use efficiency and effectiveness of local organizations.	• Development practitioners and government agents, aware of production potential and major constraints, target their interventions and investments for site-specific solutions • Suite of management options sustainably increase productivity • Incentives developed to enable farmers to adopt these options; better crop insurance products • Farmers improve their productivity by adopting improved technology and improving soil fertility management.	• Production increase because of improved ISFM, tripling yield of major food crops for potentially 15 million farmers and household members • More sustainable production and improved resilience • Significant income and food production benefits for 15 million farmers.	Food security; sustainable management of natural resources; poverty reduction

5.10.3. Problem Set 3: Increasing agricultural production while enhancing biodiversity

We will examine the benefits to crop and livestock production of diversifying agriculture in ways that reduce risk and enhance resilience. Diversification can include expanding the genetic diversity within agriculture by increasing the number of crop varieties and livestock breeds, and planting trees across agricultural landscapes. Such changes can improve productivity and reduce the impacts of uncertain rainfall, plant disease and pest infestations. We will explore opportunities for achieving desirable levels of agricultural biodiversity, in conjunction with improvements in soil and water management practices. We will determine how to achieve agricultural intensification, while preserving or enhancing biodiversity, within watersheds and across landscapes.

In conducting this research, we will consider the policy dimensions and gender aspects of efforts to enhance biodiversity in production systems, as we endeavor to strengthen the social institutions that support biodiversity enhancement (Jarvis et al., 2011).

Guiding hypothesis

It is possible to increase agricultural output and enhance biodiversity in rainfed areas through improvements in soil and water management practices.

Examples of research questions

1. What is the state of ecosystem services that underpin agricultural production and how do we map, monitor and value those services?
2. What are the most important trade-offs between short-term and long-term gains during agricultural intensification, including those pertaining to the provision of ecosystem services?
3. How can monitoring and evaluating ecosystem services improve decision-making?
4. How can biodiversity be enhanced and harnessed to increase the provision of ecosystem services including pollination, pest and disease control, and maintaining biomass to regulate water cycling and soil retention?

The impact pathway for this Problem Set is further detailed in Table 5.4.

Table 5.4. Impact Pathway: Increasing agricultural production while enhancing biodiversity

Issues	**Levers of change**	**Research outputs**	**Outcomes**	**Potential impacts**	**Contribution to SRF outcomes**
Agricultural intensification may result in degraded landscapes in which the ecosystem services that are essential for sustaining agricultural production are compromised. This is especially relevant for low- and medium-input agriculture. The loss of ecosystem function is associated with loss of biological and genetic diversity and beneficial organisms. This may refer to useful trees in the landscape that provide fuel wood and fruits, or to the loss of medicinal plants, the disappearance of predators and pollinators, and the loss of below-ground biodiversity.	• Mechanisms for sharing benefits from ecosystem services and reward mechanisms for ecosystem services will stimulate investment in resource conservation and reduce external inputs • Raising awareness and increasing knowledge on biodiversity is important for sustainable agricultural production • Regulatory frameworks and establishing protected and restricted areas; arrangements for competing claims.	• Integrated assessment and diagnosis of landscape integrity: livelihoods and wellbeing of people; food security and income generated; composition and structure of the landscape, biodiversity and ecosystem services (pollination, regulating of plant and diseases, soil erosion control, regulation of greenhouse gas emissions, regulating of water balance) • Analyses and diagnoses of land health: landscape composition and structure as a determining factor for ecosystem functioning and human wellbeing; modeling this relationship; tools for landscape design • Review and evaluation of options for reconstructing landscapes • Participatory methods for landscape and environmental planning; evaluation of options for Payment for Environmental Services and sharing benefits from natural resources.	• Management of ecosystem services and environment al quality is mainstreame d in development programs • Healthy environment that provides food security, shelter and sustained ecosystem services	• Reduced vulnerability and increased resilience • Improved sustainability of food production, reduced land degradation and halted desertification, and multi-functional landscapes.	• Significant contribution to sustainable management of natural resources

5.10.4. Problem Set 4: Enhancing availability and access to water and land for pastoralists

Increasingly pastoralists are confronted with reduced availability of and access to water resources. As the demands for food and biofuels increase, pastoralists are at risk of being deprived of access to their traditional resources, with limited possibilities to seek replacement sources of forage and water for their livestock. These land-use changes are often motivated – while bypassing the issue of who has the rights to these resources – by the argument that crop-based systems are more productive. This might be true in years of good rainfall for the more water-endowed parts of the lands used by pastoralists, but pastoralism offers more profitable use of the landscape at large. Deprivation of men and women pastoralists from their lands and resources leads to undesirable overuse, land degradation and diminished productivity.

Clearly there is a need to stop the infringement on the land and water resources used by and belonging to pastoral land users. We will help pastoralists secure rights and access to these resources and generate evidence on the resource-use economics of pastoral production. We will begin by convening stakeholders in selected regions of East and West Africa, to learn of the seemingly intractable constraints facing farmers and pastoralists in rainfed areas in light of increasing population density, rising food prices, and increasing competition for limited land and water resources.

Guiding hypothesis
Securing access to and improved water management will enable pastoralists to sustain and improve livestock productivity and enjoy better livelihoods.

Examples of research questions
1. How do competing claims for land and water affect pastoral and agro-pastoral livestock production systems and associated livelihoods?
2. How do the benefits of these competing land uses, including the various tradeoffs, compare with lands kept under pastoral and agro-pastoral management?
3. What are the opportunity costs of pastoralists and agro-pastoralists no longer being able to use land and water resources because of infringements upon their rights by outsiders?
4. What compensation would be reasonable and what are these new resource users willing to pay for the lost opportunity?
5. To what extent are livestock production and livelihood benefits lost as a result of livestock damaging soil structure and reducing their water-storing capacity?
6. What rainwater management options and practices exist that will improve forage production and water use?
7. How will the proposed agenda to secure rights of pastoralists impact e ancillary ecosystem services and international public goods such as climate regulation and biodiversity conservation and what opportunities exist for pastoralists to benefit from these rights?

8. Are different gender and generations affected differently, and how do we ensure the equitable access to and benefit from existing pastoral management practices and opportunities to change these.?
9. What are current policies and institutional arrangements under which loss of access to pastures occurs and what limits pastoralists effectiveness to secure access rights?
10. What opportunities exist for improving policies and institutional arrangements to secure access rights to lands, water and forage?
11. What will be the likely impacts of climate change on water availability and access, and what strategies might mitigate those impacts?

The impact pathway for this Problem Set is further detailed in Table 5.5.

Table 5.5. Impact Pathway: Enhancing availability and access to water and land for pastoralists

Issues	Levers of change	Research outputs	Outcomes	Potential impacts	Contribution to SRF outcomes
• Raising livestock is an effective form of food production and livelihood generation in areas where soil and water resources are not sufficient to support crop production. Yet such areas are increasingly converted for crop and biofuel production, thus increasing risk and impairing pastoralist livelihoods. Available lands are then overgrazed and degraded.	• Providing evidence that raising livestock is more productive than other land uses in many areas • Supporting pastoral communities with science-based arguments and advocacy to secure land tenure and water access rights • Providing recommendations to restore the water balance of degraded lands to increase vegetation biomass production • Demonstrating the value of restoring ecosystem services that support livestock production.	• Assessment of drivers of change and impacts of land-, water- and vegetation-related constraints leading to risk in pastoral systems • Review of options to reduce risk through securing rights to land and access to water, and improving management of land, water and vegetation, including the enabling policies and incentives required to adopt these options • Action-based research to support initiatives that secure rights and improve the use of natural resources and sustain the benefits from ecosystem services • Monitor and evaluate, with communities and development practitioners, the effectiveness of ongoing interventions aimed at the above, and enhance the research-for-development cycle.	• Government policies support rights to land, water and vegetation, and enhance incentives to reduce risk and increase benefits from ecosystem services in arid lands • Development practitioners informed about opportunities to reduce risk related to loss of access to natural resources and the potential to acquire benefits from ecosystem services • Livestock keepers secure their rights to land, water and vegetation, and adopt improved land and ecosystem management to reduce risk and increase income.	• Livestock keepers benefit from secured rights to land, water and vegetation resources, and enhanced ecosystem services • Greater national food and livelihood security – including for pastoral communities – and less reliance on food imports • Global community benefits from pastoral communities managing drylands in such a way as to provide global public goods, including enhanced biodiversity and climate regulation.	• Food security; sustainable management of natural resources; poverty alleviation; risk reduction

5.10.5. Problem Set 5: Reducing risk by providing farmers with supplemental irrigation

We will examine the potential for substantially increasing crop yields through the practice of supplemental irrigation. Our work will build on current knowledge regarding the potential yield-increasing benefits of supplemental irrigation and rainwater harvesting (Rockström et al., 2010, Wani et al., 2008). We will extend that work to consider also the potential gains in income, and improvements in livelihoods, for men and women made possible by irrigating higher-value crops. We will also examine implications for sustainability, equity, and the protection and enhancement of ecosystem services.

Guiding hypothesis

Providing sufficient water to enable supplemental irrigation will reduce the inherent risks of farming in rainfed areas, thus motivating men and women farmers to increase crop yields by applying effective amounts of fertilizer and other variable inputs.

Examples of research questions

1. What are the potential increases in crop yields made possible by providing supplemental irrigation?
2. What will be the changes in yield variability with supplemental irrigation?
3. What non-water constraints might become binding when farmers practice supplemental irrigation?
4. Will supplemental irrigation be sufficient to encourage men and women farmers to change cropping patterns, or will current crop choices prevail?
5. What will be the likely impacts on individual and household incomes and food security with supplemental irrigation?
6. What is the likelihood that supplemental irrigation can be sustained in selected areas, given that the demand for water is increasing in many regions?
7. How can water harvesting enhance soil water and provide water storage to support supplemental irrigation.
8. What are the likely consequences of upstream developments in supplemental irrigation and water harvesting on downstream water users?

The impact pathway for this Problem Set is further detailed in Table 5.6.

Table 5.6. Impact Pathway: Reducing risk by providing farmers with supplemental irrigation

Issues	Levers of change	Research outputs	Outcomes	Potential impacts	Contribution to SRF outcomes
• Water scarcity constrains agricultural production in arid and semi-arid lands. This water scarcity is caused by limited rainfall and competing claims for water resources. Climate variability and low household incomes are putting increasing numbers of rainfed farmers and pastoralists at risk of hunger and poverty.	• Persuading governments and farmers of the food security, nutrition and livelihood benefits of supplemental irrigation • Persuading governments, NGOs and the private sector of the business and poverty-reducing benefits from this strategy; build on Asian experience of water harvesting to deliver similar systems to Africa • Securing rights to water and improved water use to increase livestock production in arid lands.	• Assessment of impact of loss of access to land and water and current rainwater-use efficiency (RWUE) on livestock production • Analyses of (i) drivers of change reducing access to water, and (ii) livestock production achievable under optimal access to water and optimal RWUE • Review of options to secure water access and enhance RWUE, including analyses of incentives to land owners to adopt these options • Provide advice on policies to secure rights to water and create incentives to optimize RWUE in pastoral lands • Deliver information to support development practitioners and pastoralists to secure rights to water and enhance RWUE.	• Government policies support rights to water and create incentives to increase agricultural productivity in arid lands • Farmers and pastoralists invest in greater agricultural productivity, for example by using water-harvesting techniques.	• Secured water rights and improved agricultural productivity for 15 million men and women pastoralists • Less reliance on food imports • Pastoralists less prone to loss of land and water resources.	• Livelihoods; nutrition; food security

5.11. What we will achieve in the second five years

In years 6 through 10, we will consolidate and extend our results pertaining to the initial five Problem Sets. We will build linkages with the Basin and Information Systems SRPs to incorporate our findings into integrated land and water information products that will be made available to farmers via mobile phone technology. We will also synthesize new lessons learned about the relationships between ecosystem services and agricultural intensification into sets of regionally focused policy and management guidelines.

5.12. Implementation plan

The first step in implementing this Rainfed SRP is to convene the CGIAR partners to integrate their ongoing activities. This entails planning work at the same sites, establishing synergies between projects, and planning new projects that fully integrate soil, water and ecosystem services. We will also examine opportunities for further collaboration among CRPs at common research sites and we will establish strategic partnerships with third parties.

While focusing on our five initial Problem Sets, we will also conduct three overarching activities: 1) monitoring and assessment; 2) technology development and practice; and 3) decision support and dissemination.

The monitoring and assessment activities are currently centered on building a soil information service for sub-Saharan Africa. However, we plan to further expand these activities, increasing the density of observation on the ground and more accurately predicting land and soil properties. We also plan to include observations on water resources and above- and below-ground biodiversity, such that information services can be extended beyond soil properties. We hope also to expand these activities to other regions, such as Central and West Asia, North Africa, Central and South America, and South and Southeast Asia, partly building on existing initiatives. We will also develop watershed models and monitoring protocols that will enhance understanding of land-use impacts in areas of degraded lands and stressed ecosystems.

The Rainfed SRP links with the SRP on Information Systems for site characterization, spatial targeting of interventions, modelling, and monitoring frameworks for assessing intervention impacts. We will establish and further develop partnerships with international organizations that have an interest in resource assessment, such as the World Resources Institute (WRI), Conservation International (CI), IUCN and others.

Development and evaluation of agricultural technologies will require field testing on experiment stations and increasingly on farmers' fields. These activities will be conducted in collaboration with CRPs 1.1, 1.2 and 1.3, and the NARES. We will focus primarily on technologies and practices that maintain and restore soil fertility, improve water-use efficiency, reduce soil erosion, and restore soil carbon. We will promote investment in technologies that we think are important, such as integrated soil fertility management for major crops in the different agro-ecological zones of sub-Saharan Africa, and a supplemental irrigation package for wheat in rainfed agro-ecosystems of Central and West Asia and North Africa.

Decision support and dissemination activities are undertaken very much in support of and to improve the adoption of technologies and improved practices. Because agricultural interventions need to customized to local conditions there are a host of factors that must be addressed and understood:

- **Resource and livelihood situations (external and internal)**
  These refer to the state of the resources (land, vegetation, soil and water) and social and economic settings (e.g. poverty incidence, on- and off-farm income sources, nutritional indicators, gendered organization of farming and land tenure systems).

- **Backward linkages of the full range of technology options**
  These are factors and conditions that determine adoption: who has access to technologies (e.g. by gender, farming system or income level); their cost; institutional constraints and opportunities (e.g. credit, extension, input markets, infrastructure planning processes and management institutions, maintenance and operation, and the broader policy environment); the risks involved; and the risk-mitigation strategies adopted.

- **Forward linkages**
  These include local and regional agricultural marketing systems and price structures, access to these systems, the role of gender in agricultural marketing, communication, cold-chains, and the broader policy environment in which the markets operate

- **Externalities**
  The positive and negative impacts of technologies at the watershed and landscape levels and the environmental, social and institutional sustainability issues in the context of climate change and the adaptive management capabilities of supporting institutions.

5.13. Research outputs and outcomes

5.13.1. Increasing awareness

Outputs: Case studies and synthesis of ecosystem services measurement, valuation and tradeoff analysis for various scenarios of development in representative mixed rainfed landscapes.

Outcomes: Public society in developing countries, aware of the importance and state of agricultural production the underpinning ecosystem services, requests better governance of this natural capital.

5.13.2. Recommending policies

Outputs: Assessment of the state of the soil resource base and scenarios: biophysical assessment of soil fertility, water-use efficiency on rainfed lands, and land-use options to enhance the state of the soil and water resource base, including economics. Analysis of effects of policy on land and water allocation and farm-level incentives and disincentives for ecosystem-sustaining practices. Ecosystem services measurement and valuation to support policy-relevant insights into the feasibility of using payments for ecosystem services for selected purposes.

Outcomes: Governments, aware of the state of their agricultural production the underpinning ecosystem services, reconsider their policies and develop strategies that improve equity and allow the rural poor to sustainably manage natural resources and, where required, restore the soils and ecosystem services that support agricultural production.

5.13.3. Supporting development

Outputs: Assessment of costs, benefits and institutional and policy challenges of livelihood-enhancing interventions able to restore degraded landscapes and diversify provision of ecosystem services**.** Predict, using a variety of quantitative and qualitative modeling (SWAT, InVest), the direct and off-site impact of development plans.

Outcomes: Development practitioners disseminate effective interventions that are supported by incentives sufficiently large to allow their adoption by the rural poor.

5.13.4. Promoting participation

Outputs: Participatory land use planning and ecosystem services assessment techniques are developed, applied to case studies and synthesized.

Outcomes: Rural poor respond to incentives and information, promoting better management of the ecosystem services that support agriculture.

6. Strategic Research Portfolio: Resource Recovery and Reuse

Our vision: waste is a resource, and a business opportunity

We envision a world in which smaller and larger enterprises recover and recycle water, nutrients and organic matter from domestic and agricultural waste streams. These businesses produce safe water, fertilizer and energy for in the benefit of local markets, serving resource-poor farmers, households and industries. Such recovery and reuse activities help sustain urban food supply, generate jobs and enhance livelihoods for millions of poor households in peri-urban areas of developing countries. The water, nutrients and energy recovered from waste materials enable cost reduction or recovery in the sanitation service chain, benefiting millions of poor urban dwellers. In sum, we envision a world in which waste is a resource, and its recovery and reuse are undertaken by companies or public–private entities creating livelihood opportunities, improving waste management and enhancing food security in a sustainable and exciting fashion.

6.1. The compelling need for this research

Increasing urbanization, amid persistent poverty and food insecurity, is placing new pressures on the allocation and use of land, water and nutrients in many developing countries. While striving to increase food production to support larger local and global populations, many farmers are facing higher prices of plant nutrients, due partly to increasing demands and higher energy costs. At the same time, the amount of nutrients in domestic and agro-industrial waste streams is large and also increasing. However, those nutrients are dumped on landfills and largely unrecovered. In many areas, untreated wastewater pollutes streams and lakes, while farmers nearby cultivate soils so depleted of nutrients and organic matter that crop yields are a fraction of their agronomic potential. Something is amiss.

Why do we not see any compost project in sub-Saharan Africa operating at municipal scale or beyond its subsidized pilot phase? What is needed to transfer the business models for excreta reuse found at scale in Vietnam to neighboring countries or to Africa? How can we make nearly 20 million hectares of wastewater irrigation safer, even where treatment is not yet an option? How does the large-scale fecal sludge reuse business observed in India work, and could it be improved by moving it from the informal into the formal sector?

Answers to these questions involve complex technical, economic, ecological and social issues. Yet the potential gains to be made in addressing these issues are enormous. On one side, millions of residents of poor countries – especially women and children – are affected by inadequate sanitation and unsafe water quality. On the other side, millions of farmers struggle with depleted soils and water scarcity.

We have the technical knowledge tools, and financial means to address these critical issues in the coming 10 years, provided we conduct the research needed to answer essential questions. We need to learn much more about the potential for developing viable waste recovery business models, particularly in poor countries, where the willingness and ability to pay for sanitation are limited. We need also to learn more about minimizing the health risks to farmers, food

vendors and consumers when crops are irrigated with water containing effluent. We need more information about the value of ecosystem services from wastewater irrigation, and about how to develop new methods of creating marketable water, fertilizer and energy products from waste materials. And we must provide insight into the right mix of formal and informal programs to motivate private-sector or public–private engagement and capacity building in sanitation and resource recovery, while protecting worker safety and public health.

6.2. The scope and depth of the opportunity

Each day, two million tons of solid waste are discharged into the environment, thus polluting soils, rivers, lakes and coastal areas (UN/WWAP, 2003). An estimated 80% of the wastewater collected in Asia – and nearly all of the wastewater in sub-Saharan Africa – is discharged with little or no treatment. In most regions, there is very little planned, safe recovery of waste materials, even though the potential value for agriculture and other uses is well known (Otterpohl et al., 1997; Jiménez and Asano, 2008; Drechsel and Kunze, 2001; Qadir et al., 2007; Rosemarin et al., 2008, 2009; Rothenberger et al., 2006).

Where farmers have been mining the soil of nutrients and depleting soil organic matter content for decades (Drechsel et al., 2001; Hartemink, 2006; Bekunda et al., 2010), the potential for reversing that trend and improving soil fertility lies partly in our ability to capture, recover and re-apply the nutrients taken up by crops and discharged into urban waste streams. Improvements in agricultural productivity in Africa especially, through investments that restore soil fertility, must be part of the near-term program of any successful effort to enhance food security, increase rural incomes, and improve the health and welfare of urban and rural residents (Sanchez and Swaminathan, 2005). The recent fertilizer price peaks and the looming phosphorus crisis stress the need for resource recovery (Rosemarin et al., 2009).

Farmers in urban and peri-urban areas will also benefit from research investigating the safe, affordable use of nutrients in wastewater. An estimated 200 million smallholder households produce food for consumption in urban markets, and many of these farmers irrigate with water that contains effluent from municipal or industrial sources (UNDP, 1996). More than half of these farmers are women, and most would benefit from affordable access to safer water for irrigation. Consumers also stand to gain substantial health benefits, with reductions in the risk of eating vegetables produced using wastewater. Each day, an estimated 10% of the world's population engages in this inherently risky activity (WHO 2006).

Successful involvement of the private sector in providing sanitation services and recovering resources in waste materials will directly enhance the livelihoods of millions of smallholder households in rural and peri-urban areas of developing countries. Sanitation services are inadequate across large areas of Africa and South Asia. Women and children, in particular, experience the ill effects of exposure to uncollected and untreated waste in household settings (Hope et al., 2009; Ensink et al., 2002; Buechler, 2004). Women actively engaged in agriculture are exposed to pathogens and other harmful constituents when irrigating with wastewater. We will analyze carefully the gender implications of efforts to enhance sanitation services and promote the recovery and reuse of nutrients in waste materials.

6.3. Research, investments, capacities and better management are needed

In low-income countries, sanitation and waste management traditionally have been highly subsidized by public-sector agencies, with levels of service quality varying across locations and income levels and resulting in notable health and environmental problems. This historical reliance on public-sector provision has partly prevented the development of markets in sanitation services that might be best provided by private companies (Evans and Drechsel, 2010; Koné, 2010; Murray and Drechsel, 2010; Rouse et al., 2008). The market analysis and business planning needed to promote private-sector or public–private activity have not been conducted, although interest in developing viable business models is increasing among donors and international organizations.

Hopeful signs of viable business models pertaining to resource recovery and reuse are emerging, especially in the informal sector. For example, several analysts are promoting a shift in research focus from *treating wastewater for disposal* to *treating wastewater for reuse* (Huibers et al., 2010; Murray and Buckley, 2010). Others are describing innovative models that may address agricultural and household demands for recovered waste products. Examples include biogas production, compost–fertilizer blending, sludge fertilization, wastewater and aquaculture, and the development of markets for products derived from urine (Koné, 2010; Evans and Drechsel, 2010; Adamtey et al., 2008; Cofie and Murray, 2010). Biogas production from organic waste is particularly exciting, as the revenue generated in that market might offset the costs of recovering nutrients from sludge. Research is needed to explore such opportunities for developing viable but also safe business models for private and public entities to consider.

For the first time in history, the world's urban population exceeds the number of people living in rural areas. With increasing urbanization, the need to actively manage the cycling of water, nutrients and organic materials becomes more urgent. As increasing amounts of food are brought into cities from rural areas, larger amounts of nutrients embedded in the food are discharged into urban waste streams. Thus, the load of pollutants in urban and peri-urban waterways will increase unless the nutrients are recovered through effective water reuse or treatment programs.

For this to happen, substantial investments are needed in resource recovery and reuse to protect water quality and to recover scarce nutrients for use in agriculture. Yet the current capacity for collecting and treating waste streams is much smaller than needed in most developing countries. Models for profitable investment are not yet known. We will study the full cycle of nutrient application, use, recovery and reuse, integrated with the sanitation service chain to motivate private firms to provide essential services along this nutrient value chain.

Imagine the potential yield increases in agriculture and aquaculture for millions of smallholder farmers when they gain affordable access to nutrients previously regarded as waste, and can thus restore soil organic matter. Imagine also how much healthier will be the men, women and children living in urban and peri-urban areas when waste collection starts to offer business incentives for small to macro enterprises. The outcomes of this research and the business models we develop will improve the livelihoods of hundreds of millions of smallholder farmers and urban dwellers across Asia, Africa and Latin America.

6.4. A compelling role for the CGIAR

Many researchers in national and academic centers are examining mostly technical aspects of resource recovery and reuse (e.g. ecosan), focusing largely on household- or community-based applications, while seldom working in low-income countries beyond a subsidized pilot phase. These approaches are in most cases supply driven, initiated by the sanitation sector. Demand driven, larger-scale questions involving market-based approaches to the delivery of sanitation services and the development of business models in resource recovery and agricultural reuse are receiving less attention. Public goods aspects of such research include the spillover effects of new knowledge regarding transferable business models, public health risk mitigation strategies, and the environmental implications of alternative approaches to collecting, treating and re-applying nutrients, such as potential reductions in carbon emissions (Box 6.1). The CGIAR is well placed to bring together national and international researchers, entrepreneurs, business schools and other specialists across technical and policy disciplines to conduct innovative research on resource recovery and reuse.

Box 6.1. Resource recovery and reuse in ecosystem services and climate change
The productive use of waste resources can reduce pollution and minimize or abate environmental degradation. Thus, reusing waste resources can directly and indirectly enhance ecosystem services by promoting more effective water and nutrient recycling, and reducing market demands for fossil fuels and other inputs that release carbon into the environment. Resource recovery and reuse can also contribute to climate change mitigation by reducing methane emissions where composting of waste materials diverts organic waste from dumps and landfills, while wastewater use (including groundwater recharge) should be part of any climate change adaptation strategy.

6.5. Building on a solid research foundation

Many researchers at IWMI and other CGIAR centers have worked over many years on safely recovering water, nutrients and organic matter from liquid and solid waste streams for agriculture and aquaculture. In close collaboration with WHO and FAO, we have described the extent of wastewater irrigation, its contribution to smallholder livelihoods, gender implications, measures for reducing health risks, and other components of the social costs and benefits (Buechler 2004; Hussain et al., 2002; Ensink et al., 2002; Scott et al., 2004; Drechsel et al., 2010; Hope et al., 2009). ICARDA researchers added notable expertise in the use of other marginal-quality water sources, such as saline and sodic irrigation return flows which can be used for aquaculture (Qadir et al., 2007), while researchers with the International Fertilizer Development Centre (IFDC) and the Tropical Soils Biology and Fertility Unit of CIAT (TSBF/CIAT) have developed the program of Integrated Soil Fertility Management which involves both organic and inorganic fertilizers (Gichuru et al., 2003). That experience has been applied successfully to other biodegradable waste materials including agro-industrial waste, excreta and urine (Esrey et al., 2001; Cofie et al., 2005; 2009, 2010; Seidu et al., 2008).

This background provides an excellent base for exploring new research frontiers regarding resource recovery and reuse. Most importantly, we need to learn the best ways of extending the

technical information we have developed in the past into viable business models that can greatly increase the pace at which resource recovery and reuse activities are implemented and extended in future. The public sectors in most developing countries lack the financial and human resources needed to provide such services. The highest likelihood for success lies with private companies engaged in profitable enterprises, or public–private partnerships implementing business models developed through research conducted within this SRP.

Our research will also provide guidance regarding the size of addressable markets for resource recovery and reuse, the (initial) subsidies that might be needed to spur private-sector involvement in many settings, and the economic benefits attributable to the provision of those subsidies. We have the expertise to estimate the market and non-market benefits of resource recovery and reuse programs, to understand potential equity considerations, and to describe the potential for successful involvement of private-sector firms.

6.6. Research questions

The following research questions give a sense of the nature of research we will conduct within this SRP. We will refine these during the inception phase of our study and will continuously evaluate and modify them, as appropriate.

- What are the characteristics of a potentially viable business case for the safe recovery and reuse of water, nutrients and organic matter in a low-income country?
- How might we best identify potentially viable business cases in the informal sector, when working with resources that are viewed by many observers as inherently undesirable waste materials?
- How can we guarantee that health and environmental safety (risk minimization) are included when defining the characteristics of a promising business case?
- Which are the key enabling conditions that encourage safe and sustainable recovery/reuse businesses and support up-scaling and out-scaling?
- What constraints or barriers might prevent such businesses from being mainstreamed or taken to scale, and what should be avoided or addressed ensure success?
- How many resources can be recovered (as a proportion of a particular demand) and how might this positively affect waste management and the environment? What roles might resource recovery businesses play in financing and managing parts of the sanitation value chain?
- What barriers to business development can or have been identified in areas where businesses have tried, either successfully or unsuccessfully, to provide resource recovery services? How might those barriers be avoided or removed?
- What are the local cultural, religious, social, gender and psychological barriers to mainstreaming safe resource recovery from waste streams in agriculture? How can social perceptions be changed so as to remove these potentially stifling sources of risk and uncertainty?
- What are the organizational structures, marketing and business strategies, trading practices, operational processes, and nature of institutional linkages among different economic actors in the sanitation value chain (formal and informal contracts, and

contract design and enforcement) and the implications for the sustainability of a resource recovery approach?

- What roles do population density, household characteristics, public/sanitation infrastructure, and the nature of agricultural production play in the potential viability of resource recovery business models? Which related indicators could help decision-makers?
- What levels of public funding or donor support might be needed to stimulate business development, and how long might those funds be needed? What roles can microfinance play in promoting private-sector involvement in resource recovery? Are there incentives that might promote private equity investments in waste-based businesses? What programs might be helpful in reducing the sanitation sector's reliance on financial aid?
- Might there be merit in business models that contain several profit centers, such as a household collection and processing unit, an initial rural collection center, and a regional compilation and marketing center? How might those profit centers be connected most effectively?
- To what extent might the principle-agent model be helpful in designing successful business models for resource recovery?
- Can we develop a methodology for assessing the addressable agricultural market of resource recovery businesses that includes both spatial and temporal dimensions?
- What are the important linkages between provision of water supply, energy and sanitation, and resource recovery in developing successful business models? Are there commercial advantages in providing different sets of services? What models of public–private engagement seem appropriate, and what levels of public oversight or contractual involvement might be most desirable?
- How will climate change affect wastewater generation, collection, treatment and reuse, and how far could waste and marginal-quality water reuse increase the resilience of cities or reduce their negative footprint?
- To what degree do the answers to these questions vary across countries and regions or by the type of waste stream and business considered? What government policies, regulatory structures and environments, and incentives appear to be particularly conducive to promoting resource recovery businesses in different settings?

6.7. Our Theory of Change for resource recovery and reuse

The safe and efficient recovery of water and nutrients from otherwise wasted resources is a pillar of NRM and thus a crucial component of CRP5. Extending recovery and reuse across large areas and diverse settings can be accomplished most effectively through innovative research and partnerships that take particular account of emerging markets, business models and social benefits. Our overarching hypothesis is that change can be achieved through three primary research endeavors:

1. **Developing scalable business models that offer easy entry to enterprises of different sizes**
   Our goals include reducing poverty by supporting emerging entrepreneurs, while taking advantage of economies of scale for generating substantial social benefits depending on local conditions.

2. **Carefully addressing issues and perceptions regarding public safety and health risks**
   We will deliver options for mitigating risk and enhancing social awareness of resource recovery and reuse. We will also determine optimal forms of social marketing, regulations and incentives to encourage desirable changes in consumer and producer practices.

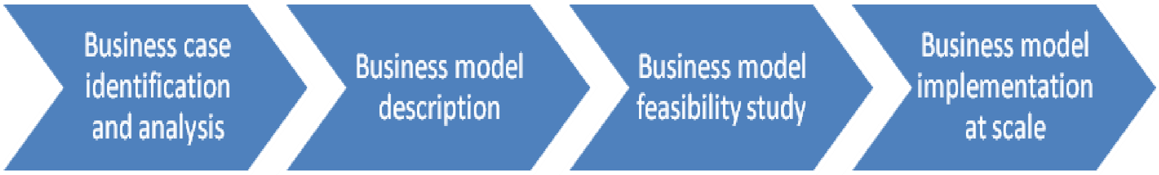
3. **Conducting institutional dialogues and developing innovative partnerships across the agricultural and sanitation sectors**
   We will work with public and private entities to promote long-term capacity building in resource recovery and reuse.

