CGIAR CHALLENGE PROGRAM ON WATER AND FOOD (CPWF) AND COMPREHENSIVE ASSESSMENT OF WATER MANAGEMENT IN AGRICULTURE (CA) RESEARCH PRIORITIES

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In collaboration with CA writing teams and CPWF secretariat

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CGIAR Challenge Program on WATER & FOOD

COMPREHENSIVE Assessment of water management in agriculture

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Introduction and Scope

The purpose of this document is to outline research needs in the field of water management for agriculture emerging from the Comprehensive Assessment of Water Management in Agriculture (CA). Through a consultative process, several priority research areas were identified where the experts involved in the CA consider that existing knowledge is insufficient. These research priorities are expected to support the CGIAR Challenge Program on Water and Food (CPWF) in furthering knowledge on water and agriculture, by helping to shape the research areas under which the CPWF will be funding projects.

About the CGIAR Challenge Program on Water and Food

CPWF is an international, multi-institutional research initiative with a strong emphasis on north-south and south-south partnerships. The initiative brings together research scientists, development specialists, and river basin communities in Africa, Asia and Latin America to create and disseminate international public goods that improve the productivity of water in river basins in ways that are pro-poor, gender equitable and environmentally sustainable.

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

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

CPWF themes (see Table 1) are a means for addressing different aspects of the water and food challenge and serve to package information at different scales on issues related to water productivity. The CPWF research strategy concentrates its attention on five thematic areas.

At the system level, the CPWF looks at (1) **Crop water productivity improvement**, (2) **Water and people in catchments**, and (3) **Aquatic ecosystems and fisheries.**

Crop water productivity improvement takes the view that water productivity can be improved through technological and managerial innovation at the farm level. Hence it seeks plant-breeding solutions for agriculture located in areas affected by drought and saline soils. It studies integrated natural resources management and crop production at field, farm and agro-ecosystem levels. This theme promotes policies and institutions facilitating the adoption of crop water productivity improvements.

Water and people in catchments **focuses** attention at the catchment level. It is concerned with water, poverty and risk in upper catchments. It seeks innovations in improved water management and aims to enable people to benefit from the improved management of land and water resources.

Aquatic ecosystems and fisheries investigates environmental water requirements; to value ecosystem goods and services; and to seek innovative ways in which to improve the productivity of aquatic ecosystems through policies, institutions, and governance.

At the basin level, the CPWF looks at **Integrated basin water management systems**, which identifies appropriate technologies and management practices designed to enable IWRM. It seeks innovative institutional arrangements and decision-support tools and information that can help with the establishment of this managerial strategy.

At the global level, the CPWF looks at **Global and national water and food systems**, which examines water, its management and use at the broadest of possible scales. Hence, globalization, trade, macro-economic and sectoral policies have an important bearing on water, how it is used, and its productivity. This theme is concerned with the kinds of investments and financing for agricultural water development and water supply that may improve water productivity or, indeed, hinder it. This theme area also recognizes that at international levels, the management of water resources is complex and therefore seeks to understand how best to formulate appropriate policy and institutions to deal with this complexity. The theme also considers changes in the global water cycle.

About the Comprehensive Assessment of Water Management in Agriculture

The CA aims to critically evaluate the benefits, costs, and impacts of the past 50 years of water development and current challenges to water management. The CA asks how water for food can be developed and managed to help end poverty and hunger, ensure environmentally sustainable water-agriculture practices, and find the balance between food and environmental security. It assesses innovative solutions and explores consequences of potential investment and management decisions. A first phase focused on gap-filling research. Building on this, the second 'synthesis' phase focused on an assessment of knowledge and experience to guide investment and management decisions in the near future in order to enhance food and environmental security.

The synthesis phase was designed along the lines of the Millennium Ecosystem Assessment and the Intergovernmental Panel on Climate Change processes with the aim of being both scientifically rigorous as well as an open forum for knowledge sharing. Chapter teams were formed comprising of lead authors, contributing authors, and a broader network, and in some cases, comprising up to 100 people per chapter. To stimulate participation, each chapter had at least one workshop, and online consultation process, and two independent reviews. Cross-cutting meetings involving members from all chapters were held to ensure integration. All chapters have undergone an extensive peer-review process.

Over the past five years the CA has been engaged in a complex process of dialogue, partnership, research, synthesis, review and outreach. The CA has brought together over 700 researchers, practitioners, development professionals, water users and policymakers from around the world. A diverse group of stakeholders, experts from different continents, disciplines, and institutions have shared their knowledge, experience and views on key issues.

Results of the CA process are documented in the report entitled *Water for Food, Water for Life: the Comprehensive Assessment*, to be published by Earthscan in late 2006. Additional outputs from the research phase are published in a book series by CABI, a Research Report series, highlighting work by partners, and several academic journal publications derived from CA supported research. The CA has also supported 30 students. The CPWF is one of the key clients of the CA.

Methodology & Structure of Document

The information on which this document is based was derived from the larger CA process, including feedback and debate - through workshops, online discussions and reviews – on issues that had been raised by networks of individuals stemming from academia, government ministries, NGOs and other local organizations associated with each of the CA chapter topics (see Table 1), peer review teams and review editors for each chapter. These groups commented on the CA chapters throughout the drafting process from outline to final drafts. The research priorities included in this document have benefited from that process. Ultimately, they have been identified through a collaborative process involving the CA secretariat and the lead authors of the CA synthesis chapters, with input from the CPWF secretariat, Basin focal project coordinators and others involved in the CPWF process. The priorities are considered to be the most significant knowledge gaps and research priorities in the various CA topics, as spelled out and justified in the CA chapters.

In some cases, the gaps and priorities were similar across chapters, and have thus been compiled and merged. The source of the priority and justification (CA chapter) has been included where possible. Priorities have been loosely clustered into sub-thematic groups within the five CPWF themes, but there has been no attempt to rank individual priorities. As the CPWF themes are not directly matched with the topics of the CA chapters, the categories have been selected mostly for the sake of user-friendliness of the document. A quick reference to priorities according to CA chapter theme can be found in Table 2. Acronyms are included in Table 3.

Each research priority has been assessed vis-à-vis each of the nine CPWF Basins. One (+) indicates that the priority is relevant in the basin, two (++) indicates that the priority is highly relevant in the basin. Where no (+) is present, the research area is not considered a priority for that basin. These are indicative only and require more discussion within the basins.

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Table 1. CA Chapter Topics and CPWF Research Themes

Comprehensive Assessment of Water Management in Agriculture	Challenge Program on Water and Food
Chapter Topics:	**Themes:**
Basins	Theme 1: Crop-water Productivity Improvement
Ecosystems	
Fisheries	
Groundwater	Theme 2: Water and People in Catchments
Irrigation	
Land	
Livestock	Theme 3: Aquatic Ecosystems and Fisheries
Marginal Quality Water (MQW)	
Policies and Institutions (P&I)	
Poverty	Theme 4: Integrated Basin Water Management Systems
Rainfed	
Agriculture	
RiceScenarios	Theme 5: The Global and National Food and Water Systems
Water Productivity (WP)	

Table 2. Quick Reference to Priorities by Topic

Topic	Priority Number
Rainfed	1, 11, 23, 38
Irrigation	6, 15, 16, 32, 36, 40, 46, 47, 60
Groundwater	14, 16, 39, 40, 41, 45
Basins	42, 43, 44, 51, 56
Livestock	22, 28, 48
Rice	2, 3, 49, 64
Fisheries	7, 31, 35, 37, 55
Land	13, 17, 18, 29, 63
Ecosystems	4, 23, 30, 31, 33, 34, 50, 52, 62
Scenarios	61, 63, 65, 66, 67, 68
Poverty	1, 12, 16, 24, 26, 27, 32
P&I	25, 47, 54, 56, 57, 58, 59
MQW	4, 5, 19, 20, 21, 53
WP	8, 9, 10

Table 3. Acronyms

CA	Comprehensive Assessment
CGIAR	Consultative Group on International Agricultural Research
CPWF	CGIAR Challenge Program on Water and Food
CWANA	Central West Asia and North Africa
IMT	Irrigation Management Transfer
IWRM	Integrated Water Resource Management
MDG	Millennium Development Goal
MQW	Marginal-quality water
NERICA	New Rice for Africa
P&I	Policies and Institutions
QTL	Quantitative Trait Loci
SSA	sub-Saharan Africa
WARDA	African Rice Centre
WTO	World Trade Organization
WUA	Water users' association
Moz	Mozambique

Acronyms for Basins

A	Andean System of Basins
IG	Indo-Gangetic River Basin
K	Karkheh River Basin
L	Limpopo River Basin
M	Mekong River Basin
N	Nile River Basin
SF	Sao Francisco River Basin
V	Volta River Basin
Y	Yellow River Basin

List of Research Priorities – Key Phrases

CPWF Theme 1

1. Improve the productivity of rainfed and irrigated agriculture for poverty reduction
2. Water scarcity in rice production
3. Rice productivity increases in rainfed and unfavourable environments
4. Long-term impacts of using marginal-quality waters on the soil-plant-aquifer system
5. New crop genotypes of increased salt-tolerance and efficient use of saline water
6. Large-scale irrigation systems
7. Methods for the valuation of fishery resources
8. Water productivity as the value or ecosystem services derived per unit of water use
9. Understand and diagnose constraints to basin water productivity

Adoption, Impact and Up-scaling

10. Lessons on adoption, non-adoption and impact of water productivity enhancing strategies
11. Scaling-up and scaling-out of best-bet options for enhancing agricultural productivity and incomes
12. Impediments to replicating local successes derived from particular farming systems

CPWF Theme 2

13. Managing soil constraints to improve water cycling and productivity in landscapes
14. Groundwater and poverty reduction
15. Irrigation investments to mitigate poverty
16. Irrigation in sub-Saharan Africa
17. Small-scale agricultural livelihoods that prevent or mitigate land degradation under high population density conditions
18. Mapping and assessment of extent, rates and drivers of land degradation and water scarcity
19. Cost-effective and innovative wastewater treatment technologies and methods
20. Effectiveness of measures, such as health risk reduction, wastewater application and human exposure control in reducing the level of pathogens and other contaminants in farms, markets and households
21. Exposure and health impacts to wastewater affected populations
22. Quantify livestock use of and impact on water resources
23. Institutional mechanisms to resolve issues of environmental services, payments
24. Concrete institutional arrangements that help enhance access for those without title to land and water
25. Research on how to enhance equity, including gender issues, poverty and corruption
26. Negotiation frameworks to bring different disciplines and stakeholders together
27. Participatory studies that directly involve members of water user associations
28. Gendered approaches for improving food production and decreasing poverty in pastoral systems

CPWF Theme 3

29. Livelihood and ecosystem impacts of water interventions at the catchment scale
30. Links between agricultural management in terrestrial systems and hydrology
31. Behaviour and responses of multi-species fish communities to changes in water availability
32. How to reduce the negative social and environmental costs of irrigation investments
33. Understand the resilience and dynamics of vital ecosystems
34. Developing mechanisms for dealing with trade-offs over space and time, and developing and understanding management practices that enhance social capacity to cope with surprising change
35. Development and application of alternative methods for enhancing fish production.
36. Enhance positive and mitigate negative environmental impacts derived from water management
37. Research-based methods for encouraging the participation of fisher communities in management

CPWF Theme 4

38. Develop integrated water management at the micro-catchment scale
39. Assess agro-chemical pollution of aquifers in developing countries
40. Development of practical methods of groundwater recharge that protect the quality of both groundwater and aquifers
41. Large-scale, research-based, regional assessments of groundwater circulation and quality on aquifer systems that are being rapidly developed
42. Understanding and quantifying water recycling through the basin
43. Processes that lead to the over-commitment and overbuilding in river basins
44. Impacts of inter-basin transfers
45. Identify the extent to which aquifer systems will be an effective and reliable buffer in the context of drought management and climate change
46. Development of practical systems of assessing supply availability and registering current water-use rights among users at the basin level
47. Implementation of IWRM
48. Research-based policy options for integrating livestock into integrated river basin management
49. Ecosystem services of irrigated rice environments
50. Multiple uses of water
51. Characterisation and quantification of environmental services in a basin context
52. Ecosystem services for food production

