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.

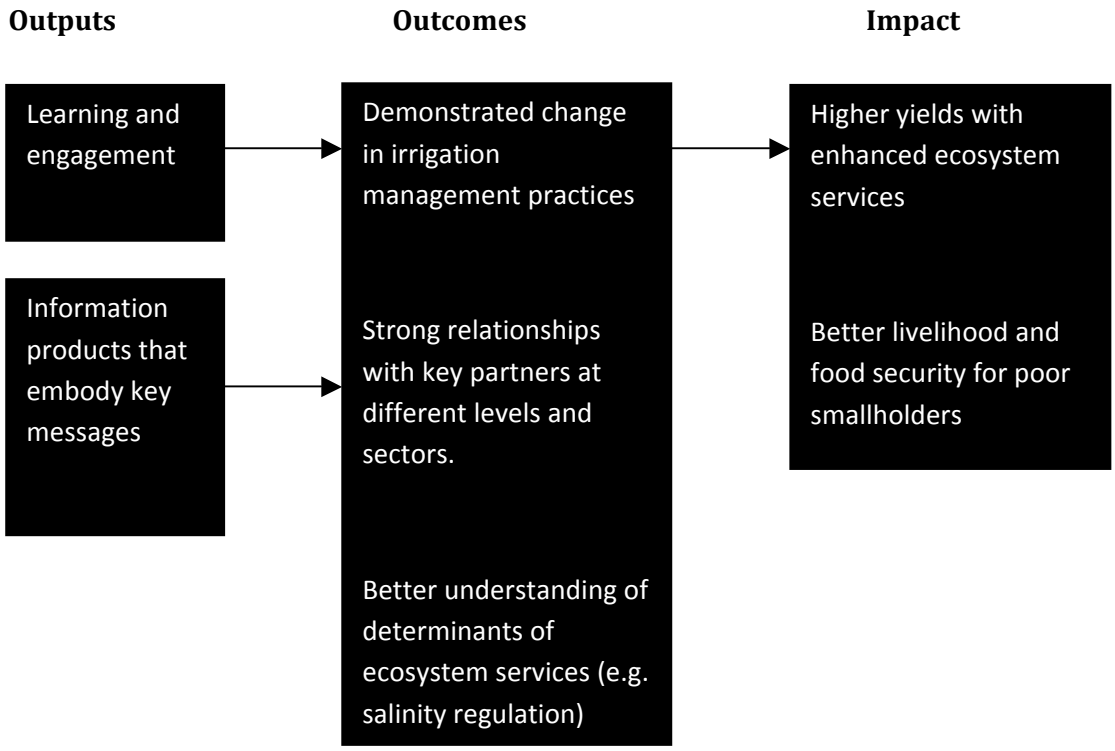
4.7. Our impact pathway

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

Synopsis: *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.