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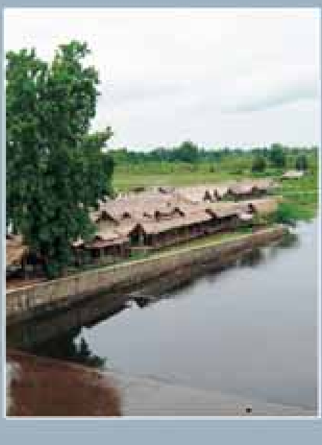
THE FUTURE OF LARGE RICE-BASED IRRIGATION SYSTEMS IN SOUTHEAST ASIA



Ho Chi Minh City,
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26–28 October 2005

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The future of large rice-based irrigation systems in Southeast Asia

Proceedings of the regional workshop on the future of large rice-based irrigation systems in Southeast Asia

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For copies write to: Zhijun Chen
Water Resources Development and Conservation Officer
FAO Regional Office for Asia and the Pacific
Maliwan Mansion, 39 Phra Athit Road
Bangkok 10200, Thailand
E-mail: Zhijun.Chen@fao.org

Foreword

Irrigated agriculture produces enough food to meet about one third of the world's food demand, contributes to about 40 percent of Asia's food production, and plays a key role in global and regional agriculture development and food security. Rapid socio-economic development in Asia in the past decades brought new challenges and opportunities to the irrigation subsector, with large rice-based irrigation systems in Southeast Asia mostly affected. In 1996, FAO organized a regional expert consultation in Bangkok on the Modernization of Irrigation Schemes: Past Experiences and Future Options. A new definition of modernization of irrigation systems to guide future understanding and efforts was coined at the meeting: "Irrigation modernization is a process of technical and managerial upgrading (as opposed to mere rehabilitation) of irrigation schemes combined with institutional reforms, if required, with the objective to improve resource utilization (labour, water, economic resources and environmental resources) and the water delivery service to farms." Options for advocating and promoting irrigation modernization were identified and recommended.

Almost ten years after the 1996 Regional Expert Consultation, FAO, with the support of the Evaluation Study of Paddy Irrigation Under Monsoon Regime (ESPIM) Project funded by the Government of Japan, and the Vietnam Institute for Water Resources Research, Ministry of Agriculture and Rural Development, Viet Nam, convened the Regional Workshop on the Future of Large Rice-based Irrigation Systems in Southeast Asia in Ho Chi Minh City in October 2005 to re-appraise the perspectives and evolution scenarios, to identify strategies, opportunities and interventions for the sustainable management of large rice-based irrigation systems in Southeast Asia over the coming decades in the context of improved management of water resources, and to promote collaboration in the region. About fifty experts and representatives from international, regional, subregional and national agencies and institutions participated in the workshop.

The workshop discussed three critical questions whose answers could determine the way that large rice-based irrigation systems will evolve over the next 20 to 25 years, namely: how will agriculture and rice production evolve in Southeast Asia? What changes will be required in irrigation service provision by the large rice-based irrigation systems? How will ongoing and expected reforms and investment programmes measure up against the projected needs of the region? Typological classification, reflecting both technical characteristics of the schemes and their socio-economic contexts, was adopted to support discussions on evolution scenarios and strategic responses.

This Proceedings is a collection of the workshop papers and outcomes. It offers a useful reference work to professionals, researchers and government decision-makers on sustainable agriculture, water management and irrigation modernization. We would like to congratulate the organizers of the workshop and the participants for all their efforts.

He Changchui
Assistant Director-General and
FAO Regional Representative
for Asia and the Pacific

Acknowledgements

The editors of this Proceedings would like to express their gratitude to the Evaluation Study of Paddy Irrigation Under Monsoon Regime (ESPIM) Project funded by the Government of Japan for kindly co-sponsoring this workshop, and to the Vietnam Institute for Water Resources Research, Ministry of Agriculture and Rural Development, Viet Nam for their great support and cooperation in executing the workshop. We owe our most sincere thanks to the various invited speakers and participants for their active participation and invaluable contributions. The painstaking contributions of language and technical editing of Iljas Baker are very much appreciated.