CPWF Theme 5

54. Studies of different structural options to manage river basins
55. Intersectoral policy framework adapted to inland fisheries
56. Action research to understand, enable and facilitate polycentric governance – where appropriate – in river basins

57. Support the process of institutional reform in agricultural water management
58. Studies of outcomes and performance of IMT reforms 10-15 years after implementation
59. Empirical research into 'rent seeking' and its impact on water resource use and management
60. Development of effective institutional, economic and governance mechanisms to sustain public and private irrigation
61. Impact of investments in agricultural water management on national economies and poverty reduction

Global Change Research

62. Links between agricultural water use and climate change
64. Impacts of rice production on climate change
65. Future impact of higher energy prices on water use
66. Future impacts of changing diets on water demand and use
67. Future impact of water productivity improvement on water quality
68. Future impact of trade and world market prices on agricultural water use

CPWF Theme 1

Under the first CPWF Theme – 'Crop-water productivity improvement' – the following CA topics are relevant: water productivity, irrigation, rainfed agriculture, rice, MQW. Overlap with livestock, fisheries, poverty, ecosystems

1. Research into how best to *improve the productivity of rainfed and irrigated agriculture for poverty reduction*.

Projections of agricultural yields and water productivity improvements from the CA indicate large opportunities to reduce the relative increase in consumptive water use in both irrigated and rainfed agriculture, but the evidence is incomplete. More complete knowledge is important because productivity improvements could reduce the future consumptive water use in agriculture significantly. Recent established but incomplete analyses show that (average) current water productivity for vegetable-based foods (grains, vegetables, fruit) amount to on average 0.5 m^3/1000 kcal (which translates to approximately 1000-1500 m^3/ton dry matter). Evidence suggests that the high risk for water related productivity loss makes farmers risk averse, which in turn determines farmers' perceptions on investments in other production factors (such as labor, improved seed and fertilizers). Further information is required on (1) how to increase yields without increasing risks (and costs) and (2) what other drivers limit farmers' attitude to risk (market access, etc.).

Established but incomplete evidence shows that there is a large untapped potential in rainfed agriculture in developing countries, even in water-scarce semi-arid and dry sub-humid regions. This is because yields oscillate around 1-2 t grain/ha compared to attainable yields of over 4-5 t grain/ha. An area of focus is the dry sub-humid and semi-arid region, subject to the largest challenges of poverty, water management and hunger, and in which the lowest yields and the weakest productivity improvements have been experienced over the past 50 years. Here, yields oscillate in the region of 0.5-2 t/ha, with an average of 1 t/ha in SSA, and 1-1.5 t/ha in CWANA for the rainfed agriculture where the lowest yields are experienced.

In addition, there are hydrological and agro-ecological limits to the expansion of irrigated agriculture, meaning that rainfed agriculture still remains an important source of food and income for a substantial number of poor people in developing countries. What, then, are the appropriate water management, technological, institutional and organizational interventions required to raise the productivity of rainfed agriculture for effective poverty reduction?

Equity issues also arise between geographical areas, and inter- or intra-households. Investment in agricultural water management will inevitably be better suited to some regions than to others, and hence geographical inequity is generally unavoidable. For instance, depression of output prices for significant numbers of poor rainfed net food producers following the introduction of irrigation in one location is a concern. Productivity raising technologies such as irrigation have equitable on-farm benefits when: they are scale-neutral and can be profitably adopted on farms of all sizes; land is equitably distributed with secure ownership or tenancy rights; efficient input, credit and product markets exist, giving all farms access to information, inputs and prevailing prices; and policies do not discriminate against small farmers and landless laborers (e.g., mechanization subsidies or anti small-scale biases in research and extension). These conditions are rarely met by irrigation and it will usually reduce equity between households. Larger and relatively 'resource-rich' irrigators will benefit most, even if the poor usually still benefit in absolute terms.

Many irrigated areas in both medium- and large-scale systems continue to remain home to a large number of the poor. This is partly due to low productivity resulting from lack of access to water, particularly in downstream areas. There are real opportunities to reduce poverty among the many poor people who are not engaged in irrigated agriculture. Ensuring a balance in national water policy is one of the principal challenges that developing countries face. New strategies that improve the productivity of water in both irrigated and rainfed agriculture, and ensure access to water and technologies by the poor are required. Some assert that there is a need to promote comprehensive approaches and get people to avoid sectoral approaches, not only on the grounds of inefficiency and unsustainability, but because they are likely to promote inequity. Research needs to be centered on small farm holders. It is critical, in particular, to create awareness among governments of the significance of water in the resources base and the need for its protection not only as a sustainable strategy for economic growth and development but also as a critical measure for poverty alleviation.

[Source: Rainfed, Poverty Chapters]

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2. Research into *water scarcity in rice production*, comprising:

(a) Mapping the extent and quantifying the magnitude of water scarcity in rice-based ecosystems;

There is no systematic inventory, definition or quantification of water scarcity in rice-growing areas. It has been roughly estimated that by 2025, 15-20 million ha of irrigated rice will suffer some degree of water scarcity. This gives us a rough idea of the extent of scarcity. But on the ground, scarcity problems are different – growing rice in arid environments, competition for a limited supply of water, or lack of infrastructure to deliver water to rice farmers. Each case needs a different type of response.

(b) Research into the development and adoption of water-saving technologies tailored to regional needs - what will work where? What will be sustainable? What is most likely to be appropriate?

Different water scarcity settings require different water savings approaches. Research is needed to tailor these approaches to different situations in light of water productivity objectives, poverty and ecological impacts, and considering factors that lead to adoption.

For example, aerobic rice shows potential as a response to scarcity in irrigated settings It is estimated that aerobic rice systems are currently pioneered by farmers on some 80 000 ha in north China. However, the development of aerobic rice systems for irrigated environments is in its infancy and more research is needed to develop high-yielding aerobic rice varieties and sustainable management systems.

While comparatively much work has been done on the development of technologies to increase crop productivity under water scarcity, little attention has been paid to long-term sustainability and to the reduction of negative environmental impacts of rice production systems that use less water. Studies are needed on the relationships between the use of organic and inorganic fertilizers and crop residue management on the one hand, and yield sustainability, greenhouse gas emissions and pathways of nutrient losses on the other. The effectiveness and environmental impacts of fertilizer management technologies such as site-specific nutrient management, slow-release fertilizers, and deep placement, need to be evaluated under various scenarios of water availability. Little is known about changing pest and disease dynamics when field conditions change from water-abundant to water-short, although initial reports suggest an increase in soil-borne pests such as nematodes.

[Source: Rice Chapter]

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3. Research into *rice productivity increases in rainfed and unfavorable environments*: develop technologies that integrate genetic improvement with natural resource management (water, soil, crop) for (a) drought-prone, (b) flood-prone, and (c) salinity-affected environments.

With the onset of climate change and other stresses, the need to identify varieties and techniques that will promote productivity increases in rainfed and unfavorable environments continues to be germane. While certain progress has been made, further advances are needed.

Drought. Most progress so far has come from the development of short duration varieties that escape drought at the end of the rainy season. But in the last decade, substantial genetic variability for grain yield under drought stress has been documented in both cultivated Asian rice, *Oryza sativa,* and its hardy African relative, *Oryza glaberrima*. Drought tolerance has been demonstrated to be moderately heritable, with repeatability similar to that of yield in non-stress environments. New breeding approaches and improved screening methods are advancing the development of drought-tolerant varieties and are being extended to national programs. The most promising strategy for developing drought-tolerant yet high-yielding cultivars is to combine selection for yield potential under favorable conditions with managed stress screening for yield under treatments that impose severe stress bracketing the drought-sensitive flowering period. This approach is resulting in the development of both lowland- and upland rice varieties that have improved tolerance to periods of severe water stress during the sensitive flowering and grain-filling stages while retaining the ability to produce high yields when water supplies are not limiting. Breeding efforts need to be specifically directed to well-defined target environments. Two specific examples for upland environments are “aerobic rice” and NERICA (New Rice for Africa). Aerobic rice is higher yielding than traditional upland varieties and combines input responsiveness with improved lodging resistance and harvest index. These new varieties are specifically designed for non-flooded, aerobic soil conditions in either rainfed or water-short irrigated environments. At the African Rice Centre (WARDA), breeders started crossing *Oryza glaberrima* with *Oryza sativa* species in the mid-nineties to combine the ‘toughness’ of the former with the productivity of the latter. These crosses have subsequently been named NERICA and aim to combine resistance to local stresses with higher yield, shorter growth duration, and higher protein content than traditional rice varieties. NERICA is specifically targeted at the upland and dryland areas of SSA.

Flooding. Though breeding for submergence tolerance and enhanced yield in flash-flood areas has been going on for over three decades, only a few tolerant lines with improved agronomic characteristics have been developed so far. For flash-flood areas, some tolerant landraces were discovered that can withstand complete submergence for 10-14 days, such as FR13A, FR13B, Goda Heenati, Kurkaruppan, and Thavalu. A few submergence-tolerant breeding lines with improved agronomic characteristics have now been developed by transferring this tolerance into semi-dwarf breeding lines. Fast progress is being made with the development of submergence tolerant lines using marker-assisted selection. For deepwater areas, elongation ability of leaves and internodes are essential to keep pace with the rising water and to escape complete submergence. Some breeding progress has been made and a few new lines with reasonable yield and grain quality have been released. Recently, three main Quantitative Trait Loci (QTL) for elongation ability were identified. Fine-mapping and tagging of these QTLs should facilitate their efficient incorporation into modern popular varieties through marker assisted selection.

Salinity. Despite its sensitivity to salinity, considerable variation in tolerance exists in rice. Combining new efficient screening techniques with conventional, mutation and anther culture techniques, salinity tolerance was successfully introduced into high-yielding plant types. Some newly released varieties have demonstrated more than 50% yield advantage over current salt-sensitive varieties. Breeding cultivars with much higher tolerance is possible if component traits are combined in a suitable genetic background. The opportunity to improve salinity tolerance through the incorporation of useful genes and/or pyramiding of superior alleles appears very promising. A major QTL, designated '*Saltol*', was recently mapped which accounted for more than 70% of the variation in salt uptake in this population. Marker-assisted backcrossing is currently being used to incorporate this QTL into popular varieties that are sensitive to salt stress.

[Source: Rice Chapter]

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4. Research into the *long-term impacts of using marginal-quality waters on the soil-plant-aquifer system* as well as the economics of marginal-quality water use projects.

Except for a few comprehensive national assessments conducted in Vietnam, Pakistan, and India, scattered information exists on volumes of raw or diluted wastewater currently used in agriculture, which is a limitation for projecting estimates of future use. Another challenge for data collection and comparison is the lack of universally accepted typology. In some cases, information regarding agricultural use of wastewater may actually be available, but not easily accessible due to government policies, or because it is found in grey literature in local/national languages. Approximate estimates of the global extent suggest that at least 2 million ha are presently irrigated with untreated, partly treated, diluted, or treated wastewater.

Some of the implications of using wastewater for irrigation are not known with certainty. Farmers, consumers, and researchers will gain knowledge regarding the potential impacts of specific constituents as experience with wastewater use increases. Given the inherent uncertainty and the potential social costs, public agencies must adopt the precautionary principle when designing policies regarding wastewater use. Policies should minimize the potentially harmful long-term impacts, even when those policies might limit the near-term financial gains to farmers and consumers. Public awareness campaigns might be helpful in gaining support for policies that reflect the precautionary principle. Special efforts will be needed in areas where many farmers or consumers are not literate and where farmers depend on wastewater to support their livelihoods.

[Source: MQW Chapter; Ecosystems Chapter]

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5. Research on the development of *new crop genotypes of increased salt-tolerance and efficient use of saline water*.