6.8. Our impact pathway

Our pathway for moving from research to development outcomes includes two main components:

1. Developing innovative partnerships aiming at private- and public-sector support for the uptake of successful business models, and

2. A four-step rolling work plan that enables our research results to be extended to feasibility studies and actual business model implementation, as shown below:

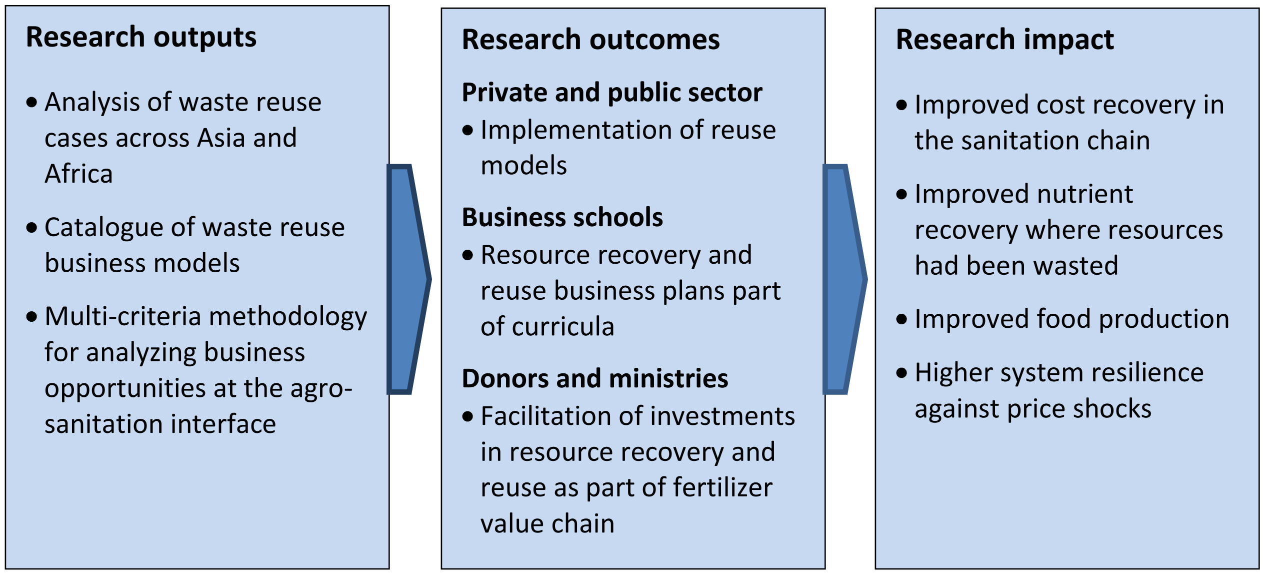


Our approach is supported by a strong emphasis on multi-stakeholder participation (Evans et al., 2010) and extensive support of capacity building in multi-criteria assessments and business modeling. We will form strategic institutional alliances involving the sanitation and agricultural sectors, in addition to conventional (rural) research partners. We will address directly the constraints that the informal and public sectors are facing in emerging economies, and we will explore opportunities for developing private-sector support for selected approaches to business development in the research process.

A key requirement for research implementation with full public support is the mitigation of possible health risks and related negative perceptions (Karg et al., 2010). Therefore, we will conduct perception studies, risk assessments and mitigation analysis for all reuse strategies, taking advantage of close links with researchers in CRP4 (Agriculture for improved nutrition and health).

An example of our pathway for moving from outputs to impacts is provided in Figure 6.1.

Figure 6.1. Pathways to impact in resource recovery and reuse



At larger scale, we will form strategic alliances (especially with WHO, IFAD, FAO and UN-Habitat) to facilitate the production of international public goods and achieve international outreach of our research results. We will also engage with selected professional networks, such as the International Water Association and the Sustainable Sanitation Alliance, to steer the development and distribution of best practices and business models to NGOs, business schools, the private sector and donors.

We will develop on all research sites links between urban and rural stakeholders, and producers and consumers engaged in agriculture and sanitation. We will also develop innovative partnerships involving universities and other research institutes in North–South and South–South collaborations. We will explore the substantial potential for increased knowledge-sharing in resource recovery and reuse, particularly involving India, Southeast Asia and Latin America, for the benefit of sub-Saharan Africa.

The impact pathways for two solutions we will examine in this research – *Creating wealth from waste* and *Promoting a grey revolution in water management* – are described in Tables 6.1. and 6.2., respectively. For each of these, we describe important issues, present our levers of change, and list our expected research outputs and outcomes. We describe also the potential impacts of our research, and we note how our results will contribute to achieving the outcomes that comprise the Strategic Results Framework of the New CGIAR.

Table 6.1. Impact Pathway: Creating wealth from waste

Issue	Levers of change	Research outputs	Outcomes	Potential impact	Contribution to SRF outcomes
• Urbanization and the growing demand from urban areas for food and water are changing traditional resource allocations, material flows and nutrient loops. While soils in production areas are mined, and fresh water competition is on the increase, huge amounts of resources are wasted in landfills or polluting the environment. There are however many little-explored options to recover nutrients, organic matter, biogas and water at scale as not only the informal sector shows us.	Safe water and nutrient recovery from otherwise wasted resources is a pillar of NRM. Change can occur through three major levers: • Scalable business models that offer easy entry to micro, small and medium enterprises • Careful consideration of safety concerns and related perceptions • Innovative partnerships across the agricultural and sanitation sectors where research works with public and private entities on resource recovery and reuse.	• Innovative business cases in low-income countries for nutrient, water, organic matter and biogas recovery from waste streams analyzed and recorded in database • Catalogue of resource recovery and reuse business models • Methodologies for business schools • Multi-location feasibility studies for the implementation of resource recovery and reuse business models • Guidelines on safety measures for resource recovery and reuse models	• Increased academic, institutional and public knowledge on scaling up safe resource recovery and reuse models in low-income countries • Implementation of reuse business models by private sector • Business models supported by donors and in business schools • Options for waste reuse incorporated into policies, strategies, investment or medium-term plans • Integration of waste streams into the fertilizer value chain.	• Improved livelihoods and food security through reduced water scarcity and negative nutrient balances • Reduced health risks from unplanned waste reuse positively affecting livelihoods • Higher overall system resilience to climate change, water scarcity and increasing fertilizer prices • Closer collaboration between the sanitation and agricultural sectors.	• **Food Secuirity** through increased availability of nutrients and water for plant growth • **More sustainable natural resource management** through reduced pollution, support of ecosystem services, and sustainable use of natural resources via nutrient replenishment • **Improved livelihoods** through productively linking the agricultural and sanitation sector.

Table 6.2. Impact Pathway: Promoting a grey revolution in water management

Issue:	Levers of change	Research outputs	Outcomes	Potential impact	Contribution to SRF outcomes
In many regions economic and physical water scarcity increases the demand for exploring all options to ensure that grey water and other marginal-quality water is safe. Safe wastewater use is crucial where farmers only have access to polluted water sources (a situation that is far more common than planned use of safe wastewater). In all cases, safeguarding public health and the environment essential. A grey revolution is needed to make a safe asset out of marginal-quality water.	• The 2006 edition of the WHO guidelines on safe wastewater and grey water reuse offer a high degree of flexibility that allows making wastewater safe and affordable, even where conventional treatment is not possible • To facilitate the adoption of the 2006 guidelines, sanitation safety plans (similar to water safety plans) should be developed where safety options are supported by a mix of incentives, social marketing, regulations and education.	• Assessment of opportunities for marginal-quality water use while minimizing potential environmental and health implications in target areas • Catalogue of health risk reduction measures where wastewater is used • Global map of wastewater and excreta reuse, and assessment of consumer risks and benefits • Acknowledged contributions to USAID–US Environmental Protection Agency and WHO–FAO–UNEP international wastewater use guidelines • Sanitation safety plans.	• Options to reduce water stress without increasing health risks taken up by national decision-makers • Data from the first global assessment of wastewater irrigation, benefits and health risks cited in UN reports • Disease burden from pathogen exposure reduced by at least half where new safety measures have been introduced.	• Fresh water savings • Reduced health risks from unplanned wastewater reuse benefiting livelihoods, particularly of vulnerable groups such as women, children and the aged.	• **Food security** through increased availability of healthy food • **Sustainable natural resources management** through proactively addressing externalities caused by urbanization and poor sanitation • **Improving livelihoods via** supporting global guidelines which steer national policy development.

6.9. Our links with other SRPs and CRPs

The focus on safe resource recovery complements the SRPs on irrigation and rainfed agriculture which aim at most efficient resource use. It also adds a grey water focus to the study of blue water (Irrigated Systems SRP) and green water (Rainfed Systems SRP). It will feed databases and global irrigation assessment in the Information Systems SRP. The SRP on Resource Recovery and Reuse is supported by CPR4 (Agriculture for improved nutrition and health), which has more capacity in health risk assessments. It will eventually feed best practices into CRP1 (on integrated agricultural systems) at the level of actual resource (re)use by farmers.

6.10. Research partners

In the *Creating wealth from waste* Problem Set the generic partnership model involves learning from more than 200 business cases (identified so far) of enterprises or projects engaged in resource recovery and reuse in Asia and Africa, a number of strategic partners are required. These partners will contribute to an interdisciplinary analysis across the sanitation and agricultural sectors addressing agronomic, economic, institutional, social, health and technical dimensions of any given case. Based on this analysis, a catalogue of business models will emerge that must be streamlined with the expectations and needs of the business development sector (e.g. business schools). The catalogue will be a living document for testing promising business models for particular waste streams and products in new settings. These feasibility studies will be carried out in our priority regions, transferring, for example, ideas from Asia to Africa. They will also strongly involve local stakeholders from the public and private sectors who will eventually also become implementers of any verified and promising model.

There will be two key outputs, both constitututing international public goods. First will be a catalogue of well researched and tested business models for resource recovery and reuse enterprise development, including the methodology for analyzing them. Second, local stakeholders will benefit from feasibility studies for concrete investments in resource recovery and reuse via the private and/or public sector. The key outreach channels will be networks of both the sanitation and agricultural sectors, while the feasibility studies will be disseminated to the private sector and donor community. Table 6.3. lists existing and proposed partners. We will also maintain close links with UN agencies in an ongoing and future effort to generate international public goods.

In West Africa, for example, we are linking local universities with municipalities (planning, waste management, public health and agriculture) and sanitation service providers. This involves internationally recognized research institutions in the sanitation sector from outside the CGIAR, The identified and verified business models will be discussed with business schools to provide international public goods that can directly feed into their curricula. Further dissemination will be through the global SuSanA and IWA networks, while donors interested in agriculture (e.g. IFAD) and sanitation (e.g. Swiss Agency for Development and Cooperation, Bill & Melinda Gates

Foundation) have already shown interest in funding any promising recommendation from the resource recovery and reuse feasibility studies.

Table 6.3 Examples of partnerships for the Resource Recovery and Reuse SRP

<table>
<tr><th>Region</th><th>Core research</th><th>Implementation</th><th>Outreach</th></tr>
<tr><td>Volta and Niger Basins</td><td>Institut International d'Ingénierie de l'Eau et de l'Environnement (2iE), Universities of Ghana, Kwame Nkrumah University of Science and Technology, Centre Régional pour l'Eau Potable et l'Assainissement à faible coût (CREPA), Council for Scientific and Industrial Research Ghana, IFDC, Emory Univerisity, Wageningen University; farmer associations; Enterprise works</td><td rowspan="4">Private and social entrepreneurs and their associations engaged in waste management (e.g. Waste Enterprises Ltd., Waste Concern, DEWATS; Waste Busters; Terra Firma; Vermi Gold; Zoomlion)
Municipal Sanitation and Waste Management Departments and Providers
Urban Planning
Ministries of Agriculture, Water Supply & Sanitation, and Environment
Public Health Agencies
Environmental Protection Agencies/Authorities</td><td rowspan="4">• Sanitation provider networks (e.g. IWA)
• Information & capacity building networks and focal points (e.g. SuSanA; IRC)
• UN (especially WHO, IFAD, FAO, UN-Habitat)
• Agricultural networks (e.g. RUAF)
• CGIAR (ICARDA, ILRI; IFPRI)
• IDRC, SDC, BMGF, WSP
• Business schools and training centers (national and international, e.g. CEWAS)</td></tr>
<tr><td>Mekong Basin</td><td>Asian Institute of Technology
AVRDC; Hanoi University of Science & Technology
Various research partners in China; farmer associations</td></tr>
<tr><td>Indus and Ganges Basins</td><td>TERI; Indian Council of Agricultural Research; various universities, farmers associations, Practical Action, IDE</td></tr>
<tr><td>Global</td><td>SANDEC/EAWAG, WASTE, UNESCO-IHE, ICARDA, Brazilian Agricultural Research Corporation (EMBRAPA), IFDC, Universities of Loughborough (WEDC) and Cambridge; Swedish University of Agricultural Sciences; University of Copenhagen (Dept of International Health); Stockholm Environment Institute; University of California (Berkeley)</td></tr>
</table>

6.11. Where we will work

We will conduct our research at the rural-urban interface, primarily in developing countries, where the amounts of waste materials generated each day greatly exceed collection and treatment capacity. We will also seek areas where farmers have inadequate access to affordable water, nutrients and organic matter. It is in such areas that the prospect for developing successful business models is greatest. We will work in such settings in Africa, South and Southeast Asia, and parts of the Middle East.

6.12. What we will achieve in the first five years

Within five years of implementing this SRP, we will have generated the following outputs:

- A catalogue of innovative business cases in low-income countries for nutrient, water, organic matter and biogas recovery from waste streams.

- A catalogue of resource recovery and reuse business models developed by examining a range of cases, for use in developing sanitation and resource recovery curricula for business schools.

- A set of feasibility studies describing options and scope for implementing the analyzed business models in resource recovery and reuse.

- A catalogue of safety measures for resource recovery and reuse models, adapted to local opportunities and constraints, in line with WHO recommendations on food safety and occupational health risks.

- Description of opportunities for using marginal-quality waters in agriculture and aquaculture, and the potential environmental and health implications, assessed in selected countries.

- A global map of wastewater and excreta reuse, with assessment of consumer risks and benefits easily accessible in the public domain.

- Acknowledged contributions to USAID–US Environmental Protection Agency and WHO–FAO–UNEP international wastewater use guidelines and sanitation safety plans.

6.13. What we will achieve in the second five years

During years 6 through 10, we will further increase scientific understanding and public awareness of the feasibility of recovering and safely reusing water, nutrients and organic matter from waste materials. We will further extend our results and recommendations along the impact pathway we have identified for this research. We will continue engaging with physical and social scientists, entrepreneurs, and public officials involved in technical and policy aspects of programs to promote wider uptake of resource recovery and reuse at scale.

You will find us most often in developing countries, where we conduct most of our research activities. Yet we will also interact on regular base with specialists at WHO, FAO, UN-Habitat and UNEP, as we broaden international appreciation for the potential gains in health and welfare that can be achieved by implementing successful resource recovery and reuse programs.

We will prepare enhanced business models for resource recovery and reuse, which will be adopted by donors and used as business cases in MBA programs in developed and developing countries. We will complete the first global assessment of wastewater irrigation, with comprehensive discussion of the costs, benefits and health risks, for publication in appropriate UN reports.

As we complete the first decade of our work, 'Options and guidelines for waste reuse' will be incorporated into public policies and strategies, as well as the investment plans of donors and private companies. Training programs will be developed for the safe and effective reuse of waste materials in small and medium cities throughout Africa and South Asia. We will have started those programs, but public agencies and private companies will have grown them into thriving, sustainable enterprises. The integration of waste streams into the fertilizer value chain will be commonplace across agricultural landscapes and in the peri-urban areas of many developing countries.

Slowly, but steadily, millions of farmers and consumers and thousands of waste recovery entrepreneurs will be contributing to closed nutrient loops and safer wastewater use for increased food security while the sanitation sector will benefit from innovative options for cost recovery.

6.14. Implementation plan

When initiating this SRP, we will (1) develop strategic partnerships, (2) promote stakeholder participation, (3) prepare a well-defined workplan, and (4) a engage in a multidisciplinary research framework.

Our partnerships will include collaboration with conventional CGIAR partners (e.g. NARES and ARIs in NRM) and private and public entities (e.g. micro, small and medium enterprises, and social entrepreneurs). We will also collaborate with emerging macro-enterprises, business schools and research partners in the sanitation sector.

Our workplan will include a four-step assessment for each business case we examine. Each step is essentially one component of our impact pathway:

1. We will identify and describe business cases pertaining to resource recovery and reuse, using a multi-criteria analysis involving local stakeholders and advisory groups, consultants and in-situ analysis. This effort will generate a catalogue of assessed business cases.

2. We will describe related business cases as business models, while noting opportunities and limitations across selected sets of criteria and indicators. Through this effort, we will produce a business model catalogue and we will prepare training materials for business schools.

3. We will conduct a multi-stakeholder feasibility analysis of opportunities for scaling up identified business models in selected locations.

4. We will implement the most promising business models, in conjunction with an appropriate monitoring and evaluation program.

We will conduct these steps concurrently, in different projects and locations. We will base our work on multi-stakeholder participation and consultation, such as learning alliances (e.g. www.irc.nl/page/14957) that build on existing local, national and regional platforms, while fostering any missing integration and close collaboration between economics and reuse, and between the public and private sectors involved in agriculture, health and sanitation.

Each criterion within our multi-criteria analysis will have its own set of indicators, which will be analyzed using sets of research questions. Our preliminary criteria for analyzing solid and liquid waste streams are:

- Waste supply and availability (quantity and quality)
- Demand quantification for resource recovery
- Waste transport, storage, valorization (setting values), process and product safety
- Productive and safe resource use
- Institutional and legal settings, and public support
- Financial feasibility and viability, and business modeling
- Valuation of economic benefits and assessment of externalities.

We will select performance indicators for each of the criteria, to allow comparisons between options and business cases to assess their viability, scalability and sustainability. Examples of potential indicators includes cost-effectiveness ratios, recovery percentage, technical efficiency, market share, net present value, public perception, space requirements, gender roles, carbon-to-nitrogen ratios, human and ecological risk assessments, and the degree of risk reduction (microbial counts). Most indicators will be specific for a given criterion, but a few might apply to all criteria, such as when evaluating opportunities and constraints for moving a business model to scale.

We will identify overarching and component research questions. All questions will be formulated either to (1) determine the indicators, (2) provide background information on a reuse case, or (3) assess the suitability of the indicator and functionality in a given biophysical (soil, plant or climate) or socioeconomic setting (institutional capacity, infrastructure or technology). This third part may be accompanied by action research, such as improving the co-composting process or identifying safer sludge application options.

7. Strategic Research Portfolio: Improved Management of Water Resources in Major Agricultural River Basins

Our vision: equitable sharing of water for agricultural and environmental purposes

Our vision is better and more equitable sharing of water and land resources worldwide. We see river basins in which flows are managed to minimize the impacts of rainfall variability; where agricultural productivity, livelihoods, water quality and ecosystem services are protected through reduced land degradation, control of erosion and pollution. Similarly, we see governance and institutional arrangements that protect access to land and water resources for the poor and which recognize the importance of ecosystem services to agriculture, other water consumers and the environment.

7.1. The compelling need for this research

As populations grow and incomes rise, resulting in more demand for staple foods and water-intensive high-value food products, the demand for water increases. Non-agricultural water needs increase similarly, while some water must be reserved to maintain essential freshwater ecosystem services. Approximately 3 billion people experience various forms of water scarcity already (CA, 2007), and in the 2050 world of 9 billion people, water scarcity may become the unpleasant 'norm.' The magnitude, type and extent of scarcity vary across river basins. Some basins are closed and water is over-allocated (physical water scarcity). Others are open with relatively abundant water resources that can be (but are not yet) harnessed through improved infrastructure (economic water scarcity). In some, institutions limit access to certain groups and exclude others (institutional water scarcity).

Land degradation reduces agricultural system productivity, threatens livelihoods, jeopardizes ecosystem services and reduces water quality – exacerbating the effects of water scarcity. Climate change, combined with land degradation and water scarcity, causes greater spatial and temporal variability in water availability, thereby increasing risk and reducing resilience. This variability of an already scarce resource is the major natural issue for agricultural water and overall water resources management in all areas with physical water scarcity (Figure 1.4 on page 19).

7.2. Building on a solid research foundation

Previous basins-related research has been significant. Examples of previous research on river basins are given below (see Appendix 1b for details on the research foundation of water scarcity).

Open and closed basins

Seckler (1996) introduced the 'basin view' into agricultural water management. Subsequent studies examined various stages of basin water resources development up to water 'reallocation' at the time of 'basin closure,' introduced basin water accounting procedures and the use of remote

sensing and modeling tools for integrated assessment of water availability and access (Keller et al., 1996; Seckler et al., 1998; Molden, 1997; Kite and Droogers 2000; Molle, 2003). The concepts of closed basins and global water scarcity had significant impact worldwide and were further illustrated in individual basins globally: diagnosing cases of physical and economic water scarcity, exploring the societal factors leading to basin closure, examining future scenarios of water availability with in-built environmental water allocations, and exploring both drivers of change on basin water resources and the response options in the face of water scarcity (Amarasinghe et al., 2004, 2008; Biggs et al., 2007; Giordano and Vilholth 2007; McCartney and Arranz 2007; Venot et al, (2008); CA, 2007; Smakhtin et al., 2004; Molle and Wester, 2009).

Water storage
Keller et al., (2000) formulated the main principles of sustainable water storage development. IWMI has subsequently recommended that all forms of water storage including – large dams, through small reservoirs, rainwater harvesting, groundwater and conjunctive use of wetlands – should be considered in the development of locally appropriate solutions to provide insurance against drought and rainfall variability (McCartney and Smakhtin, 2010).

Tradeoffs at basin level
Molle (2003), Molle et al. (2005); Ringler (2001), Cai et al. (2003), Smakhtin et al. (2007) and many others have explored tradeoffs and water-allocation scenarios among various basin water users.

Adaptive river basin management
Lankford et al. (2007) formulated an adaptive framework for river basin management in developing countries, and Sadoff and Grey (2002) developed the concept of benefit-sharing in river basin management.

Water and development challenges
Recent CPWF research, through a number of basin focal projects (Cook et al., 2009), identified a range of development challenges in several of the world's largest river basins. They found that improved water productivity was often the basis of economic development, but analysis of basin conditions shows a complex dynamic between development processes and the natural resources they consume. This dynamic can push river basins, or parts of them, beyond the level at which ecosystem services of water provision, food production, energy and others can be delivered sustainably. This raises problems of potential conflict over limited resources among communities within river basins. An alternative situation occurs when resources are effectively underdeveloped. In such cases, poverty is associated with low productivity of land and water.

7.3. The compelling role for the CGIAR

River basin management in developing countries is generally in its infancy. The CGIAR can muster the range of disciplinary approaches and has the ability to integrate these in a way that has not yet been achieved by national institutions that tend to focus on individual issues. The CGIAR can also help fledgling river basin authorities compile data and information vital to evidence-based

decision-making and water allocation procedures. This is regionally critical given the significant number of transboundary river basins.

The CGIAR has experience in basin-, sub-basin- and landscape-level innovations in land and water management (not just plot- and farm-level innovations); in the introduction of benefit-sharing mechanisms that feature negotiations among upstream and downstream water users; and in anticipating and measuring the whole-basin, cross-scale consequences – including consequences for ecosystem services – of modifications in water allocation and landscape management.

Furthermore, the CGIAR can draw lessons from governance and management approaches in basins in developed and emerging economies (e.g. the Colorado in the United States and Mexico, the Yellow River in China, and the Murray-Darling in Australia) and contribute knowledge of what elements might be successfully transferred to our target basins. Finally, the strong linkages developing between CRP5 and the CRP7 (Climate change for agriculture and food security) gives the CGIAR a critical ability to link climate change predictions to estimations of water availability, variability and how these will affect basin water resources and their allocation.

This SRP will build on the work of the CPWF and its partners. We aim to further develop the paradigms for river basin management and explore how improved and better integrated information will provide policymakers with compelling evidence on which to base basin development and management decisions. We recognize the political issues associated in land- and water-use planning and the tradeoffs that come in to play when power development is pitted against agriculture and the environment. However, we also recognize, based on previous IWMI and CPWF work, that clever solutions can be found to optimize resource use, and that water also has to be viewed in the context of general development issues rather than in isolation. Successful examples of previous work include 'water banking' in the Ferghana Valley in Central Asia (capturing of hydropower water releases in winter and storing them in aquifers for subsequent summer irrigation), multiple use systems in southern Africa, payment for environmental services in South American Andes group of basins, and innovative rice–shrimp systems to cope with increasing salinity in parts of the Mekong Delta in Vietnam. Similarly, CRP5 will begin to address some of the basin development challenges described by Cook et al. (2009).

7.4. The scope and depth of the opportunity

Given the increasing pressure on water and land resources some significant problems must be overcome. For example:

- **Water scarcity**
  The often preferred response to water scarcity is to improve or increase water supply. The development of new supply sources (both conventional and unconventional) is often constrained by the cost and a range of hydrological, social and political risks, which negatively affect the livelihoods of the poor (World Commission on Dams, 2000). These risks are not always well understood and quantified. Negative consequences of investments in water supply

infrastructure are all too often transferred to the poorest and most vulnerable groups, to the environment, and to the next generations.

- **Water resources variability**
  Water resources variability – in time and space – remains a critical problem in water management, and hence sustainable agriculture and food production worldwide. This problem is increasing with climate change. Socially and ecologically responsible approaches to managing this variability are required. These will include developing, managing and diversifying supply, water-storage infrastructure and distribution networks

- **Coordinating water and land management**
  Water and land management are inherently linked. Land-use change and loss of agricultural biodiversity, driven by population and economic growth, has pronounced impacts on water. Issues of sedimentation due to soil erosion, soil and water salinization, and pollution strongly link this SRP with the Rainfed Systems, Irrigated Systems, and Resource Recovery and Reuse SRPs. This SRP can help assess the consequences for ecosystem services of land and water management innovations introduced by other SRPs – and possibly other CRPs. Managing land, water and agricultural biodiversity in ways that benefit the poor and maintain or reduce impacts on ecosystems services remains one of the main basin development challenges.

- **Dwindling resources**
  Another common response to water scarcity is to produce more with fewer resources. Land and water productivity remain lower than they could be. Cases where improvements in both are possible, and means of improvement need to be identified and pursued. There is a clear lack of up-scaling of promising interventions – e.g. from irrigated or rain fed agriculture – to the basin scale. Agricultural intensification in an ideal world should aim to double production on half the area. The impacts of intensification on water resources and human health need to be understood, as does the role of diversity and diversification in increasing water-use efficiency.

- **Competition for water resources**
  One challenge for river basin management comes from the de facto reallocation of water out of agriculture to urban and industrial uses. While this is in general administered centrally with little transparency, there is a need to better identify the impacts of such reallocation, and how these can be mitigated.

- **Environmental water allocations**
  Global interest in environmental water allocations is growing rapidly. Examples include the Murray-Darling Basin in Australia, and the European Union, where the Water Framework Directive attempts to restore “good ecological status” of European rivers. However, this ‘new’ issue exerts pressure on conventional uses of water, particularly agriculture, and particularly in the developing world, where food production is the number one priority. No ecologically relevant thresholds for surface or groundwater use exist or are implemented in developing countries. This SRP will look at how environmental flows can coexist with other water uses.

- **Lack of good data**
  Measured reliable data (that reflect natural variability) on any water component remain lacking. Good policy and management must be based on sound scientific data. The maxim of 'if you can't measure it, you can't manage it' is never truer than for water resources management. This SRP will consider data needs in target basins, and will also link strongly with the Information Systems SRP to deliver regional-scale generic assessments of water availability and variability, and factors such as drought and flood risks.

- **Transboundary basins**
  Transboundary basins are dominant features of the water landscape in both Asia and Africa (Wolf et al., 1999). These basins are home to significant numbers of the world's poor, and are sources of international and interstate cooperation as well as conflict. Developing effective governance structures and understanding and managing river flow variability in these basins will be keys to peace as well as agricultural and economic development and thus poverty reduction.

The above are just a few problem areas and research hypotheses that need to be addressed. Testing these in a selection of target geographical areas, as well as globally, will demonstrate how and where we can prove the overarching theses that 1) agricultural production can be intensified, diversified and expanded without further degradation of the natural resource base and supporting ecosystems, and 2) it is possible to improve water governance, institutions and management so that the impact of water scarcity and variability are reduced.

7.5. Our Theory of Change for improved management of water resources

There are several entry points (all having both land and water dimensions) that can be used to increase the magnitude, value and equitable sharing of ecosystem services and benefits in and from river basins.

1. **Understand and consider resource variability in basin management**
   Most, if not all, water management interventions are triggered not only by limited water availability in general, but also by fluctuations over time (which are increasing globally with climate change). This SRP will highlight the issue of variability for policymakers and land and water managers. Research can provide information to characterize variability of land and water resources in time and space, as well as recommendations of how best to deal with variability at the basin scale (in particular through storage and combined use of surface and groundwater).

2. **Invest in water infrastructure**
   This issue is closely related to 1), above. Where economic water scarcity prevails, this can improve water availability for many users. Complementary land and ecosystem management practices are needed to take full advantage of infrastructure investment and to avoid land

degradation, one consequence of which can be infrastructure deterioration. This SRP aims to influence how these investments are made, by direct advice to key investors or policymakers, or by developing decision support tools that highlight the tradeoffs and complementarities among land, water, ecosystem services and outcomes for rural livelihoods. A related strategy is to inform and thereby influence the discourse on investments. Research can provide information on: 1) alternative investments covering a range of infrastructure practices and storage options; 2) magnitude and distribution of benefits and costs from infrastructure investments (of special interest to investors concerned with their reputational risks); and 3) the extent to which infrastructure can help mitigate the effects of hydrological extremes (e.g. floods and droughts) while maintaining or enhancing social and environmental goals

3. **Allocate and manage basin water and land to raise productivity, improve equity and safeguard ecosystem services**
   Water in a basin can be reallocated from less productive to more productive uses with appropriate attention to water rights, including compensation. The productivity of water in different uses is affected by land management practices. This SRP will inform and influence the discourse about water rights and water allocation. Research can provide science-backed information on water productivity for different uses (and how productivity is affected by land management decisions) and indicators for suitable levels of compensation for those who cede water rights. Water resources can be reserved for environmental flows and research can examine the consequences of that for other water users. The recent introduction of these concepts into discourse on the National River Linking Plan in India was the result of good science and the 'right' relationships that jointly ensured a positive impact.

4. **Introduce and consistently follow the principles of benefit-sharing**
   Upstream land and water management practices affect the quantity, quality and reliability of water available to downstream users (e.g. urban communities, fisheries, and hydropower and irrigation facilities). Institutional innovations can be introduced whereby downstream users invest in suitable upstream land and water management practices, thus improving the livelihoods of upstream communities and maintaining essential environmental services (e.g. reducing sediment flow, and stabilizing downstream water availability). Research can quantify upstream–downstream interactions and inform the design of related institutional innovations, which can then be tested with stakeholders and their achievements measured.

5. **Pay attention to the political economy of policy selection**
   Decision-making must be understood within the existing governance framework, including both state and non-state actors, their respective political power, worldviews and interests. Hydrological and economic approaches may identify the costs, benefits and risks associated with particular courses of action, but they may also be confronted with the existing players and coalitions endowed with their own resources and logics. This opens the way for research that facilitates the development and use of tools such as multi-stakeholder platforms and other social learning techniques.

7.6. Where we will work

Target areas will include basins and basin groups with both physical and economic water scarcity. The original set will comprise such eight basins/groups: **Mekong** in South East Asia, **Indus and Ganges** in South Asia, the **Aral Sea Basins** of the Syr Darya and Amu Darya in Central Asia, **Tigris and Euphrates** in the Middle East, **Nile** in East and North Africa, **Limpopo and Zambezi** in Southern Africa, **Volta and Niger** in West Africa, and the **Andes group of basins** in Latin America.

These target areas have high potential for poverty alleviation, established partnerships, solid track records of previous CPWF and CGIAR research, and good potential for one or more levers of change to be applied. This SRP will however not limit itself entirely to these basins/target areas, but will keep a global outlook commensurate with its vision.