Table of contents

Table of contents *(continued)*

Page

Issue papers

Annexes

Executive summary

The Regional Workshop on the Future of Large Rice-based Irrigation Systems in Southeast Asia was convened by FAO in Ho Chi Minh City, 26–28 October 2005, with the support of the Evaluation Study of Paddy Irrigation Under Monsoon Regime (ESPIM) Project funded by the Government of Japan and the Vietnam Institute for Water Resources Research, Ministry of Agriculture and Rural Development, Viet Nam. The major objectives of the workshop were to identify strategies, opportunities and interventions for the sustainable management of large rice-based irrigation systems in Southeast Asia over the coming decades in the context of improved management of water resources, and to promote collaboration in the region.

The workshop included a half-day's field trip to an irrigation system and two-and-a-half-day's plenary presentations, group discussions and plenary discussions, which focused on three crucial questions whose answers could determine the evolving character of large rice-based irrigation systems over the next 20 to 25 years, namely: How would agriculture and rice production evolve in Southeast Asia? What changes would be required in irrigation service provision by the large rice-based irrigation systems? How would ongoing and expected reforms and investment programmes measure up against the projected needs of the region? About fifty experts and representatives from international, regional, and subregional organizations and national agencies and institutions, including Cambodia, China, Indonesia, Lao PDR, Malaysia, Myanmar, Philippines, Thailand and Viet Nam, participated in the workshop.

In addition to a general review and analysis of regional trends and challenges related to water, rice, agriculture, economy and environment, as well as irrigation policies and strategies recommended and adopted previously, the workshop produced three major outcomes:

- A typology of irrigation schemes, categorized by socio-economic contexts and hydraulic characteristics, was developed. Main drivers, strategic responses and evolution scenarios were identified and outlined for each type of irrigation scheme as summarized in Table 1.

- Based on identification of the implications of the evolution scenarios and the re-appraisal of current strategies and options, recommendations for new strategies, directions and concrete actions were proposed in terms of: financing and multifunctionality; design and operation; management and institutions; and new systems, as shown in Table 2.

- Six general conclusions were generated concerning the current status of large rice-based irrigation schemes in Southeast Asia, the way forward and the measures that need to be taken; these are:

  1) Modernization of the irrigation systems and their management to increase their flexibility and insert them into river basin management, while taking into account the multiple functions of agricultural water management, is more required than ever.

  2) New layers of complexity have been added to our understanding of irrigation, from multiple use and social complexity, to multiple use, multiple ecosystem and livelihood functions, and agro-socio-economic-ecological complexity.

  3) To respond to this complexity, management needs to be made more professional and present institutional reform models need to be evaluated and overhauled to respond to new demands and characteristics of farmers.

  4) Evolution scenarios, objectives and strategic responses will vary greatly according to the types of irrigation systems and their socio-economic contexts. Non-rice drivers will play an important role in their evolution.

  5) New recommendations can be characterized as: moving away from the generation of both positive and negative externalities by accident and from development of autonomous farmers' responses by neglect, to explicit management of multiple roles and explicit recognition of farmers' service

and other objectives, and of their contributions to overall efficiency and productivity, for instance by pumping, and of the costs thus incurred by them.

6) The main focus in irrigation modernization will remain improving the performance of existing assets. New systems may be still developed in predominantly agrarian economies and in ecosystems with comparative advantages, but their planning and appraisal processes should be reformed to adhere to improved water governance.