Public agencies can motivate farmers to improve the management of saline and sodic waters. Pertinent policies include requiring farmers to re-use or dispose saline drainage water within their farming operation. Water quality agencies might limit the discharge of saline drainage water to surface streams or enforce ambient water quality standards pertaining to constituents found in saline drainage water. In many areas, enforcement of water quality standards will require farmers and water user associations to reduce the discharge of saline drainage water. Public research and development of new methods for utilizing saline and/or sodic waters also will be helpful in improving management.

More research is needed regarding the optimal management of salt-tolerant crops, particularly when combining irrigation waters of high and low salt content. Blending of irrigation waters might be appropriate in some applications, while sequential re-use might be appropriate in others. Improvements in extensions services are needed also to inform farmers about new methods for utilizing saline/sodic waters. There has been a steady increase in the concentration of salts in sewage, soils, and aquifers in many areas of the world. There are no inexpensive ways to remove the salts once they enter the sewage. Governments and farmers are coping with the problem by means of several parallel approaches consisting of reduction in salt content of supplied water and/or treated effluents, reduction of salt addition during industrial and residential use of water, reduction of evaporation losses during wastewater storage, use of drip irrigation methods, adequate drainage of irrigated fields, discharge of the salty first-flood waters of the rainy season, soil application of amendments supplying calcium, and planting salt-tolerant crops.

Considerable variation (almost 10-fold) exists among crops for their ability to tolerate saline and sodic conditions. Therefore, selection of crops suitable for ambient saline and sodic conditions is essential to produce economically acceptable yields. In addition, factors such as the type and concentration of salts, soil type, rainfall amount and distribution, groundwater level and quality, and irrigation management practices must be given due consideration when irrigating with saline and/or sodic waters. Irrigation with saline water may also improve the quality of some crops as the sugar content in sugar beet, tomato, and melon is increased.

[Source: MQW Chapter]

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6. Research on *large-scale irrigation systems*. In particular, more information is sought on the management, technological and institutional adaptation required in large irrigation schemes to:

(a) improve water productivity (improve economic output, save water) by upgrading canal systems and management systems;

(b) enhance positive and minimize or mitigate negative environmental and health impacts, and:

(c) promote institutions that can adapt to changing demands of the agricultural community and broader society.

Large-scale irrigation remains important for food security, employment, economic growth, environmental sustainability and poverty alleviation. Yet, many large-scale public irrigation systems fall below their potential in terms of productivity and economic efficiency. Moreover, there are a range of reported environmental impacts of irrigation that are not dealt with in design and management of systems. The reasons for poor performance are several:

- Engineering designs sometimes do not match the management capacities of agency officials or farmers. Even simply structured, large-scale irrigation systems with proportional division of flows through branching networks of canals, (typically in Asia) require well-trained professional managers and operators to achieve acceptable levels of performance in water delivery service. Another factor that contributes to poor operational performance of large-scale irrigation systems, particularly in Asia, is the change in the conditions on which design assumptions, such as cropping intensities and cropping pattern, have been based. Canal systems are often designed to meet the water needs of cereal grains, and pose a constraint to farmers who wish to shift to more income generating crop. Clearly, this shift will not happen across all land currently dedicated to irrigated wheat and rice. It will, however, be important at the margins and will offer a primary way of addressing economic growth objectives, as well as rural employment objectives, now that food security needs have largely been met at national scales. Melons on a vine, farm ponds, continuous delivery with automatic flow control, and probably other techniques have been tried or proposed. Particular efforts should focus on how poor and smallholder farmers can reap the benefit.
- Large-scale surface irrigation systems are characterized by massive volumes of water in circulation through surface drainage, seepage and percolation from farmers' fields. Because these flows can often be recaptured downstream, water-saving technologies may not contribute to savings at larger spatial scales, such as the irrigation system or the river basin. In some situations, reducing percolation from irrigated fields can lower groundwater tables and negatively affect yield-water application relations at the field level, while increasing the cost of pumping for reuse downstream. When planning to increase water use efficiency in irrigation, it is therefore important to select the appropriate set of water balance and water productivity indicators. A full understanding of the hydraulic system is essential to determine water balance related objectives and water management strategies to achieve them.
- Private irrigation, be it large-scale commercial or individual farmers responding to the local market, is particularly vulnerable to health and pollution problems and requires special attention from public authorities. Implications of the use of raw wastewater or misuse of pesticides and fertilizers have substantial impacts on farmer workers, consumers and water users downstream.

Areas that require further research include:

- The management of within-system and downstream environmental impacts of irrigation. This requires the development of interventions at field, farm and system level that address specific, and well quantified targets. Research is also required in identifying and quantifying impacts and establishing such targets.
- Improving water control capability and supply predictability, with increased transparency and accountability to the user.
- Enhancing flexibility in existing systems, and the potential for operation to enhance system multi-functionality.
- Modernization of canal irrigation systems and their adaptation to new, more remunerative crops.
- How to incorporate new thinking in irrigation in institutions, management practices and education systems.
- Regulation, policies emphasizing human health concerns and targeted extension activities.
- Full understanding of the hydraulic system to determine water balance related objectives and water management strategies to achieve them.
- Acknowledging, accounting for and mitigating as far as practicable the unavoidable alterations of ecological systems while ensuring that avoidable negative impacts are reduced to zero.
- Better understanding of the circulation of water is required, and this requires development and adoption of methodologies to measure existing patterns, and predict changes.

[Source: Irrigation Chapter]

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7. Research-based development of *methods for the valuation of fishery resources* and its contribution to water productivity.

There is an urgent need for more holistic evaluation techniques that take into account the different aspects of the contribution of fish to water productivity. In the last two decades environmental economics theory has made tremendous progress in incorporating the 'non-market' goods and services provided by natural ecosystems into economic frameworks and decision-making arenas through the methodological development and implementation of valuation techniques and concepts such as total economic value, existence or option values, or contingency valuation. In the case of fisheries there is a need to develop similar approaches that quantify less tangible (social) functions and services, such as food security, provision of financial safety-nets or the spreading of risk. Where better valuation has occurred, the profile of fisheries has been raised and adjustments made to national policies regarding water allocation to support fisheries. The new evaluation techniques need to draw upon recent innovative approaches that attempt to include the community perception of these different 'social' services and functions through an adaptive and participatory integrated assessment. The emerging challenge, therefore, is to internalize these hitherto overlooked benefits into a new interpretation of water productivity.

[Source: Fisheries Chapter]

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8. Tools and case studies that express the *water productivity as the value or ecosystem services derived per unit of water use*, especially at system and river basin scales.

Despite the progress made in environmental economics, values and ecosystem services derived from the use of water across sectors remain poorly understood, especially where multiple benefits and costs are derived from its use. There is little information about the value of water in fisheries and livestock, and there is little information about the value of water in its multiple uses. Moreover, the chapter argues for decision making processes that take into consideration these values, yet there are few examples that illustrate how this can be effectively done.

[Source: WP Chapter]

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9. Integrated techniques to *understand and diagnose constraints to basin water productivity*, including techniques to quantify flow paths of water, understand the value of water in each use, and understand trade-offs between uses.

When water is reallocated across uses, an analysis is required of the changes in flows and the changes in the benefits and costs of a transfer. The first part requires a hydrologic analysis to understand changes in quality, quantity and timing of water for different uses. This is not always obvious because of complex hydrologic inter-connections. People who tap into a stream in the hills may have no idea that water to downstream agriculture or wetlands is reduced. There are only few examples of where such integrated analysis has been done.

[Source: WP Chapter]

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Adoption, Impact and Up-scaling

10. *Lessons on adoption, non-adoption and impact of water productivity enhancing strategies.*

Gains in water productivity that increase the welfare of the poor and sustain ecosystem services are elusive. While there are many techniques available, uptake is slow. When applied, desired results are not always achieved because of complex hydrological and institutional interconnections that are not well understood. Further analysis is required to understand the institutions and incentives at play affecting different actors across scale.

Where water productivity enhancing strategies are in place, a level of frustration exists about the lack of adoption. There are few studies that point to reasons for adoption or non-adoption, differentiated by poverty, gender, and other socio-economic considerations. A better understanding of the various incentives that people respond to is required to help out-scale practices that hold promise within a basin setting.

[Source: WP Chapter]

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11. Research on *scaling-up and scaling-out of best-bet options for enhancing agricultural productivity and incomes* through diversification, capacity building and institutional development.

Strategies to enable upgrading including technologies and management are generally known. However, the missing links for scaling-up and scaling-out are the processes and institutions which can link to suitable policies. In India, it has been observed that when a compartmental approach was adopted for watershed programs, the benefits in terms of increasing productivity were not realized to the desired extent, and equity issues were not addressed. Moreover, community participation did not come through, resulting in neglect of the various water harvesting structures in the watersheds. However, with a new integrated approach, which included assured tangible economic benefits through increased productivity for a greater number of beneficiaries, these farmers looked after the structures and the adoption rate was faster and more widespread. The question is how to enable a process of up-scaling and out-scaling and how that links to policies and institutions. The emphasis is on the specifics of how to achieve integration, not a general prescription for an integrated approach.

[Source: Rainfed Chapter]

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12. What are the impediments to replicating local successes derived from particular farming systems?

Farming systems which use fewer external inputs (e.g. fertilizer, pesticides, etc.) have shown tremendous potential to meet local needs and aspirations. But these local successes have barely been replicated at the larger scale. What are the lessons that are coming out from different farming systems?

[Source: Poverty Chapter]

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CPWF Theme 2

Under the second CPWF Theme – 'Water and people in catchments' – the following CA topics are relevant: poverty, land, groundwater. Overlap with MQW, irrigation, rice, livestock, ecosystems, rainfed and P&I.

13. Research into *managing soil constraints to improve water cycling and productivity* in landscapes.

Land-use choices and soil quality are primary determinates of water cycling in landscapes. Soil degradation is a major cause of degraded water productivity because it results in changed patterns of water flow, increasing runoff and reducing below-ground flows, increasing the unproductive evaporative losses of water, and limiting plant growth, thus limiting water productivity. There is great potential to manage and improve water cycling through soil management, but there is not yet sufficient understanding or appreciation of these interactions to make the best management choices. There is a need to quantify these effects (reduction in recharge, increased evaporation etc.).

[Source: Land Chapter]

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14. Research on *groundwater and poverty reduction* to address the circumstances under which access to groundwater significantly improves livelihoods vis-à-vis access to surface water alone.

If groundwater irrigation around the world were to suddenly come to a halt, the global economy would be none the poorer. Yet, the socio-economic impacts of intensive groundwater use in agriculture are important to understand because of the critical linkages between groundwater use and livelihoods and food security of some 1.2-1.5 billion rural households in some of the poorest regions of Asia and, to a limited extent, Africa. In peasant farming systems in South Asia and North China, agricultural groundwater use generates relatively little wealth and has low productivity, but supports vast numbers of rural poor households. Indeed, groundwater irrigation has emerged as one of the largest and most potent poverty alleviation interventions in South Asia, and probably also in the North China plain. In Africa, where improving rural livelihoods has remained a persistent challenge, groundwater-supported extensive pastoralism is critical in evolving a global picture of groundwater's contribution to human welfare. In peasant framing system-regions, advantages of groundwater irrigation translate into powerful positive impacts on rural poverty, food security and livelihoods. In subsistence agriculture of South Asia and North China plain, rapid expansion of groundwater irrigation has produced profound region-wide positive impacts on land productivity, total food production and livelihoods of smallholders. However, there is little literature and evidence on the livelihood and poverty reduction impact of groundwater use in agriculture in regions with arid agrarian systems and industrial agriculture systems.

[Source: Groundwater Chapter]

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15. Estimation of the potential of and mechanisms used for different *irrigation investments to mitigate poverty* and/or improve livelihoods, especially with respect to other investments.

There is extensive evidence, particularly from studies in Asia, that irrigation can provide a pathway out of poverty for the rural poor. This research has documented conditions under which this is possible. These include slow rate of rural out-migration, high incidence of un- and under-employed labor, and high dependence on agriculture for livelihoods. Poverty reduction and rural employment strategies may justify investments in rural agriculture-dependent areas which cannot be justified in direct economic terms. In such cases, the financial analysis of irrigation improvements should be based on the 'sustainability' cost, i.e. cost of operation, maintenance, and replacement (but excluding initial capital investment). However, to take this information to the next step is to apply it practically. This requires more site-specific research on how to overcome barriers where irrigation is present but is not impacting poverty in a positive way. Few studies are available indicating how to achieve poverty reduction through irrigation when the identified conditions are not in place.