7.7. Links to other CRPs and SRPs

This SRP will link closely with the Irrigated Systems SRP given the strong connection between irrigation, water availability and water allocation. The SRP will also have major linkages with work in CRP7 (climate change) given the need for information on the impacts of climate change on hydrology. The availability of down-scaled climate predictions will be very important for basin modeling. Similarly the SRP will build linkages with the Rainfed Systems and Information Systems SRPs to link terrestrial changes in land cover to hydrological impacts via sentinel sites. From a policy perspective, this SRP will link to CRP2 (Policies, institutions, and markets to strengthen food security and incomes for the rural poor). We will also link with relevant parts of CRP1 (agricultural systems in dry, humid and aquatic environments) to coordinate on-farm NRM and basin responses.

7.8. What we will achieve in the first five years

In the next five years, a this SRP will develop a much better understanding of how best, in different settings, to deal with water resources availability and variability in time and space –the primary issues in water resources management globally. How land and water are used in specific locations can have profound impacts on people and environment. This SRP aims to quantify the impacts of different land uses and management practices on water processes, flows and quality, on livelihoods, and on ecosystem services. This information will be used to help water authorities adopt new policies for land and water planning and management that will assist in poverty reduction and positive environmental outcomes in major target areas. We will integrate into other SRPs and relevant CRPs the cumulative impacts of and changes to agricultural activities at basin scale. Below are a few examples of the key problem sets and associated research directions that we will pursue in some of our target areas.

Andes Group of basins – Latin America

Benefit-sharing mechanisms as a water management tool.

Previous CPWF research suggested that the socio-political environment is ripe for pushing the full-scale adoption of payment for environmental services in this region. The idea is that rich(er) downstream water users co-invest in improved upstream land and water management so that all users benefit. Benefits include higher water productivity (upstream), improved livelihoods, reduced land degradation and a more stable supply of higher quality water downstream – hence reduced siltation and pollution, improved irrigation, etc. The impact pathway for this work is described in Table 7.1.

Ganges and Indus – South Asia

Integrating environmental water allocations and climate change impacts with water resources development

Climate change impact on glaciers and snow in the Asian Tower are amongst the hottest topics debated at present, but the impacts remain largely unclear in both basins. In parallel, IWMI's previous work in India in the field of environmental flow management has stirred the national interest to the topic and has a high potential for impact in the near future. This research will include a mix of assessments of glacier and snow impacts on water availability downstream, optimal water allocation scenarios for the future, new models for conjunctive use of surface water and groundwater, and assessments of environmental flow impacts from increased groundwater use on rivers and flood in particular. The work will link closely with CRP7, under which the probable impacts of climate change are assessed. The impact pathway for this work is described in Table 7.2.

Mekong – Southeast Asia

Harmonizing the water–energy-environment nexus

The Mekong is one of a few major river basins in Asia that remain relatively unregulated. A hot issue in the Mekong is, however, planned hydropower development. This output will include the tools to assist with managing future reservoirs and their cascades with inclusion of ecological and livelihood considerations, quantified impacts of possible hydropower development scenarios on livelihoods, and quantified alternative scenarios for large-scale irrigation development and alternative energy sources. The impact pathway for this work is described in Table 7.3.

Nile – East and North Africa

Managing water resources to reduce poverty and improve wetland management in upstream countries

Upstream Nile countries generate most of the Nile flow, but receive the smallest share of benefits from it. Work here will include science-backed plans for optimal water storage development (currently almost non-existent), up-scaled information for water productivity improvement in rainfed areas, and quantified services of basin wetland ecosystems – all in the context of a complex transboundary perspective. The impact pathway for this work is described in Table 7.4.

Table 7.1. Impact Pathway: Benefit-sharing mechanisms as a water management tool in the small Andean basins

Issue	Levers of change	Research outputs	Outcomes	Potential impact	Contribution to SRF outcomes
• In many small basins in the Andes, conflicts among water users are increasingly common. Downstream communities, lowland commercial farmers and highland irrigated farmers want year-round availability of clean water. Highland urban areas need, and highland mines want water for ore processing with the freedom to discharge polluted water back into rivers. Highland rainfed farmers and herders want to expand and intensify production systems, although this may lead to overgrazing and erosion with implications downstream. Hydropower operators need the flexibility to rapidly change the volume of water flowing through turbines to meet power demand. However, alpine communities and those who value biodiversity want alpine lake levels to remain stable and highland nature reserves properly maintained.	Improved energy, food and environmental security in the Andes can be achieved through (1) rewarding for positive and penalizing for negative incentives, (2) investments in water storage and water treatment, and (3) broker 'benefit-sharing mechanisms'. The latter are when downstream water users co-invest in highland management focusing on practices that improve highland community livelihoods and stabilize water availability for downstream consumers. All three levers require strategies that integrate policies, institutional arrangements, technologies and stakeholder engagement.	**Information and tools** • A good understanding of land and water management practices by different stakeholders, and negative and positive externalities of such practices for downstream water users and the overall production of ecosystem services • A good understanding of the distributional and cross-scale consequences, including costs and benefits, of alternative strategies • datasets and tools to support all of the above. **Range of solutions** Strategies for investing in water infrastructure, treatment and benefit-sharing, with an understanding of the performance of different strategies under various conditions. **Improved capacity** A good understanding of how to encourage stakeholders to define problems, target solutions, understand their consequences, and negotiate evidence-based benefit-sharing agreements.	• National and provincial governments establish and implement policies favorable to the introduction of evidence-based negotiations to develop suitable benefit-sharing mechanisms • Institutional arrangements to share water, or water-related benefits • Investments made in water storage, management and treatment, with costs shared equitably by stakeholders • Improvements made in land and water management by farmers and herders that improve livelihoods, stabilize water flow, reduce sediment flow, and produce and support a wide range of ecosystem services.	• Livelihoods of poor highland communities improved • Greater and more stable availability of water to downstream communities • Increased and more flexible power generation • Reduced water pollution from mines and urban areas • Improved preservation of alpine nature reserves including lakes • Reduced water-related conflict.	• Sustainable NRM; poverty reduction

Table 7.2. Impact Pathway: Integrating environmental water allocations and climate change impacts with water resources development in the Ganges and Indus River Basins

Issue	Levers of change	Research outputs	Outcomes	Potential impact	Contribution to SRF outcomes
• The environmental and spiritual significance of Ganges for India is very high, as is the desire to keep it healthy, despite massive development plans. Climate change impact on glaciers and snow in the Asian Tower, coupled with projected changes in monsoon pattern are among the hottest topics debated at present, but the impacts remain largely unclear in both Indus and Ganges. Both basins are home to some 600 million people. Water productivity improvement in both basins is high on the agenda. Water resources planning and management is carried out in conditions of limited or no access to limited or no data on virtually any component of water balance. Transboundary cooperation between India and Pakistan, and India and Bangladesh, needs significant improvement.	• No matter how uncertain the projections are, the general biophysical trend in both basins seems to be towards the significant increase in water resources variability. Understandin g this trend and communicati ng it to responsible authorities is imperative, as both basins will become much more vulnerable, and both may not be able to support their populations in 20 years' time.	**Water resources:** • Impact of climate change on river flows and groundwater recharge in the Indus and the Ganges; availability of surface/groundwater resources in different parts of both basins • Quantification of disastrous events (e.g. flooding), their impacts on agricultural production, and formulation of preventive strategies. **Food security:** • Role of changed/improved water resources in continued intensification of food production. • Assessment of regional hotspots and ways to improve low water productivity. • Basin-wide, interstate hydro-economic models that allow the simulation of optimal water-allocation scenarios to meet future water demands. • Standard datasets and institutional arrangements accepted by all basin states, on which transparent decisions on water and benefits-sharing can be made **Environment:** • Environmental flows for both basins included into development planning; • Thresholds for groundwater development in underused parts of both basins established.	• Individual riparian countries and regional bodies use knowledge and recommendations to create policy. • National planning bodies and development banks support proposed strategies. • New water-sharing arrangements concerning the Himalayan region • Increased donor coordination and improved use of resources	• Enhanced food security for over 170 million rural inhabitants in both basins • Reduced vulnerability to climate-induced water extremes in the basin. • Better cooperation and reduced water conflict in the region. • Improved health of two of the major endangered rivers (Indus and Ganges) of the world.	• Food security • Poverty reduction • Sustainable NRM

Table 7.3. Impact Pathway: Harmonizing the water–energy–environment nexus in the Mekong Basin					
Issue	**Levers of change**	**Research outputs**	**Outcomes**	**Potential impact**	**Contribution to SRF outcomes**
The Mekong hosts a range of biophysical and socioeconomic attributes, reflecting the degree of economic development of countries. Economic growth triggers the development of water resources for hydropower production and associated related areas. The Mekong however remains yet one of the few unregulated large river basins in the world, but for how long? Changes in the flow regime due to water infrastructure development will have both positive (water for irrigation, flood control) and negative (decline in fisheries, potential salt-water intrusion) impacts. Balancing these competing uses is an imperative in influencing the basin development trajectory that ensure equity and sustainability.	The recent push for mainstream dams at Xaybury and Don Sahong adds a new level of urgency to understanding impacts of water infrastructure development. Improved understanding of basin hydrology over the last 10 years provides the basis to – to incorporate ecological, social and economic consequences and tradeoffs of basin development. Structures for transboundary cooperation, such as the Mekong River Commission (MRC), provide pathways for putting new knowledge into practice	**Transboundary cooperation** New tools for land and water resources monitoring using space technologies and public domain data to demonstrate data-sharing benefits for transboundary management **Livelihoods** • Development and assessment of livelihood strategies for communities affected by large water resources development • Practices to enhance productivity of seasonal floodwaters for the benefits of the poor (rice-fish systems, recession agriculture, maintenance of wild capture and harvest) • Management of saline/fresh water to enhance livelihoods in Mekong delta **Environment** • Improved watershed management to reduce sediment generation through 'smart' incentives to enhance adoption of conserving practices • Quantification of the impact of water resources infrastructure on fisheries and aquatic resources and potential mitigation strategies **Trade-offs** Economic and environmental evaluation of multipurpose dams in meeting energy, livelihood and environmental targets	• Mekong basin countries and regional organizations, such as the MRC and the private sector, use knowledge and recommendations to create policy and influence the decision-making process in water infrastructure development; e.g. reservoir planning explicitly includes environmental and livelihood parameters • Development partners support and adopted these strategies • Free flow of water data in the entire basin	• Water and electricity supply improved for about 50 million people in the Basin. • Mekong becomes the first large river basin in Asia, where sustainable water and land management policies are introduced before massive adverse environmental and social impacts manifest themselves	• Sustainable NRM • Poverty reduction

Table 7.4. Impact Pathway: Managing water resources to reduce poverty and improve wetland management in the Nile River Basin					
Issue	**Levers of change**	**Research outputs**	**Outcomes**	**Potential impact**	**Contribution to SRF outcomes**
• Upstream Nile countries generate most of the Nile flow, but receive the lowest share of benefits from it. They are very poor and very vulnerable to climate change. Ethiopia's agricultural GDP, for example, fluctuates almost in perfect correlation with annual precipitation. Agricultural intensification, irrigation and hydropower development in Sudan and Ethiopia – which are needed urgently for poverty alleviation – will affect downstream flows and wetland systems (e.g. Sudd) that are critical to local livelihoods. Strategies are needed to optimize upstream development and water access while minimizing downstream impacts. All of this must occur in a complex transboundary context	Current and proposed investments (e.g. Tekeze and Merowe dams) and population growth mean that rapid change is already underway; the challenge and opportunity is to influence development through better understanding of where benefits from water accrue. The major change lever is investment in water storage, but how will this, if it happens, affect wetland ecosystems, for example?	**Hydrology and Water Resources:** • Science-backed plans for optimal water management and storage in upstream Nile countries, including groundwater options – all with implications to downstream wetland systems • Management strategies for major wetland systems of southern Sudan (Sudd, Machar, Bahr el Ghazal) **Livelihoods** • Strategies to improve water productivity and decrease drought risk in rainfed agricultural and pastoral systems • High-potential water and land interventions for poverty reduction in the Blue Nile Basin – based on analysis of water availability, access and productivity in Ethiopian Highlands; **Ecosystem services** Quantification of relative importance of ecosystem services from the river and wetlands as the basis for negotiating tradeoffs among sectors and countries	• Sustainable production systems in rainfed areas and major wetland areas of southern Sudan and the Equatorial Lakes region • Reduction of vulnerability to drought in the upper basin through improved water storage and access to groundwater • Basin-wide cooperation in identifying development projects with transboundary benefits • Development banks and donors support proposed strategies	• Significant increases in food production from rainfed agricultural and pastoral systems, and reduced incidence of famine in Ethiopia and Sudan • Reduction in tension between upper basin and Egypt by identifying upstream development options with minimum downstream impacts • More equitable distribution of benefits from Nile basin water • Protection of key wetland sites	• Wetland protection leading to sustainable management of natural resources • Poverty alleviation through benefit-sharing • Food security via increased productivity

Amu Darya and Syr Darya – Central Asia

Transboundary water management solutions in transition economies

Syr Darya and Amu Darya are the only two major water sources in Central Asia. Political relations between the countries in Central Asia are driven by access to the water in these two rivers. Key here will be analyses of past and current water-related benefit-sharing agreements, and changes in them (before and after independence); assessments of possible options for water reallocation with environmental consequences; transparent decision support tools for basin-wide assessment of these options; possible data-sharing agreements; illustration of the benefits of an as-yet completely underused resource – groundwater – in agriculture; and analysis of the wider costs and benefits of sharing the water in the Syr Darya / Amy Darya, including potential new players such Afghanistan. The impact pathway for this work is described in Table 7.5.

Volta and Niger – West Africa

Water storage to reduce regional drought risk

Previous IWMI and CPWF research in the region demonstrated the potential of shallow groundwater and small reservoirs for agricultural production and poverty alleviation. The subsequent research will deliver guidelines on best possible combination of storage options (e.g. various size reservoirs and groundwater) to alleviate drought impacts – the major climatic factor hampering agricultural development in the region. Close collaboration with CRP7 (climate change), and CRP1.1. (drylands) is envisaged. The impact pathway for this work is described in Table 7.6.

Zambezi and Limpopo – Southern Africa

Harvesting transboundary aquifers

Southern Africa is characterized by high level of surface-water resources development, and, ironically, rather limited amounts of surface water. A push for regional agriculture may be expected from groundwater development in large transboundary aquifers. This research will include assessment of groundwater availability in these aquifers, establishing ecological thresholds for groundwater use (still possible prior to major harvesting of groundwater), and relevant governance models.

Table 7.5. Impact Pathway: Transboundary water management solutions in transition economies: Amu Dary and Syr Daria Basins

Issue	Levers of change	Research outputs	Outcomes	Potential impact	Contribution to SRF outcomes
• Soviet era cooperation in Central Asia (Amu and Syr Darya Basins) largely collapsed after 1991, resulting in misuse of water for both agriculture and energy, with substantial environmental costs. Yet a set of past agreements is still in place, and irrigation infrastructure has gone largely unnoticed despite huge local and international investments to craft new basin-scale water management plans – e.g. for Syr Darya. The major plans for massive inter-basin water transfers from Russia to Central Asia are back on the regional agenda. Afghanistan may also enter the stage soon. Drawing lessons from past functioning agreements, and quantifying possible trends will pave the way to improved basin management. It also points to the benefits and limits of basin-scale approaches.	• Coordinated management can improve energy, food and environmental security in the basins. But for it to happen, all parties need to benefit. One way to change is to learn from natural and social environments in which bright spots of cooperation (if any) occurred. Yet, considering the transitional nature of regional economies, identifying 'second best' solutions for immediate implementation is another strategy. This two-tier approach may provide the breakthrough that the region has been missing for over 20 years.	**Transboundary cooperation:** Inventory and analysis of past and current water related agreements **Irrigation/livelihoods** • Analysis of regional changes/variations in water control, and their impact on possible cooperation, poverty alleviation, equity and gender • Demonstration of benefits of groundwater use in agriculture for immediate water scarcity relief **Environment** Assessments of environmental flow impacts (with or without cooperation) including those on the Aral Sea, and of industrial/urban effluents and agricultural return flow on drinking water **Overall cost and benefits** Analysis of the wider costs and benefits of sharing the water including: agriculture, energy, environment, and drinking supply	• Regional states and organizations use knowledge and recommendations to create policy • Development banks support proposed strategies • Increased Donor coordination /decreased aid fragmentation • Institutionalization of enforceable transboundary cooperation	• Livelihood security of the Fergana Valley's 10 million inhabitants increased • Water and electricity supply improved for the region • Environmental damage to basins reduced • Lessons applied to other basins in the region and beyond	• Significant contributions to livelihood and sustainable NRM SLOs

Table 7.6. Impact Pathway: Water storage to reduce regional drought risk in the Volta and Niger River Basins *(applicable to most of Africa)*					
Issue	**Levers of change**	**Research outputs**	**Outcomes**	**Potential impact**	**Contribution to SRF outcomes**
Inability to predict and manage climate and hence water variability lies behind much of the prevailing poverty and food insecurity in West Africa. Declining rainfall since the mid-1970s, has exacerbated the problem and it is anticipated that climate change, which will most likely increase the frequency and severity of droughts, will do so further. Previous IWMI and CPWF research has shown that access to groundwater and a range of water storage options can contribute to increased food security and better livelihoods. However, as a rule, past storage interventions have failed for a variety of reasons. Past water storage development has occurred in a piecemeal fashion, largely through local initiatives and with minimal planning.	Investment into various forms of storage is the main path to sustainability and food security in the region. It will be imperative to develop and test structured and science-backed and tested short- and long-term basin-wide storage plans, taking into account all possible and socioeconomically acceptable and feasible plans, rather than follow an ad-hoc path.	**Improved understanding of storage efficacy:** • Insights into the need, suitability and effectiveness of different water storage options, under different agro-ecological and socioeconomic conditions (i.e. what works where, when does it work and why does it work). • Better understanding of synergies and tradeoffs associated with combinations of different storage types. • Insights into how different groundwater and surface storage options are managed in terms of access, institutions and the distribution of benefits. **Livelihoods:** Gendered evaluation of the direct and indirect impacts of different water storage options on livelihood strategies, poverty alleviation and equity **Improved planning and management:** Tools and approaches for better integrated planning and management of surface storage and groundwater	• West African states and organizations like the Volta Basin Authority use knowledge and recommendations to inform water resource policy. • West African states and river basin authorities develop water storage strategies to better plan and manage the full range of water storage options, in an integrated fashion, factoring in climate change too. • WB and AfDB support proposed water storage strategies and imbed them firmly in their investment policies • Increased coordination between NGOs, governments and basin planners in storage development, and awareness at all levels	• Livelihood security and resilience of around 120 million (mostly rural) inhabitants in the Volta and Niger River Basins increased. • Lessons applied to other basins in the region and beyond	• Poverty reduction • Food security

7.9. What we will achieve in the second five years

In years 6 to 10, lessons from the above impact pathways will be used to extend sustainable land, water and ecosystem management practices into other water-stressed basins. Significant attention will be given to monitoring the impact on ecosystem services from diversified management practices, and to cooperation with the SRP on Information Systems to develop regional analyses and information products on drought risk, soil-water storage, environmental flow recommendations and groundwater recharge possibilities.

7.10. Examples of research questions

We will test several hypotheses in this SRP. The following are examples of those hypotheses, along with associated research questions.

Guiding hypothesis
Water scarcity can be alleviated by improved water supply, by management of water demand and, in particular, by reducing water resources variability.

Research questions
- To what extent is water physically/economically scarce in a basin?
- How is scarcity the result of past policy decisions and how can it be prevented from becoming worse?
- How is water used in a basin? How much recycling is observed and what is the scope for 'real' water savings?
- What are the appropriate basin/regional strategies for improved water supply and demand management considering particular physical and socio-political contexts
- What are the hydrological, socio-political and ecological risks associated with water resources developments, as well as other policy options, that negatively affect the livelihoods of the poor? How can they be best quantified?
- How can groundwater abstraction be controlled and how to integrate the combined uses of surface and groundwater at the basin level?
- How does water quality affect water availability for various uses?
- How can hydrological extremes (droughts and floods) be better predicted and managed to minimize their negative impacts on agriculture?
- What are the best water-storage options for managing water resources variability?
- How best to manage water resources variability in transboundary river basins (international or state boundaries)?

Guiding hypothesis
River Basins can be managed to maximize the value of ecosystem services and benefits.

Research questions
- How best to quantify and map various ecosystem services and the components that provide these services in basins/landscapes?

- How are water-related ecosystem services for different groups affected by land management?
- How can ecosystem services and benefits of land and water be best shared across sectors, improving the livelihoods of the poor, fostering gender equity, and minimizing environmental impacts?
- What water and land management practices enhance or create ecosystem services for current and future use to reduce poverty?
- What composite of research, rules, monitoring and governance is best suited to ensure that negative impacts of an intervention in one part of a basin are not transferred to another?
- How to ensure that international agreements contribute to the protection of ecosystem services and poverty alleviation?

Guiding hypothesis
Agricultural intensification is possible without detrimental impacts on water and land.

Research questions
- What are the limits of water productivity improvement in different geographical and socio-political settings, and how can they be achieved?
- How to best up-scale promising interventions from irrigated or rainfed agriculture to the basin?
- What are the impacts of agricultural intensification and diversification on water resources?
- What are the tradeoffs between environmental water allocation and 'conventional' uses of water, particularly agriculture in the developing world, where food production is a first priority?
- How best to set and implement ecologically relevant thresholds for surface or groundwater use in developing countries?

Guiding hypothesis
Global drivers of change can be explicitly accounted for in basin management.

Research questions
- Which drivers of change are most pronounced in different geographical and socio-political settings?
- How do various external drivers affect the availability of land and water, and the magnitude, value and distribution of water- and land-related ecosystem services and benefits?
- How can macroeconomic, trade and agricultural sector policies be harnessed to support enhanced water, land and ecosystem outcomes for poverty alleviation?
- What are the hydrological and social dynamics of competing water uses and drivers of change within river basins/landscapes?
- What tools can be developed to predict and manage change?

7.11. Implementation plan

Research will be conducted in target basins that represent different poverty levels, hydrological conditions, levels and types of water scarcity, and development and closure, and where the

CGIAR already has a strong presence. By conducting studies across a wide range of basins and landscapes there are multiple opportunities for:

- New partnerships with relevant international research institutes and academic institutions.
- Complementarities between other SRPs and CRPs. Examples may include scaling up the findings of the Irrigation Systems and Rainfed Systems SRPs to landscape/basin levels; use of Information Systems SRP outputs for better quantification of basin land and water availability and ecosystem services; how upstream developments will impact coastal areas (link with CRP1.3); what are the downstream impacts of upstream development in highlands (link with CRP1.1 and CRP1.2), or how to adapt water storage structures, groundwater use and basin governance to increasing water and climate variability under progressive climate change (CRP7).
- Action research mode for stimulating water- and land-related benefit-sharing arrangements.
- Comparative analysis to generate international public goods.

7.12. Research outputs and outcomes

Generic research outputs from cross-basin research

- ***Institutional, policy and technical innovations*** to i) increase water and land productivity ii) arrest land degradation; iii) alleviate adverse impacts of spatial and inter- and intra-annual water resources variability, iv) improve resource governance and benefits sharing

- ***Information and guidelines*** on i) value and productivity of water in different uses (including aquatic and terrestrial environment); ii) selection and evaluation of various water storage options and their combinations at basin scale; iii) planning and implementation of benefit-sharing mechanisms; and iv) best water and land allocation practices with socially and ecologically responsible goals.

- ***Methods and techniques*** to: i) analyze trade-offs between different water and land uses; ii) evaluate the distribution of land and water related benefits; iii) evaluate water availability, allocation and access

- ***Improved capacity*** in the form of i) non-specialists who are aware of and have access to advanced technologies and data resources for policy-making (remote sensing, modeling, GIS); ii) trained specialists including M.Sc. and Ph.D. students

Outcomes
In 10 years it is expected that:

- Current and future (under changing climates) water resources variability is mainstreamed into water resources planning in all target areas.
- Decisions on investments in water infrastructure and on the selection of water management policy options (notably allocation) in water-stressed river basins are informed by the

research of this SRP in all major river basins, considering both physical and socio-political contexts.

- Water storage development becomes a structured process worldwide. Governments and development agencies pay attention to the variety of storage options (and their combinations) available, as part of the 'storage continuum,' and consider economic, social and ecological implications of storage development.
- Benefit-sharing mechanisms and payments for ecosystem services, designed or influenced by this SRP, are in place in target river basins (where proved feasible and relevant), and are considered for adoption in other major agricultural river basins/regions of the world.
- All water-related data and information (including ground observations from all national archives) required for informed water and land management in all world river basins (including all transboundary ones) are freely shared with all national and international stakeholders. This outcome is anticipated through work with the Information Systems SRP.
- Allocation of water for environmental and social needs is firmly included in national water policies in all countries that share the target basins, and has become the internationally accepted water management practice.
- A shift to combined surface-groundwater management and use is practiced in regions where groundwater is currently underused. Agricultural groundwater use has increased by an anticipated 30% in sub-Saharan Africa, Central Asia and East India/Nepal. Policies specifying environmental thresholds of groundwater use are in place in all above river basins whether closed or open. Managed aquifer recharge has become a viable alternative to the National River Linking Program (NRLP) in India. This outcome is anticipated through work with the Irrigated Systems SRP.
- The quantified impacts of land-use change on water availability are considered in all basin management decision in the target areas.
- The number of people experiencing various forms of water scarcity globally is substantially and clearly reduced – directly or indirectly influenced by the results of the work of this SRP.
- Improved research capacity to quantify ecosystem services, analyze land and water-related benefits, improve water and land monitoring, and mitigate negative impacts of human interventions is in place and doubled in all target areas.

7.13. Research partners

Table 7.7 indicates the types of partners we are currently working with, or plan to work with. More detailed partnership arrangements by basin, country or region will be developed during the implementation phase of the program. Apart from already existing strong partnerships in regions with individual organizations, one intention is to develop links with *networks* of organizations on one hand (to broaden the overall partnership web and increase visibility), and with *new partners* – to address specific technical needs of the new projects under this SRP. As this is an integrating SRP, additional partnerships will also naturally be established through four other SRPs. Many partnerships (e.g. with FAO, IUCN, the UN Conventions, UNESCO-HELP Program, and ARIs) will deal with sustainable NRM in world basins, regions and globally.

Table 7.7. Partners in SRP River Basins

Region/ basin	Core research	Implementation	Outreach
Limpopo–Zambezi	Agricultural Research Council (ARC) and Council for Scientific and Industrial Research (CSIR, South Africa); WRC (South Africa); Texas A&M University, USA; DHI and Geological Survey of Denmark (GEUS)	Southern African Development Community (SADC); Ministry of Agriculture and Food Security, Malawi; LimCom (Limpopo Basin Commission); Department of Water Affair (South Africa)	FANRPAN (Food, Agriculture and Natural Resources Policy Analysis Network), South Africa; UNEP; IUCN,
Nile	Bahir Dar and Arba Minch Universities (Ethiopia), WaterWatch and IHE (Netherlands), Cornell and Utah State Universities, USA; Stockholm Environment Institute (SEI); Ethiopian Economic Policy Research Institute; Ethiopian Institute of Agricultural Research; ARC and NWRC in Egypt	Nile Basin Initiative (NBI); Alliance for a Green Revolution in Africa (AGRA); Eastern Nile Technical Regional Organization (ENTRO); Ethiopian Rain Water Harvesting Association (EWRHA) network; Ministries of Water Resources and Agriculture in Sudan, Ethiopia and Egypt;	RAMSAR; IUCN, UN Economic Commission for Africa; Alliance for a Green Revolution in Africa (AGRA);
Volta–Niger	AGRHYMET, West Africa- Niger; Council for Scientific and Industrial Research (CSIR), GHANA; Institute for Environment and Agricultural Research (INERA), Burkina Faso; ZEF-Bonn; WASCAL Project located in Ghana-Burkina Faso, engaging multiple East Africa and German Universities; CIRAD and IRD (France)	Volta Basin Authority (VBA); Water Research Commission (WRC)- Ghana; Alliance for a Green Revolution in Africa (AGRA); Bill & Melinda Gates Foundation, USA; Water Resources Commission (WRC, Ghana), IDE	UN Economic Commission for Africa; Alliance for a Green Revolution in Africa (AGRA);
Mekong	CSIRO- Australia; Chinese Academy of Agricultural Sciences (CAAS), China; National Agricultural and forestry Research Institute (NAFRI)- Laos; Stockholm Environment Institute (SEI); Soils and Fertilizer Research Institute (SFRI), Vietnam; National Agriculture and Forestry Research Institute (NAFRI), Lao PDR; Utah State University, USA; IRD (France)	MRC, FAO, Ministry of Water Resources and Meteorology – Cambodia; Ministry of Agriculture, Forestry and Fisheries (MAFF – Cambodia; Ministry of Natural Resources and Environment (Vietnam) Water Resources and Environment Administration (WREA), Lao PDR	MPOWER, MRC
Indus–Ganges	ICIMOD, ICAR, Pakistan Agricultural Research Council, IITM- Pune, India, IWM (Bangladesh); WWF-India; San – Diego University	Ministry of Water Resources, India; Ganga Water Authority (GWA India), WAPDA (Pakistan); WARPO (Bangladesh); Nestle	WWF-India, IUCN, Water Footprint Network, GWP, International Water Stewardship Network
Aral Sea Basins	SIC-IWC, National Hydrometeorological Service, Uzbekistan; The Institute of Hydrogeology and Engineering Geology, Tashkent	GTZ, WUAs in Fergana Valley; SIC	
Andean Basins' group	COSUAN (network of 16 Andean country universities); Consortium for the Sustainable Development of the Andean Ecoregion (CONDESAN), Peru;	FUNDESOT (Foundation for Sustainable Development), Andes; RIMISP (Latin American Center for Rural Development)	

8. Strategic Research Portfolio: Information Systems for Water, Land and Ecosystems

Our vision: better information enables better managent of water, land and ecosystems.

Our vision is of a world where decisions on natural resource and environmental policy and management in agriculture are increasingly based upon sound scientific evidence. Farmers, resource managers, planners and politicians will rely on ready access to site-specific data on land, water and ecosystems to increase productivity and enhance the ability of people to sustain ecosystem services. Participatory approaches using this information will be greatly enhanced.

Global and regional agro-ecological information and assessment tools will be made available through user-friendly interfaces to stakeholders, including other SRPs in CRP5 and other CRPs. We will develop innovative spatio-temporal surveillance methods and standards to facilitate evidence-based planning and evaluation of agricultural interventions, and we will improve the ability of stakeholders to develop information and surveillance systems in data-sparse regions. (see Box 8.1 for an explanation of surveillance).

Box 8.1. Surveillance
Surveillance is the ongoing, systematic collection, analysis and interpretation of data essential to the planning, implementation and evaluation of land and water management policy and practice, and the application of these data to promote, protect and restore land, water and ecosystem health. A surveillance system includes a functional capacity for data collection, analysis and dissemination linked to land and water management programs. Spatio-temporal surveillance places emphasis on location-specific monitoring using scientifically rigorous protocols.

8.1. The compelling need for this research

Current land and water planning and management approaches in the developing world use at best rather general or insubstantial information on land use and the state of the environment (Paradzayi and Rüther, 2002). Data collected are rarely comparable across ecological zones because of inconsistencies in methods or in the spatial scale at which observations are made. Most long-term ecological monitoring networks have focused on natural ecosystems rather than agro-ecosystems (Sachs et al., 2010), and such data are rarely available in developing countries (Vorosmarty et al., 2002). The absence of systematic data collection and processing not only limits evidence-based planning but also prevents reliable feedback and learning mechanisms on what works, where it works, and why it works (see Box 8.2).