Table 1. Evolution scenarios of different irrigation schemes

National and Sub-national context	Economic and agriculture profile	Strategy and policy	Type 1: Reservoir gravity	Type 2: Off-river gravity	Type 3: Off-river pump	Type 4: Conjunctive	Type 5: Integrated management of deltas
Focus is outside agri. Post-agriculture	highly diversified agriculture; resources competition; high environmental concern; diets shifting; need to conserve certain level of food production capacity; water-multifunctionality link (more classical environmental issues)	Reduction/ decomissioning of rice irrigation areas; specialization; improve water productivity; protect environment and water quality; government investment for modernization	0	-	+	+	-
			Optimizing multiple use; economically justified; limited number of sites available for new systems	Reduce, merge or neglect because of low reliability; convert to type 3 or 4; convert to different crops/land use	Increasing energy costs; crop diversification; rice phased out economically justified; limited number of sites available for new systems	Highly flexible; farmers decide; market rules (export possibilities) (many more use pumps)	Urbanization; optimizing multiple use (environment, drainage issues, peri-urban agriculture, urbanization); more crop diversification
Agriculture export main focus; intermediate	On the way to diversification; quick demographic transition; further improvement of food security; need rice exports for foreign exchange earning+C6 to stabilize rice production	Stabilization and modest development of rice irrigation areas; development of small systems; increase financial self-sufficiency	Not economically justified by agriculture alone but may expand	0	0/-	+	Expand in the short term then decline because of urbanization, sea level rise, salinity?
			Anticipate multiple uses	Improve, modernize (endless); inherent limitations of supply	Likely reduction because of energy costs (for paddy)	Highly flexible: farmers decide; market rules (export possibilities) (several farmers use pumps)	Optimize multiple use; expensive drainage (environment, drainage issues, peri-urban agriculture, urbanization)
Agriculture main focus; low level of development	Rely on rice production; urgent need for food security; possess comparative advantage; few alternatives; link between water, ecosystems, and livelihoods	Further water resources development; further rice irrigation expansion; strong government financial support and external assistance	0	+	+	+	Expand in the short term then decline because of urbanization, sea level rise, salinity?
			Too expensive for rice but plan for future or multipurpose structure	Low costs; comparative advantage (compared with other options)	Affordable investment; subsidized O&M	Highly flexible: farmers decide; market rules (export possibilities) (some rich farmers use pumps)	Developing paddy systems; not yet urbanized

Table 2. Recommendations from four thematic working groups

Financing and multiple roles	Design and operation	Management and institutions	New large irrigation projects
1. Modernization should aim at improving water service and responding to farmers' needs. 2. Adapt water delivery systems for multiple users. 3. Irrigation financing mechanisms should move progressively from subsidies to market-based incentives, and to public-private cost-sharing, as economies evolving from lower level to high level. 4. "Early economies" should take into consideration long-term development to harmonize water management for ecosystem services.	1. Develop excellent "water control engineering" programmes in universities and colleges; and establish national or regional Centers of Excellence for irrigation modernization. 2. Continue regional training programmes on irrigation modernization and RAP; RAPs should be carried out before any new investment is put in place. 3. Revise national design standards and operation manuals to take advantage of new knowledge in the irrigation sector and state-of-the-art technologies. 4. Replicable pilot projects to demonstrate modern technologies; learn from practical experience for a relatively small cost. 5. Consider use of new donor lending instruments – e.g. adjustable programme loans.	1. Invest in making irrigation management more professional through continuous in-service training focused on operational management. 2. Operationalize and mandate a suite of assessment and performance measures to monitor and improve irrigation performance and externalities, such as RAP, benchmarking, service-oriented irrigation management, balance sheets and improved data collection and processing. 3. Diagnose existing PIM approaches; identify and replicate successful experiences. Focus initiatives on: minimizing transaction costs; creating incentives for participation; promoting self-financing; making functional WUAs and federations; and improving the performance of WUAs and federations. 4. Propagandize! Take these messages to governments	1. Before committing to new, large-scale irrigation developments a comprehensive options assessment should be made of the land and water existing use values and development options in that place. 2. If a new, large-scale irrigation development is proposed, the design must recognize and be flexible enough to take account of the inevitability of future demand changes. 3. Large-scale irrigation projects, as with any others, should be planned, built and operated within a governance regime that embodies social justice ethics, is transparent, and participatory. 4. If a new, large-scale irrigation development is proposed, it is essential to increase efforts to boost the capacity of local stakeholders playing many different roles. 5. In addition to the overall economic assessment, it is critical that an adequate financial strategy is put in place, covering the whole construction, operation and maintenance cycle. 6. The impacts of an irrigation project on the local environment, ecosystems and livelihoods need to be closely assessed and monitored.