[Source: Irrigation Chapter]

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16. Research on four aspects of *irrigation in sub-Saharan Africa*:

(1) the extent and distribution of areas in SSA that are suitable for (a) micro-scale irrigation development (shallow groundwater), and (b) small check dams and other water harvesting techniques;

(2) the relevant potential (region of application) and importance of small-scale low-cost technologies for poverty alleviation (treadle pump micro-drip systems);

(3) evaluation of irrigation costs, benefits and niche; and

(4) the future of groundwater irrigation and its sustainability.

Case studies to examine the impact of low-cost technologies on poverty, including who benefits and what kind of support systems work best to promote their wider dissemination.

Some irrigation systems in SSA show considerable promise in terms of poverty alleviation and food security, yet results of application are mixed. More evidence is required on what works, what does not work, and under which situation. This calls for comparative analysis, detailed case studies, and action research.

The priority for research and action specifically in SSA with respect to the prospects for expansion of groundwater irrigation and its sustainability are threefold: (a) expanding groundwater use for food security and livelihoods in a *planned* and *scientific* manner; (b) ensuring inter-personal and gender equity in groundwater access and use; and (c) putting in place systems for monitoring, data collection and regulation well ahead of the stage when environmental problems become overwhelming.

[Source: Irrigation Chapter; Groundwater Chapter; Poverty Chapter]

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17. The development of research-based approaches for *small-scale agricultural livelihoods that prevent or mitigate land degradation under high population density conditions*.

The interlinkages between growing population densities, the context within which this occurs, and land degradation are not well understood. For the time being, most interventions designed to mitigate land degradation are based on the premise that high and growing population densities constitute a key driver of land degradation. But this premise itself is questionable, as high population densities have been shown to stimulate conservation and good land husbandry in some areas. On the other hand, there is a link between land degradation and poverty, as the poor are clustered on the most degraded and fragile land. Populations will continue to grow, while pressures to increase productivity on existing agricultural lands will increase if the expansion of agriculture into forests or onto increasingly marginal areas is to be avoided. In the future, therefore, it will be necessary to better integrate these drivers into a positive synergy wherever possible. The current state of knowledge on policy, institutions and technologies to make this possible are lacking.

[Source: Land Chapter]

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18. *Mapping and assessment of extent, rates and drivers of land degradation and water scarcity.*

There is a huge information gap with respect to the extent of land degradation, the rates of degradation processes, the drivers of degradation and possible rehabilitation trajectories.

[Source: Land Chapter]

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19. Research into *cost-effective and innovative wastewater treatment technologies and methods* including decentralized systems that conserve nutrients while effectively removing pathogens.

Treatment of wastewater before agricultural use is an important response to mitigate health risks. But raw wastewater use persists because of the non-existence or non-effectiveness of wastewater treatment facilities in many cases due to finance or management constraints. Constraints with large-scale centralized wastewater collection and treatment systems in many developing countries, including the difficulty of effectively integrating water use with the wastewater management systems, have led to the development, promotion and, in a few cases, the application of decentralized systems for the collection, treatment, and disposal of wastewater. Decentralized management systems are flexible and compatible with the local demands regarding effluent use for agriculture but also require inputs and collapse when their capacity is overstretched. The use of wastewater can motivate communities to operate and maintain local systems, ensuring long-term operation as well as financial sustainability in favorable cases. Because these decentralized systems show potential to mitigate health risks and support agriculture, more research is warranted in areas of design and management, and integrating these systems into overall natural resource management. Part of the research should include low-cost analytical techniques for chemical and pathogen determination that can be used by communities to manage their waste.

[Source: MQW Chapter]

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20. Research into the *effectiveness of measures, such as health risk reduction, wastewater application and human exposure control*, in reducing the level of pathogens and other contaminants in farms, markets and households. Research into methods of cost-benefit evaluation for these measures.

Some of the implications of using wastewater for irrigation are not known with certainty. Farmers, consumers, and researchers will gain knowledge regarding the potential impacts of specific constituents as experience with wastewater use increases. Given the inherent uncertainty and the potential social costs, public agencies must adopt the precautionary principle when designing policies regarding wastewater use. Policies should minimize the potentially harmful long-term impacts, even when those policies might limit the near-term financial gains to farmers and consumers. Public awareness campaigns might be helpful in gaining support for policies that reflect the precautionary principle. Special efforts will be needed in areas where many farmers or consumers are not literate and where farmers depend on wastewater to support their livelihoods.

[Source: MQW Chapter]

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21. Investigations that examine the *exposure and health impacts to wastewater affected populations* (workers, farmers, communities near land application sites, consumers, etc.) using epidemiological and quantitative microbial risk assessment methodologies.

In 1971, the World Health Organization (WHO) addressed the health concerns that arose from the use of wastewater in aquaculture and agriculture. An expert committee recommended the water quality standard of a maximum of 100 faecal coliforms per 100 ml for the irrigation of crops consumed uncooked. This was however relaxed in 1987 to 1,000 per 100 ml, based on a compilation of the findings of past studies on wastewater irrigation. In addition, a quality guideline for intestinal nematodes was imposed of less than 1 intestinal nematode egg per liter. Unfortunately, many past studies that have looked at the negative health impact of wastewater use in agriculture lack statistical rigor and often had simply qualified the water used in agriculture as clean or untreated without quantifying the exact concentrations of pathogens. Additionally, the majority of the studies that have investigated the risk of consumption of wastewater irrigated vegetables have linked a high prevalence of infection in a population with the widespread use of wastewater in agriculture in that city. The studies are therefore epidemiologically flawed as they do not assess the risk of exposure at the individual level.

Ever since the revision of the WHO guidelines in 1989 they have been criticized as being either too lenient or too strict. Recent studies that have been conducted in Pakistan, India and Vietnam have and will again challenge the validity of the global (helminth) water quality guideline. This is because there are too few studies that have combined an epidemiological component with a water quality assessment and those studies that have, were conducted under different environmental, cultural and climatic conditions making comparison and extrapolation of findings nearly impossible. The major question when it comes to wastewater use in agriculture is not whether wastewater irrigation is unhealthy – which it is, as past research has clearly shown – but at which pathogen concentration does this increased risk occur? The corollary is to which level wastewater really needs to be treated or what are the alternatives to treatment that can be implemented to eliminate this additional risk, so that wastewater can be safely used in agriculture?

[Source: MQW Chapter]

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22. Research to *quantify livestock use of and impact on water resources* indiverse production systems.

Livestock-water interactions have been largely neglected in both water and livestock research and planning. Unlike for irrigation and crop sciences, there are relatively few examples of research and assessments that attempt to understand total water needs of livestock and how animals affect water resources. The consequence has been lost opportunities in past investments in water and livestock development to maximize investment returns.

Additional reasons why this is important:

- Excessive numbers of animals with low productivity put excessive pressure on land and water resources and there is need to decrease numbers, increase productivity and find alternatives ways of meeting human needs such providing alternative wealth savings strategies.
- Limiting stocking rates to levels below carrying capacity can have beneficial impacts on water, land and vegetative resources in watersheds and river basins.
- Any withdrawals of water for livestock industries (particularly for feed production) can affect river flows and have direct impact on the downstream countries and/or users
- There are major opportunities to increase water productivity of livestock through improved animal breeding, health, husbandry and marketing.

Because livestock exist in virtually every agricultural production system around the world, including pastoral lands, irrigated lands, mixed rainfed crop-livestock systems, intensified urban systems, and others, the scope of issues and needed technologies, policies and behavioral changes is immense. Evidence from many places confirms the need for an enhanced understanding of livestock-water issues, both to help highlight the role that animals have on using and degrading water resources and the role that they have in improving water resources management.

There may be a need to choose some very specific livestock-water productivity questions and mainstream them into surveys of CPWF benchmark basins to help highlight the role that animals have on using and degrading water resources and in some cases in improving water resources management. For example, in rangeland areas, much is known about the impact of different levels of grazing pressure on vegetation and soil erosion. Where impact of livestock on water has been measured, such as in soil erosion studies, little thought has been given to the implications for water management policy.

Also, unlike research on drinking water, relatively little is known about water required for animal feed production. However, evidence suggests no other branch of agriculture can match the potential existing within the livestock sub-sector for increasing agricultural water productivity. Achieving this requires a mix of feed sourcing, water conserving, and animal productivity enhancing strategies that are well known in animal science but that have never been systematically applied to making better use of water resources.

Competition between livestock keepers and crop producers, particularly in areas of expanding rainfed and irrigated crops is a major cause of conflict in Africa driving people rapidly into poverty and helping to keep them there. Significant opportunities for conflict resolution exist.

[Source: Livestock Chapter]

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23. Research on *institutional mechanisms to resolve issues of environmental services, payments*, and quantifying environmental services provided by upstream farmers.

Emerging evidence illustrates the economic pay-off for downstream societies from investments upstream in improved water and land management. Examples are emerging in different parts of the world, where downstream communities compensate upstream communities for economic gains for environmental services downstream received thanks to wise water management investments upstream (for example, in South Africa, India, Colorado).

It is hypothesized that investments in water management to upgrade rainfed agriculture may be more resource effective – resulting in a lower reduction in water availability to other sectors compared to investments in irrigation. This is a result of larger opportunities to improve water productivity, and large evaporative losses of water flowing from rainfed agricultural land (if unused) to recharge rivers and groundwater, available for irrigation further downstream.

Tools in terms of creating incentives and formulating regulation policies can assist in making trade-offs between ecosystem services. New tools are emerging and increasingly being used. Some available tools include economic valuation and cost-benefit analysis of ecosystem services, assessment and establishment of environmental flows, risk and vulnerability assessments, environmental impact assessments, and modeling approaches. However, there is a need for broader adoption, and continued development of tools that can be used in striking trade-offs between water for different sets of ecosystem services. It is acknowledged that successful employment of such tools should benefit from an adequate information base and improved predictive capacity about how ecosystems respond to change, and articulation of what is unknown or uncertain. Whilst their use has been increasingly promoted through international fora, including conventions, their acceptance and use have been delayed, most likely because of lack of awareness and capacity.

[Source: Rainfed Chapter; Ecosystems Chapter]

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24. More case studies that look at *concrete institutional arrangements that help enhance access for those without title to land and water*.

Apart from ownership, leasing and sharecropping are other ways in which farmers can have access to land. Research is needed to look at the evidence in terms of equity and water productivity. What kind of policies would support revisions of current legislation dealing with sharecropping and leasing? In particular, there is a need to do more research on women's rights to land. Recently innovative legislation has been introduced in some parts of Latin America to provide women with joint titling. How is this being put into practice?

[Source: Poverty Chapter]

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25. *Research on how to enhance equity, including gender issues, poverty and corruption*.

Cross-cutting all of these research topics is the importance of examining (a) how to promote greater attention to equity including gender issues, poverty reduction, innovative ways to promote integrated water supply systems at local levels (which tend to cut across government agencies with different mandates), (b) effective support for scaling up new low-cost small-scale water technologies, and (c) how to integrate attention to ecosystem services and provision of other essential water services.

Some experts suggest that most user organizations failed in India because they focused on areas of concern to the government, and not necessarily to the farmers. To be successful, they recommend that user organizations need the authority to levy water fees, carry out maintenance tasks and represent farmers' interests with government agencies. Moreover, strengthening the water rights of user groups may provide a strong incentive for farmers to participate in organization and management. Where farmers are involved in maintenance activities, the resources mobilized are significant – sometimes several times greater than the irrigation charges paid to the state. This demonstrates the potential – but the implication is that successful irrigation management transfer (IMT) requires much larger policy and institutional changes (well established). There is also considerable evidence that the sticking point even where the formal conditions seem to be in place, as in the state of Andhra Pradesh, India, is the unwillingness of government organizations to delegate or share power with users' organizations.