Deploying scientific, evidence-based and location-specific surveillance approaches, similar to those used in public health surveillance, has potential to accelerate reliable learning on agro-ecosystem management through systematic monitoring of resource conditions, trends, risks and intervention impacts. Modern earth observation techniques have potential to put such approaches into operation and provide specific empirical information on the state of land and water resources, and on the impact of interventions at different scales. Remote sensing techniques are available or emerging that enable measurement, monitoring, modeling and

mapping of vegetation condition, soil fertility, soil moisture status, groundwater levels, water quality, and other elements of the hydrological cycle (e.g. Bjerklie et al., 2003; Tang et al., 2009; Wagner et al., 2009). New multifractal scaling theory, for example, could offer an efficient means of providing information at different spatial scales for decision-making at reasonable costs (e.g. Posadas et al., 2005). The challenge is to apply these scientific and technological advances to routine operations in water, land and agricultural management.

Box 8.2. Lessons learned

There is a large gap between the potential and actual use of environmental information in decision-making (e.g. Paradzayi and Rüther, 2002). For example, despite the role of remote sensing in problem identification and policy formulation, policy implementation, and policy control and evaluation, de Leeuw et al. (2010) found that out of more than 300 peer-reviewed articles, none described actual policy support. A key challenge for this SRP is to make better use of the latest geo-information and surveillance science and technology. Some examples of successful applications of information and surveillance systems in land and water management are summarized below.

The Africa Soil Information Service (AfSIS; www.africasoils.net) has attracted US$18 million in funding over four years to provide new empirical data on the functional capacity of African soils and make this information widely available to farming communities, extension services, development workers, project designers, planners, policymakers, the private sector and scientists. The project is building a soil health surveillance system based on recent CGIAR advances in digital soil mapping, infrared spectroscopy, remote sensing, statistics and integrated soil fertility management to improve the way that soils are evaluated, mapped and monitored. An important component of the project is the use of standardized protocols for measurement, data management and statistical analysis. These are being taken up by a number of sustainable land management and conservation projects outside the CGIAR system for intervention targeting and impact monitoring. These include the private sector in Kenya for rangeland management, Mars Inc. for improving smallholder cocoa production in West Africa, the Kenyan Government for carbon inventories of Mount Kenya, and sustainable land management projects in China, Kenya, Rwanda and Uganda. Dissemination occurs through web-based interfaces and on-the-job capacity building. New thinking is needed to migrate the project to a demand-driven service provider operating with a business mindset, but backed up by solid science.

Water Information Systems are an essential component in the successful management of water resources and in targeting appropriate interventions. IWMI has developed various tools, frameworks and datasets for this purpose, including global data sets and maps on Environmental Flow Requirements and Environmental Water Stress, a Water Atlas (www.iwmi.cgiar.org/WAtlas/Default.aspx), a Water Accounting Framework, approaches for hydronomic zoning, mapping water availability, crop water productivity, wetlands, and global maps of irrigated and rainfed areas (www.iwmigiam.org/info/main/index.asp).

Some prototype tools, such as drought monitoring systems, are based on remote sensing; others, such as water audit systems (http://slwa.iwmi.org/), include spatial, time series, social and legal information that can be updated to monitor the overall status of water resources at a national scale.

We do not know whether we have provided information effectively until we observe changes. There are unprecedented opportunities for leveraging information and communications technology to help the poor through improved polices and planning and even direct provision of information services to land users.

Widespread access to computing and low-cost connectivity is transforming the way science for development is conducted (Ballantyne et al., 2010). Advances in web services, applications programming interfaces, cloud computing and automated work flows are enabling researchers to explore massive datasets and cooperate in new ways. Meanwhile, rapid developments in digital platforms and interfaces and open standards that facilitate interoperability across systems are providing new opportunities for universal access to science data products, tools and information. Mobile phone technology is opening up possibilities for two-way data and information flow with resource-poor land and water users in remote areas.

A key challenge for this SRP is to harness these advances for both accelerated scientific progress and effective decision support for stakeholders at different levels, and to engage stakeholders in surveillance and information and systems design and evaluation, so that evidenced-based decision-making becomes part of everyday policy and practice.

8.2. A compelling role for the CGIAR

The need for this SRP is succinctly expressed by the winner of the 2009 Nobel Prize in Economics Elinor Ostrom (2006), who argues that the study of complex ecosystems requires the conduct of, "long-term research programs that use research methods that focus at different temporal and spatial scales, such as time series remote sensing images, repeated on-the-ground social-ecological surveys of local stakeholders and their [resources], and experimental laboratory studies." The big gap that the CGIAR can fill is to co-develop, apply and disseminate new methods, protocols and tools for improving and standardizing the way spatio-temporal data on water, land and ecosystems is generated, stored, aggregated, transformed and communicated, to better inform decision-making at local to global levels. The CGIAR has notable experience in the development and practice of information systems (Box 8.3). This new opportunity for the CGIAR is further expanded in the following section.

Box 8.3. Examples of other CGIAR spatial information and surveillance systems

- Africa Environmental Information System, including mapping of land–water health metrics encompassing evapotranspiration, water productivity, irrigated area and estimates of biomass (ICRAF-IWMI)
- DIVA GIS – free open source GIS system (CIP)
- Spatial pest and disease modeling (CIP)
- Climate reconstruction, data gap filling, interpolation and downscaling tools (CIP)
- Landslide modeling (CIP-WUR)
- 3-D internet-based modeling interface for soil and water modeling (CIP)
- Crop wild relatives information at global level (Bioversity International)
- Digital Soil Map of the World initiative (www.globalsoilmap.net) linked to AfSIS.

8.3. The scope and depth of the opportunity

Remote sensing has potential to provide low-cost, location-specific information to aid land and water management decisions, but the ability to deliver reliable information is impeded by lack of consistent ground data for its calibration and interpretation. However, on-the-ground

monitoring is seldom rewarded by funding agencies (Nisbet, 2007), despite being one of the most deserving areas for future investment (Patching together a world view, 2007). The CGIAR has a comparative advantage in designing scientifically rigorous ground-sampling protocols across sentinel sites[8], and providing oversight and capacity building in systematic data collection, management and analysis.

Data collection and management of natural resources needs long-term thinking. Tighter connections are needed with providers of remote sensing data such as the National Aeronautics and Space Administration (NASA), the United States Geological Survey (USGS), the European Space Agency (ESA) and the Joint Research Centre of the European Commission (JRC) as well as with global environmental data archives, such as the Global Monitoring for Environment and Security (GMES). CGIAR long-term monitoring sites can provide essential calibration and validation data for remote sensing algorithms and applications.

Land and water management interventions are seldom monitored systematically in a scientifically rigorous and integrated way, especially at the programmatic level. As a result, there is little reliable knowledge on what works, where and why. The CGIAR can change this by developing and implementing scientifically rigorous monitoring protocols for intervention evaluation across sentinel sites. There is further potential to integrate land and water surveillance systems with those on human welfare, including human health, towards fully integrated surveillance systems.

Stakeholders at all levels can benefit from improved information systems, but their relevance and use is often limited by a number of factors, including the degree of participation in their development, the demand for the information, ease of access and technical capacity. The CGIAR consortium is well placed to provide a boundary-spanning role (Clark et al., 2011; Giller et al., 2008), sharing science and technology with stakeholders at the different levels and harnessing digital technology to provide easy-to-use and relevant applications. This includes engaging local communities in data collection and providing them with location-specific information.

Data sharing by national programmes, especially on water (streamflow, rainfall and groundwater), is a constraint to development of surveillance systems. Innovation is needed to encourage data sharing. Development of open data-sharing platforms that encourage others to share data could encourage or put pressure on governments and other agencies to release valuable data and information into the public domain. Highly effective spatial decision support tools could provide incentive for programmes to contribute data. Alternatively, open access to remote sensing data could lessen the need for governments to restrict access to information.

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[8] The aim of this approach is to obtain high-quality, consistent data from a network of sites selected to sample a wide range of conditions or specific target conditions. The type and size of the sites will vary with the monitoring objective and can be a selection of river basins, watersheds, irrigations schemes, bore holes, stream monitoring networks or land units.

8.4. Our Theory of Change for information systems

The desired change is for the generation and use of data relevant to policymakers and land and water managers. Our change theory is that this will happen through three main interventions (Figure 8.1):

1. **Focusing data generation efforts and information products on stakeholder decisions that have high value**, by (1) strengthening the use of fields, such as decision sciences, social network analysis and applied information economics, to better understand stakeholder decision processes and prioritize interventions, (2) pinpointing high-value information needs, and (3) involving key stakekholders in product design.

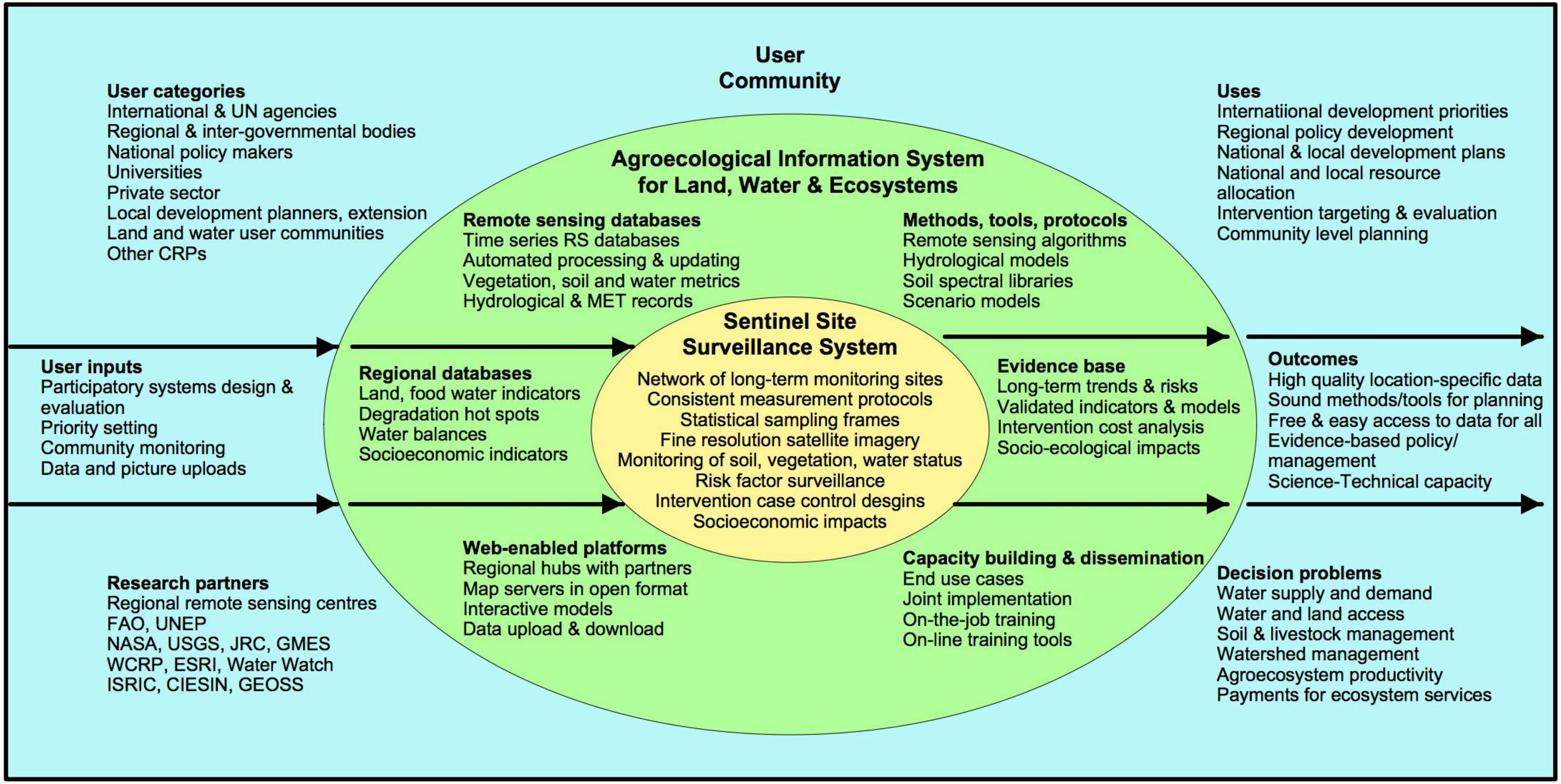
2. **Designing integrated and standardized multi-scale information systems on land and water management to serve regions that are vulnerable to poverty and ecosystem degradation.** Currently, CGIAR and external research in this area is fragmented and yet there are good opportunities to combine information and surveillance concepts, methods, models, databases and map servers, and applying these resources to practical decision problems at common sites. Standards and protocols will help partners contribute data to global information systems and to benefit from them.

3. **Amplifying our ability to deliver high-value information products to our stakeholders** through: (1) providing remote sensing and other information using new open platforms, to create demand and and stimulate the provision of more open access data, (2) building the capacity of different stakeholders to contribute to, share and use information products, and (3) building into projects near real-time mechanisms for assessing how products are influencing decisions and changing actions, to expand our knowledge of what is working.

8.5. Where we will work

Agro-ecosystem information systems will be developed globally for some products, but comprehensively at the scale of CGIAR regions: sub-Saharan Africa, Central and West Asia and North Africa, South America, South Asia, East Asia, Southeast Asia, and Central Asia. Our highest-priority target areas are data-poor regions, mainly developing countries of Africa and Asia. Sentinel site surveillance will be conducted at CGIAR benchmark sites, with first priority given to CRP5 SRP sites where land and water management interventions are being tested. Priority will be given to major geographic foci of CRP5: the Mekong, Indus and Ganges plains and hills, the Aral Sea basins (Amu Darya and Syr Darya), the Nile (East Africa), the Limpopo and Zambezi basins, the Volta basin (Niger), and the Andean basins. In addition CRP5 will continue development of the Africa Soil Information Service, covering non-desert portions of sub-Sahran Africa.

Figure 8.1. Information system for Land, Water and Ecosystems



8.6. What we will achieve in the first five years

Within the first three years, key milestones that are not part of existing funded projects include: (1) data portals for agro-ecosystem information systems for Africa, South Asia, Southeast and East Asia, and Latin America established; (2) technical specifications for regional agro-ecosystem and sentinel site data available; (3) existing global and regional spatial databases, including simulated data, compiled according to technical specifications; (4) decision support priorities and use cases established with end users from different categories/scales leading to a defined workflow catalogue; (5) sentinel site data collection in three priority benchmark rivers/basins underway; (6) advances in remote sensing for measuring components of the water balance; and (7) business plan vision for up-scaling data collection and information provisioning through partnerships with development and private-sector organizations.

8.7. What we will achieve in the second five years

Stakeholders from local to global level will have free access to spatial information and decision support tools allowing them to assess land health (the capacity of land to sustain delivery of essential ecosystem services, or the benefits people obtain from ecosystems) and water scarcity and quality, and to evaluate intervention impacts. Agro-ecosystem information systems and sentinel site frameworks and decision support applications will inform land and water management decisions at different scales in five benchmark river basins. Spatially explicit ex post environmental and socioeconomic impact assessment methods and protocols will be mainstreamed in the planning and evaluation all CGIAR funded projects concerning land, water and ecosystem management.

Ultimately in 10–15 years we envisage that all scientifically sound, location-specific data and information in the world of water and land management for agriculture will be freely available to interested stakeholders, leading to increased productivity, sustained environmental benefits and reduced poverty. Remote sensing of the water balance will be in routine operation, well calibrated with ground data. Capacity will be developed among regional and national partners in 15 benchmark river basins in developing countries across Africa, Asia and South America, allowing stakeholders to use improved information tools to plan land and water management interventions in agro-ecosystems and assess impacts at community to regional levels.

8.8. Implementation plan

The work will be done at two levels: (1) agro-ecological information systems at global to regional scales; and (2) sentinel site surveillance systems for monitoring land and water problems and risks and evaluation of interventions. The two levels are hierarchically linked: the sentinel site framework includes observation at nested scales from plot to watershed or household to district, and provides calibration and validation data for models and digital maps applied at regional scales. This SRP supports the other SRPs in CRP5 and other CRPs by providing easy access to data, information, modeling approaches and protocols to help with problem prioritization, intervention targeting, and evaluation of intervention impacts.

Ad hoc approaches to compiling regional agro-ecosystem databases and site characterization will be phased out and characterization will be much better standardized and harmonized across CGIAR regions and sites. CRP5 will play a lead role in coordining standard CGIAR approaches to regional, research site and landscape characterization, and this process has already begun.

8.8.1. Agro-ecosytem information systems

One of the first tasks will be a systematic information needs analysis, but using protocols developed from new science drawing on areas such as decision analysis, applied information economics and social network analaysis. This science-based approach will focus information system products on decisions, information and measurements that have high value in terms of reducing uncertainty of risky decisions for stakeholders at different levels. This area of work will involve developing new partnerships with ARIs in decision sciences.

At the global to regional level, agro-ecological databases will be compiled, standardized and made accessible to researchers and stakeholders through web-based map servers in open access format and for direct download access and viewing in Google Earth. This will allow researchers, managers and the public to use datasets for monitoring, modeling or forecasting with other available models. Specific platforms for tailor-made products will be developed.

The agro-ecological databases will combine time series of high (15–30 meters) and moderate (250–1000 meters) spatial resolution satellite images with near-real-time updating and freely available ancillary data, including socioeconomic data. From the present generation of satellite sensors and those expected to be launched within the next five years, the project will monitor the biophysical properties of the land surfaces, lakes and near-shore areas, including vegetation density and biomass production, soil properties, above- and below-ground carbon storage, and key components of the hydrological cycle such as precipitation, evapotranspiration, soil moisture and infiltration capacity. Ground data and fine resolution imagery will be available from CGIAR sentinel sites (see section 8.8.2.).

The dynamic flows and fluxes of water, carbon and key nutrients ranging from plot scale (1000 m^2) to river basins will be approached by a suite of modeling techniques, including simulation models for plot and basin scale, and statistical modeling. This SRP will ensure that models are empirically grounded through the sentinel site surveillance network and emphasize objective validation and uncertainty analysis.

8.8.2. Sentinel site surveillance

Across CGIAR regions, CRP5 will establish sentinel sites in partnership with other CRPs at which ecological and socioeconomic baseline conditions will be measured at the start of the interventions, with monitoring at least every five years, for intervention evaluation and impact assessment. In some cases, sentinel sites will be dispersed networks of measurement sites across river basins (e.g. groundwater monitoring, evapotranspiration flux towers). A standardized protocol will be used across all sites, which can be supplemented with additional measurements of local interest.

In the case of land health, the surveillance methodology will build on the protocols currently applied in the Africa Soil Information Service (AfSIS). Field measurements of vegetation and soil condition are taken using a standardized protocol, which is applied the same way everywhere. Soils sampled from these sites are characterized in the laboratory using low-cost, high-throughput spectroscopic techniques. The protocol includes a carbon stock assessment and information on a range of land health metrics.

The land health surveillance protocol includes assessment of a number of indicators related to hydrological regulation (e.g. flood risk, vegetation cover, topography and soil hydraulic properties), and these protocols will be extended to include other aspects of water health (e.g. water quality, streamflows and groundwater status). Sampling designs that help to better integrate biophysical and socioeconomic information for risk and impact analysis will be further developed, as will ways of linking land health surveillance to agrobiodiversity status and change assessments. Opportunities for combining efforts with other CRPs will be sought, for example with CRP7 (climate change) on household survey protocols for climate adaptation assessment.

Protocols will be designed for statistically rigorous evaluation of interventions designed to improve land and water management (e.g. case-control studies, randomized and non-randomized designs and time series analysis), including socioeconomic and ecological impacts. Scenario modeling (e.g. Grimm et al., 2005, de Fraiture et al., 2007), empirically grounded in the data generated in the sentinel sites, will simulate the trends and effects of key risks on water supply and demand, land health, system productivity, and ecosystem services.

We will carry out meta-analysis of trends and intervention impacts across sites and regions, made possible by the use of standardized protocols and data storage. All synthesized data will be made freely available using the Open Data Commons Attribution License (ODC-BY; (www.opendatacommons.org).

8.9. Examples of research questions

Key research questions to be addressed are:

1. What are the critical high-value decisions being made by different stakeholders in water, land and ecosystem management, and what additional information can most reduce uncertainty in those decisions?

2. What are the few key risk factors common to several land and water degradation problems that can form a basis for targeting preventive intervention programs (e.g. exposure of soils, drought, flooding, waterlogging, fire and insecure land tenure)?

3. Which remote sensing and spatial metrics, indicators and scaling techniques are most informative for measuring and monitoring productivity and scarcity and use of land and water resources, and for indicating scope for improvement at different scales? What tools can be produced, from space observations, that allow more balanced water use? Can all water-balance components and uses be measured reliably and monitored remotely? What are the limits to remote sensing of soil functional capacity? Can

measures of agrobiodiversity status and change be linked to the other measures of ecosystem function?

4. What protocols are required for scientifically sound evaluation of impacts of land and water interventions at different scales? What land and water metrics can be used as a basis for reward schemes for environmental services?

5. How can land and water surveillance be incorporated into routine decision-making processes into local participatory land use planning, and into national, regional and international policymaking processes? How can surveillance data guide policy and action on improved agricultural land and water management for the poor? How can land and water surveillance be integrated with human welfare and human health surveillance systems? How can information and communications technology be most efficiently harnessed to this end?

6. What is the most effective way to build capacity in agro-ecosystem information systems and surveillance methods and tools at regional and national levels? What are the limitations to stakeholder use of spatial surveillance information in decision-making for improved land, water and ecosystem management? What incentives and benefit-sharing mechanisms need to be put in place to encourage stakeholders to contribute water data? How can farming communities contribute data to surveillance systems and receive location-specific advice?

7. At regional and global scales, what will be the impact of various land and water changes and interventions under different scenarios of change, using this information as well as simulation- and agent-based modeling?

8.10. Research outputs, outcomes and impact pathways

CRP5 will support the development of spatial information and surveillance hubs by implementing standardized approaches and methods that will serve as platforms for data collection and harmonization, dissemination and capacity building. Each hub, implemented through regional and national partners where possible, will serve a specific region and set of sentinel sites. This SRP will ensure that hubs are uniformly equipped and staffed to implement the standardized procedures. This will include data and map servers linked with high-speed internet connections, soil infrared spectroscopy labs, and scientific and technical staff trained in the latest scientific and technical advances.

The sentinel sites of CRP5 and other CRPs will serve as the principal platforms for engaging end users in the design and testing of information and surveillance systems, dissemination and capacity building. These partners will include the global agricultural monitoring community, regional and national research and extension organizations, universities, natural resource managers, development agencies, and land- and water-user groups, and are described in the individual SRPs. Capacity building in research methods will focus on regional and national researchers, principally through on-the-job training through joint implementation. Business

models for scaling up innovations in information systems will be explored with development partners, agricultural service providers, the private sector and donors.

8.10.1. Research outputs and outcomes

Two examples of Problem Set impact pathways including specific examples of outomes are provided in Tables 8.1 and 8.2.

Agro-ecosystem information systems outputs

- Analysis of stakeholder decision processes and economic value of information on water and land resources and management, to identify high-value information products.
- Comprehensive, web-enabled agro-ecosystem database and map server for CGIAR regions including surrounding near-shore areas for regional remote sensing monitoring of soil and vegetation conditions and water resources status (also see section 8.8.1).
- Standardized datasets of simulated water data, based on hydrological models and agro-ecosystem databases, at fine spatial resolution for basins and continents.
- Land and water health indicators mapped for CGIAR regions, basins and research sites at nested levels of spatial resolution. New remote sensing techniques for measuring components of the water balance (rainfall, streamflow and groundwater) in partnership with ARIs.
- Innovative approaches to improving use of land and water data, including providing incentives for data sharing, and delivering data to end users via mobile phone technology.
- Increased capacity of regional and national organizations in design and application of environmental information and stronger surveillance systems, including end-user cases, decision profiles and example decision support modules.

Sentinel site surveillance system outputs

- A sentinel site surveillance system consisting of a set of well-characterized, long-term monitoring sites within CGIAR benchmark sites, with standardized databases supporting ecosystem risk assessment and monitoring, intervention targeting and evaluation, and impact assessment.
- Standardized protocols for land, soil and water health surveillance and intervention evaluation, with a web-based infrastructure to collect, centralize and analyze sentinel site data.
- Site-level harmonized baseline of land, soil and socioeconomic conditions at landscape and plot levels for key CGIAR research sites, with monitoring plan.
- Meta-analysis and mapping of land and water management problems, risks and intervention impacts across CGIAR sentinel sites in priority basins, linked to the regional agro-ecosystem databases. Prevalence data and fine resolution digital soil maps on key soil functional problems and risks in sub-Saharan Africa.
- Stronger capacity of regional and national organizations in spatial surveillance and intervention evaluation. This will be achieved through online learning tools, methods, standards, analytical tools, end-user cases, decision support products and joint implementation.

We expect the following outcomes:

- Scientifically sound methods, models and tools for systematic collection, analysis and interpretation of data on land and water trends and risks are being used for the planning, implementation and evaluation of land and water management policy and practice at local to global scales.

- Land and water surveillance systems are adopted as an integral part of decision-making processes on land and water management in regional, national and local systems, resulting in policies and practices that are well targeted to key risks to land, water and ecosystem health.

- A wide range of stakeholders engaged with land and water management, from international and regional policymakers and donors to individual users, contribute and have access to high-quality spatial information and decision support systems, which include benefit-sharing mechanisms to access and use information on land and water resource conditions and trends (from plot to regional scales) and on intervention performance.

Table 8.1. Monitoring longer-term spatial and temporal change in agroecosystems

Issue	Levers of change	Research outputs	Outcomes	Potential impact	Contribution to SRF outcomes
If we are to harmonize agriculture and the environment and manage the impacts of agricultural intensification, we must monitor impacts to provide feedback to policymakers and managers	• Ensuring national governments and international agencies see the value in long-term sentinel sites • Commitment from NARES to assit in monitoring and data management • Encouraging free and easy sharing of natural resources data among providers and users.	• A sentinel site surveillance system consisting of a set of well-characterized, long-term monitoring sites • Standardized protocols for land, soil and water health surveillance and intervention evaluation • Site-level harmonized baseline of land, soil and socioeconomic conditions at landscape and plot levels for key CGIAR research sites • Meta-analysis and mapping of land and water management problems, risks and intervention • Online learning tools, methods, standards, analytical tools, end-user cases, and decision support products.	• Capacity of regional and national organizations in spatial surveillance and intervention evaluation strengthened • Feedback to policymakers and managers of appropriate and risky interventions.	• Scientifically sound methods and models for systematic collection, analysis, and interpretation of data on land and water trends and risks used for the planning, implementation, and evaluation of land and water management policy and practice at local to global scales • Policies and practices that are well targeted at key risks to land, water and ecosystem health.	Increased environmental sustainability in rainfed agro-ecosystems Improved food security at local and regional levels Improved agricultural and NRM policy development

Table 8.2. Harnessing water information to improve management

Issue	Levers of change	Research outputs	Outcomes	Potential impact	Contribution to SRF outcomes
There is a compelling need to make available information on soil water storage (e.g. when to apply fertilizers) to enable farmers to reduce risks and to improve quantification of basin flow and yield.	• Development of *pro bono* partnerships with data providers to enable free access to remote sensing data • Use of mobile phone networks to deliver information • Capacity building in NARES to facilitate improved advice to farmers on how to respond to information.	• High-resolution water-storage assessments • Basin flow models better calibrated for land use • Guidelines for fertilizer management under given soil-water scenarios • Drought risk assessments • Standardized datasets of simulated water data, based on hydrological models and agro-ecosystem databases, at fine spatial resolution for basins and continents.	• Water surveillance systems are adopted as an integral part of decision-making processes on land and water management in regional, national and local systems • Delivery to farmers of water information by mobile phone • Improved drought prediction.	• Smallholders increase yields and livelihoods because of reduced risks • Improved water yield forecasting assists water allocation planning • Impact of drought reduced through more opportunity to foresee consequence and plan mitigation strategies at government level.	Improved food security at local and regional levels Improved livelihoods for smallholders Increased environmental sustainability in rainfed agro-ecosystems

8.10.2. End-user engagement and dissemination

The regional and sentinel site framework will engage stakeholders in design and assessment through several mechanisms. First, rigorous survey and scientific analysis of decision processes will guide prioritization of information products, and end-user engagement will be taken through all stages of development. Second, study designs, metrics and monitoring processes will be designed so as to acquire more rigorous and immediate feedback on the effectiveness of information products than has been achieved in the past. A variety of communication channels will be used to communicate information to potential users including policymakers, local communities, agricultural extension workers, land-use planners, wildlife managers, ecosystem managers, research scientists and climate modelers.

Innovation in dissemination of information through Enterprise 2.0 (social media) tools, and crowdsourcing (outsourcing tasks to an large group of people or a community) of data capture through mobile phone technology will be explored. Rapid development of smartphones will make it feasible to send and share maps and pictures.

Sustainability of this initiative will be achieved through embedding surveillance and spatial impact assessment in regional, national and local planning processes through capacity building at various levels. This will include interfacing and building business models for up-scaling information services with development partners and agricultural input and information providers. These models will contain appropriate benefit-sharing mechanisms for information providers from developing countries. The focus of CGIAR capacity building will be on training-of-trainers, including regional- and national-level scientists, development partners, educators and students, through joint implementation, student supervision and development of online tools. Online tools include self-help spatial information, methods guidelines, standards, materials for university curricula and statistical workflows.

8.10.3. Links to others CRPs

Links to other CRPs will be at two levels. Agro-ecosystem information systems, models and information products will be improved and made more relevant through collaborative work with other CRPs; and joint implementation of sentinel site surveillance will help identify intervention priorities and assist with evaluation of the larger hydrologic and landscape implications of field-scale interventions. Examples are given below.

CRP1 (Integrated agricultural systems)
Improve spatial information for targeting agricultural systems for the poor and jointly monitored sentinel sites for landscape-level evaluation of improved systems.

CRP2 (Policies, institutions, and markets)
Jointly develop policy priorities to reduce risks to land and water health based on surveillance data and involve policymakers in the design of information and surveillance systems. Improve spatial data sets on policy, market and institutional indicators.

CRP3 (Wheat; maize; rice; roots, tubers and bananas; grain legumes; dryland cereals; and livestock and fish)

Orient spatial information on agro-ecosystem conditions for input to crop models and improve spatial information on crop productivity and production potential.

CRP4 (Agriculture for improved nutrition and health)
Improve spatial decision support for safe wastewater use and nutritional aspects of increased productivity.

CRP6 (Forests, trees and agroforestry)
Joint analysis of surveillance information on land and water health risks in forestry and agroforestry systems and co-develop improved hydrological models for tree-based systems. Joint design of CRP5 sentinel sites within CRP6 proposed sentinel landscapes.

CRP7 (Climate change, agriculture and food security)
Improve information on carbon stocks in agro-ecosystems and develop strategies for climate change adaptation. Shared household/village survey protocols. Input climate change projections in agro-ecosystem resilience and scenario analysis.

8.11. Research partners

Existing spatial databases will be integrated by drawing on partnerships within and outside the CGIAR, including the CGIAR Consortium for Spatial Information (CSI), the Africa Soil Information Service (www.africasoils.net), HarvestChoice (http://harvestchoice.org/), World Climate Research Programme (WCRP), FAO (GLADIS, AQUASTAT), ESRI, Water Watch, ISRIC, CEISIN, and GEOSS.

Strategic research partnerships with centers of excellence in the North will build on existing CGIAR links. For example, collaboration with the Center for International Earth Science Information Network and the Earth Institute at Columbia University through AfSIS will facilitate access to satellite imagery and IT infrastructural developments. Planning is underway with a global consortium led by the Bill & Melinda Gates Foundation and Conservation International to design a global agricultural monitoring framework. National programs will be key partners in compiling time series hydrological and meteorological data.

Partnerships for engaging different stakeholder groups and for the constructing cases will be developed through the sentinel sites, including national institutions and development organizations. Partnerships for capacity building will also use the sentinel sites as nodes, but also include regional centers engaged in land and water management (e.g. RCMRD in Eastern Africa, AGRIMET in West Africa). Details of other partners are shown in Table 8.1.