Introduction

Thierry Facon[1]

1. Rationale, concept, approach and objectives of the workshop

1.1 Modernization of irrigation systems: the previous consensus and agenda

In 1996, FAO organized a regional expert consultation in Bangkok on the Modernization of Irrigation Schemes: Past Experiences and Future Options. The rationale of this meeting was that as irrigated agriculture met about one third of the world's food demand and contributed to about 40 percent of Asia's food production, increasing competition with the urban and industrial and environmental sectors limited the quantities of water available for further irrigation expansion. Moreover, as the availability of land and water resources that could be developed economically was limited, the main option which remained was to increase land and water productivity. It was affirmed that: irrigation systems must be responsive to farmers' needs; supply and demand should match as closely as possible; losses of water should be minimized; and cropping patterns must respond to changes in the habits of societies.

The implication was that new objectives must be established for irrigation systems and this required changes in their physical and management systems. Modernization of irrigation systems could provide a part of the solution, but the traditional approaches to modernization and improvement of irrigation systems needed to change in the light of the new challenges facing the irrigation sector. A new definition of modernization of irrigation systems to guide future understanding and efforts was coined at the meeting:

> *"Irrigation modernization is a process of technical and managerial upgrading* (*as opposed to mere rehabilitation*) *of irrigation schemes combined with institutional reforms, if required, with the objective to improve resource utilization* (*labor, water, economic resources, environmental* resources) *and water delivery service to farms*."

The meeting had concluded that there existed significant justifications for irrigation modernization in each country, although the specific reasons would vary by country and system. Broader criteria that could be used to assess the needs for modernization included water conservation, improving the reliability of water distribution, reduction of environmental degradation, support of crop diversification, reduction of operation and maintenance costs, and increasing farmer income. It was highly desirable to be able to predict and verify the benefits that would result from modernization actions, and more attention must be given to the development of evaluation procedures, monitoring of existing and new projects, and isolation of cause/effect relationships so that benefits can be more accurately estimated. There was a strong need for more and better adaptive and diagnostic research, especially coupled with effective information dissemination programmes. An essential ingredient of any modernization programme was an initial status and needs survey to establish baseline conditions. Appropriate selection or upgrading of equipment for improved water control was important for achieving a better water delivery service throughout an irrigation project, and technological improvements must always be accompanied by managerial and/or institutional changes.

Such software changes might be as simple as training in the proper maintenance and operation of the new structures, but more significant institutional changes would usually be required. The importance of a sense of ownership by all stakeholders was emphasized and although water user associations (WUAs) are indeed weak or non-existent in many projects at the moment, widespread success of many future modernization efforts will depend upon their existence and viability and vice versa.

[1] Senior Water Management Officer, Regional Office for Asia and the Pacific, Food and Agriculture Organization of the United Nations, 30 Phra Athit Road, Bangkok 10200, Thailand.

Essential institutional and policy changes identified at the meeting included:

- creation of accountability by the providers of water services (i.e. irrigation authorities) and also responsibilities of the water users, through the establishment of water rights for individuals or WUAs, or through suitable amendment of existing irrigation acts;
- establishment of enabling legislation and enforcement capabilities, which would allow WUAs to operate as businesses in the sense that they could borrow money, have legally binding contractual agreements for provision of services, and have a legal system which would impart both protection and responsibilities;
- development of a service attitude by government agencies; and
- decentralization to enhance the clarity of operation policies, ease the involvement of farmers or WUAs in decision-making, and facilitate the establishment of incentive structures for farmers and employees.

The meeting identified a need for strong leadership, training at all levels and the development of upgraded design/procedure manuals as key actions to promote and support future modernization effort and called on international organizations and financing institutions to support these interventions.