This is a fundamental issue: while governments are often happy to transfer the hard work and expense of local water management to users, they are rarely willing to re-structure their hydraulic bureaucracies and make other legal and structural changes needed to achieve a new balance of political power favoring users, as part of an incentive package to accept IMT (Mexico is a partial exception). Similarly, after a few seminal papers in the 1980s, the continuing serious problem of corruption – an institutional issue par excellence – has barely been addressed. This research would include looking at regulatory requirements for decentralization to ensure equity and voice for the poor and comparative studies on local institutions as integrating organizations to examine whether decentralization leads to better integration.

[Source: P&I Chapter]

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26. Research to develop *negotiation frameworks to bring different disciplines and stakeholders together* to address contentious issues, especially the implications of water storage and inter-basin transfers on environment, stakeholder rights and economic growth.

Increasing seasonal and inter-annual variation in rainfall poses a significant supply challenge, particularly in areas in Asia, Africa and South America. Water storage strategies that are more environmentally friendly are needed. The combination of local versus central storage and delivery systems that is most effective from the perspective of sustainability and livelihood options is not always clear. Analyses that expose the key issues in making such a choice are needed.

[Source: Poverty Chapter]

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27. More in-depth *part\icipatory studies that directly involve members of water user associations* so as to assess how the latter can become a more effective means to achieve improved water management for poverty reduction and equity.

A challenge related to water governance is that of ensuring the rural poor a voice in decision-making with respect to the allocation and administration of water resources. In many places, the response to this challenge has been the creation of water-user boards, aiming to represent all relevant stakeholders. However, experience has been disappointing in at least two ways. First, comprehensive stakeholder participation in water governance as a whole in the formulation and renegotiation of policy, legal and regulatory frameworks has been limited. Second, the ways in which social and economic relations shape the access to and management of water and their effects on the interactions between stakeholder representatives are rarely clearly recognized and addressed. In this situation and within their limited and often unclear mandates, water-user boards tend to reproduce existing power balances among stakeholders, and thus have come to legitimize rather than challenge and alter these relations.

[Source: Poverty Chapter]

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28. The development of *research-based gendered approaches for improving food production and decreasing poverty in pastoral systems* through the better management of water resources.

Just as science-based knowledge of livestock water interactions is lacking, the gendered aspects of improving livestock-water productivity have not been addressed more than to a limited extent. In the past, livestock research has been one of the most gender blind fields of study. Although some work has been able to generate a framework to help understand gender in the context of livestock-water productivity, this work is still in its infancy. Livestock keeping is a highly gendered issue and presents some very good opportunities to help bring marginalized female farmers out of poverty. For example, studies from Kenya and Ethiopia demonstrate the income-generating potential of using agricultural water to promote dairy production. Common recommendations such as shifting from grazing to zero-grazing animal production, however, may well have the affect of decreasing male labor in tending grazing and watering animals and shifting the burden to females.

Additional reasons why this is important:

- Many smallholder and poor farmers think dairy products from cows, goats, camels and eggs are the best nutrient for children because they supply protein and calcium.
- The marketing of dairy products, small ruminants and chickens is done by women while the marketing of oxen and camels is done by men.
- Women benefit by selling dairy products, eggs and chickens to support their families.

Because all three strategies for improving livestock water productivity are highly gendered, there is need for complementary assessments of the likely impacts they will have on who benefits from and bears the costs of proposed 'improvements' to the use of water for animal production.

[Source: Livestock Chapter]

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CPWF Theme 3

Under the third CPWF Theme – 'Aquatic ecosystems and fisheries' – the following CA topics are relevant: fish, ecosystems. Overlap with rice, water productivity, land, poverty, irrigation and rainfed.

29. Research on the *livelihood and ecosystem impacts of water interventions at the catchment scale.*

Considerably more research is needed – particularly at water catchment scales – to better understand the multiple drivers underpinning land degradation, and the ways in which land users respond to these. The intensification of smallholder rainfed agriculture is necessary to achieve the MDGs, and feed a growing population. This will, however, entail significant changes to the water-use landscape. Sustainable intensification requires research on the larger-scale impacts of these interventions, to ensure equitable benefits and to avoid unintended negative social and environmental consequences. 'Win-win' opportunities with respect to food and the environment are also better understood at the larger scale, when food production is integrated into multi-functional landscapes, which then also better provide other ecosystem services.

[Source: Land Chapter]

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30. *Links between agricultural management in terrestrial systems and hydrology.*

The hydrological changes that occur as a result of agricultural expansion into forests are seldom thought of in terms of 'water management in agriculture', although globally, deforestation for agriculture is contributing to hydrological changes on at least the same magnitude as irrigation. It is well established that clearing of forests for agriculture will have hydrological consequences; however, the uncertainty about these is high, and the evidence incomplete. It is established that deforestation can lead to land degradation through, for example, salinization, but the evidence is incomplete, with almost all examples coming from Australia and little evidence from the rest of the world.

[Source: Ecosystems Chapter]

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31. Research into the *behavior and responses of multi-species fish communities to changes in water availability*. Research on environmental flows for ecosystems and fisheries.

Many species of fish and other aquatic organisms are sensitive to the timing, quantity, quality and temperature of riverine water as essential triggers to migration and breeding. The habitats used by fish are often diverse with separate regions of a river system being used for feeding, breeding and refuge. Because of the high degree of adaptation of river fish to the natural flow regime, many species react negatively to changes in the hydrograph. For example, altered flows that modify river morphology may interfere with the connectivity and channel diversity that are essential for the survival of many species. Many other changes also affect different fish species in different ways, in rivers, wetlands, lakes, reservoirs, marine and brackish waters, and aquaculture areas. The negative impact of flow alterations due to damming and abstractions to fish and fisheries means that efforts have to be made to maintain flows in rivers and other flow sensitive systems if fisheries are to be sustained. There is a need for research on the links between fish communities and changes in water availability.

Due to increased abstraction of water from rivers and aquifers, as well as changes in run-off from agro-ecosystems, there is an increased need to consider how much water is left for aquatic ecosystems (e.g. wetlands, rivers, and coastal zones, including the fish and fisheries). An estimated 15% of terrestrial land areas, inhabited by some 1.4 billion people, suffer from stream flow depletion to an extent where the water requirements of the downstream aquatic ecosystems cannot be met. While the assessment of water availability, water use, and water stress at the global scale has been the subject of on-going research, the water requirements of aquatic ecosystems have not been estimated globally and considered explicitly in these assessments. Estimates of flow requirements range globally from 20-80% depending on the ecosystems being considered and the species composition. It could be possible to establish an environmental allocation beyond which substantial degradation of ecosystem services and human well-being results. Defining this allocation also entails defining what constitutes a degraded ecosystem.

More research is needed on methods to determine environmental flows on large rivers and flood plains for fisheries**.** Freshwater fish resources are probably among the most resilient harvestable natural resources, provided their habitat and the quantity, timing and variability of river flows are maintained. Changes in flow and fisheries production in rivers and river-dependent water bodies may arise naturally due to climatic variability; however, more commonly they result from human modifications to the flow regime. The negative impact of flow alterations due to damming, abstractions and land-use change to fish and fisheries means that efforts have to be made to maintain flows in rivers and other flow-sensitive systems if fisheries are to be sustained. Methods to determine the environmental flow requirements for rivers, wetlands and estuaries exist, however, most are of use only in small rivers in temperate zones. Methods applicable to large systems are currently being developed and applied although these are by no means complete at present.

[Source: Ecosystems Chapter; Fisheries Chapter]

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32. Research into *how the negative social and environmental costs of irrigation investments can be reduced*. Research to identify the institutional/management interventions and investment options needed to enhance the poverty reducing impact and sustainability in existing irrigated lands.

There is a need to address whether it is possible to avoid or reduce the social and environmental costs of irrigation investments, and what the possible ways out of this there are for reducing poverty and sustaining the environment. Investment in irrigation and/or agricultural water management varies across the world. Generally, those regions that have invested in irrigation have seen substantial reductions in poverty although with some social and environmental costs. It is expected that those currently with low levels of investment in water resources development will begin sooner or later.

Irrigation has played a central role in poverty reduction in the past by providing food security, protection against famine, and expanded opportunities for employment both on and off the farm. While evidence shows that irrigation contributes to poverty alleviation, both for farmers and landless laborers, this is contingent upon a wider framework of pro-poor policies and is only true where suitable conditions for irrigation development prevail. Investment in agricultural water management affects poverty through its effects on production, employment, food prices, income stabilization, nutrition and socio-economic variables. Its net welfare effect depends on the prevailing supportive policies, governance, institutional arrangements, access to infrastructure, resources and markets.

Irrigation may worsen absolute poverty for some if it reinforces processes of land consolidation in which poor households lose rights to land, or if it is associated with displacement of labor by mechanization or herbicide use. Poor people may be displaced by the construction of reservoirs and canals, or their livelihoods may be adversely affected by upstream or downstream impacts. Productivity raising technologies such as irrigation have equitable on-farm benefits when: they are scale-neutral and can be profitably adopted on farms of all sizes; land is equitably distributed with secure ownership or tenancy rights; efficient input, credit and product markets exist, giving all farms access to information, inputs and prevailing prices; and policies do not discriminate against small farmers and landless laborers (e.g., mechanization subsidies or anti-small-scale biases in research and extension). These conditions are rarely met by irrigation and it will usually reduce equity between households. Larger and relatively 'resource-rich' irrigators will benefit most, even if the poor usually still benefit in absolute terms

Investments in agricultural water management have both negative and positive environmental and health impacts. The possible negative environmental impacts of irrigation are extensively documented. Most commonly cited are the upstream and downstream impacts of dams or diversions, waterlogging and salinization within command areas and increased agro-chemical usage. When these threaten the livelihoods of the poor they may worsen poverty. Moreover, badly designed or managed irrigation can negatively impact public health and human capital through the spread of water-borne diseases, usually with a greater incidence for the poor. On the positive note, improved income due to irrigation or agricultural water management can enhance farmers' ability to invest in land improvements that enhance sustainability. Investment in irrigation can also reduce the pressure on surrounding marginal areas and hence avoids loss of biodiversity, land degradation and loss of forest. The population absorption capacity of an irrigation-led strategy may be greater, and pressure on natural resources less severe, than for alternatives.

Negative social and environmental consequences often adversely affect the poor more than the non-poor people, as the poor lack political power and financial resources to avoid potential adverse impacts of irrigation whether they relate to displacements, health risks or land degradation.

[Source: Irrigation Chapter; Poverty Chapter]

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33. Research is needed to *understand the resilience and dynamics of vital ecosystems* and to avoid the loss of ecological services that support human well-being.

There is increasing evidence for the risk of regime shifts in ecosystem behavior as a consequence of a reduction in or loss of ecosystem resilience, with important consequences for human well-being. It is increasingly being recognized by scientists that pressure from drivers such as over-harvesting, climate change, invasive species, and nutrient loading can push ecosystems towards thresholds that they might otherwise not have encountered, and that once exceeded may be irreversible. Increasing evidence points to a situation where periods of abrupt ecological change are expected to increase in frequency, duration and magnitude in the future. There is a need to develop mechanisms for dealing with uncertainty and being proactive rather than reactive to change.

Regime shifts are often rapid, following from a slower change in the resilience of an ecosystem that can be difficult to detect; there is very little known about how to monitor changes in resilience before a system hits the threshold level. A regime shift that leads to the loss of ecological components of the ecosystem (e.g. specific food products) can have very costly consequences for people using and/or depending on the ecosystem services formerly available. The understanding that ecosystems will be changing with socio-economic development and that the challenge is therefore 'living with acceptable change' is now being increasingly acknowledged. This makes protection of resilience of ecosystem functioning in order to avoid flips and collapses in life support systems essential.

One of the main gaps in scientific understanding of ecosystem services and the ecosystem functions supported is where thresholds lie and how far a system can be changed before it loses too many essential functions, loses its resilience and changes its behavior. It will be necessary to develop the scientific and administrative capacity to analyze the conditions necessary for securing social and ecological resilience to change in ecosystems, especially those that are also particularly vulnerable to fire, droughts, floods, pollution, etc.