Table 8.3. Partnerships for the Information Systems SRP

Region/ basin	Core research	Implementation and outreach
Limpopo and Zambezi	National Agricultural Research (IIAM), Mozambique; CSIR (South Africa), University of Malawi, Bunda College Malawi; Forestry Research Institute of Malawi-Forestry;	Southern African Development Community; Department of Agricultural Extension Services and Department of Agricultural Research and the Land Resources Conservation Department from the Ministry of Agriculture and Food Security, Malawi; WRC (South Africa); CARE International, Tanzania; UNEP; Mzuzu University, Malawi; Ministry of Natural Resources, Energy and Environment, Malawi; Total Land Care and National Association of Smallholder Farmers.
Nile	Addis Ababa University, Ethiopia; University of Göttingen, Germany; University of Makerere, Uganda; University of Nairobi, Kenya; Mekelle University, EthiopisKenya Agricultural Research Institute (KARI), Kenya; Regional Center for Mapping of Resources for Development (RCMRD), Nairobi, Kenya; National Agricultural Research Organization (NARO), Uganda; WaterWatch (Netherlands), IHE (Netherlands); Cornell University, USA; Bahir Dar University (Ethiopia)	Aga Khan Foundation; Ministry of Environment and Natural Resources, Kenya; Rwanda Agriculture Development Authority (RADA), Rwanda; Nile Basin Initiative (NBI)
Volta and Niger	AGRIMET, West Africa; Centre National de Recherche Agronomique (INRA), Cote D'Ivoire; Center for Scientific and Industrial Research (CSIR), GHANA; Institut d' Economie Rurale (IER), Mali; Institute for Environment and Agricultural Research (INERA), Burkina Faso; Water Research Institute – CSIR, Ghana, ZEF- Bonn;	Mars Inc., USA, Volta Basin Authority (VBA) ; Water Research Commission (WRC)- Ghana

Mekong	Chinese Academy of Agricultural Sciences (CAAS), China Mongolian Society for Range Management; National Agricultural and forestry Research Institute (NAFRI)- Laos; CSIRO- Australia; Xishuangbanna Tropical Botanic Garden (XTBG-CAS); Kunming Institute of Botany (KIB-CAS); Northwest University (NWU), Vietnam	Ministry of Water Resources and Meteorology, Cambodia; WREI- Water Resources and Environment Institute, Laos; Yunnan Department of Agriculture Yunnan and Department of Forestry, China; Ministry of Agriculture and Forestry, Laos; Department of Forestry of Luang Prabang Province, Laos; Ministry of Agriculture and Rural Development, Vietnam; Department of Agriculture and Rural Development (DARD) of Son La, and Dien Bien provinces, Vietnam; Department of Forestry, Myanmar; Yezin Forestry University, Myanmar
Indus and Ganges	National Remote Sensing Centre, India; ICIMOD, ICAR, Pakistan Agricultural Research Council, IITM- Pune, India, IWM (Bangladesh); WWF-India	Ministry of Water Resources, Ganga Water Authority (GWA India), WAPDA (Pakistan); WWF-India
Amu Darya and Syr Darya	National Hydrometeorological Service (SIC), Uzbekistan; The Institute of Hydrogeology and Engineering Geology, Tashkent	GTZ, WUAs in Ferghana Valley
Tigris and Euphrates	Arab Center for the Studies of Arid Zones and dry lands (ACSAD); International Center for Biosaline Agriculture (ICBA);	(In development)
Andes Basins	Embrapa (Brazil); INIA (Peru); IIAP (Peru); INIAP (Ecuador); Corpoica (Colombia); CIAT-Santa Cruz (Bolivia)	GIZ (regional); Ministry of Environment (Peru); UNALM (Peru); UNU (Peru); UFPA (Brazil); UFRA (Brazil); FVPP (Brazil); IPHAE (Bolivia); UNIAMAZONIA (Colombia)
AfSIS- SSA (in addition to Limpopo and Zambezi; Nile;	MTT Agrifood Finland; Sokoine University of Agriculture, Tanzania; University of Columbia, USA; Tanzanian Agricultural Research Institutes; Macaulay Land Use Research Institute;	Alliance for a Green Revolution in Africa (AGRA); Bill & Melinda Gates Foundation, USA; Conservation International, USA; WWF, USA; Wajibu MS, Kenya; Ministries of Agriculture in 42 sub-Saharan Africa

and Volta and Niger basin partners)		countries; Bill & Melinda Gates Foundation; Center for International Earth Science Information Network (CIESIN), Columbia University, USA;
Global (apply to most basins)	Colorado State University; Michigan State University; University of Florida, USA; University of Hohenheim, Germany; United States Geological Survey (USGS); National Aeronautics and Space Administration (NASA), USA; Global Water Systems Project (GWSP)	Agilent Inc, UK; Bruker Optics and Bruker AXS, Germany & South Africa; Google Inc, USA; Perkin Elmer, UK; Faculty of Geo-Information Science and Earth Observation (ITC); Food and Agricultural Organisation (FAO), Rome, Italy; Global Earth Observation System of Systems (GEOSS), Switzerland; Global Monitoring for Environment and Security (GMES); World Soil Information (ISRIC), Netherlands; Joint Research Centre of the European Commission (JRC); United Nations Development Programme (UNDP); United Nations Environment Programme (UNEP); World Bank; World Climate Research Program (WCRP)

9. Mainstreaming gender and equity in CPR5

The inclusion of gender as a key analytical variable is good science. It will provide more detailed knowledge and insights into farming systems and practices, technology adoption rates, extension methods, and will lead to the development of agricultural policies that will be of equal benefit to male and female farmers, fishers, and pastoralists.

It has long been recognized that women are central actors in agricultural production but that most have unequal access to land, technology, credit, education and other resources. This is mainly due to prevailing cultural norms, which are often reinforced by legal instruments. Figure 9.1 illustrates five key areas of agricultural research that can be, and usually are, strongly impacted by gender. Men and women have different levels of access to all of these resources, but there are also big differences within groups of men and groups of women, depending on their social class, caste, wealth, level of education.

Figure 9.1. Gender differentials in rural livelihoods

CRP5 recognizes that a rethinking of approach is necessary to ensure that the rural poor gain adequate access to and input into the development of science and technology-based applications aimed at making their work easier. Women farmers should be seen as the innovators they are, rather than as passive recipients of information through extension systems. A bottom-up approach is needed where they are seen as actors and fully involved in the process of science and technology development and dissemination. By introducing gender analysis as a core methodology within CPR5, the SRPs will be able to isolate and analyze the extent to which the uptake of new technologies and approaches will be affected by gender-related obstacles and barriers.

9.1. Approach

Several measures will be taken to ensure that gender is mainstreamed through CPR5 and all the SRPs:

- A CPR5 Gender Strategy will provide guiding principles for research in all the SRPs.
- A gender and equity (G&E) leader will be appointed, reporting directly to the CRP leader.
- Certain team members will be appointed as G&E focal points in each SRP.
- A G&E team made up of the G&E Leader, focal points and outside specialists as needed will work with the SRPs to provide expertise and resources to support consideration of gender within each of them and to ensure that programs are designed so that later monitoring and evaluation can examine gender and equity impacts.
- The G&E team will oversee the creation of internal capacity building for gender disaggregated research and partnership building with policymakers, NGOs, senior program managers, private investors, and centers of excellence in gender studies.
- A small G&E grant competition will be established to cover innovative research components or projects that link gender, equity issues, environment and food production.

The role of the gender focal points in each SRP will be of primary importance in implementing the CRP5 gender strategy. Focal points should be experienced and respected scientists, both male and female, who have a good understanding of the role of gender analysis in research on agriculture. Similarly, the G&E team should have a good balance of male and female members.

9.2. The CRP5 gender strategy

The gender strategy contributes to the CRP5 goal to sustainably improve livelihoods, reduce poverty, and ensure food security through research-based solutions to water scarcity, land degradation and ecosystems sustainability. The gender team must ensure that gender and equity objectives, indicators, analysis and evaluations are incorporated into research projects where and whenever this is relevant. The work supported under CRP5 is intended to be pro-poor and, since women are overrepresented among the rural poor, explicit attention will be given to gender-based inequities. An gender analysis should be undertaken whenever and wherever it is appropriate.

"Not appropriate" – and therefore not necessary – is too often the default assumption. For example, remote sensing data do not seem to relate to people directly, but when you look at who farms in rainfed areas, we find quite a high proportion of women. When we look, for example, at how irrigation systems are spreading, we will find that women are less likely to be benefiting. When we look at how river basins are being reengineered, we will find that planners are not given due attention to women's needs. Finally, when remote sensing researchers talk to communities about land and water use, they have in the past been less likely to be talking to women or to the least empowered members of the community.

The specific objectives are to:

- ensure that all research and associated work undertaken in CRP5 is pro-poor and benefits both men and women

- ensure that, where appropriate, all data are sex-disaggregated and analyzed from the perspective of gender and other factors that relate to equity issues
- examine the extent to which male and female farmers have different adoption rates and identify gender-specific barriers that may work against adoption
- identify gender bias in agricultural policy and in extension systems
- improve women's access to and involvement in the management of major resources, including land, water, infrastructure and other public services
- develop gender-sensitive policies for land and water management.

While not all projects in CRP5 will directly address all these objectives, most should include one or more in their research design.

Implementation of the gender strategy

Research Design. The G&E focal point in each SRP should work with his/her colleagues to introduce gender-sensitive questions and tools into the research design. When necessary, additional technical support can be provided by the G&E team.

At least some of the research objectives for each project should refer explicitly to anticipated gender outcomes. Baseline studies will be undertaken to collect information on male and female stakeholders, their separate and communal activities, and their separate needs and priorities. Gender-sensitive baseline data will provide a standard against which project impact can later be assessed. The type of data will vary depending on the specific project, but it could include:

- age
- education
- marital status/stage in the life cycle, i.e. whether women have young children whose care limits their time for agricultural and/or community works to improve water, land, soils or ecosystems, or have older children/daughters-in-law who can provide labor
- wealth, i.e. access to land, livestock and productive assets, experience/skills in agriculture and indigenous knowledge, etc.

Research implementation. While the gender focal points in each SRP will act as resource persons, team members will be responsible for doing the gender-related research themselves. Ideally, the gender aspect of research projects will not be 'add-ons' but will be a central part of the research design, with full support from all research team members.

Monitoring and evaluation. Monitoring and evaluation should be ongoing throughout the projects, and each SRP will develop a set of gender indicators that will allow it to judge at different stages whether it is meeting the project objectives and to make corrections as necessary. Research teams can make use of the impact pathways methodology developed within the CGIAR system or other appropriate tools, but in either case they will set gender-specific outcome targets. For example, researchers might question the extent to which women farmers are receiving support from extension services or they might ask whether the views of both men and women have been sought in testing an innovation.

Small grants program. The G&E team will manage a small grants program to support innovative research on gender and/or to test new tools and methodologies. Grants will be made

available annually on a competitive basis to researchers in CRP5. While most grants will support stand-alone projects, a few will be available to add a gender component to larger projects that are already underway.

Capacity building. In some cases, gender analysis skills are not present in SRPs. It may be necessary for the person assigned as G&E focal point to participate in short training programs set up by the G&E team to learn about the methods and tools that can be used to do gender-sensitive research. When teams already include an experienced member, he or she may be the only researcher with such knowledge. However, there is great potential for these isolated researchers to network across SRPs and to learn from one another. The G&E team will organize regular research fora where focal points can present their ongoing work and receive constructive feedback from other members of the team. Since CPR5 considers gender analysis to be good science, it is important that all team members have at least a rudimentary understanding of gender concepts and applications. Consequently, the G&E team will prepare a set of introductory tools that can be used for reference.

Global gender conference. As part of its commitment to gender-sensitive research, CRP5 will co-organize as one of its first activities a Global Conference on Gender in Agricultural Land and Water Management. There has not been such a conference since the Gender Analysis and Reform of Irrigation Management conference held in Sri Lanka in 1997.

Accountability framework. Senior management has made a firm commitment to ensure that gender is mainstreamed into CPR5. It is expected that all SRPs will appoint a gender focal point and will incorporate gender-sensitive objectives into their research.

10. Partnership and capacity building strategies

The key to CRP5's success is working in new ways with partners. In addition, it is making sure all partners involved, including CGIAR centers, NARES, partner NGOs, governments and end users have the capacity to succeed. The partnership and capacity building strategies of CRP5 outline the approach that will be taken to engage, interact and learn through the program.

10.1. Partnership Strategy

Good partnerships are the major way that CRP5 can add scientific weight to its work, ensure uptake of results, and learn what is working and what is not. Effective partnerships need to be nurtured, and they can bring both benefits and transaction costs. CRP5 will leverage the wide experience it has to maximize the former. Partnerships bring benefit by exposing people to new ideas, ways of thinking and resources. CRP5 will draw on these to stimulate innovation. Using research to solve real problems involves strengthening and adding to existing partnerships. CRP5 will seek partners who can contribute across the entire research-to-impact pathway.

However, the different functions in this pathway require different sets of partners. In fact, we recognize several different partnership roles and we are differentiating partners according to program functions and needs (see Table 10.1). Similarly, the geographic scale of our activities, as demonstrated in Chapter 2, also needs consideration in terms of partner selection. Thus we see the need for the following types of partnership:

Core research partners: to assist in conducting the research. These will include ARIs, NARES and the private sector.

Core research partners will:

- Commit to engage intellectually and financially in the program and share common goals
- Have a track record of successful research and development in the overall program area and with the SRPs
- Have a demonstrated capability to assist in fundraising to facilitate achievement of the program's goals and objectives
- Have a demonstrated commitment to development principles including gender and equity, knowledge and data sharing, and capacity building.

Examples of current and potential core partners include FAO, Centre de coopération Internationale en Recherche Agronomique pour le Développement (CIRAD), Institut de Recherche pour le Développement (IRD), the Indian Council of Agricultural Research (ICAR), the Commonwealth Scientific and Industrial Research Organisation (CSIRO Australia), ISRIC (The Netherlands) and numerous universities in developing and developed countries. Private sector partners who are prepared to support the above principles will also be core partners. We expect to build on current work undertaken with Water Watch, Nestlé, the Sir Ratan Tata Trust and Jain Irrigation under CRP5. We also expect to build on existing partnerships with specific NGOs (e.g. Stockholm Environment Institute, Stockholm International Water Institute, and IDE International) as core partners, where they have a capability to contribute to the core research agenda. Links with the Soil Health Program of the Bill & Melinda Gates Foundation and the

Alliance for a Green Revolution in Africa will be pivotal in raising agricultural productivity in sub-Saharan Africa.

FAO has already agreed to be a partner in CRP5. Specific activities will include integration of CRP5 and FAO information products on water, soil and biodiversity, so that these can be better targeted at users and benefit from FAO's strong regional and global networks. FAO envisage an in-kind contribution of US$10m per year through these joint activities. Discussions are underway as to how CIRAD and IRD can link their programs through specific activities with CRP5 in a number of regions including Southeast Asia, West Africa, and the Middle East and North Africa. Discussions have been held with the Indian Council for Agricultural Research to facilitate improved interaction in India.

Implementing partners**:** to assist in delivering policy reform and on-the-ground change. These will include government agencies, river basin authorities, development banks, NGOs and some private sector agencies. The private sector is becoming increasingly concerned with improved management of the natural resource base for long-term farm and environmental sustainability. We will develop partnerships with the fertilizer, irrigation, food and beverage industries, and other rural service providers that enhance the flow of information to farmers via private-sector networks and, at the same time, introduce efficiency concepts and waste management technologies to rural agricultural production facilities, including dairies and food processing plants.

Implementing partners will need to be engaged from the outset of the program to help shape the outputs. Their role will be to assist in promoting the uptake of the changes to policies and land and water management practices developed by the program core partners. This role is critical in terms of impact. They will need to demonstrate:

- Intellectual capacity to contribute to project design
- Demonstrated capability to initiate policy change at government level
- On-ground capacity and capability to roll out innovation and new practices
- Commitment to development principles including gender and equity, knowledge and data sharing, and capacity building.

Implementing partners include:

- Multilateral/International organizations
- Regional and subregional organizations
- International and regional development banks and major bilateral investors
- Bilateral donors and foundations
- National governments and local government
- Civil society organizations (policy, advocacy).

Specific examples are the NARES in all the proposed regions: the Mekong River Commission, the Volta Basin Authority, (Scientific Information Center of International Water Commission (SIC-IWC) in Central Asia and similar agencies elsewhere. At this level we see emerging and strengthening relationships with regional research organizations including CONDESAN, Central Asia and the Caucasus Association of Agricultural Research Institutions (CACAARI), Association for Strengthening Agricultural

Research in Eastern and Central Africa (ASARECA), Asia-Pacific Association of Agricultural Research Institutes (APAARI) and agencies like the Alliance for a Green Revolution in Africa (AGRA), who will provide direct linkages with the Global Conferences on Agricultural Research for Development (GCARD) community in terms of the two-way process of priority setting and information transfer to farmers. Equally important at this level are the government ministries that implement agricultural, water, soils and environmental policies and that control land and water management practices, including irrigation. Finally, many NGOs and civil-society organizations (CSOs) will also be engaged at this level, given their ability to assist in scaling up research outcomes.

Influence and outreach partners**:** to assist in creating an environment in which change can be implemented. Partners in this category include:

- global, regional and local networks such as Improved Management of Agricultural Water in Eastern and Southern Africa (IMAWESA)
- UN Conventions and professional associations, such as International Water Association (IWA)
- the educational sector
- stakeholder platforms at different scales
- some specific NGOs and CSOs.

Specific examples include treaty organizations including the United Nations conventions on desertification and land degradation (UNCCD), biodiversity (UNCBD), climate change (UNFCCC), The Ramsar Convention on Wetlands, international agencies like FAO and the UN Educational, Scientific and Cultural Organization (UNESCO) and influential NGOs such as the World Wildlife Fund (WWF). We will also build stronger linkages with the UNESCO HELP (Hydrology, for Environment, Life and Policy) program in terms of on-ground research and global outreach. CRP5 will also interact with groups such as the Water Footprint Network and the International Water Stewardship Network to assist them in improving their strategies, as well as to explore additional ways that our outputs can be used and incorporated into standards and international agreements.

Influencing and Outreach Partners must demonstrate a commitment to the goals and objectives of the program, as well as an ability to integrate program outcomes into their global and regional environmental best practice strategies and policies. They must also have an understanding of the importance of agriculture in development and the fact that achieving improved harmonization of agriculture and the environment will require integrative R&D and complex trade-offs.

Clearly, however, there can be overlap between these functional partnership levels in some organizations that have broad mandates. Further detail is given in the text on individual SRPs.

Figure 2.2 (page 55) also deals with scale issues and partnership to some extent. As indicated in Figure 2.1 (page 26) as we move to smaller scales (i.e. larger areas) partnerships will need to focus on national and international institutions. In contrast at larger scales (i.e. smaller river basins, landscape components and local districts), partnerships will be with the groups and agencies focusing on similar areas. Given that some partners operate across scale, it is hard to

be specific, but implicit in Table 10.1 is the concept that as you go down the rows, there is a tendency to move from the specific and local to the more general and regional to global.

Table 10.1. CRP5 partnership levels and collaborative roles

Partnership objective	Type of partners	Area of collaboration	Examples of partners
Core Research			
Hypothesis testing Methodology development	ARIs National universities Private companies	Remote sensing analytical solutions, improving hydrological measurement and modeling, economic modeling, etc.	University departments; CSIRO Australia; ITC Delft; IRD and CIRAD; Water Watch
On-ground research	• NARES • Regional research organizations, e.g. CONDESAN, ASARECA, APAARI	Studies of nature and extent of nutrient decline and land and water degradation, field trials	• ICAR (India) • NAFRI (Laos) • CSIR (Ghana)
Implementation			
Changing on-ground management practices	NARES; private sector; FAO		Jain Irrigation; Nestle; R. Tata Foundation; WWF
Changing policy at government level	Ministries of Water, Natural Resources, and Agriculture	Developing policy options	All major countries in which we are operating
Changing river basin policy and management	River basin organizations	Water accounting, allocation, biodiversity and environmental flow assessment, water economics	Mekong River Commission Volta Basin Authority Nile Basin Authority SIC (Uzbekistan)
Up-scaling management practices	NARES; NGOs; FAO; private sector; World Bank; Asian Development Bank; African Development Bank; Islamic Bank	Roll-out of new technology and innovation	ISRIC; FAO; IDE International; Care
Influence and Outreach			
• International treaties and conventions • Global and regional networks	• International conventions • FAO • Transboundary water agreements	• International public goods relating to wetland and habitat protection • Regional synthesis and map products	RAMSAR; UNCBD; UNCCD; FAO; UNESCO; IMAWESA

10.2. Partnership funding

CRP5 will build on the model used by IWMI and the CPWF that encourages the development of strong regional and global partnerships. Approximately 25% of current funding to these

organizations goes to partners for a range of activities included in the categories outlined above and in Table 10.1. Other CGIAR partners have similar levels of partner funding. Our challenge in this area is both to increase the total quantum of funding from traditional sources via better focused, well-planned integrated projects, but also to seek new sources of funding to support partners.

Under the implementation phase of CRP5 we will increase our focus at regional and basin levels and develop new proposals for bilateral funding that will maintain and potentially increase funds for partners. We will also develop strategies at country level that assist the implementation partners leverage new sources of funding such as the Global Food Security Trust for project implementation. We are also seeking to leverage private sector investment in the CRP. To date, Jain Irrigation has indicated a five-year contribution of approximately US$1.5 million.

Significant efforts are also underway to interest non-traditional CGIAR partners in the water treatment sector to contribute to the Resource Recovery and Reuse SRP. It is likely that the business models being developed within this SRP will provide attractive investment opportunities for private sector companies.

Specific details of partnerships are outlined for each SRP.

10.3. Capacity building strategy

Capacity building is the development of abilities in participants to critically evaluate and contribute to development options and outcomes. This includes capacity in terms of resources, technical skills, knowledge content and institutional ability. CRP5's approach is to play a catalytic role in capacity building by working with local capacity-building institutions, designing and disseminating training materials in appropriate formats, and most importantly, leveraging investments in capacity building. Our approach is to target capacity building within the following areas:

Learning through research-for-development

CRP5 will promote an inclusive, learning approach to research. Essentially, all partners, including CGIAR centers, will learn from the research-for-development exercise, a process which will change their knowledge, attitudes and skills. This process will be documented, shared and fed back into research design by the M&E and Impact Assessment unit.

Learning alliances and partnerships

Promote learning alliances. A learning alliance is a process undertaken jointly by research organizations, donor and development agencies, policymakers and private businesses. The process involves identifying innovators and sharing good practices in research and development in specific contexts. These practices can then be used to strengthen capacities, generate and document outcomes, identify future research needs or areas for collaboration, and inform public- and private-sector policy decisions. Learning alliances also help to broker key relationships between different groups such as farmers, policymakers and researchers. CIAT, IWMI, the CPWF and several other CGIAR centers and programs have been experimenting with various models of learning alliance, with good results.

Technical skills, training and mentoring
CRP5 will focus on developing capacity in a range of technical areas, including using remote sensing technology to model changes in resource use over time and implementing on-farm practices for better soil and water management. Specific capacity building initiatives will be developed through each of the SRPs. CRP5 will engage training institutions to manage, coordinate and deliver training programs and try to leverage funding for technical skill building. Where there is a gap, the CRP5 partnership will develop and implement specialized training programs. IWMI and IRRI are already well into the development of planning for an agricultural water management course that will initially be rolled out in several Asian countries and potentially into Africa and Latin America. CRP5 will also engage with and mentor university and post-graduate students in research that directly contributes to the CRP research-for-development agenda.

Institutional and organizational capacity
Institutional capacity is often a critical aspect needed to solve problems. We recognize that capacities for crafting and implementing policies, managing changes and reform, and delivering services require investment into training, leadership and technical skills. Where there is a need for developing institutional and/or human capacity, CRP5 will work with existing organizations and strengthen networks to leverage development funds for increasing capacity-building opportunities.

We envisage CRP5 investments in capacity building growing rapidly in the first years. In addition, we would like to influence major investments in capacity building to use the material and carry out recommendations generated by CRP5. Each of the SRPs will define specific capacity building strategies based on the problem set and the country contexts they operate in.

11. Marketing, communication and knowledge management strategy

CRP5 is predicated on the assumption that major changes in knowledge, attitudes and skills are needed to address the challenges of how water land and ecosystems can be managed to reduce hunger and poverty.

The Theory of Change, Impact Pathway and Partnership Strategies all contribute towards achieving impact. Marketing, communication and knowledge management (MC&K) cut across all these areas and will play a crucial role in building the overall strategy to achieve impact. Traditionally, CGIAR MC&K were pigeonholed as corporate services, thereby isolating them from the research effort and marginalizing their importance in achieving impact.

MC&K are in themselves valid and rich disciplines with their own set of concepts, theories and rigorous scientific processes. It is now recognized that MC&K must also be part of the research effort from the outset in order to bring about the desired changes.

There has also been a shift from linear, top-down MC&K (i.e. sender–receiver) to more participatory, collaborative and customized approaches for different users and contexts. The use of social media is the most outstanding example of this, whereby users and their own networks are the ones actively communicating ideas and messages. Likewise it has been demonstrated that effective internal communication in a research program is a prerequisite to achieving and ensuring effective external communication.

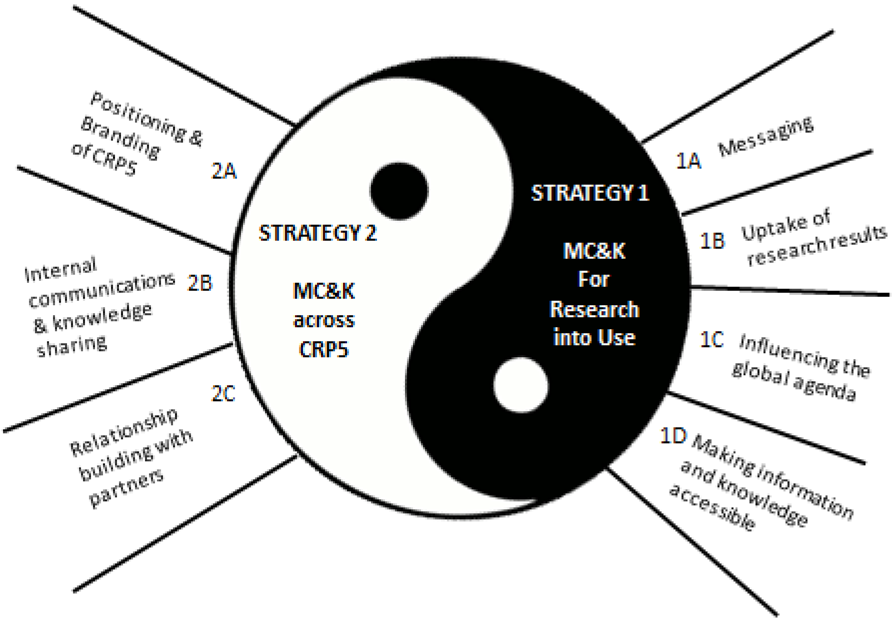
Goals and principles

The overall goals are to contribute to greater impact of the CRP5 research through both internal and external MC&K.

Programmatic areas of work, focus and follow up

The CRP MC&K strategy takes an innovative and integrative approach. As Figure 11.1 shows, the strategy integrates the MC&K sciences into the research effort while also recognizing the importance of supporting traditional efforts to improve MC&K across the whole Program. To do this, there are two overarching strategies and six component areas. All component areas are inter-linked, and systems and messages will cut across and support the CRP as a whole (SRPs, regional efforts and the Program).

Figure 11.1. Marketing, Communications and Knowledge Management (MC&K) Strategy for CRP5



11.1. Strategy 1: Marketing, communication and knowledge management for research into use

Research utilization is seen as just as important as the generation of research itself. For either to be effective, they need to be integrated.

Area 1A: Messaging

Messaging is about collaboratively developing and explicitly clarifying what the key messages are. It is an area rarely given dedicated time and efforts. Emphasis on messaging is a new way of contributing to building a collaborative approach, engaging partners, building awareness and contributing to the greater chances of achieving uptake.

It is important that messaging is seen as a process and not a top-down exercise where messages are developed through an iterative process amongst partners at various levels. The CRP will develop processes for achieving this.

Developing and clarifying what the key messages are will be critical for:

- to targete uptake strategies for research results
- developing strategies to raise awareness and influence the global agenda
- building the links across SRPs and to contextualize this into the regional situation
- feeding into the internal communications and knowledge sharing
- being made available in the broad access strategies.

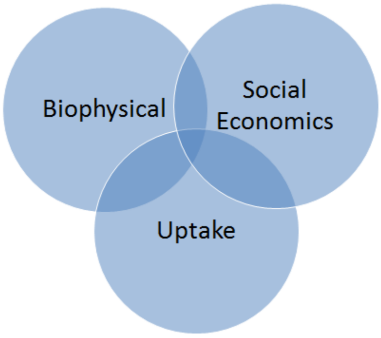
Area 1B: Uptake of research results

The *Developing uptake strategies* section details the need to see uptake as another discipline in a multidisciplinary approach and to ensure that uptake strategies are developed as part of, and integrated into, the research. Uptake is about scaling up and out, ranging from uptake at policy level to on-farm. MC&K is integral to this and should work hand in hand with the team.

The theory of change (see Chapter 3) underpins the research, ensuring that its selection and implementation are driven by an understanding of the problem and what is needed to make a positive change.

This leads to identified levers of change and research outputs as indicated in Table 3.1. Uptake strategies are the 'how to' of the theory of change and are needed to ensure results are being used to effect positive change. A main feature of an uptake strategy is that it is integrated into the research at the outset and seen as an integral part of the research effort, not as an afterthought (see Figure 11.2). An uptake strategy can comprise a number of different approaches, including involvement of stakeholders and relationship building, establishment of platforms, policy advocacy, capacity building, and information and communications.

Figure 11.2. Uptake seen as another discipline in a multidisciplinary approach to research



Impact Pathways are used to identify the process and roles of actors to achieve impact. Uptake strategies are developed to help move along the Impact Pathway. A dual approach to targeted uptake strategies is recommended:

Approach 1: Targeted SRP uptake strategies

Projects now form part of the bigger picture of a SRP strategy and a SRP impact pathway. This allows moving from project-based uptake strategies to a more integrated approach where the 'sum is greater than its part' and projects' uptake activities are integrated into an SRP uptake strategy.

SRPs will be identifying problems/opportunities and matching SRP solutions to these. The SRP uptake strategies are built into this to operationalize the efforts needed to achieve uptake of the solutions. Developing and implementing uptake strategies at a SRP level will help ensure the SRP topics are elevated onto the agenda of different stakeholders.

A SRP uptake strategy aims to contribute to and achieve uptake through topic-based messages and identifying how projects will work towards changing the knowledge, attitudes

and skills of target audiences. These topic-based messages may range from the need to revitalize irrigation, to the reuse of wastewater for irrigation, to the need to regulate and support ecosystem services.

This will also include identifying issues of relevance globally and developing a targeted strategy to influence the global agenda.

Approach 2: Targeted regional uptake strategies
These strategies build linkages across SRPs to provide synthesized messages and integrated solutions to a targeted geographic area.

The regional uptake strategies take a problem-solving approach by matching identified problems in the region with potential SRP solutions. In this way, solutions are mixed and adapted to the specific situation and problem set identified. This then takes on a much more focused research-for-development approach. This becomes a key mechanism to integrate and link the SRPs by operationalizing the SRP impact pathways.

A region may represent different levels – for example, a basin, a country, an area like West Africa or even a state/province. How a 'region' is defined needs to be flexible, taking into consideration who the common target audiences are especially, but also the messages, solutions and levers of change needed to achieve action.

The regional hubs and partners within the relevant regions will be critical in developing the regional uptake strategies.

Processes for developing targeted uptake strategies need to be selected and continual lessons learnt should be fed back into the process. Typically, developing a targeted uptake strategy will involve:

- identifying the key challenges and problems in an identified geographic area and detailing the impact pathway
- matching research results that might solve the identified problems
- undertaking market research to further detail the levers of change
- developing strategies to move along the impact pathway
- undertaking monitoring and evaluation to continually assess the progress and feed back into the strategy.