1.2 FAO's response

FAO acted on the recommendations of the expert consultation and developed an irrigation modernization programme whose main component is a regional training programme. This programme aims at disseminating modern concepts of service-oriented management of irrigation systems in member countries with a view to promoting the adoption of effective irrigation modernization strategies in support of agricultural modernization and improving water productivity and integrated water resources management. FAO has developed training materials and detailed curricula (an update of the World Bank training manual on improving canal operations, a series of training materials for field training workshops based on Irrigation Training and Research Centre materials and other sources, a training module, with the University of Melbourne, on strategic planning and management of irrigation and drainage systems) as well as specific tools for the appraisal of irrigation systems for benchmarking and the development of appropriate modernization plans for irrigation systems (the rapid appraisal process (RAP)), and a Website for dissemination of information and experience (www.watercontrol.org). The first training workshop under the programme was organized in Thailand in 2000 and since that time China, India, Indonesia, Malaysia, Nepal, Pakistan, the Philippines, Thailand, Turkmenistan and Viet Nam have benefited from the support of the regional training programme to organize national training workshops on irrigation modernization and benchmarking. More than 600 engineers and managers have now been trained with support from the programme and the programme itself is supported by a series of technical and advocacy publications.

The programme is having an impact in member countries. The Royal Irrigation Department (RID) of Thailand is using the tools and methodologies introduced by the programme for the appraisal of projects and has included the training workshops in its regular training programme. Modernization concepts will support future irrigation sector reform and strategic planning for restructuring of RID through an ongoing technical assistance project. In Viet Nam, an ongoing World Bank-funded investment project has a large irrigation modernization component based on the concepts introduced through training at preparation stage, which was instrumental in the adoption of revised design criteria. Malaysia has included the training programme and its tools in its quality and modernization strategies: proposals for modernization of the rice granary systems in the country now have to be submitted to decision-makers based on modernization plans developed by system managers following their training and the appraisal of their systems with RAP introduced by FAO. Inputs have been made to the preparation of investment projects in Sindh. The programme is now expanding rapidly in several states of India as well as China and is also supporting the Mekong River Commission.

1.3 The need and opportunity to re-appraise perspectives, evolution scenarios and interventions in large rice-based irrigation systems in Southeast Asia

Almost ten years after the FAO regional expert consultation on the modernization of irrigation systems in 1996, a re-appraisal of the perspectives, evolution scenarios and proposed interventions in large rice-based irrigation systems in Southeast Asia was felt to be timely. Since 1996, the main trends and challenges faced by these systems had been confirmed and exacerbated by continued socio-economic growth and the transformation of the agrarian societies of the countries of Southeast Asia, and substantial poverty reduction challenges persisted. Although the region includes some of the most rapidly expanding economies of the world, agriculture continues to provide significant employment in the region. Transfers of water allocation away from agriculture and to urban areas and other sectors had taken place in many basins, agricultural production and policies had moved ever faster towards market-oriented farming systems under the growing influence of globalization and the liberalization of trade, which had become a major international agenda, and the importance of preserving and restoring the environment and aquatic ecosystems was increasingly recognized as an explicit goal of national governments. New challenges had emerged or were better understood, such as climate change associated with global warming.

The water management landscape and the institutional set up of the irrigation subsector had been deeply transformed by the recent wave of sectoral and institutional reforms, which presented further challenges as well as opportunities for improving the performance of irrigation systems. A number of the recommendations or prescriptions to improve the performance of irrigation systems, which were developed at the 1996 expert consultation and subsequent conferences, had been implemented through reform programmes or projects, and their impacts and outcomes had been evaluated. It was therefore possible to review these recommendations and build on lessons learned, and particularly to appraise whether disappointing outcomes resulted from a too narrow focus on the irrigation systems themselves, insufficient implementation of the actions proposed to the national governments and international community, erroneous or ill-adapted prescriptions, or other factors. The review would also enable successful developments and case studies to be built on. More generally, the review would allow the recommendations to be appraised from the perspective of new or evolving challenges.