[Source: Ecosystems Chapter]

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34. Research-based management recommendations on (a) *developing mechanisms for dealing with trade-offs over space and time*, and (b) *developing and understanding management practices that enhance social capacity to cope with surprising change*.

As changes in land use are expected to continue and may be unavoidable, societal responses are needed to ensure that water allocations between ecosystems can meet priority needs. As trade-offs between ecosystem services will also be unavoidable we require tools to deal with these, especially when we are constrained by understanding and the expectation that there will inevitably be ecological surprises – we do not know the ecological consequences of all trade-offs and responses. There have been many past trade-offs between ecosystem services, sometimes intentionally, but also inadvertently. On the whole, people have shown limited capacity to adequately address changes within and between ecosystems, partly because the value of regulating, cultural and supporting ecosystem services relative to provisioning services, especially food production, has been under appreciated. Given the state of many ecosystems and ecosystem services as a consequence of past water management in agriculture, further trade-offs are expected – striking these trade-offs will require a change in approach if past problems are to be avoided. The cost of not striking these trade-offs will be further ecosystem degradation and decline of human well-being, especially for the poorer rural populations.

[Source: Ecosystems Chapter]

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35. Research-based *development and application of alternative methods for enhancing fish production.*

There is a general lack of reliable data and scientific literature on freshwater-dependent fishery production, due mainly to the majority of freshwater fisheries being small-scale, spatially diffused activities, where a significant part of the production is not commercialized. The lack of data has been problematic for research and management and may have biased policies and allocation of national development resources towards agricultural crops.

Evaluation of alternative methods for fish production, such as manipulation of fish stocks through species introductions, stocking in lakes, reservoirs, rivers and floodplains, and aquaculture, is needed. For example, many stocking programs are carried out without clear definition of objectives or evaluation of potential/actual success of the activity. Further investigation into the opportunities associated with integrated agriculture-aquaculture activities is needed, due to the potential economic synergies and reduction of risks to vulnerable, often rainfed, small-scale farming systems. Finally, the potential and actual value of cage aquaculture technology in increasing production of valuable table fish while mitigating the effects of environmental changes is a specific area highlighted.

[Source: Fisheries Chapter]

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36. Develop measures to *enhance positive and mitigate negative environmental impacts derived from water management.* A first step is quantification, including a better understanding of processes, of the global and local scale environmental impacts of irrigation on:

(a) biodiversity through land-use change;

(b) aquatic ecosystems through diversion and transpiration of stream flow; and

(c) downstream pollution of aquatic and terrestrial ecosystems.

A second is the development of diagnostic tools to inform management.

The environmental impacts of irrigation can be positive or negative. The design of new irrigation or modernization of existing systems must be done in such a way to ensure better identification and understanding of the externalities related to irrigation so as to promote the positive impacts and mitigate the negative ones, including limits on the proportion of water abstracted for agriculture. Additional research is needed to assess the positive contributions of irrigation systems to supporting biodiversity and other ecosystem services, as well as to understand the diversity and magnitude of ecological and socio-economic tradeoffs involved with irrigated agriculture in different contexts.

[Source: Irrigation Chapter]

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37. The development of *research-based methods for encouraging the participation of fisher communities in management.*

Research is needed to guide a broader policy and governance environment that will stimulate pro-poor growth through adequate support to investment and public-private partnerships. These should ensure high levels of participation by all stakeholder groups in the decision-making process and should create and enforce mechanisms to ensure the accountability of the different public and private actors whose actions impact on the allocation of water and water productivity.

Unfortunately, effective governance of aquatic resources is relatively rare, especially in developing countries. In most countries, governments and institutions have failed to design governance mechanisms and policy formulation processes that truly encompass and account for the aspirations and needs of the rural populations that depend on inland aquatic resources for their livelihoods. Decentralization and participatory democratization, in particular, are seen as the new type of reforms necessary to improve these governance mechanisms. In fisheries, community-based management and co-management arrangements are now frequently promoted as part of this governance reform. However, the decentralized level provides very little opportunity to address issues of transboundary resources and shared or migratory fish stocks. Nor is it possible to create the managerial conditions and knowledge necessary to integrate the water flow requirements of fisheries into watershed or basin-wide Integrated Water Resource Management (IWRM). The level of co-ordination and information necessary for a sustainable and equitable allocation of water between the different users across a basin is rarely achieved. Many of the proposed reforms contravene existing legislation in many countries, particularly with regard to access to the fishery and land and water tenure. To be fully effective, decentralization reforms will need to include changes in legislation to favor local community ownership and control of resources, but also provision of support facilities by central governments, such as research, mechanisms for dealing with issues at basin, national and international levels and education of communities in management.

[Source: Fisheries Chapter]

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CPWF Theme 4

Under the fourth CPWF Theme – 'Integrated basin water management systems' – the following CA topics are relevant: basins, land. Overlap with P&I, livestock, fisheries, water productivity, irrigation, rice, groundwater, ecosystems and MQW.

38. Research on how best to *develop integrated water management at the micro-catchment scale* involving communities for increasing productivity. Research on the on- and off-site impacts of micro-catchment rainwater harvesting and management in terms of addressing issues of equity, poverty, productivity and the environment.

A new water policy paradigm needs to focus more explicitly on the smaller catchment scale, which often corresponds to the community, small-township or village scale (10-1000s of ha). This scale corresponds to the relevant water resource management scale of rainfed farmers in the world where a new green revolution will have to occur over the next decades in order to achieve the MDGs. To capitalize on the untapped potential to upgrade rainfed agriculture, water management investments are required at the small catchment scale, i.e., the tributary scale in river basins, where runoff flow often is ephemeral (i.e., only flows during short periods after rainfall events). This is the relevant scale for small-scale farmers. A new water policy framework for IWRM is required, where rainwater management is planned and allocated at catchment scale. Policy support and human capacity are essential, but it is not known how to generate this support and capacity. Currently there is no water legislation supporting a policy shift towards the meso-scale for rainfed agriculture. Water policies are designed for allocation of irrigation water from large rivers, groundwater and dams, and not adapted to collection of rainfall at the meso-catchment scale in small micro-dams, farm ponds, and percolation tanks. Approaches to legal ownership of rainwater at the catchment levels will have to be developed.

[Source: Rainfed Chapter]

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39. Research to *assess agro-chemical pollution of aquifers in developing countries* to avoid the creation of 'time-bombs' and identify the prospects for regulating non-point agricultural pollution of aquifers.

Pollution threats to groundwater are numerous. They can be of a localized nature, or they can be more widespread, when excess fertilizers or inappropriate fertilization methods are used. Pollution from pesticides can be of both natures as they are both spread across the fields, yielding non-point source pollution, and can be leached in excessive quantities locally during mixing and cleaning procedures, often occurring next to a water source, like a well, that gives a potential direct conduit to groundwater. The general expansion of groundwater irrigated areas around the world is very likely increasing the contamination levels of nutrients and pesticides in agricultural areas and areas downstream, in both surface and groundwater. Very little is, however, known about the extent of this since continuous and reliable monitoring of these substances is an exception, rather than the rule in most countries. Due to the relatively low flow rates of water in soils and aquifers, groundwater contamination due to leaching of agrochemicals can be an incipient, but persistent problem that is not easily reversed or solved. Thus, research is needed to assess agro-chemical pollution of aquifers in developing countries and to identify how to regulate it.

[Source: Groundwater Chapter]

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40. Understand and evolve policy and strategies to manage surface and groundwater in a sustainable manner, in full recognition of their interdependence. This includes research into the *development of practical methods of groundwater recharge that protect the quality of both groundwater and aquifers*. Focus on India as the world's largest groundwater user for lessons and best practices.

Options for improving irrigation system flexibility and reliability include conjunctive use of surface water and groundwater, and recirculation of drainage water. Conjunctive use of surface water and groundwater in large-scale irrigation systems offers a viable alternative to under-performing water services. It will continue to do so, subject to the constraints of salinity trends, energy costs, and specific chemical problems such as arsenic and fluoride which result in significant health problems when water developed for irrigation is also used for domestic and drinking purposes. However, management strategies that explicitly consider groundwater are rarely taken into consideration, and the strategic use of aquifers warrants more research exploration.

India is the world's largest groundwater user and many lessons could be learned from the experience on the ground. India has a massive popular program for constructing recharge structures, but there is little science behind it. For this reason, numerous questions remain unanswered and few studies have been able to shed light on the science and technologies behind groundwater recharge. Thus, there is dire need to answer the many questions about the way recharge activities are proceeding in India, including the outcomes of managed recharge projects. In particular, there is a need to address whether managed recharge has an impact on groundwater storage, overall water availability and distributive equity? Are hydrological and economic gains made or is it simple re-allocation of resources and benefits within the same water balance?

[Source: Irrigation Chapter; Groundwater Chapter]

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41. *Large-scale, research-based, regional assessments of groundwater circulation and quality* on aquifer systems that are being rapidly developed.

Data on groundwater are scarce. Data on the impact of agricultural groundwater use of food security, rural livelihoods and ecological systems even more so. A complete global picture of groundwater use in agriculture is not available. The FAO AQUASTAT database provides national data on irrigated areas supplied by groundwater and surface water as reported by national agencies from developing countries and countries in transition. But since many of these countries do not regularly report data on groundwater irrigated areas this coverage is not comprehensive and does not necessarily present an up-to-date picture. Information available from other sources, however, suggest that groundwater irrigated areas of the world in 2005 may be 25-40% higher than reported. For many countries, accurate official estimates are just not available. For many other countries, estimates available are out of date by a decade or longer.

Overall, there is dire need to improve data on extent of groundwater irrigation, to improve and standardize assessment and reporting methods for groundwater irrigated areas and water extracted for groundwater irrigation. Large-scale regional assessments of groundwater availability and use and groundwater quality have not been addressed in aquifer systems that are being rapidly developed.

[Source: Groundwater Chapter]

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42. *Understanding and quantifying water recycling through the basin.*

The temporal and spatial interconnectedness across scales, in both hydrologic and policy terms, is a crucial point in the functioning of river basins. Because the closure of river basins results in a growing interdependence of the users within the basin, one must carefully analyze how rainfall is partitioned between green (evaporated) water and blue (flowing) water, how the paths of the different surface and underground flows are interrelated, and how any local intervention that modifies the quantity, quality or timing of one of these flows impacts on the whole system. What is stored, conserved or depleted at point A dictates what is available at point B, further downstream. There are numerous examples of such interactions which, if not comprehended, lead to misconceived policies or faulty decisions. More research is needed on the effects of micro-irrigation on return flows available downstream and overall water savings, the hydrological interconnectedness of groundwater with surface water resources, and the links between land use practices, such as deforestation/afforestation, on hydrological events.

[Source: Basins Chapter]

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43. Documenting and drawing attention to the *processes that lead to the over-commitment and overbuilding in river basins.*

Basin closure is by definition a human-induced or anthropogenic process: a host of driving forces work to produce 'developed' and, often, 'overbuilt' basins. Overdevelopment of river basins is a common phenomenon that goes beyond the mere continuation of supply-oriented strategies accompanied by disregard for demand-management strategies and for the environment. It includes the development of infrastructure with a potential demand for water that outstrips basin resources and ecosystem resilience. Unpacking the logic that drives the overbuilding of basins is essential because of its dramatic impact on water management and allocation.

Many factors are presented that shed light on the pattern leading to basin closure, including the post-WWII development of river basins with large infrastructure, the lack of definition of water rights, the malleability of cost-benefit analyses, and the complexity of river basins as ecosystems. Pressure over water resources is often understood as a management issue (the difficulty to control or cap individual abstraction) while it is foremost a planning problem (how to limit the development of infrastructure, notably large-scale irrigation projects, so that they do not outstrip resources). More research is needed in understanding these processes. This research should lead to material improvement in the specification and development of rational allocation systems at basin level.

[Source: Basins Chapter]

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44. Research into the *impacts of inter-basin transfers*.