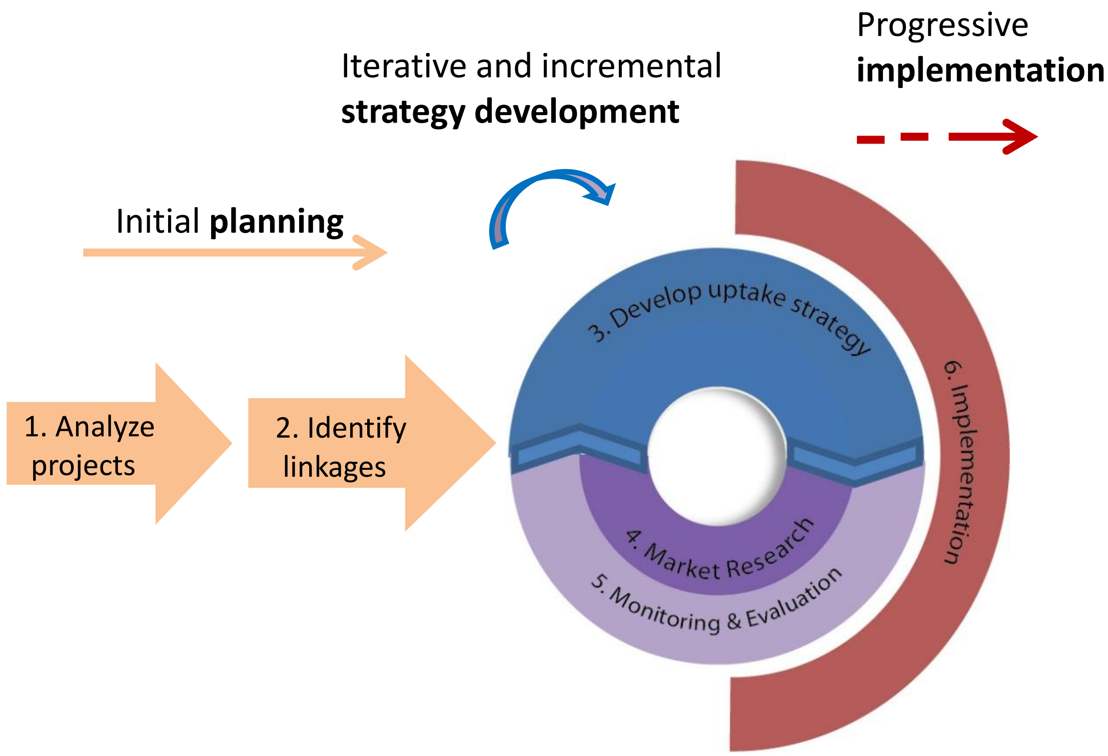
A typical uptake strategy may include:

- involvement of stakeholders (taking a participatory approach)
- internal communications
- relationship building and management
- capacity building
- information and communications.

Uptake requires an open, flexible approach, that is 'whatever it takes' to stimulate action. It also requires getting stakeholders involved from the start of research, rather than handing over the results after it has been completed. Iterative and incremental approaches should be

taken while developing the uptake strategy to allow for a continual process of monitoring and evaluation feeding back into the development of the uptake strategy (See Figure 11.3).

Figure 11.3: Iterative and incremental approach to developing uptake strategies



Area 1C: Influencing the global agenda
Clear objectives are needed to determine which issues and agendas need to be influenced, such as introducing water and agricultural issues into the COP agenda. Targeted strategies then need to be developed to achieve this. MC&K are critical for achieving this.

Area 1D: Broad access strategies for international public goods
This involves making all information and knowledge available as broadly as possible, ensuring that it is easily accessible and promoted widely. This is complementary to the targeted (SRP and Regional) uptake strategies and supports their effectiveness by creating a broader reach, increasing awareness and building the credibility of its messages.

Work will be closely coordinated with the SRP on information to develop systems and procedures for sharing information and knowledge across the CRP, as well as contributing to the global knowledge system.

A focus on Area 1D ensures that efforts are make to identify international public goods and also that practices and systems are put in place to promote these globally.

11.2. Strategy 2: Marketing, communication and knowledge management across CRP5

This strategy focuses on developing CRP-wide systems for marketing, communication and knowledge management.

Area2A: Positioning and branding of CRP5
CRP5 will follow CGIAR family branding but will also need to reflect the partnership approach. Positioning of CRP5, through all its outputs and activities, needs to reflect the CGIAR strategic research objectives and the overall position of the CGIAR as being a leader in agricultural research for development.

Area2B: Internal communications and knowledge sharing
Internal communications and knowledge sharing is given high priority in order to build a sense of community, share results and lessons learnt more widely, and communicate messages to staff and partners working across SRPs and regions.

A range of web-based tools will be used to share and exchange information. A number of CGIAR institutes have already developed a number of knowledge-sharing tools. Thus, emphasis will be on building on tools and systems that already exist rather than developing new systems.

Tools and systems are only one part of achieving effective internal communications. The MC&K area needs to coordinate and mentor internal communications efforts with management, leaders and the human resources department.

Area 2C: Relationship building with partners
As a research-for-development initiative CRP5 is inherently partner-driven in identifying issues, undertaking research and achieving uptake (see section on development partnerships). Thus relationship building will be a critical element of the marketing and communication strategy. The aim of this area is to enhance and strengthen new and existing partnerships in the SRPs and regions.

The focus will be developing cross-program approaches to relationship building, providing tools and strengthening capacity in partner management, and establishing cross-institutional contact management systems to avoid duplication. Ensuring that CRP staff are not 'approaching the same people with different messages' will be one focus of this area, as it is a common dilemma in many programs.

12. Monitoring, evaluation and impact assessment

Immediate funding is required to establish a CRP5 Monitoring, Evaluation and Learning (ME&L) unit to further design and implement the CRP5 monitoring, evaluation and impact assessment (ME&IA) system outlined below. The system is, and will be, designed in accordance with Consortium Level Monitoring Principles.

ME&IA in CRP5 has three dimensions: 1) an internal monitoring and evaluation (M&E) role associated with project and programmatic quality assurance and improvement; 2) an external impact assessment role one related to providing stakeholders with evidence of outcomes and impacts, both potential and achieved, resulting from CRP5 work; and 3) a commitment to ensuring accountability to CRP5 stakeholders. There are strong interactions between the three in terms of learning; being evaluative; and working to test, validate and revise project, regional, SRP and programmatic theories of change.

12.1. Monitoring and evaluation

Monitoring and evaluation will take place at different levels and scales: for the CRP as a whole, for individual SRPs, for regions, and for projects and stakeholders. Regular monitoring of progress and achievements, combined with opportunities to synthesize lessons learned and improve the program, form the basis for a flexible and adaptive management system.

We recognize in our theories of change a host of other drivers and factors that ultimately influence desired development outcomes. To better understand causal links and relationships, the ME&IA system will track the emergence of development outcomes to which CRP5 work has contributed, both expected and unexpected. This progress will be monitored through quantitative – and, where appropriate, qualitative – approaches that are transparent and independently verifiable. The actual choice of tools will be made by CRP5 scientists, with backstopping from the ME&L unit where needed.

Monitoring provides the intelligence needed to evaluate whether CRP5 is working as expected at its different levels. Monitoring and evaluation does this by seeking to test the logic and assumptions implicit in the theories of change, in part through the use of indicators derived from changes described in each theory. Learning what is working, and what is not, in terms of leveraging change provides the intelligence required for good adaptive management and supports programmatic improvement. It also tests the extent to which external drivers and other factors influence change processes. It is a social science / action research endeavor in its own right. It also a practice that ensures commitment to accountability and, through its process, the strengthened capacity and empowerment of those directly involved and implicated.

Monitoring also seeks to identify unexpected and emergent opportunities and outcomes, through the collection of outcome stories that provide plausible evidence of expected change, both positive and negative. The exercise of deriving indicators from program- and SRP-level theories of change will provide the indicators required by the Performance Indicators Matrix (required by the Fund Council) and will be a priority during the CRP5 inception phase.

Monitoring of activities and outputs
Monitoring activities are based on logical frameworks derived from theories of change specified at different scales (project, region, SRP, program). The theories of change will be developed collaboratively with partners, with support and capacity building from the ME&L unit. Each partner is responsible for achieving a set of milestones and outputs, derived from agreed theory of change, which will be incorporated into partner agreements, linked to partner payments and evaluated based on 6-month progress reports by the SRP Manager. The overall quality of the SRP project outputs will be overseen by the SRP Manager. Budgetary compliance will be monitored by the lead center.

We expect that the lead agency for each SRP project will have its own standardized institute quality-management procedures for documenting, reporting, monitoring and reviewing projects. Projects can continue to make use of these for the time being. How these will comply with standards for monitoring and reviewing to be set by CRP5 will be determined at the start of the CRP, and minimum requirements will be agreed, including agreement on 6-month reporting against milestones.

The monitoring of progress in executing project activities will be the responsibility of each Project Leader (PL), who is to be appointed by the lead agency of each project and activity. The PLs will produce 6-month progress and financial reports to consolidate progress in terms of processes, tangible activities and outputs. This will ensure close monitoring of progress and will identify the need to change the implementation plans if necessary. Workshops with the project team and stakeholders (partner meetings) at crucial points during the project duration will provide opportunities for planning, identifying and articulating emerging key messages. This design of the monitoring system will learn from relevant experience from partner organizations, including the CPWF.

Evaluation
Evaluation is the periodic analysis of data and information, as distinct from monitoring, to learn, improve and assess performance. Types of evaluation include *ex-ante* and *ex-post* impact assessment, external reviews, and self-evaluation that takes place during team meetings and workshops. Evaluation will take place at all levels in the CRP. Key operational and strategic lessons learned will be used for future priority setting, project and activity design, and adaptive management.

The ME&L unit will work with CRP5 management to instill an evaluative learning culture in CRP5, one which supports self-reflection and self-examination, seeking evidence on which to make decisions, making time to learn, and encouraging experimentation and change in others – including seeking to learn from failure as well as success.

12.2. Outcome and impact assessment
Research is risky. Only a small portion of any research portfolio will lead to widespread uptake and impact. Proving attribution, particularly in natural resource management, is difficult because of the long and convoluted pathways linking research to impact. Experience shows that in research carried out in partnership it is more realistic, and better for the partnerships themselves, to seek to demonstrate contribution rather than attribute a percentage of the

benefit to a single organization. The 'contribution not attribution' principle reflects the core elements in the design of CRP5. including joint problem definition and solving, working in multi-institutional and multi-disciplinary teams and linking up across a wide diversity of partners.

CRP5 ME&IA system recognizes the inherently unpredictable and risky nature of research-to-impact pathways. We will seek to minimize the risk in the first place through *ex-ante* impact assessment, priority setting and making explicit theories of change at different levels in the program. The initial research portfolio will be developed based on workshops, e-consultation and existing assessments of the magnitude of problems. Constructing theory of change will prioritize what research is conducted where to help tackle the problems.

To facilitate outcome and impact assessment, monitoring and evaluation of baseline information on key indicators will have to be collected and agreed upon. It will not be possible to have full sets of baseline data for all CRP5 activities. Therefore, intelligent choices need to be made to focus on some key indicators and specific sites selected in each region, initially using theories of change as guidance. Special attention will be paid to monitoring changes in knowledge, attitudes and practice of project stakeholders. We will also collect outcome stories to provide evidence that change is happening and that it happened because of the program, i.e. plausible contribution.

The ME&L team will work closely with the gender team in developing gender indicators and integrating a gender and diversity approach across the ME&L system. Gender and diversity will be included in theory of change in terms of expected outcomes and impacts. It will also be included in the very process of ME&L, including tool design, selection, implementation and sense-making.

Ultimately, we will want some indication of development impact. The ME&L unit will commission outcome and impact assessments, both *ex-post* and *ex-ante*, on a proportion of the research portfolio, using both in-house and external expertise. A few selected impact assessment studies will be conducted annually, starting in year 3 of the CRP. Case studies for impact assessment will be identified with SRP Managers. In recent years the Standing Panel for Impact Assessment and various other groups and programs have provided inputs and support in this area. Support in the development of impact assessment methods will be sought whenever required.

Sentinel sites, presented in the Information SRP, will play a role in this as well. Sentinel site information will include key socioeconomic, gender and equity data and information, as well as key biophysical parameters. While CRP5 impact will expand well beyond the sentinel sites, long-term monitoring of change in these locations will allow for detailed understanding of research-influenced innovation processes that will guide uptake strategies in other locations, as well as providing a basis for rigorous impact assessment.

12.3. Setting up the ME&L system

The starting point for CRP5 support strategies, including ME&L, are the theories of change developed at different levels in CRP5. This is because in describing who the projects, SRPs, basins and the Program intend to influence, researchers and managers are letting it be known

what should be monitored, evaluated, as well as where they need help with marketing, communications and uptake. A cross-functional team will be formed to work with researchers and stakeholders to develop theories of change, taking a ‘learning by doing’ approach to building necessary capacity. This team will begin holding theory of change workshops in the inception phase.

At the same time the ME&L unit will lead a team to develop a MEL&IA strategy for CRP5 to ensure close monitoring and evaluation of project results, outcomes and impacts. The team will work with the participating CGIAR centers and other lead agencies to build on their internal systems to develop a lean and ’least cumbersome’ MEL&IA framework. In the first year, a workshop with SRP Managers and key project leaders will be held to discuss proposed ME&IA frameworks and suggestions for impact assessment and baseline studies.

The ME&L unit will be led by the CRP5 Management Committee member responsible for M&E and include one full-time evaluator and part-time ME&L leads from each of the SRPs. The M&E leads will be responsible for co-developing the MEL&IA framework while at the same time building capacity in its use. Experience from the CPWF shows that building a lean ME&L system for users requires a significant investment in co-design and capacity building. The unit will call on and build a cadre of consultants to be used for training and evaluation purposes.

13. Governance and management

CRP5 has inputs from 14 CGIAR centers/programs and numerous external partners. This means that governance and management may be more complex than in a commodity CRP, for example. To ensure the development of an effective and efficient program, CRP5 is developing a governance and management structure that builds on the following principles:

- clear lines of responsibility and accountability
- a significant degree of independent oversight via a steering committee
- governance principles developed for the CPWF, as a basis
- the need for professional project/program management expertise
- minimal duplication of existing structures and functions
- the need for a responsive and flexible structure as the CRP evolves.

The governance and management structure of the CRP has the following major components:

1. a lead center (IWMI)
2. a steering committee
3. a management committee.

The governance and management structures are shown in Figure 13.1. The respective roles and responsibilities of these components and of contributing partners are summarized in Table 13.1.

Figure 13.1. Governance and management arrangements for CRP5.

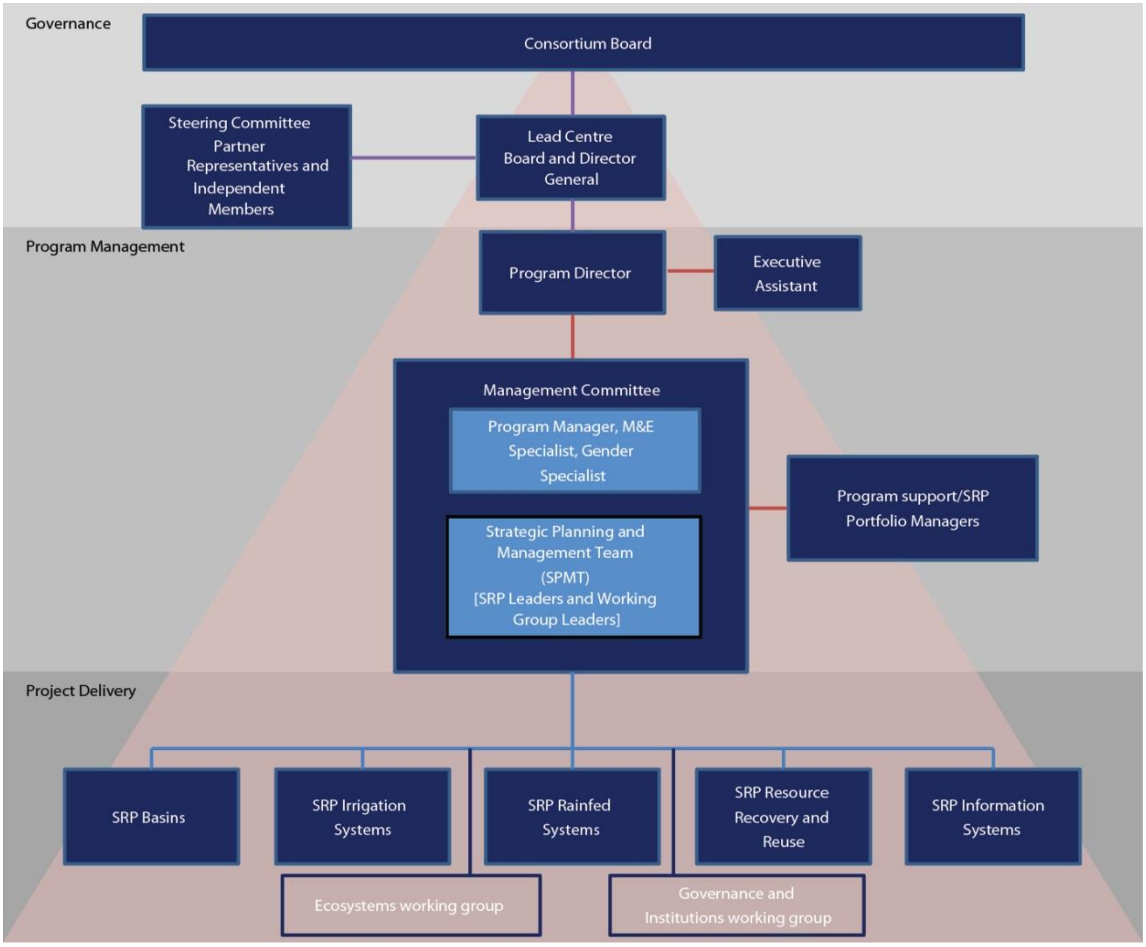


Table 13.1. Governance and management roles and responsibilities (table should be read in columns rather than along rows)

Lead Center Board (CB)	**Lead Center Director General**	**Steering Committee**	**Program Director**	**Management Committee**	**Program Participants**
Legal accountability	Supervision of CRP Director	Strategic directions	Intellectual and management leadership	Program delivery and outputs	Project execution
Fiduciary accountability	Development and implementation of Program Implementation Agreement and Program Participant Agreements	Development of the prioritization process for the CRP	Budgeting and financial management	SRP and cross-cutting theme leadership	Reporting against budget
HR and financial policy development	Overall reporting on Program budget to Consortium Board and Fund Council	Effectiveness of partnerships	Resource mobilization	Resource mobilization	Assistance with resource mobilization
Oversight of risk and compliance (e.g. audit and M&E)	Appointment of Program Director	Science quality	Implementation of M&E, capacity building and partnership strategies	Regional implementation of research program	Engagement with local communities and stakeholders
	Ensuring Program core staff comply with lead center HR, financial and other policies	Recommends annual workplans & budgets to lead center Director General for implementation	Program reporting to CB and FC via Lead Center	Strategies for integration between SRPs	Regional integration at project and output level
Input re: lead center interests into strategic direction setting		Advice on impact pathways	Representation of the Program at international fora	Impact Assessment	Project reporting to Management Commitee and Program Director
Oversight of development of dispute resolution processes between program participants		Dispute resolution mediation	Initial settlement of disputes between Program Participants	Initial settlement of disputes between Program Participants	

Role of the lead center

The role of the lead center includes the following:

- Be accountable to the Consortium Board for program execution, delivery and use of FC funds in accordance with the Program Implementation Agreement (PIA) between the Consortium Board and the Lead Center.
- Governance, fiduciary oversight and financial management of the PIA for CRP5 will be the responsibility of the Lead Center and its Board of Trustees (i.e. there will not be a separate board for the CRP).
- The lead center's board of trustees will coordinate the audit and other due diligence and oversight responsibilities required by the Program Implementation Agreement.
- The IWMI board chair and director general will report to the Consortium Board on CRP5 as a whole, including an annual financial and progress report in relation to the Performance Implementation Agreement signed between the Consortium Board and the lead center.
- Review and evaluate Program Participants' reports and performance, and via the Program Director will monitor, direct, supervise any CRP5 related activities of any Program Participant.
- Enter into partnership agreements, via the Program Participant Agreement (PPA), with centers or other institutes that will be responsible for leading major component projects related to SRPs.
- The lead center board will oversee monitoring and evaluation processes for the CRP consistent with CB and ISPC guidelines.
- The lead center may amend the Work Plan and/or the Budget of the entire CRP, and of a Program Participant, based on a change in strategic prioritization by the Steering Committee or to reflect any additional bilateral funding received by the CRP or by a Program Participant, according to the relevant provisions of Program Participant Agreement.
- The lead center may suspend or terminate any Program Participant Agreement on the recommendation of the Steering Committee.
- The lead center director general will also work closely with the Consortium CEO on matters related to CRP5 and with respect to resolution of conflict between Program Participants in the case that resolution cannot be achieved first by the Management Committee or by the Steering Committee, before bringing the matter to the attention of the Consortium Board.

The respective roles of the Lead Center Board and Director General are indicated in Table 13.1)

Composition and role of the CRP Steering Committee

The Steering Committee will provide independent scientific advice and strategic oversight for CRP5. It will comprise main CGIAR and external partners (based on significant financial and/or in-kind contributions to the CRP) and independent members including a representative/ nominee of GFAR. CGIAR and external partner representatives will include IWMI, CIAT, ICARDA, ICRISAT, Bioversity, CPWF[9] and World Agroforestry along with FAO and ICAR. Independent members will be sought based on advice of program partners and the Consortium Board. The lead center (IWMI) director general and an independent member (initially, Dr Johann

[9] until the completion of the CPWF Phase 2 by early 2014

Rockstrom of the Stockholm Environment Institute) will co-Chair the Steering Committee. The Program Director will be an *ex officio* member of the Steering Committee. The Steering Committee will focus on program planning and prioritization, science quality advice, partnership and impact issues. The Steering Committee is accountable to the Lead Center Board and responsible for:

- recommending to the lead center board strategic and annual plans prepared by the Management Committee.
- exercising general scientific and partnership oversight for the Program as a whole and making necessary recommendations or directions to SRPs and Program Participants through the Management Committee.
- developing and implementing prioritization processes for the CRP.
- establishing guidelines for membership of new program participants as the CRP evolves.
- facilitating collective agreement on equitable mechanisms, processes and decision criteria for funding allocations.
- mediating any dispute between the Lead Center and Program Participants or between Program Participants.
- recommending budget allocations between Program Participants to the lead center board.
- organizing Steering Committee meetings once a year, preferably back-to-back with a periodic annual CRP5 science forum.
- providing advice on scientific direction, science quality and feasibility of proposed approaches to the Lead Center and the Management Committee.
- providing advice on partnership and uptake/impact strategies.
- providing oversight and advice on gender and capacity-building issues.
- recommending the Lead Center to suspend or terminate Program Participant Agreement, or amend the budget and/or Work Plan on the basis of its evaluation of a Program Participant's performance; changes in strategic direction or priority within the CRP; additional funds brought in by a Program Participant or the reports submitted by such Program Participant.

Composition and role of the CRP Management Committee

The Management Committee will have two tiers:

- A core team will consist of the Program Director, a Program Manager, and Monitoring & Evaluation and Gender & Equity specialists. This team will be supported by two Program Administrators, who will deal with management of the contracts, finances and milestones of the SRP portfolio. The Program Director will be appointed by the lead center following consultation with other major partners in CRP5. The Director will be supported by a personal assistant. The Program Director will report to the IWMI director general and work closely with the Steering Committee in terms of overall program goals and outputs/outcomes.

- The second tier will be a Strategic Planning and Management group consisting of key contributors from the centers and partners. This group will include individuals selected to lead the SRPs and the working groups (Ecosystem Services, Institutions and Governance). The members be selected from among the program participants. Gender and diversity considerations will be a factor in team composition. The SPMG would meet in person 2–3 times per year and more often virtually. The combined Management Committee is

responsible and accountable for program delivery as specified in the Performance Contracts. The SRP leaders will be responsible for scientific management and outputs in each respective SRP and required to seek better ways of integration between SRPs.

The Performance Implementation and Program Participant Agreements will be the basis of determining expected outputs and performance against these. The CRP Program Director will report to partner institutions on performance and if major disputes arise regarding performance or delivery of outputs that cannot be resolved by the Management Committee, these will be dealt with initially at Steering Committee level. The entire Management Committee (Core team and SPMG) will be responsible to the Program Director for:

- fostering integrative and innovative solutions to key issues identified as the focus of CRP5
- planning scientific inputs and delivery of CRP outputs via the development of rolling annual work plans
- recommending budget allocations to the Steering Committee, based upon evaluation of the Program Participants' performance and reports and the recommendation of the Steering Committee. The budget allocations will be the basis for performance contracts between the lead center and the Program Participants.
- integrating outputs regionally and between SRPs within the CRP and for complementarity and reduction of overlap with other CRPs – bringing context, contribution and synergy between different CRPs and CRP components
- ensuring that gender issues are mainstreamed in the research.
- in conjunction with the Steering Committee and lead center, overseeing monitoring and evaluation processes for the CRP that are based on the Performance Implementation Agreement, Program Participant Agreement, and CB and ISPC requirements
- ensuring that the CRP outputs are of the highest scientific quality
- ensuring that partnerships are developed to deliver on-ground impact
- submitting CRP documentation and funding requests to the Steering Committee
- collaborating with the CRP Director and all partners for receiving and reviewing of technical report, annual activity report, financial report and final report from Program participants
- providing evaluation of the Program Participants' reports and their performance
- giving necessary directions and advice on the implementation of the CRP5 proposal by the Program Participants
- supervising the communications strategy
- reporting against work plans, milestones and outcomes
- finding amicable resolution of disputes between Program Participants.

Role of the CRP5 Program Director

This position will be filled following advertisement and an international search. The responsibilities are:

- intellectual and management leadership
- strategic planning
- ensuring that CRP components work as a team to deliver high-quality, integrative outputs to users
- ensuring that the CRP has a well-designed and implemented gender strategy

- ensuring that a coherent and comprehensive monitoring and evaluation strategy is implemented across the CRP
- representing the CRP within and outside the CGIAR
- leadership of the Management Committee
- managing relationships with SRP Managers
- assuming decision-making authority with respect to day-to-day operations of the CRP and, in accordance with the Program Participant Agreements, the release of funding to partners
- final approval of reports and project deliverables prior to their public release.

Management of regional integration

To ensure regional and basin integration CRP5 will nominate regional leaders from the lead center and major partners. Strong Regional Leadership is key to ensuring integration around coherent problem sets. Regional Leaders will be empowered to assess whether activities in the region meet the development goals and will convene periodic think tank meetings to meet with policy advisors from key countries and influential members of civil society and investors.

The terms of reference for a Regional Leader will include:

- acting as focal point for regional partners and main spokesperson for the CRP5 in that region, promoting interaction among and between SRP Managers
- developing, monitoring and revising theories of change and uptake strategies
- ensuring that gender and equity issues are given appropriate attention
- promoting interaction with other CRPs working in the same region and at the same research sites
- troubleshooting, suggesting solutions for, and facilitating corrective action
- developing and maintaining relationships with partners, resource persons and experts
- ensuring that partner activities are supporting the respective SRPs
- communicating consistent messages about the CRP; these should be consistent with messages communicated by SRP Managers
- ensuring information flows to and from the CRP Management Committee
- ensuring that research outputs and international public goods are suitable for the region and are published.

Program coherence means that individual projects have functional links; for example, the output of one project is an input into another project. This has to be planned, with all project leaders and other stakeholders helping. It is dangerous to underinvest in this process.

Outlined below is a process to ensure this happens. This process is noted in the work plan (Appendix 4) under the heading *Develop regional program plans.*

1. Based on existing experience, develop initial problem sets (regions, basins, sub-basins, ecosystems).
2. Design and implement a process of defining and prioritizing a more complete set of regional problem sets – including consultation workshops and synthesis of information.
3. For each regional problem set, develop a coherent program based on the theory of change logic and SRP logic presented here. Use SRPs to integrate across regions. Include

an exit strategy for each research site. Figure 1.1-1.3 exemplifies how different SRPs will contribute to CGIAR Strategy and Results Framework goals.

4. Set budget goals for regional programs and projects, consider existing or ongoing projects and design new ones, and calculate which budgets need to grow and which need to decline.

How existing structures will complement CRP5

A critical aspect of implementation of CRP5 will be using the existing regional management structures of the centers and partners to facilitate delivery of regionally integrated outputs. This will also enhance linkages withe GFAR and its regional constituency, networks such as Improved Management of Agricultural Water in East and Southern Africa (IMAWESA) administered by IWMI and other existing communities of practice.

Because staff will contribute to CRP objectives and projects from their own centers or partner organisations, there will be no need to duplicate human resource, communication and other administrative functions. Communications and reporting on the program as a whole will be coordinated by the CRP5 Director, but will use inputs from the network of partners with their respective roles and inputs defined in the Program Participant Agreements. Resource mobilization will be coordinated at CRP level under the leadership of the CRP Director. Human Resources support will be provided by IWMI for Program positions and by the respective partners for positions required to deliver CRP5 outputs. Monitoring and Evaluation and Gender and Equity issues will also be dealt with at Program level by specific appointments to the Management Committee.

Dispute Settlement Mechanism

Disputes between Program Participants shall be resolved amicably by the Management Committee. Failing that, the Steering Committee shall mediate the dispute and submit its report to the IWMI board, whose decision shall be final.

Disputes between a Program Participant and the Lead Center shall be resolved amicably by the parties themselves. Failing that, the Steering Committee shall mediate the dispute. If, after the Steering Committee's mediation, the dispute remains unsettled then the parties to the dispute shall submit it to the Consortium board. Only after a party is not satisfied by the decision of the Consortium board can it request for arbitration according to the provisions of the Program Participant Agreement.

Risk Management Strategy

Administrative and management risks

CRP5 includes 13 CGIAR Centers and many other partners. The first year will present many challenges resulting from new forms of collaboration, the transition from individual projects to a coherent research agenda, the different organizational cultures and disciplines, and various other dimensions of a large complex research consortium. With all centers moving into CRPs there is also a risk that researchers may be distracted by new procedures, reporting lines become unclear, and other changes may lead to delays and non-delivery of outputs. Efficient monitoring, evaluation and learning systems, an effective Management Committee, and decentralization to existing centers rather than trying to build another bureaucracy will be key

strategies to mitigate this risk. We will implement a simple and clear management system that draws on competencies in the centers and recognizes lessons learned from earlier systemwide initiatives and challenge programs.

Partnership risks

A wide range of partners is expected to participate in CRP5 to achieve the goals of the program. Lack of capacity of partners is often considered a key risk. However, at least as vital is the risk that the CRP5 does not engage with the right partners to achieve impact on the ground. Non-traditional partners will play a crucial role and there is still only limited experience in engaging with these partners (e.g. the private sector). During the first year of the CRP5, a gap analysis will form the basis for further partner selection, and a partnership working group will be established to work with the ME&L unit on partnerships.

Financial risks

There is a risk that the funding base is insufficient or too fragmented to achieve significant goals. To mitigate, CRP5 needs to concentrate funding on a clear set of priorities (SRPs) and to actively and collectively seek additional funds for activities. Coordinated fund-raising will be crucial. CRP5 will work together with the CGIAR Fund and Consortium Board to engage donors on the need for funding.

Political and social risks

There is a risk that research ideas and partnerships will not be received favorably or be a voice at the table because of changes in politics or situations of conflict. This is mitigated by taking a long-term view and monitoring the political landscape where we may, at times, have to wait for opportunities to engage. In the meantime, we have the flexibility to move to a more receptive environment. We will be taking advantage and building on long-term engagements.

14. Budget

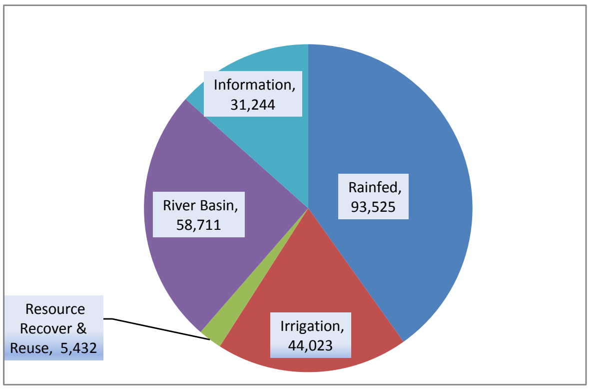
In line with most other CRPs, we have prepared a detailed 3-year budget. However, the intention is that CRP5 will require an initial 5 year's funding. The annual budget for CRP5 is US$76 million in the first year (starting in 2011) as shown in the figures and tables below. This budget is expected to increase to $87 m in 2013 resulting in the 3-year total budget of $246 m. The CRP5 total budget assumes a reasonable annual average growth of 6.8% over the 3 years; this is in line with the last 3 years' recorded average annual growth in CGIAR total funding, which was in excess of 8% in nominal terms.