One response to solving water scarcity within a river basin is by augmenting supply from existing sources, such as diverting water from neighboring basins. Inter-basin transfers may offer a way to augment allocation by bringing in large amounts of water, but they may also be inappropriate responses to water shortages, where their social and environmental costs are seldom fully identified and in nearly all cases they will only exacerbate problems. They clearly help in restoring a balance between supply and demand, but usually gloss over the losses in terms of direct impact and long-term foregone opportunities for the giver-basins, may foster lavish use of water in low-return activities, and have potentially substantial ecological impacts. Such transfers pose specific problems that tend to be proportional to their scale, but they are almost invariably designed in secrecy and imposed by strong political will rather than discussed publicly and openly. All these potential problems command great caution, but the site-specific and highly political nature of these projects tends to remove them from public debate and makes general statements difficult. It is safe to assume that inter-basin transfers will both increase and be subjected to growing scrutiny and opposition. Inter-basin transfer must not be ruled out but instead open to the scrutiny of the stakeholders concerned and have their costs fully accounted for. Thus, more research is needed on the impacts of inter-basin transfers.

[Source: Basins Chapter]

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45. Research to *identify the extent to which aquifer systems will be called upon to provide an effective and reliable buffer in the context of drought management and climate change*. Research to address where shallow groundwater circulation currently mobilized for agriculture is going to reach limits and where there is scope for development.

There are many favorable characteristics of groundwater as a resource, which shed light on the reasons behind the groundwater revolution. One characteristic is that groundwater irrigation demonstrates greater drought-resilience: groundwater aquifers keep yielding during a dry year even when all surface water bodies dry up. This is perhaps why, almost everywhere, well-digging activity intensifies during drought periods. However, questions exist regarding the exact extent to which groundwater will provide sustainable and effective buffers against drought and climate change. Key issues are not just the absolute volume but the cost of abstracting it as water tables fall, the consequences of lower water tables on saline intrusion, salinity gradients and other aspects of groundwater quality, and the ability to recharge groundwater.

Research is needed to identify when groundwater exploitation can be considered sustainable, in environmental and socio-economic terms. This will help shed light on when groundwater utilization, in terms of volumetric use, causes impacts that are unacceptable to society as a whole. These questions are central to the contemporary and increasingly important debate on groundwater over-exploitation. Notions of 'sustainable yield' or 'safe yield' used by scientists and managers imply that there is a fixed, well-defined quantum of groundwater that can be extracted for use without negative consequences. However, these have recently been widely criticized in the academic groundwater community. Above all, there is no clear definition of the terms and how to determine them. A critique of the 'safe yield' or 'sustainable yield' approach indicates further research needs, particularly on the determination of discharge and recharge rates.

[Source: Groundwater Chapter]

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46. Research into the *development of practical systems of assessing supply availability and registering current water-use rights among users at the basin level*. Research into *water rights*, in particular formalization of water rights to include traditional systems and not to disenfranchise established water users.

In countries where water rights exist and are separate from land rights, markets can, in theory, ensure efficient re-allocation of water among sectors. In practice, water trading has, so far, clearly only re-allocated small volumes of the resource (less than 1% per annum of permanent entitlements in the Western USA and Australia). It is unlikely that water markets will make a big impact on irrigation water use and re-allocation in most countries of Asia or SSA in the coming 20-30 years because of: (1) the time lag in the development of suitable water rights and allocation frameworks, and (2) the marginal nature of markets once they are established. A major challenge in the formalization of water rights is to include traditional (often small-scale) systems and not disenfranchise established water users.

[Source: Irrigation Chapter]

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47. Comparative studies on the *implementation of IWRM*, how it is used/interpreted, and outcomes, including a global survey of developing country experience with IWRM, focusing on success stories.

IWRM has become a rhetorical buzzword but there are very few studies of the actual processes of implementation, and the outcomes of these processes. As governments create new water laws for implementing IWRM, there is an increasingly important issue around the incompatibility of state laws imposing uniform and relatively rigid principles and requirements, and the diversity and flexibility of local customary laws, principles and practices. This issue is very complex, and there is incomplete evidence. Often, local practices are equitable and effective, and undermining them may be counter productive. On the other hand, there may be serious equity issues, particularly biases against women in land and water rights that governments rightly may wish to address. However, the role of national laws in addressing such issues is often very limited.

IWRM is especially becoming an increasingly important concept in the irrigation community. However desirable, it is difficult and expensive to implement, as experience in South Africa and elsewhere shows. An early step in the process is to determine what resources are available and existing uses – also not easy, but less daunting than the political process of creating suitable stakeholder representation and making and implementing collective decisions about resource development, protection, and reallocation. Basic methodologies are known, but applied research to develop and disseminate a simple-as-possible methodology for this would be useful. It is necessary to understand how to reconcile equitable local arrangements with equity amongst different users across the basin, particularly those downstream.

[Source: P&I Chapter; Irrigation Chapter]

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48. The development of *research-based policy options for integrating livestock into integrated river basin management*, with a particular emphasis on intra-basin links including hydrology, trade, and epidemiology. Policy recommendations are also needed for the development of institutional capacity to cope with conflict between pastoralists and encroaching irrigated and rainfed crop production.

The issue of integrating livestock into the development of agricultural water resources is a global issue which is critical in diverse production systems and cultures and relevant at local, national, river basin and international scales. One of the key lessons learned is that if livestock people are the only ones looking at policy issues, decision-makers in the water sector will be, at best, very slow to change their thinking to include livestock production as a factor in water resources planning.

Additional reasons why this is important:

- In the past, much irrigation development did not take account the role of livestock in the irrigation design.
- Excessive exploitation of groundwater for livestock production could result in fatal water shortages.
- Non-point pollution from livestock industries must be taken into consideration particularly for South Asia.
- If water is not managed well there is a possibility of diseases from water bodies and grazing being transmitted to humans via livestock.
- The bio-physical and socio-economic conditions of Asia and Africa (where most livestock research has been carried out) are different.

Regarding institutional capacity to cope with pastoralist-farmer conflict, the institutional arrangements involved in the intensification of agriculture have not adequately addressed conflicts between pastoralists and encroaching irrigated and rainfed crop production. There is a great need to look at this issue, but normally livestock sections of Ministries have little or no interaction with water sector researchers and managers.

[Source: Livestock Chapter]

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49. Research into the *ecosystem services of irrigated rice environments*: develop methodologies to characterize, quantify and value the various ecosystem services (multi-functionality), besides the provision of rice, of irrigated rice environments.

There is an increasing awareness that lowland rice environments provide an unusually rich variety of ecosystem services, but only few studies have been conducted so far. Besides the provision of rice, services include flood mitigation, erosion control, groundwater recharge, biodiversity, remover of water pollutants (P and heavy metals), fish production, cultural aspects, and the impacts of changing to lower water-use rice production systems. In Japan, Taiwan, and the Republic of Korea, the growing interest in identifying ecosystem services is partly stimulated to justify the high support prices for rice to the World Trade Organization (WTO). But trade is not at all the only reason for CGIAR and CPWF to be interested. Rather, it is important to consider these multiple ecosystem services. Many are important for the rural poor to provide more incomes, for example through fishing, or to reduce vulnerability to floods and erosion. Many are important for resilience of the rice-based ecosystem itself.

Although some methodologies exist to measure and estimate different services of agricultural systems, quantifying and valuing the positive and negative externalities still presents a major problem. In many countries, relevant data at the appropriate geographical level are not available. Furthermore, there is a potential for the erroneous estimate of services because of double counting, failure to recognize interactions among the services, and failure to consider the potential services from other uses of the land.

More case studies are needed to identify local or regional specific characteristics of ecosystem services, and management practices need to be developed to sustain and enhance the ecosystem services of rice-based landscapes.

[Source: Rice Chapter]

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50. Multiple uses of water.

Increased attention to ecosystem services provides an opportunity to promote the dual outcomes of (1) placing greater emphasis on multi-functionality within agro-ecosystems, and (2) emphasizing the connectivity between and within agro-ecosystems and other ecosystems. It is often assumed that agricultural systems are only managed for optimal (or maximum) production of one ecosystem service (i.e. food or fiber). However, agricultural systems can also generate ecosystem services and we need to improve our capacity to assess, quantify and value these. Nurturing multiple benefits from these systems can generate synergies resulting in win-win solutions. Managers and society should look for these synergies and attempt to take advantage of them. If properly done, ecosystem-based approaches to water management need not contradict agricultural development, but can be point of convergence for poverty reduction, resource conservation and international concerns for global food security, biodiversity conservation and carbon sequestration. They also aim to maintain and where possible enhance diversity to build the ecological resilience of the agricultural landscape as well as other systems altered by agriculture.

[Source: Ecosystems Chapter]

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51. Research on *characterization and quantification of environmental services in a basin context*.

Conceiving the river basin as a continuum of nested ecosystems assists in the understanding more widely how changes in one part of a basin impact on both water availability and environmental health in other parts of the basin. The systemic and complex nature of river basin ecosystems has often compounded the direct impacts of dams, irrigation and pumping schemes and led to a series of destructive effects that have frequently been overlooked or not identified at the outset. The complexity of river basins as ecosystems is such that most environmental assessments of large projects miss many externalities. Consequently, projects whose overall costs may exceed benefits are allowed to go ahead because externalities are simply not factored into decision-making. In a bid to combat the neglect of ecological impacts derived from land and water resources development, environmentalists have centered efforts on various points, one being the economic valuation of ecosystem services as a means to make the hidden costs of interventions explicit and to influence cost-benefit analysis and feasibility studies. Environment tends to be the ultimate loser in water allocation decisions, therefore environmental flows are a starting point for negotiations and, when enforced, incorporate the environment into allocations.

[Source: Basins Chapter]

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52. Research into *ecosystem services for food production*.

It is well established that aquatic ecosystems provide a wide array of ecosystem services, but the nature and value of these is not consistent, and our understanding of how ecosystem processes support many of these services needs to be improved. There is established but incomplete evidence that the loss and collapse of ecosystem services have adverse effects on livelihoods and economic production. There are also competing explanations (often manifesting as conflicts between agronomists/engineers and ecologists) as to whether the positive outcomes in terms of increased upstream production of food outweigh the negative consequences for people dependent on downstream ecosystem services.

So far there is a general lack of understanding of ecosystem services, how they contribute to human well-being and the role of water for sustaining these. Greater awareness and attention from decision-makers and land/water managers is still needed if the current paradigm for water management in agriculture is to change and more transparent and informed decisions are made about the trade-offs with the wider array of ecosystem services and human well-being.

[Source: Ecosystems Chapter]

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53. What are the *implications of growing urbanization on the generation and re-use of wastewater in a basin context*? What institutional arrangements and policy development are required to manage equitable re-allocation and safer re-use of wastewater?

Better data regarding the nature and extent of wastewater use for irrigation will enhance the efforts of public agencies, researchers, and policy makers. Information describing the volume and quality of wastewater used, and the geographic distribution of wastewater use within peri-urban areas will be helpful when designing policies to improve wastewater management and protect public health. Incentives might be offered to small-scale farmers to report the use of wastewater, the yields achieved, and observable impacts on humans, plants, and soils. Public agencies also might work with farmers to establish wastewater monitoring programs.

[Source: MQW Chapter]

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CPWF Theme 5

Under the fifth CPWF Theme – 'The global and national food and water system' – the following CA topics are relevant: P&I, scenarios, fish, basins, irrigation, ecosystems, land, rice.

54. Comparative *studies of different structural options to manage river basins* and criteria to evaluate options for reform.

The management of water resources is complex. It involves and affects a host of people and organizations. There is a large range of institutional models to choose from for water resources management: from direct public management (government) to direct private management (by a private operator) and from delegated management by an agency or utility to community self-management. But even if a system is formally under government management, farmers and private contractors play an important role; even in farmer-managed systems, the state and markets are still critical.

Unfortunately, most water sector reform has been single-organization or single-institution focused. For instance, most irrigation reforms have focused on one type of institution or organization as the linchpin of the policy: reform of water bureaucracies, irrigation management transfer to water users' associations (WUA), development of water markets, or currently and normatively, the introduction of river basin authorities. This is like building on a single pillar: it may look elegant, but it requires a very flat foundation and the pillar itself must be very strong. A more appropriate model would be a tripod with several branches, each of which may not be strong enough, but through mutual support, the whole structure is stronger and more flexible.

What is critical, then, is not finding a single 'right' type of institution or organization, but to identify the conditions under which each can play an effective role, what can be done to strengthen them, and ensuring effective co-ordination and negotiation mechanisms among different types of organizations involved. More research is needed to examine different institutional models in order to identify these conditions, and to find an appropriate mix of institutional arrangements in a given specific context

[Source: P&I Chapter]

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55. Developing an *intersectoral policy framework adapted to inland fisheries.*

There is a need for new evaluation techniques, investment approaches, and governance reforms that can support and improve the contribution of fisheries and aquaculture to water productivity. The implementation of these approaches still represents an enormous challenge for a large number of institutions in developing countries. There is an urgent need for all countries to develop and implement an individual framework specific to inland fisheries. This framework should in particular have explicit links to other freshwater sectors such as irrigated agriculture and power generation, but also to land planning and environmental protection. In integrating these different components, an important part of the framework should address biodiversity conservation issues.

[Source: Fisheries Chapter]

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56. *Action research to understand, enable and facilitate polycentric governance – where appropriate – in river basins.*

Much attention has been given to pursuing an ideal organizational model for river basin management through the creation of River Basin Organizations, while much less emphasis has been placed on the process dimensions of building, managing and maintaining collaborative relationships for river basin governance. To improve river basin management, institutional interplay is crucial and there is a need for collaboration between existing organizations. While integrated management at basin level tends towards the unicentric model, decentralization, involvement and participation of users/stakeholders, local/community management of upper watersheds, and the principle of subsidiarity point towards polycentric governance.

The polycentric model provides for a strong political base for action, since collaboration involves voluntary agreement among participating jurisdictions. The collaborative process also leads to a more responsive governance process. Intersectoral linkages remain intact, since co-ordination is among stakeholders, agencies and other jurisdictions responsible for a range of policy sectors. Decision making can be cumbersome, co-coordinating costs may be high, and political changes in participating jurisdictions can upset agreements. Polycentric and multi-level governance seeks to reconcile local values and objectives with basin constraints by ensuring that information becomes available to all stakeholders and that conflicting actions are flagged in advance and duly debated. Nested or polycentric patterns of governance seem more appropriate but each solution must reflect the societal context, the phase of development, and the specific problems of each locale.

Proper and integrated river basin management is predicated upon suitable governance, with two main challenges having to be addressed: ensuring that all stakeholders, including the environment, have a voice, and finding a way to co-ordinate uses and policies within the basin. Nested or polycentric patterns of governance, whereby a brokering institution provides scientific knowledge, monitoring, and a negotiating arena, perform better, but they can only be effective in settings where participation and democratic practices are well established.

[Source: Basins Chapter; P&I Chapter]

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57. Research to *support the process of institutional reform in agricultural water management*. Studies on water institutional reform processes – what works and why, necessary conditions, strategies, etc.

The central importance of policies and institutional capacities to promote sustainable development has been recognized rhetorically for decades. Nevertheless, it is remarkable how little research has been done to understand how to support reform processes in the agricultural water or indeed any other sectors. There are a few case studies, some important and insightful, but most too superficial or too partisan to contribute much; there are very few comparative analyses across countries and regions, and almost no in-depth long term or historical studies of processes and the underlying drivers. Further, most research has focused more on the ‘what’ question rather than on ‘process’: many studies begin with an assumption that a specific reform model like management transfer, privatization or river basin organizations is the way to proceed, without addressing the strategic process of implementation. This gap in social science research underlies the relatively high level of uncertainty regarding the precise way forward in policy and institutional reform.

A research program specific to irrigation reform has been proposed, emphasizing three themes: the resilience of irrigation bureaucracies, the role of international development funding agencies, and the capture of irrigation reform implementation by elites. The types of research needed are rigorous comparative analyses as well as contextualized case studies using appropriate methodologies and asking the right questions. While case studies of 'successes' are useful, it is essential to have a representative picture of the range of 'success', 'failure', and in-between cases.

It is well-established that knowledge and human capacity are critical to successfully integrate water management and to crafting the institutions and policies required for successful IWRM. More data needs to be generated and turned into reliable information, and shared widely with stakeholders to raise their awareness and understanding. Further, IWRM requires new skills and capacities within water management institutions – at a time when various forces are weakening governments' capacities to attract and hold people with this expertise.

Another critical area needing far more attention than we can give here is the growing mismatch between the multi-disciplinary technical capacity required for IWRM and the dwindling and narrow capacities of most government water agencies. A combination of budget reductions, unattractive salaries and career prospects compared to other alternatives, and conservative university curricula are making it increasingly difficult for government agencies to attract and hold the kind of expertise required. To support this, comparative studies of (human) capacity requirements to implement institutional reforms, what – if any – gaps exist, and options to fill these gaps.

[Source: P&I Chapter]

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58. Comparative *studies of outcomes and performance of IMT reforms 10-15 years after implementation* and lessons for the future.

It was only during the 1990s that some governments made more serious attempts at IMT, a movement that continues today and even has its own network, the International Network for Participatory Irrigation Management, (INPIM).

Pilot projects to transfer management from the state to user groups on government-built schemes have only rarely been scaled up effectively to cover larger areas. This is due, in part, to the failure to recognize the critical differences between government- and farmer-managed irrigation systems. Management transfer programs in countries as diverse as Mexico, Colombia, Senegal, the United States, Mali, Australia, New Zealand, Turkey, Sri Lanka, and Indonesia have demonstrated some positive results in involving farmers and reducing government expenditures, but have rarely shown improvements in output performance or in quality of maintenance. The few notable exceptions are in middle-level developing countries such as Mexico and Turkey and rich countries such as New Zealand, Australia and the United States. Research during the 1990s on IMT processes and outcomes produced many case studies and some useful guidelines for implementation. There is broad agreement on the necessary conditions, but very few cases where these were met.

[Source: P&I Chapter]

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59. *Empirical research into 'rent seeking' and its impact on water resource use and management.*

Studies on incentives, positive and negative are needed. Since Robert Wade's 1982 paper there has been almost no further work on 'rent seeking', despite its continued prominence in the water sector, and there is hardly any evidence on responses to water pricing in the agricultural sector. When talking accountability, social auditing, participatory budgeting and the like, this is a central issue. Similarly, there has been no work on the role and politics of budget allocations in reform processes.

[Source: P&I Chapter]

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60. Research into the *development of effective institutional, economic and governance mechanisms to sustain public and private irrigation*, particularly private groundwater development.

It is clear that sectoral reforms in irrigation management cannot succeed in a vacuum and are heavily dependent on broader scale reforms in governance and transparency at national level and on agriculture policies. This will largely dictate the effectiveness of institutional reform in the irrigation sector in the future. Poor performance of irrigated agriculture may be the result of non water-related constraints, in which case irrigation management reforms will attract little attention from farmers who may therefore not back the process. The ingredients for institutional reform are well known: strong political backing, a clear role for the different stakeholders, support to the empowerment of institutions at all levels (including WUAs, local governments etc.); the level of autonomy of the WUAs and development of the legal framework needed to accommodate the proposed changes in authority; capacity building of the people governing the transferred system; functioning infrastructure and success in recovering operation and maintenance costs. Research is needed on processes of uptake of these mechanisms, including research to understand the reasons why these ingredients are taken up, or not.

[Source: Irrigation Chapter]

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61. *Impact of investments in agricultural water management on national economies and poverty reduction.*

Investment costs in water infrastructure tend to be high, particularly in SSA. What are the opportunity costs? Little is known on the impacts of these investments on the larger economy, as compared with investments in other sectors. Would it be more beneficial for poverty reduction to invest in sectors other than water (roads, governance, education, industry) to boost the economy and create jobs outside agriculture? Or do investments in agricultural water provide a necessary stepping stone to lift subsistence farmers out of poverty?

[Source: Scenarios Chapter]

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62. Links between agricultural water use and climate change.

There is increasing speculation about the manner in which altered green water flows affect local, regional and global climate. There are several competing explanations for changes in climate that have already occurred, including natural variation, and change occurring in response to increased emissions of greenhouse gases. Whatever the reasons, alterations of the microclimate can have threshold effects on ecosystems, causing rapid and possibly irreversible change. Most of the evidence for this is from tropical semi-arid to humid climates with little from temperate regions.

[Source: Ecosystems Chapter]

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63. Responding to climate change: *better understanding of adaptation options for variability in water availability.* What is the impact of climate change and increased climate variability on agricultural water demand and supply? Do we need more irrigation? Do we need more reservoirs to deal with larger variation in water supply?

There is high uncertainty with regard to future water supplies in the context of climate change. Responses to this uncertainty may include irrigation and more storage, but little work has been done to assess what the optimal and most sustainable options are.

[Source: Land, Scenarios Chapter]

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64. The *impacts of rice production on climate change.*

There are many unknowns with respect to the impact of rice production on climate change. It is known that climate change will affect rice production both positively and adversely, so reducing the impact of rice production will help reduce the eventual impact of climate change on rice production. For one, the uncertainty in methane emissions from rice fields is among the highest of all sources in the global methane budget. Another issue is the possible shift in the use of pesticides by farmers as a response to changes in water availability, and what this means for the environment. Less ammonia volatilization and methane emissions are expected under non-flooded conditions, but higher nitrous oxide emissions and more leaching of nitrate. The net greenhouse gas impact is as yet unknown. While direct evidence from converted paddy fields is still missing, it is likely that growing rice under increasingly aerobic conditions will reduce soil carbon contents. This change in soil organic matter will be accompanied by changes in the microbial community, shifting from predominantly anaerobic to aerobic organisms. It is not clear if or how these changes will affect soil fertility.

[Source: Rice Chapter]

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65. The future *impact of higher energy prices on water use*.

Energy prices may remain high or even increase further. The impact on agricultural water use is twofold. First, the demand for cheaper and cleaner energy sources will increase: hydropower and biofuels both require water. Some guesstimates indicate if all energy needs are met by biofuels, agricultural water demand will double. The impact of biofuel-crop production on water and land-use competition with other uses (like food security) is unknown. Second, groundwater pumping will become more expensive. For example, India may no longer be able to afford the low subsidized energy prices. Many poor depend on groundwater irrigation and may no longer be able to afford it. On the other hand, higher energy prices may reduce groundwater overdraft. Further clarity is sought on how to value or quantify this trade-off.

[Source: Scenarios Chapter]

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66. The future *impacts of changing diets on water demand and use* (especially increased meat consumption).

It is expected that meat consumption will increase with higher incomes. For example, per capita pork consumption in China nearly tripled over the past decades and is expected to grow even more. This will increase the demand for feed grains and hence water to grow these. There is large uncertainty how much more water this will require.

[Source: Scenarios Chapter]

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67. The future *impact of water productivity improvement on water quality* and how to model this impact.

To meet future demands for agricultural products and deal with increasing competition for water from other sectors and environmental uses, water productivity improvements are essential. To achieve these more agro-chemicals will be required, particularly in areas where actual use is low. This will lead to increased non-point pollution from agriculture. More research is needed to identify how to value or quantify the environmental trade-offs between improved water productivity (and hence more land and water for nature) and increased pollution. The few existing models to quantify this for large river basins are insufficient.

[Source: Scenarios Chapter]

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68. The future *impact of trade and world market prices on agricultural water use* at basin and country scale.

It is likely that the push for agricultural trade liberalization will continue, despite setbacks in recent WTO negotiations. This will change the agricultural production patterns. For example, China is becoming an exporter of fruits and vegetables. But this has enormous implications for the already water scarce basins where most of the agriculture takes place. What are the environmental and water scarcity implications? How will water be allocated and who will be able to benefit from new export opportunities? Will small farmers lose their water to big firms? Models that link global economic processes like WTO with basin level issues such as water scarcity and allocation are in their infancy and need further methodological development.

[Source: Scenarios Chapter]

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