The budget will be distributed between the five SRPs and core program management costs. Of the SRPs, Rainfed and River Basins will use approximately 40% and 25% respectively, followed by Irrigation and Information. While Resource Recovery & Reuse has the smallest budget allocation, this is relatively new research area for the CGIAR, which we are confident will grow significantly in future years. The in-kind or own funding of non-CGIAR partners has not been included in the budget, though some partners (FAO, for example) have already indicated their willingness to commit resources.

Core program funding is required for management, coordination, integration, Monitoring Evaluation & Learning, gender and equity, capacity building, marketing and communications, and uptake. The complexity and size of the program will necessitate some additional staffing and operational expenses to facilitate smooth implementation and quality enhancement. The budget for these activities has been arrived at using various assumptions such as additional staffing requirements, expected travel related to these activities and coordination costs that do not form part of the center's overheads. These costs are relatively lower because the costs of most of the management team members are assumed to be already included in individual centers programmatic costs. It is further assumed that the participating centers will be able to capitalize on existing structures and use the increase in funding and resultant overheads in later years to support any increase in these activities. This, however, will have to be revisited in future years to reflect the actual programmatic and management structure as proposed in the proposal. However, we expect that the Management Committee will be able to do this within the budgeted financial resources of this proposal.

The percentage allocations for CRP5 are showed in the table below. More than half of the total budget is devoted to sub-Saharan Africa and CWANA, while South Asia and South East Asia accounts for one-quarter of the total budget. The regional allocation of the budget demonstrates the CGIAR centers' focus on Africa and Asia.

Figures 14.1 and 14.2. Budget by SRPs and allocation by regions (excludes essential programmatic activities)



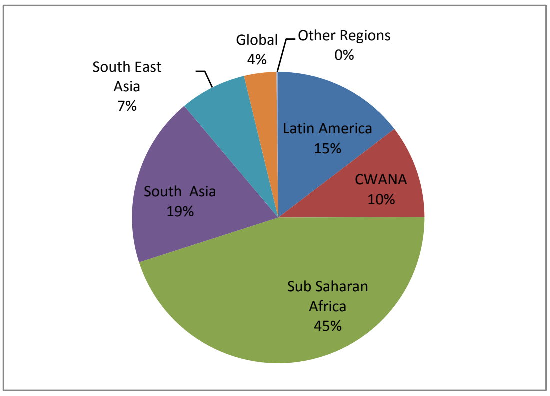


Table 14.1: Budget allocation by SRPs by Region

Amounts in 'USD'000s

Strategic Research Portfolios	Latin America	CWANA	Sub Saharan Africa	South Asia	South East Asia	Global	Other Regions	SUBTOTAL
Rainfed	18,396	9,289	44,382	16,039	2,725	2,582	113	93,525
Irrigation	203	8,614	15,883	14,534	3,304	1,382	102	44,023
Resource Recover & Reuse	-	1,949	1,655	1,406	231	183	8	5,432
River Basin	7,407	2,190	27,983	10,351	9,313	1,330	138	58,711
Information	8,008	2,046	15,138	1,625	1,552	2,818	57	31,244
Subtotal	**34,013**	**24,087**	**105,024**	**43,931**	**17,109**	**8,320**	**451**	**232,935**
Essential Programmatic Functions								
Gender and Equity								3,070
Monitoring, Evaluation and Learning								2,585
Coordination and Management								4,331
Marketing, Communications and Knowledge Management								712
Capacity Building								726
Information systems								1,897
Subtotal								13,320
Grand Total	**34,013**	**24,087**	**105,024**	**43,931**	**17,109**	**8,320**	**451**	**246,254**

Table 14.2. 2011–2013 Budget by center by Strategic Research Program

Table D 2011-2013 Budget By Center by SRP

Amounts in 'USD'000s

2011	AFRICA RICE	BIOVERSITY INT'L	CIAT	CIP	CPWF	ICARDA	ICRAF	ICRISAT	IFPRI	IITA	ILRI	IRRI	IWMI	WorldFish	Total
Rainfed	296	813	8,597	1,062	-	1,999	728	4,677	422	1,210	923	-	7,746	-	**28,473**
Irrigation	296	271	-	-	-	1,708	-	293	1,169	-	-	635	9,377	-	**13,749**
Resource Recover & Reuse	-	-	-	-	-	556	-	-	121	-	-	-	1,019	-	**1,695**
River Basin	168	1,084	-	-	13,854	273	485	-	362	-	-	-	1,223	694	**18,144**
Information	-	542	2,866	1,206	-	505	3,398	-	-	518	-	-	408	-	**9,442**
Essential Programmatic Functions															**4,639**
Total	761	2,710	11,463	2,268	13,854	5,041	4,611	4,970	2,073	1,728	923	635	19,772	694	**76,142**

2012	AFRICA RICE	BIOVERSITY INT'L	CIAT	CIP	CPWF	ICARDA	ICRAF	ICRISAT	IFPRI	IITA	ILRI	IRRI	IWMI	WorldFish	Total
Rainfed	263	1,515	9,027	1,164	-	2,199	764	5,145	443	1,449	1,365	-	8,133	-	**31,467**
Irrigation	263	505	-	-	-	1,879	-	321	1,228	-	-	667	9,845	-	**14,708**
Resource Recover & Reuse	-	-	-	-	-	611	-	-	127	-	-	-	1,070	-	**1,808**
River Basin	137	2,020	-	-	15,327	301	510	-	380	-	-	-	1,284	709	**20,667**
Information	-	1,010	3,009	1,373	-	555	3,568	-	-	621	-	-	428	-	**10,564**
Essential Programmatic Functions	0														**4,097**
Total	662	5,050	12,036	2,538	15,327	5,545	4,842	5,466	2,177	2,070	1,365	667	20,761	709	**83,311**

2013	AFRICA RICE	BIOVERSITY INT'L	CIAT	CIP	CPWF	ICARDA	ICRAF	ICRISAT	IFPRI	IITA	ILRI	IRRI	IWMI	WorldFish	Total
Rainfed	294	1,575	9,478	1,303	-	2,419	803	5,658	465	1,603	1,447	-	8,540	-	**33,584**
Irrigation	294	525	-	-	-	2,067	-	353	1,289	-	-	700	10,338	-	**15,566**
Resource Recover & Reuse	-	-	-	-	-	672	-	-	133	-	-	-	1,124	-	**1,929**
River Basin	158	2,100	-	-	14,284	331	535	-	399	-	-	-	1,348	744	**19,899**
Information	-	1,050	3,159	1,536	-	610	3,746	-	-	687	-	-	449	-	**11,239**
Essential Programmatic Functions	0														**4,583**
Total	746	5,250	12,638	2,839	14,284	6,100	5,084	6,011	2,286	2,290	1,447	700	21,799	744	**86,800**

Grand Total Year 1 to 3	**2,169**	**13,010**	**36,136**	**7,644**	**43,465**	**16,686**	**14,537**	**16,447**	**6,536**	**6,088**	**3,735**	**2,003**	**62,332**	**2,147**	**246,254**

Table 14.3. Project expenditure by cost categories and funding sources

Table E Project expenditure by Cost categories and Funding Sources

Amounts in 'USD'000s

CRP 5	2011	2012	2013	Total
Personnel Costs	26,743	29,029	30,870	**86,642**
Travel	2,915	3,278	3,461	**9,654**
Operating Expenses	9,770	10,818	11,634	**32,221**
Training & Workshop	2,750	2,385	3,004	**8,139**
Collaborators/Partnership Costs	21,907	24,693	23,804	**70,403**
Capital and other equipment	1,443	1,503	1,609	**4,556**
Contingency	859	803	879	**2,542**
Subtotal	66,386	72,508	75,262	**214,156**
Institutional Overhead (% of direct cost)	9,756	10,803	11,539	**32,098**
TOTAL	76,142	83,311	86,800	246,254

Projected Funding Sources	2011	2012	2013	Total
CGIAR Funding (W1 & W2)	**40,367**	**55,361**	**68,052**	**163,781**
Restricted Funding	35,111	27,289	18,087	**80,487**
Other Income	664	660	661	**1,985**
TOTAL	76,142	83,311	86,800	246,254

The partnership budget is expected to be 29% of the total budget and not only reflects the Challenge Program funding of partnerships but also funding of partners of the participating centers. This amount is almost double the average CGIAR budget allocation on partners/consultants between 2005 and 2009 and emphasizes the priority placed on partnerships in CRP5. The indirect cost is about 15% of the total direct costs, although it may differ at center levels as every center included their respective indirect cost rates following full cost recovery principles.

The Window 1&2 funding includes budget requirement for essential programmatic activities. The funding expected from CGIAR under Window 1 &2 for CRP5 is 67% of the total budget and includes the funding for CPWF. The total W1&2 funding after adjusting for CPWF funding (since it is 'restricted' in nature) is around 49% of the total funding. The proportion of W1&2 funding to total budget in the 6 approved CRPs ranges from 29% to 65%, averaging around 50%.

Each participating center submitted budget proposals with separate allocations for funding from the CGIAR Fund and current restricted funding. It is assumed that centers' allocation of restricted and unrestricted funding reflects the actual cost of running projects that would contribute to the outputs. It is not clear how much the CGIAR Fund would provide and, based on this number, center budgets will have to be adjusted upwards or downwards based on priorities endorsed by the Steering Committee. The annual percentage increase in CGIAR funding – although it is similar to CGIAR funding requests included in other approved CRPs – reflects that the GCIAR fund is expected to increase in future years. (One of the purposes of the Consortium is "Together with the Fund Council, expanding the financial resources available to the centers to conduct their work.")

Table 14.4. 2011 Budget by center by cost category

2011 Budget By Center by Cost Category

Amounts in 'USD'000s

2011	AFRICA RICE	BIOVERSITY INT'L	CIAT	CIP	CPWF	ICARDA	ICRAF	ICRISAT	IFPRI	IITA	ILRI	IRRI	IWMI	WorldFish	Essential Program Activities	Total
Personnel Costs	250	1,410	3,225	549	1,620	1,247	1,919	2,082	1,005	663	254	200	10,107	267	1,946	**26,743**
Travel	30	60	704	147	-	336	260	307	119	121	30	30	416	11	344	**2,915**
Operating Expenses	100	640	1,838	613	1,463	1,350	664	622	356	277	142	125	1,038	175	368	**9,770**
Training & Workshop	50	50	38	9	345	280	93	75	87	46	20	30	798	20	809	**2,750**
Collaborators/Partnership Costs	100	130	3,866	490	10,426	662	699	660	219	244	383	80	3,467	80	400	**21,907**
Capital and other equipment	50	-	419	82	-	326	175	173	-	89	-	30	79	20	-	**1,443**
Contingency	68	-	-	-	-	-	-	195	-	-	94	30	462	10	-	**859**
Subtotal	648	2,290	10,089	1,890	13,854	4,201	3,811	4,114	1,786	1,440	923	525	16,367	582	3,866	**66,386**
Institutional Overhead (% of direct cost)	113	420	1,373	378	-	840	800	856	287	288	-	110	3,405	112	773	9,756
TOTAL	**761**	**2,710**	**11,463**	**2,268**	**13,854**	**5,041**	**4,611**	**4,970**	**2,073**	**1,728**	**923**	**635**	**19,772**	**694**	**4,639**	**76,142**

Projected Funding Sources	AFRICA RICE	BIOVERSITY INT'L	CIAT	CIP	CPWF	ICARDA	ICRAF	ICRISAT	IFPRI	IITA	ILRI	IRRI	IWMI	WorldFish	Essential Program Activities	Total
CGIAR Funding (W1 & W2)	**605**	**2,230**	**1,415**	**426**	**12,111**	**2,379**	**1,667**	**1,859**	**1,223**	**1,126**	**196**	**635**	**9,662**	**195**	**4,639**	**40,367**
Restricted Funding	156	480	10,048	1,829	1,743	2,662	2,871	2,836	850	574	727	-	9,836	499	-	35,111
Other Income	-	-	-	14	-	-	73	275	-	28	-	-	274	-	-	664
TOTAL	**761**	**2,710**	**11,463**	**2,268**	**13,854**	**5,041**	**4,611**	**4,970**	**2,072**	**1,728**	**923**	**635**	**19,772**	**694**	**4,639**	**76,142**

Table 14.5. 2012 Budget by center by cost category.

2012 Budget By Center by Cost Category

Amounts in 'USD'000s

2012	AFRICA RICE	BIOVERSITY INT'L	CIAT	CIP	CPWF	ICARDA	ICRAF	ICRISAT	IFPRI	IITA	ILRI	IRRI	IWMI	WorldFish	Essential Program Activities	Total
Personnel Costs	257	1,800	3,386	614	1,701	1,372	2,015	2,291	1,055	796	626	210	10,612	280	2,014	**29,029**
Travel	30	240	739	165	-	370	273	338	125	142	43	32	436	11	334	**3,278**
Operating Expenses	104	1,190	1,930	686	1,536	1,485	697	684	373	382	123	131	1,090	184	224	**10,818**
Training & Workshop	-	250	39	11	-	308	98	82	92	57	64	32	838	21	493	**2,385**
Collaborators/Partnership Costs	100	750	4,060	548	12,090	728	734	726	230	286	282	84	3,641	84	350	**24,693**
Capital and other equipment	10	50	440	92	-	359	184	188	-	62	-	32	83	5	-	**1,503**
Contingency	62	-	-	-	-	-	-	215	-	-	-	32	485	10	-	**803**
Subtotal	563	4,280	10,594	2,115	15,327	4,621	4,001	4,524	1,875	1,725	1,137	551	17,185	595	3,414	72,508
Institutional Overhead (% of direct cost)	99	770	1,442	423	-	924	840	942	302	345	227	116	3,576	114	683	**10,803**
TOTAL	**662**	**5,050**	**12,036**	**2,538**	**15,327**	**5,545**	**4,842**	**5,466**	**2,177**	**2,070**	**1,365**	**667**	**20,761**	**709**	**4,097**	**83,311**

Projected Funding Sources	AFRICA RICE	BIOVERSITY INT'L	CIAT	CIP	CPWF	ICARDA	ICRAF	ICRISAT	IFPRI	IITA	ILRI	IRRI	IWMI	WorldFish	Essential Program Activities	Total
CGIAR Funding (W1 & W2)	527	2,600	5,936	2,119	13,231	2,883	2,000	3,587	2,003	1,441	592	667	13,462	217	4,097	55,361
Restricted Funding	135	2,450	6,100	401	2,096	2,662	2,765	1,608	174	606	773	-	7,027	492	-	27,289
Other Income	-	-	-	17	-	-	77	271	-	23	-	-	272	-	-	660
TOTAL	**662**	**5,050**	**12,036**	**2,538**	**15,327**	**5,545**	**4,842**	**5,466**	**2,177**	**2,070**	**1,365**	**667**	**20,761**	**709**	**4,097**	**83,311**

Table 14.6. 2013 Budget by center by cost category

2013 Budget By Center by Cost Category

Amounts in 'USD'000s

2013	AFRICA RICE	BIOVERSITY INT'L	CIAT	CIP	CPWF	ICARDA	ICRAF	ICRISAT	IFPRI	IITA	ILRI	IRRI	IWMI	WorldFish	Essential Program Activities	Total
Personnel Costs	265	1,860	3,555	687	1,786	1,509	2,116	2,519	1,107	881	707	221	11,143	294	2,221	**30,870**
Travel	30	230	776	184	-	407	287	372	132	153	43	33	458	12	344	**3,461**
Operating Expenses	108	1,220	2,026	767	1,613	1,634	732	753	392	440	118	138	1,145	193	357	**11,634**
Training & Workshop	50	240	41	12	460	339	102	92	96	63	51	33	880	22	523	**3,004**
Collaborators/Partnership Costs	100	840	4,263	613	10,425	801	771	799	242	313	288	88	3,823	88	350	**23,804**
Capital and other equipment	17	50	462	103	-	394	193	207	-	58	-	33	87	5	-	**1,609**
Contingency	66	-	-	-	-	-	-	236	-	-	-	33	509	10	25	**879**
Subtotal	636	4,440	11,123	2,366	14,284	5,083	4,202	4,978	1,969	1,908	1,206	579	18,045	624	3,819	75,262
Institutional Overhead (% of direct cost)	110	810	1,514	473	-	1,016	882	1,033	317	382	241	122	3,754	120	764	**11,539**
TOTAL	**746**	**5,250**	**12,638**	**2,839**	**14,284**	**6,100**	**5,084**	**6,011**	**2,286**	**2,290**	**1,447**	**700**	**21,799**	**744**	**4,583**	**86,800**

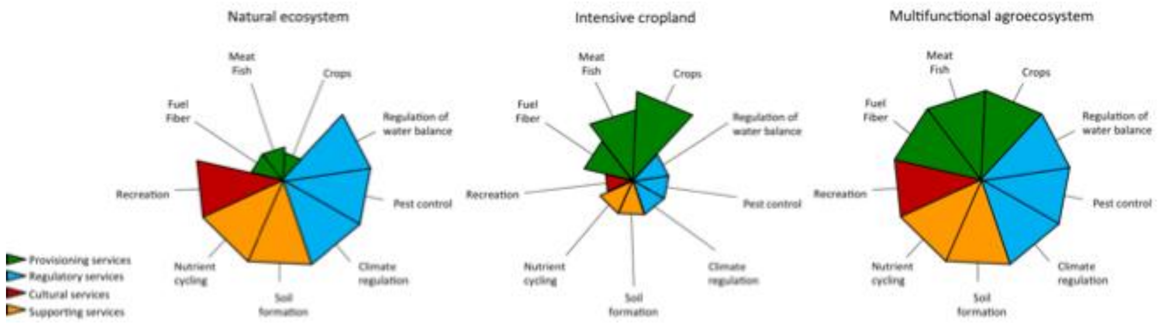
Projected Funding Sources	AFRICA RICE	BIOVERSITY INT'L	CIAT	CIP	CPWF	ICARDA	ICRAF	ICRISAT	IFPRI	IITA	ILRI	IRRI	IWMI	WorldFish	Essential Program Activities	Total
CGIAR Funding (W1 & W2)	597	2,850	10,914	2,750	12,211	3,437	3,304	4,944	2,245	1,731	737	700	16,781	267	4,583	68,052
Restricted Funding	149	2,400	1,723	71	2,073	2,662	1,699	802	41	536	710	-	4,743	477	-	18,087
Other Income	-	-	-	19	-	-	80	265	-	23	-	-	274	-	-	661
TOTAL	**746**	**5,250**	**12,638**	**2,839**	**14,284**	**6,100**	**5,084**	**6,011**	**2,286**	**2,290**	**1,447**	**700**	**21,799**	**744**	**4,583**	**86,800**

CRP5 appendices

Appendix 1 Supplementary scientific information

Appendix 1a) The science behind ecosystem services and resilience

The interest of agricultural development research in ecosystem services and resilience reflects a core idea well framed in the Millennium Ecosystem Assessment, that the human condition is tightly linked to environmental condition, and that services provided by nature have recently become so imperiled that we can expect negative feedbacks to people (MA, 2005). Agricultural ecosystems have been managed primarily to optimize provision of food, fiber and fuel. However, these services depend on a web of supporting and regulating services as inputs to production (soil fertility and pollination), and people's lives depend on a further web of services (flood control, climate regulation) to control risks and vulnerability or to be resilient to shocks (Zhang et al., 2007).



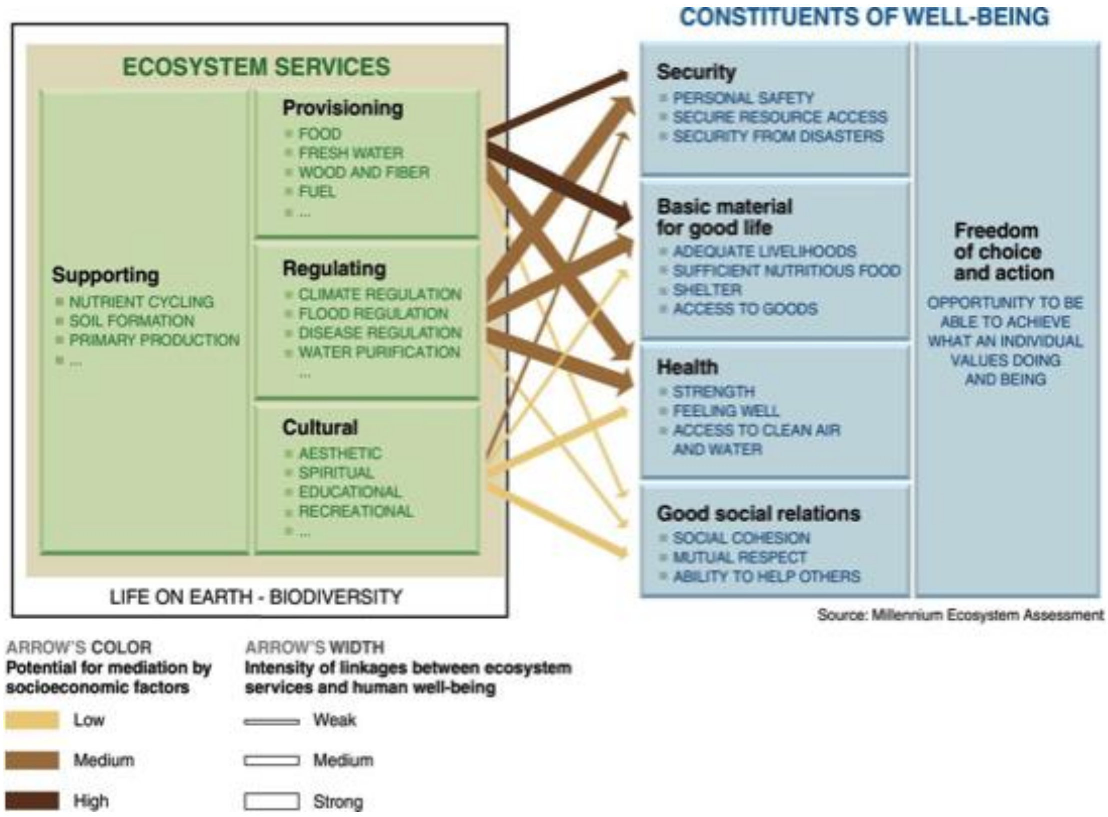
In most agricultural systems (center), provisioning ecosystem services are increased at the expense of regulatory, cultural and supportive ecosystem services, as compared to natural ecosystems (left). Managing for multifunctional agroecosystems (right) would help a more balanced provision of services (adapted from CA 2007 and Gordon et al. 2010).

Ecosystem services and resilience perspectives encompass a wide body of integrated research into sustainability, ecology and economics, and social-ecological systems. Sustainability science involves understanding the complex dynamics between human and environmental systems, which are tightly coupled (Clark, 2007; Tallis, et al., 2008). Sayer and Campbell (2004) review its application to sustainable development. Ecosystem services has become an important component in trade-off analysis and decision-making (Fischer et al., 2008; TEEB, 2010); and resilience, defined by Holling and Gunderson (2002:28) as "the magnitude of disturbance that can be absorbed before the system changes its structure by changing the variables and processes that control behavior," offers a vision of sustainability, not as stability, but as persistence borne out of change (Gunderson and Holling, 2002; Berkes and Seixas, 2005).

Sustainability science seeks to facilitate a 'transition toward sustainability,' improving society's capacity to simultaneously "meet the needs of a much larger but stabilizing human population . . . sustain the life support systems of the planet, and . . . substantially reduce hunger and poverty" (NRC,1999). In agricultural systems sustainability research is needed to underpin development

that aims at sustainable intensification. The interpretation of sustainable intensification can be as narrow as that of Cassman (1999), where increased cereal production without ecological damage is emphasized, or as broad as Chevassus au Louis and Griffon: (2008) “intensification in the use of the natural functionalities that ecosystems offer.” On a practical level important steps have been taken towards making agriculture more sustainable by evaluating on-site and off-site effects of different farming systems. Advances are being made in measuring and monitoring trends and changes in important natural capitals including carbon stocks, hydrologic systems, biodiversity, soil health (Hansen, et al., 2008; Boettinger et al., 2010). Still much more can be done to make these evaluations address social and cultural outcomes and a comprehensive range of environmental impacts (Sachs, et al., 2010).

Ecosystem services have become an important area of research over the last decade (Fischer et al., 2008), bringing frameworks for more holistic analysis of on-site and off-site impacts of agriculture (Zhang, et al., 2007). A number of authors have recently argued that there are strong links between ecosystem services and sustainable development, and reduction of rural poverty (Kareiva and Marvier, 2007; Sachs and Reid, 2006; Kaimowitz and Sheil, 2007; TEEB, 2010). Daily (1977) defined ES as “the conditions and processes through which natural ecosystems, and the species that make them up, sustain and fulfill human-life.” There are multiple frameworks for defining ecosystem services. The best known is that of the MA (2005), which has been very useful for thinking holistically about the range of ecosystem services people depend on for their livelihoods. To operationalize the measurement and valuing of services various researchers have proposed alternative frameworks such as intermediate and final services (Fisher, et al., 2008), and indirect and direct services that allow e.g. valuing services without ‘double counting’ (Fisher, et al., 2007), and very usefully Zhang et al. (2007) define ecosystem services and ecosystem dis-services, such that the flows of these ES and ESD’s rely on how agroecosystems are managed at the site scale and on the structure and functioning of the surrounding landscape (Tilman, 1999).



Much research has focused on biophysical mapping and valuation assessments of ecosystem services (Costanza, et al., 1997, Cowling et al., 2008; TEEB, 2010) and many notable examples are found in van Wilgen et al. (1996), Becker (1999), and Daily and Ellison (2002). This continues to be an important pursuit, bringing together the disciplines of ecology and economics, and underpins payment for environmental service schemes, and potentially large-scale investment in natural capital (Daily and Matson, 2008). Ecosystem services frameworks have also become the preferred tool for research into trade-off analysis and decision-making scenarios. It allowed for example Steffan-Dewenter et al. (2007) to evaluate tradeoffs along intensification gradients between income and biodiversity. It is also provides the conceptual framework for evaluating alternative 'multifunctional' landscapes and quantifying the generation, consumption and flow of ecosystem services through modeling tools such as InVEST (Integrated Valuation of Ecosystem Services and Tradeoffs; Tallis and Polasky, 2009), ARIES (ARtificial Intelligence for Ecosystem Services), (Villa, et al., 2009), and POLYSCAPE (Sinclair, 2011).

Resilience has multiple definitions (Brand and Jax, 2007), and now underlies a broad body of work, including a considerable number of detailed studies of regional social-ecological systems (see any issue of *Ecology and Society,* and most of the chapters in Gunderson and Holling 2002 and Berkes et al. 2003). It is suggested that in a context of accelerating global change, and increasing evidence for non-linear responses in social-ecological systems, these approaches are needed to meet the natural resource – food - poverty challenge, in part because management has tended to focus on average conditions and on particular time and space scales, ignoring extreme events (Walker et al., 2010). Resilience frameworks have been applied in developing country agricultural contexts to analyze changes that result in degradation, and also changes then required to shift to a higher productivity, self-maintaining state (e.g. Fernandez et al., 2002;

Enfors and Gordon, 2007). Still, despite a wave of recent interest in resilience in agricultural development contexts (von Braun et al., 2009; FAO, 2008; IAASTD, 2009; UNEP 2009), empirical studies and evidence to demonstrate how resilience may be enhanced in developing country agricultural systems is lacking (Walker et al., 2010).

Appendix 1b) The science behind water scarcity

Water scarcity can be defined as a situation when a large number of people in an area are water insecure (lack of access to safe and affordable water to satisfy her or his needs for health and livelihoods) for a significant period of time (Rijsberman, 2006). Many indicators of scarcity have been suggested, including the widely used Falkenmark indicator (Falkenmark et al., 1989) relating renewable water resources to population; a number of indicators relating supply to demand (Shiklomanov, 1991, Raskin, 1997, Alcamo, 2000, Vorosmarty, 2000). IWMI (Seckler, 1998, Molden et al, 2007) define physical water scarcity in terms of supply and demand, but introduce an indicator for economic water scarcity, indicating situations where there are available water resources, but access to that water is difficult for reasons of financial, human or institutional capacity. WaterSim (de Fraiture et al, 2010) was used to map the situation of scarcity within major river basins of the world, concurring with other reports that there water scarcity is widespread. In addition to prospective views to explore various scenarios and strategies (Rosegrant et al, 2002, FAO 2006, de Fraiture et al, 2007), there is need for a better local strategies for adapting and coping with scarcity.

A critical response when water is scarce is to increase the productivity of water, defined as the ratio of benefits produced to the amount of water used to produce those benefits (Molden et al, 2010), where benefits are reported in terms of physical yield per cubic meter (kg/m3) or value per cubic meter. Zwart et al, (2010), used remote sensing for a global study that indicated a variation in water productivity for wheat between 0.2 to 1.8kg of harvestable wheat per cubic meter of ET, indicating large potential for improvement. There are a range of farm level practices to enhance water productivity including crop breeding to increase harvest index, or to reduce mortality caused by pests, disease and drought (Bennet et al, 2003), convert non-productive evaporation into productive transpiration through conservation practices (Rockström et al, 2007), water harvesting (Oweis and Hachum, 2003), alternating wet and dry irrigation of rice (Bouman et al, 2007), and improved soil nutrient management (Breman et al., 2001; Bindraban et al., 1999). There are practices in livestock (Peden et al, 2007), fisheries (Verdegem, 2006) and integrated systems that raise both physical and economic productivity of water (Mainuddin and Kirby 2009).

Gains at the farm level aimed increasing water productivity or aimed at harvesting additional rainwater do not necessarily relieve basin wide water scarcity because of a high degree of reuse prevalent (Ahmad, 2007, Loeve et al, 2007), and that a change in water use often impacts other users (Seckler, 1996, Molle et al, 2004. Practices that increase productivity create an incentive for farmers to produce more, and use more water. Developing solutions requires a combined hydrologic-economic- ecological analysis that analyzes changes in quality, quantity and timing of water for different uses combined with a valuation exercise to assess marginal water productivity and the nonmarketable values associated with water use such as the those derived from ecosystem services (Ward and Michelsen, 2002). A starting point is water accounting, a topic receiving increasing attention (Perry 2007 , Molden 1997, Godfrey and Chalmers 2011,

ABS 2006, UN 2007 and 2009). These need to be expanded to better include landscapes and rainfed agriculture. Flow and ET estimates are particularly challenging in data scarce environments, but remote sensing techniques hold promise (Bastiaanssen, 2005, Ahmad et al, 2009, Cai et al, 2010) fill the data gap.

Uptake of water productivity enhancing approaches is slow in spite of the urgency. Factors that influence the uptake of practices that that enhance water productivity include costs, profitability, risks, access to markets, water availability, education, incentives and institutional structures (Molden et al, 2010). Incentives for water productivity increases are rarely in place, and there are questions as to the viability of pricing or administrative allocation of water (Chartres and Varma, 2011, Hellegers and Perry, 2006; Molle and Berkoff, 2006). Clearly there is further research to be done on these enabling conditions including economic incentives that take into consideration risk.

Appendix 1c) The science behind managing land degradation

Land (terrestrial ecosystem) degradation is decline in land health – the capacity of land to sustain delivery of essential ecosystem services (Millennium Ecosystem Assessment, 2003). Major processes include loss of biodiversity, reduction in vegetation cover, reduced hydrological regulation in landscapes, decline in soil nutrient and water retention capacity and supply, soil salinization, and accelerated soil erosion. Desertification results when several degradation processes acting locally combine over large areas in drylands (UNEP, 2007). Land degradation is recognized as a major global environmental and development problem, undermining productivity, food security, ecosystem resilience, and resulting in off-site damage such as reduced water quality, lowering of groundwater, siltation of water bodies, and increased greenhouse gas emissions. However, despite much investment in research and assessments, the degree, extent and impacts of land degradation remain controversial, especially in developing countries (Young, 1998; UNEP, 2007, Vogt et al., 2011). This is largely due to a lack of standardized sampling frames, measurement methods, and reference values. The lack of specific evidence and information at all scales makes it difficult for international and governmental policy makers to prioritise and direct interventions to improving and protecting land health.

Responses to land degradation have tended to focus on treating the problem. There is increasing recognition of the value of integrated and landscape level approaches to improved land management, such as integrated soil fertility management (Vanlauwe et al., 2010), agroforestry (Garrity, 2004), ecoagriculture (Scherr, 2009), and agroecology (Wezel and Soldat, 2009). However, individual soil improving technologies (e.g. fertilizers, conservation agriculture, improved tree fallows) often have a high failure rate, especially in Africa where variation in soil mineralogy produces high spatial variability in limiting factors at a site (Voortman, 2010), resulting in slow adoption rates. A lack of objective and systematic multisite research and intervention evaluation is limiting researcher’s ability to provide information on conditions for success and advise land users and planners on benefits and how to reduce investment risks.

There has been much less attention paid to preventive actions, which require understanding and acting on drivers and risk factors associated with land degradation. The principal driver is unprecedented land-use change to meet the demands of a burgeoning population, economic

development and global markets (UNEP, 2007), but a number of social, economic and biophysical factors operate at local, national and regional scales (Geist and Lambin 2004). However, what counts most is not so much what land is used for but on how well it is managed, and yet there is limited systematic information on quality of management and its determining factors. Generally, factors that reduce incentives for investment in land include insecure resource tenure, high prices of agricultural inputs, and limited infrastructure and market access; however, education and access to information are also important factors. Better and more specific evidence is needed for the design of preventive policies.

New science and technology are providing unprecedented opportunities for overcoming the limitations to evidence-based land and water management. Advances in remote sensing, accurate georeferencing of field observations, and high-throughput light-based methods of soil analysis, coupled with scaling theory and data mining methods, can enable land and water surveillance systems for guiding policy and practice (Wagner et al., 2009; UNEP, 2011). Mobile phone technology and internet services are providing new opportunities for getting high value information to users even in remote areas. What is missing is a coherent effort to harness these advances to provide systematic, science-based approaches that generate and communicate consistent data and knowledge on land and water degradation, their risk factors, and the performance and impact of rehabilitative and preventive interventions.

Types of degradation

Loss of forests, grasslands and wetlands reduce habitat, biodiversity, stored carbon, and soil water retention and regulation, and contribute to both local and global climate change (MA, 2005; UNEP, 2007). About 30% of greenhouse gas emissions derive from land use and land use change. Loss of continuous vegetative cover reduces organic inputs to soils, reduces nutrient recycling, and exposes soil to erosion.

Loss of soil organic matter and soil biological and physical degradation not only reduce nutrient availability but also have significant negative impacts on: infiltration and porosity that consequently impact local and regional water productivity; the resilience of agroecosystems; and global carbon cycles; 41% of sub-Saharan Africa land mass is threatened by degradation (Vlek *et al*., 2008b).

Soil nutrient depletion and chemical degradation. Annually, 230 million tons of nutrients are removed from agricultural soils in terms of agricultural products (Vlek et al., 1997). Further losses result from erosion, leaching and burn-off, but are difficult to calculate. Globally, there is sufficient fertilizer supply to meet growing demand. However, many poor farmers do not have sufficient finance to purchase fertilizer and consequently their soils are becoming increasingly nutrient poor and susceptible to erosion. Phosphate deficiency continues to be a major factor limiting yields over much of Africa (Sanchez, 2002).

Soil erosion and sedimentation. Accelerated on-farm soil erosion leads to substantial yield losses and contributes to downstream sedimentation and the degradation of water bodies, a major cause of investment failure in water and irrigation infrastructure. Across Asia, 7,500 million tons of sediments flow to the ocean (see Vlek, 2010).

Water pollution and salinization. Globally, agriculture is the main contributor to non-point-source water pollution while urbanization contributes increasingly large volumes of wastewater. Water quality problems can often be as severe as those of water availability, but have yet to receive as much attention. Global net outflows of dissolved inorganic nitrogen to the oceans have been estimated at 18,300 tons.

Salinization and waterlogging. Globally, secondary soil salinization and waterlogging in irrigated areas are major threats to existing production and productivity gains. Few irrigation schemes have managed to overcome them completely, but innovative technical measures and cropping practices can often minimize their impact.

Disturbances in water, carbon and nutrient cycles. The integrity of water, carbon and nutrient cycles determine the health and resilience of ecosystems, and their capacity to provide services. Land-use change has been responsible for about one-third of the increase in atmospheric carbon dioxide over the last 150 years, mainly through loss of soil organic carbon. Also well established are the links between soil erosion and sediment deposition, between nitrogen and phosphorus fertilizers and eutrophication, and between emissions of sulphur and nitrogen oxides to the atmosphere and acid contamination of land and water (UNEP, 2007). Harmful and persistent pollutants are still being released to the land, air and water from mining, manufacturing, sewage, energy and transport emissions; from the use of agrochemicals (UNEP, 2007).

Appendix 2 CRP5 Development Processes

Appendix 2a) Recognizing regional priorities

To align the overall and specific CRP5 strategic research portfolios with regional needs, the strategic plans of the regional and subregional NARES fora under the umbrella of GFAR were consulted. The consultation showed a high degree of commonality in problem identification and research priority setting:

- The Forum for Agricultural Research in Africa (**FARA**) highlights in its 2007-2016 Strategic Plan key areas which require attention. CRP5 will address 4 of the identified 11 areas, namely stress on land and water resources and accelerated soil degradation, water becoming an increasingly scarce commodity, crops/livestock practices and systems, and the conservation and sustainable use of water catchments and biodiversity (www.fara-africa.org/about-us/strategic-plan/strategic-plan-download/). FARA's strategic plan was based on the targets and aims of the CAADP, and aligned with the strategic plans of the African Sub-Regional Organizations.

- The Vision 2025 of the Asia Pacific Association of Agricultural Research Institutions (**APAARI**) fosters novel partnerships among NARES and other organizations for sustainable improvements in the productivity of agricultural systems and improved quality of the natural resource base which underpins agriculture. In its *Research Need Assessment and Agricultural Research Priorities for South and West Asia* which was jointly organized with the CGIAR, the need for INRM to address degradation of natural resource, water scarcity, and low productivity was highlighted (www.apaari.org/wp-content/uploads/2009/05/sw-asia-needs-assessment.pdf).

- The Central Asia and the Caucasus Association of Agricultural Research Institutions (**CACAARI**) highlights in its *Priorities for Agricultural Research-for-development in Central Asia and the Caucasus* (Dec. 2009) soil salinity and water and irrigation management, livestock research including rangelands, and the protection of biodiversity as priority research areas (www.cacaari.org/filesarchive/publications/GCARD_CAC_Final_Report_En.pdf).

- The Forum for the Americas on Agricultural Research and Technology Development (**FORAGRO**) describes its research priorities in its *FORAGRO Position 2010* document. The preservation and sustainable management of natural resource: i) Technologies and good practices for the use of soil and water; ii) Use of environmentally friendly practices; iii) Preservation and sustainable use of biodiversity; iv) Promotion of agro-ecological production systems, is one of its seven priority subjects and action areas. Other action areas include better exploitation of productive lands and protection of fragile ecosystems or highlight urban farming systems (http://infoagro.net/shared/docs/a2/Summary%20FORAGRO%20Position_Eng.pdf).

- The Association of Agricultural Research Institutions in the Near East and North Africa (**AARINENA**) emphasizes in its Vision 2025 the fragility of its natural resource base with especially acute shortage of water and arable land. Opportunities for *expanding* cultivated rain-fed or irrigated lands in the region are low, while most change can be realized through

increasing factor productivity and technologies, enabling policies and appropriate institutions. The challenge for agricultural research is to increase productivity without further threatening natural resource while favoring the poor (www.aarinena.org/rais/documents/General/nars0059.PDF).

The regional stakeholder consultations during the preparation of CRP5 allowed fine-tuning the research agenda in order to cover more detailed regional challenges and priorities.

Appendix 2b) Participants who attended CRP5 Regional Development Workshops

Participants from online consultations and e-discussions

Dr.Angel Elias Daka (ACTESA); Kabatabazi Patricia, Community based Impact Assessment Network for Eastern Africa (CIANEA); Fernando Cesar Serafim Particular; Desta Gebremichael, Relief Society of Tigray; Ali Ünlükara, Erciyes University Agricultural Faculty Agricultural Structures and Irrigation; Ananda Wijayaratna, Daham Pasal; Raymond Ouedraogo, 1- PhD student at BOKU-University of Natural Resources& Life Sciences, Vienna, Austria, 2-Senior Offiecr of Fisheries at the Fisheries Department, Ministry of Agriculture, Water and Fish Resources, burkina Faso; Raga Mohamed Elzaki, University of Gezira – Sudan; Lalit Mohan Sharma, Institute of Rural Research and Development; Ben Aston, Gantry House; Dr. V.E.Nethaji Mariappan, Sathyabama University; K.D.N.Weerasinghe, University of Ruhuna; Abraham Ndungu, Rosedale College; Victor Kongo, Stockholm Environment Institute (SEI); Dr.Mustafa Yousif Mohamed, AA University; Elena Lopez-Gunn, FMB-Water Observatory and LSE; Gashaw Alemye Agegne, Mekelle university; Romel B. Armecin, Visayas State University – Philippines; Assem Tesfaw Ayelle, ORDA; Dov Pasternak, ICRISAT; Kristina Toderich, ICBA-CAC , under umbrellla of ICARDA, and Department of Desert Ecology and Water Resources Research, Samarkand Division of the Academy of Scinces of Uzbekistan, Central Asia; John Lamers, (ZEF/UNESCO); Mamadou Khouma, (IDEV); Palaniappan Venkatachalam, Tamil Nadu Agricultural University, Coimbatore, India; K.Palanisami (IWMI); Carlo Carli (CIP); Dr. Firdaus Fatima Rizvi, IIDS, New Delhi; Tilahun Amede, ILRI/ IWMI/ CPWF; Vladimir Smakhtin (IWMI); Luna Bharati (IWMI); Peter Messerli, Centre for Development and Environment (CDE), University of Bern Muhammad; Rafique, Villagers Development Organization; Gunnar Jacks, KTH; Nirad Chandra Nayak, CGWB, Min. of Water Resources; Lalit Mohan Sharma, Institute of Rural Research and Development; Anik Bhaduri, Center for Development Research (ZEF), University of Bonn; Shabbir Ahmad Shahid, ICBA, Dubai, UAE; Alim Pulatov, Tashkent Institute of Irrgation, EcoGIS center, Uzbekistan

Participants at the regional stakeholder meetings:

Aleppo: Dr. Awni Taimeh, University of Jordan, Jordan; Dr. Dia El Din Ahmed El-Qousy, National Water Research Center, Egypt; Dr. Ahmed Hachum, Mosul University, Iraq; Eng. Ali El-Zain, AGA KHAN Foundation, Syria; Dr. Omran Al Shihabi, The Arab Center for the Studies of Arid Zones

and Dry Lands (ACSAD), Syria; Dr. Awadis Arslan, General Commission for Scientific Agricultural Research (GCSAR), Syria; Dr. Jamil Abbas, Aleppo University, Syria; Aleppo; Dr. Faisal K Taha, International Center for Biosaline Agriculture (ICBA). UAE; Dr. Ahmed Mohamed Abdelwahab, International Center for Agricultural Research in the Dry Areas (ICARDA), Syria; Dr. Theib Oweis, International Center for Agricultural Research in the Dry Areas (ICARDA), Syria; Dr. Fadi Karam, International Center for Agricultural Research in the Dry Areas (ICARDA), Syria; Dr. Fawzi Karajeh, Nile Valley and sub-Saharan Africa Regional Program (NVSSARP) International Center for Agricultural Research in the Dry Areas; Dr. Rolf Sommer, International Center for Agricultural Research in the Dry Areas (ICARDA), Syria; Dr.Ahmed M. Al-wadaey, International Center for Agricultural Research in the Dry Areas (ICARDA), Syria; Dr. Mohamed Al-Azhari Saleh, International Centre for Agricultural Research in the Dry Areas (ICARDA), Syria; Dr. Ahmed Amri, International Centre for Agricultural Research in the Dry Areas (ICARDA); Dr. Zieaoddin Shoaei (ICARDA – Tehran office), Iran; Dr. Michael C. Shannon, USAID.

Lusaka: Pius Chilonda (IWMI); Fred Kalibwani (IWMI); Seleshi Bekele Awulachew (IWMI); Rudo Makunike, NEPAD Planning & Coordinating Agency (NPCA), South Africa; Almeida Almeida, National Directorate of Agricultural Services, MINAG/DNSA, Mozambique; Andrew Sanewe, Water Research Commission (WRC), South Africa; Fhumulani Mashau, Southern Africa Confederation of Agricultural Unions (SACAU), South Africa; Alfred Mtukuso, Ministry of Agriculture and Food Security, Malawi; Ishmael Sunga, Southern Africa Confederation of Agricultural Unions (SACAU), South Africa; Graham Jewitt, University of KwaZulu-Natal; Helder Gemo (IWMI), South Africa; Elijah Phiri, AU-NEPAD/ CAADP Pillar 1/UNZA-SADC LWMP, University of Zambia, Zambia; Mwase Phiri, Ministry of Agriculture and Cooperatives, Zambia; Angel Daka, COMESA/ACTESA, Zambia; Simunji Simunji, Golden Valley Agriculture Research Trust (GART), Zambia; Moses Mwale, Zambia Agricultural Research Institute (ZARI), Zambia; Sesele B. Sokotela, Zambia Agricultural Research Institute (ZARI), Zambia; Peter Manda, CARE Zambia; Martin N. Sishekanu, Ministry of Agriculture and Cooperatives, Zambia; DCW Nkhuwa, University of Zambia, Lusaka; Sina Luchen (FAO); Andy Levin USAID - Zambia

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Nairobi: Sibonginkosi Khumalo (Bioversity); Elizabeth Nambiro (CIAT); Linda Wangila (CIAT); Jeroen Huising(CIAT)-TSBF; Peter Okoth (CIAT)- TSBF, Paul Woomer, CGIAR FORMAT; Edwudo Bamos (ICRAF); Keith Shepherd (ICRAF); Samuel Gaturu (ICRAF); KPC Rao (ICRAF-ICRISAT); Ephraim Nkonya (IFPRI); Duncan Turere (ILRI); Jan de Leeuw (ILRI); Jane Gitau (ILRI); Julius Nyangaga (ILRI); Mohamed Said (ILRI); Polly Ericksen (ILRI); Tilahun Amede, (ILRI-IWMI); Lisa-Maria Rebelo (IWMI); Izzy Birch, Ministry Of Nothern Kenya & other Arid Lands; Charles Gachoki, Ministry Environment And Natural Resources, Kenya; Callist

Tindimugaya, Ministry of Water and Environment, Uganda; Daniel Atula, National Irrigation Board; Emmanuella Olesambu (FAO); Michael Gitonga (FAO); Tara Garnett, Food Climate Research Network (FCRN); Steve Twomlow (UNEP); Jane W. Wamuongo (KARI); Edward Mare Muya (KARI); James K. Ndufa, Kenya Forestry Research Institute (KEFRI); John Mulumba, NARO, Uganda; Emmanuel Mwendera (IUCN); Byron Anangwe, Regional Centre for Mapping of Resources for Development; Finn Davey, Wajibu MS, Kenya.

Delhi: Arun Pal (ICRISAT); Ashutosh Sarker (ICARDA); Dar MH (IRRI); Dindo M Campilan (CIP); Iain A Wright (ILRI); Jagat Devi Ranjit, Nepal Agricultural Research Council (NARC); Lalit Mohan Sharma, Institute of Rural Research and Development; Kuhu Chatterjee, Australian Centre for International (ACIAR); Mathur PN (Bioversity); Minhas PS, Indian Council of Agricultural Research (ICAR); Munasinghe MAK, Natural Resources Management Centre, Sri Lanka; Parvati Krishnan, Coca-Cola India Inc.; Pawan Kumar, Institute of Rural Research and Development; Peter Q Craufurd (ICRISAT); Prabhat Kumar (ICRISAT); Ramesh Rawal , BAIF Development Research Foundation; Ruchi Srivastava (ICRISAT); Virendra Sharma (DFID-India); Sharma KD, National Rainfed Area Authority (NRAA); Tewari RK , Department. of Agriculture & Co-operation; Upali Amarasinghe (IWMI); Venkateswarlu B, Central Research Institute for Dryland Agriculture; Wani SP (ICRISAT)

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Tashkent: Victor Dukhovny, (SIC ICWC); Hamdam Umarov, Republican Water Inspection; Gayrat Rahimov, Republican Water Inspection; Kushiev Habib, Gulistan University; Alim Polatov, Ecogiscentre, TIIM; Mehriddin Tursunov, TIIM; Myagkov Sergey, Scientific Research and Hydro-meteorologic Institute, UzGidroMet; Raisa Tarannikova, Methodology and Agro-meteorologic Observation Services, UzGidroMet; Dr.Abdukhalil Kayimov, Forestry and Forest Amelioration Department; Dr. Evgeniy Butkov, Agro-forestry Department; Omina Islamova, (SDC); Djamshid Begmatov (EU); Makhmud Shaumarov (UNDP); Rustam Murodov, (UNDP); Dr. John Lamers, (UNESCO/ZEF); Shavkat Rakhmatullaev, (GTZ); Dr.Hafiz Muminjanov, Grain and Seed Testing Laboratory of Tajik Agrarian University, Tajikistan; Erkin Satenbaev, KazAgroInnovations JSC, Ministry of Agriculture, Kazakhstan; Dr.Nikolay Zverev, Head of Forest and Natural Rangelands Department, Turkmenistan; Dr. Zakir Khalikulov (PFU, ICARDA CAC); Dr. Stefanie Christmann (ICARDA CAC); Dr. Carli Carlo, (CIP); Dr.Muhabbat Turdieva, (Bioversity); Dr. Kristina Toderich, (ICBA); Dr.Ravza Mavlyanova (AVRDC)

Cali: José Manuel Sandoval, Ministry of Environment, Colombia; Wilson Otero, FUNDESOT, Colombia; Jose Antonio Gomez, PNUD-GEF-Federacion Nacional de Cafeteros Colombia; Christopher Hansen, IICA, Colombia; Jorge Rubiano Professor, Universidad del Valle Colombia; Alex Bustillo, CENICANA (sugarcane research center –Colombia) Colombia; Inés Restrepo, CINARA, Colombia; Fernando Gast, CENICAFE, Colombia; Andrés Felipe Batancourth, Red Interinstitucional para el Oriente de Caldas, Colombia; Robert Hofstede, Ecuador; Juan Rodríguez (GTZ –GESOREN), Ecuador; Martha Liliana Cediel, Ministry of Environment – Ecosystems Division, Colombia; Jorge Uribe Calle, ANALAC, Colombia; Luis Alberto Duicela, COFENAC, Ecuador, Ruben Dario Estrada, Colombia; Rao Idupulapati, (TSBF CIAT); Steve Fonte (TSBF CIAT); Aracely Castro (TSBF CIAT); Jeimar Tapasco (CIAT)

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Appendix 3 Integration of CPWF in CRP5

The Consortium Board has directed that the CPWF work be fully integrated into CRP5. This has been considered in detail between the CPWF Board, Advisory Committee and Management Team and IWMI, its host. There is agreement for the following actions:

- CPWF is one year into its Phase 2 Projects that involve very significant external partnerships. We see the CPWF model as a good guide to the development of effective implementation partnerships. The Phase 2 projects will be allowed to continue for the next 15-18 months to their natural conclusion. However, they will operate primarily, but not exclusively within the SRP on Basins and will be enhanced by, and in turn enhance new CRP5 projects. We consider that building improved scientific capacity and more focused hypotheses into this framework will be highly beneficial.
- There will be a gradual merging of CPWF management and support functions with those of CRP5 and IWMI respectively to ensure continuity and accountability at CPWF level and to enhance the new CRP5 Management Committee. IWMI has commissioned a review being conducted by Accenture Development partnerships to advise on the most effective ways to enhance support of CRP5 at all levels and to suggest optimum management and support structures for the program taking into account the skill base in IWMI and CPWF.
- The CPWF Board has been merged (effective August 1st, 2011) with the IWMI Board. The merged Board will have full accountability for the continued delivery of CPWF outputs and for CRP5 from the perspective of the lead center. This merger will reduce dual lines of reporting.
- The CPWF Advisory Committee lead by Johann Rockstrom from the Stockholm Environment Institute will cease to function separately, but will become part of the new Steering Committee for CRP5. Responsibilities of this Committee are defined in the section on Governance and management. The aim of the merger is to increase synergy and to assist focus on the new directions predicated in this proposal.
- CPWF ongoing funding is included in the CRP5 budget request.

Appendix 4 Work plan for CRP5

		Year 1				Year 2				Year 3				Year 4				Year 5			
	Activities	1	2	3	4	1	2	3	4	1	2	3	4	1	2	3	4	1	2	3	4
1	Confirm teams																				
2	Restructuring and setting up systems																				
3	Development of indicators for outputs all levels (Inception Workshop)																				
4	Overall Management, Coordination & Integration																				
5	Development of Regional Plans																				
6	Integration of existing projects near completion into new portfolio																				
7	Implementation of new – fully aligned - CRP5 projects																				
8	Implementation of quality and impact enhancement activities																				
	Milestones																				
A	CRP5 Inception Workshop	X																			
B	Strategies / Frameworks approved by Steering Committee			X																	
C	Annual (rolling) Workplan approved by Steering Committee				X				X				X				X				X
D	CRP 5 Mid-term Science Forum											X									
E	Mid-term Evaluation											X									
F	CRP5 Synthesis Forum																			X	
G	End of First Phase Evaluation																				X

1. **Confirm teams:** The proposal requires that teams be established to start working on Overall management, Coordination of SRPs and regions, gender and equity, ME&L, communications and uptake and capacity building. This requires reallocation of workloads for existing staff and some new recruitment.
2. **Restructuring and setting up systems:** At the start of CRP 5 a number of activities will need to take place. For example, mapping of existing projects and linking to SRPs including analysis of overlap in existing projects and plan for integration and sharing of experiences; inventory of present partnerships and stakeholders and gap analysis, further development of the partnership strategy; development of ME&L framework; further development of gender and equity strategy; development of overall communication strategy, uptake strategy.
3. **Overall Management, Coordination & Integration:** Immediate deployment of CRP5 coordination team, SRP and Regional Leaders; establishment of Management Committee, Science and Impact Advisory Committee and Steering Committee.
4. **Development of Regional Plans:** Each region will require a set of research questions based on assessment, prioritization and synthesis unique to that region and the natural resource challenges of its farming systems. Based on this, specific uptake strategies will be formulated with partners. Research sites will often overlap with other CRPs and within each site there will be interaction among and between SRPs.
5. **Transition from existing projects to the new portfolios:** Existing projects will continue to be implemented and their outputs synthesized through SRPs.
6. **Implementation of new – fully aligned - CRP5 projects:** Develop and implement a coherent set of new projects to deliver CRP5.
7. **Implementation of quality and impact enhancement activities:** Officially launch platforms and strategies for ME&L, gender, new partnerships and enhanced capacity building and continue with implementation.

A. **Inception Workshop:** In Year 1, an Inception Workshop will be organized to gain support and input from all partners, stakeholders and anticipated users of research results.
B. **Strategies / frameworks approved by Science and Impact Advisory Committee**: The ME&L framework, partnership strategy, gender and equity strategy and uptake strategy and resultant implementation plans will be presented to and approved by the Science and Impact Advisory Committee.
C. **Annual (rolling) workplan approved by Steering Committee:** The Management Committee will prepare annual (rolling) workplans with the support of the SRP managers and Regional Leaders. These will be presented to the Steering Committee for approval.
D. **Mid-term Science Forum:** In Year 3 a mid-term Science Forum will be held to present and discuss research results.
E. **Mid-term Evaluation:** The Management Committee must commission a full-scale mid-term evaluation and report its findings. Terms of Reference have to be written for the evaluation and a team selected to conduct it.
F. **Synthesis Forum:** In Year 5 a Synthesis Forum will be held to present and discuss research results, synthesize lessons and plan for future priorities.

G. **End of First Phase Evaluation:** The Management Committee must commission a full-scale evaluation and report its findings. Terms of Reference have to be written for the evaluation and a team selected to conduct it.

Immediate funding is required to establish Strategic Research Portfolio teams, gender and ME&L (including partnerships) working groups to ensure this transition happens as quickly and efficiently as possible.

Principles for phasing out old and phasing in new activities

In the revised draft of this proposal, we have emphasized the new activities that will be undertaken. We recognize, however, that currently all CGIAR centers involved have existing portfolios of projects that must be completed. Our aim is to map these projects to the new SRPs. In the vast majority of cases these projects are funded by restricted bilateral funding. However, many of these projects provide essential building blocks for the new activities. As the projects are completed in 2012 and 2013, the SRP leaders and regional directors will be asked to ensure that new proposals are developed that are aligned with the SRP objectives and outcomes required. The detailed timelines for this process will be compiled during the inception phase. The Program Director and Steering Committee will oversee the process to ensure that all partners adhere to these principles. The key principles to be followed are:

- Map all projects to new SRPs;
- Consider relevance to new objectives;
- Identify termination dates for work that will be discontinued based on restricted funding agreements;
- Identify projects that may need to be renewed to deliver against new objectives of the SRPS/CRP and develop new partnerships/proposals to seek restricted funds;
- Identify gaps in the portfolio that have to be filled to deliver against CRP objectives;
- Develop teams of CGIAR and external partners to fill these gaps and seek additional restricted funding;
- Ensure that the emerging new portfolio is aligned with the overall CRP global and regional goals.

Acronyms

3R	Water Recharge, Retention and Reuse
ACSAD	Arab Center for the Studies of Arid Zones and Drylands
ACTS	African Centre for Technology
AfSIS	Africa Soil Information Services
AGRA	Alliance for a Green Revolution in Africa
AIT	Asian Institute of Technology
AMAZ	Reconstruction of Eco-efficient Landscape in Amazonia
APFAMGS	Andhra Pradesh Farmer Managed Groundwater System
AQUASTAT	FAO's global information system on water and agriculture
ARC	Agricultural Research Center
ARI	advanced research institute
ASARECA	Association for Strengthening Agricultural Research in Eastern and Central Africa
AVRDC	World Vegetable Center
AWADI	Alternate Wet and Dry Irrigation
AWF	African Wildlife Foundation
BMZ	Federal Ministry for Economic Cooperation and Development
BORDA	Bremen Overseas Research and Development Association
CA	Comprehensive Assessment of Water Management in Agriculture
CAAS	Chinese Academy of Agricultural Sciences
CABI	CAB International
CARE	Cooperative for Assistance and Relief Everywhere
CC	climate change
CGIAR	Consultative Group on International Agricultural Research
CGWB	Central Ground Water Board
CIAT	International Center for Tropical Agriculture
CIAT	International Center for Tropical Agriculture
CIESIN	Center for International Earth Science Information Network
CIP	International Potato Center
CONDESAN	Consortium for sustainable development of the Andean ecoregion
CPWF	Challenge Programme on Water and Food
CREPA	Centre Régional pour l'Eau Potable et l'Assainissement à faible coût
CRP	Consortium Research Program
CSI	CGIAR Consortium for Spatial Information
CSIR	Council for Scientific and Industrial Research
CSIRO	Commonwealth Scientific and Industrial Research Organisation
CSM-BGBD	Conservation and Sustainable Management of Below Ground Biodiversity
CSO	civil-society organization
CWANA	Central and West Asia and North Africa
DALY	disability-adjusted life years
DANIDA	Danish International Development Agency
DEWATS	Decentralized Wastewater Treatment Systems
DFID	Department for International Development
DPU	Development Planning Unit

EMBRAPA	Brazilian Agricultural Research Corporation
ESA	European Space Agency
ESPA	Ecosystems Services and Poverty Alleviation
ET	evapotranspiration
FAO	Food and Agricultural Organisation
GAAS	Guizhou Academy of Agricultural Sciences
GCSAR	General Commission for Scientific Agricultural Research
GEF	Global Environmental Facility
GEOSS	Global Earth Observation System of Systems
GIS	geographical information systems
GLADIS	Global Land Degradation Information
GLASOD	Global Assessment of Human-Induced Soil Degradation
GMES	Global Monitoring for Environment and Security
IAAST	International Assessment of Agricultural Science and Technology
ICAR	Indian Council of Agricultural Research
ICARDA	International Center for Agricultural Research in the Dry Areas
ICBA	International Center for Biosaline Agriculture
ICRAF	World Agroforestry Centre
ICRISAT	International Crop Research Institute for Semi Arid Tropics
IDRC	International Development Research center
IFDC	International Fertiliser Development Center
IFPRI	International Food Policy Research Institute
IHE	Institute for Water Education
IITA	Agricultural Research-for-development in Africa
ILRI	International Livestock Research Institute
IMT	Irrigation Management Transfer
IPTRID	International Programme for Technology and Research in Irrigation and Drainage
IRC	International Water and Sanitation Centre
IRRI	International Rice Research Institute
ISRIC	International Soil Reference and Information Centre
ISFM	Integrated Soil Fertility Management
ITC	The International Institute for Geo-Information Science and Earth Observation
IUCN	International Union for Conservation of Nature
IWA	International Water Association
IWMI	International Water Management Institute
IWMI	International Water Management Institute
IWRM	Integrated Water Resources Management
JRC	Joint Research Centre
LSHTM	London School of Hygiene and Tropical Medicine
MAR	Managed Aquifer Recharge
MASSMUS	Mapping systems and Services for Multiple Uses
MFA	Material Flow Analysis
MIS	management information system
MP	Mega Programme

MUS	Multiple Use Systems
NARES	National Agricultural Research and Extension Systems
NASA	National Aeronautics and Space Administration
NEPAD	New Partnership for Africa's Development
NERC	Natural Environment Research Council
NGO	nongovernmental organisation
NGRI	National Geophysical Research Institute
NPK	nitrogen, phosphorus, potassium
NRM	natural resource management
NWRC	National Water Research Center
O&M	operation and maintenance
ODC	Open Data Commons
PDR	People's Democratic Republic
PES	Payment for Environmental Services
PIM	Participatory Irrigation Management
PRADAN	Professional Assistance for Development Action
QMRA	Quantitative Microbial Risk Assessment
QSMAS	Quesungual Slash-and-Mulch Agroforestry System
R&D	research and development
RAP	Rapid Appraisal Procedure
RCMRD	Regional Center for Mapping of Resources for Development
RIMISP	Latin American Center for Rural Development
RS	remote sensing
RUAF	Resource Centres on Urban Agriculture and Food Security
SANDEC/ EAWAG	Department of Water and Sanitation in Developing Countries at the Swiss Federal Institute of Aquatic Science and Technology
SE	South East
SEA	Strategic Environmental Impact Assessment
SGRP	System-wide Genetic Resources Programme
SPS	Samaj Pragati Sahyog
SRI	System of Rice Intensification
SSA	sub-Saharan Africa
SuSanA	Sustainable Sanitation Alliance
SWM	Soil and Water Management
TSBF	Tropical Soil Biology and Fertility Programme
UK	United Kingdom
UN	United Nations
UNDP	United Nations Development Programme
UNEP	United Nations Environmental Program
USA	United States of America
USAID	United States Agency for International Development
USAID	United States Agency for International Development
USBR	United States Bureau of Reclamation
USD	United States Dollars
USGS	United States Geological Survey
VSF	Vétérinaires Sans Frontières

WAU	Wageningen University
WCRP	World Climate Research Programme
WEDC	Water, Engineering and Development Centre
WHO	World Health Organisation
WISP	World Initiative for Sustainable Pastoralism
WRI	World Resources Institute
WUA	Water Users' Association
WUR	Wageningen University
WWAP	World Water Assessment Programme

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Appendix 1a: The science behind ecosystem services and resilience

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