At the international level, but also at the regional and national levels, the focus on integrated water resources management had fostered increasing and fruitful dialogues among the water, environmental and agricultural sectors, which provided a more comprehensive framework for discussions on the future of irrigation and for collaboration among agencies and professionals from various sectors and disciplines, and a better understanding of the multiple roles of rice-based irrigation systems and their place in and impact on river basins, rural livelihoods and ecosystems. At the First Southeast Asia Water Forum, convened by the Global Water Partnership Southeast Asia (Chiang Mai, 2003), the water and food session of the forum addressed the three challenges cited in the Kyoto Ministerial Recommendation of the Third World Water Forum on Water and Food, i.e. food security and poverty alleviation, sustainable water use, and knowledge and partnerships. One of the conclusions of the Forum, endorsed in the Forum's declaration, was that "*Southeast Asian countries should collaborate to find ways to improve and transform large rice irrigation systems for participatory decentralized management, improvement of efficiency and service, multiple use, financial sustainability through payment of service and IWRM*".

1.4 The regional workshop on the future of large rice-based irrigation systems in Southeast Asia

With this in mind, FAO, with the support the Evaluation Study of Paddy Irrigation under Monsoon Regime (ESPIM) Project financed by the Government of Japan and the Vietnam Institute for Water Resources Research, Ministry of Agriculture and Rural Development, Viet Nam, convened a Regional Workshop on the Future of Large Rice-based Irrigation Systems in Southeast Asia in Ho Chi Minh City in October 2005 to identify strategies, opportunities and interventions for the sustainable management of large rice-based irrigation systems in Southeast Asia over the coming decades in the context of improved management of water resources, and to promote collaboration in the region.

The workshop intended to address three critical questions (and a number of questions derived from these) whose answers could determine the character that large rice-based irrigation systems evolve over the next 20 to 25 years, namely:

- **How would agriculture and rice production evolve in Southeast Asia?** How would agriculture evolve to provide viable employment for an agricultural labor force that was expected to reduce substantially, given current population projections and predicted demographic changes; changing nutritional and dietary expectations; changing irrigated and rainfed agricultural areas and yields; and increasing competition from the urban, industrial and environmental water sectors? What changes would be required in agricultural water services to support the projected evolution of the sector?
- **What changes would required in irrigation service provision by the large rice-based irrigation systems?** What institutional, managerial as well as technological changes would be required for the large-scale irrigation systems to be able to provide the new range of services required by users and perform their new functions?
- **How would ongoing and expected reforms and investment programmes measure up against the projected needs of the region?** How should public sector irrigation agencies develop to support new agricultural demands; what might be the role of the private sector in future development? How could participatory management become effective? Could institutions recently or in the process of being created evolve towards becoming managers of multiple use systems if needed? Were there alternate approaches to irrigation and agricultural water management reforms that may be more effective and responsive to the sector's requirements? Were present models for management of large rice-based irrigation systems able to evolve towards future requirements? Were investments programmes on large rice-based irrigation systems of the current generation responding adequately to the future challenges? Did current models for river basin management represent an optimal context for an evolution of the large rice-based irrigation systems towards sustainable management?

The workshop gathered fifty experts and representatives from:

- national irrigation agencies and institutions, river basin and water resources management agencies and national water apex bodies;
- agriculture ministries and environmental agencies as well as academic and non-governmental organizations from countries in the region: Cambodia, China, Indonesia, Lao PDR, Malaysia, Myanmar, Philippines, Thailand and Viet Nam;
- regional bodies and institutions such as the Asian Institute of Technology (AIT) and the Mekong River Commission;
- international organizations such as FAO, the International Rice Research Institute (IRRI) and the International Water Management Institute (IWMI);
- the donor community, with the Asian Development Bank and the World Bank;
- internationally recognized centres of excellence such as the California Polytechnic State University;
- international initiatives such as the Comprehensive Assessment of Water Management for Agriculture;
- environmental INGOs such as the International Conservation Union (IUCN), Wetlands International and the World Wildlife Fund; and
- respected resource persons.

1.5 The workshop process

The workshop adopted a multidisciplinary strategic process:

- review trends and challenges related to water resources management, socio-economic development, trade, agriculture and rice production and the environment, and the present performance of large-scale rice-based irrigation systems in Southeast Asia;

- review national current and planned strategies, programmes and goals for large rice-based irrigation systems;
- assess the rate of adoption and effectiveness of previous recommendations;
- identify the main drivers of change;
- outline main scenarios for the future evolution of large rice-based irrigation systems, based on a typology of their characteristics and socio-economic environments;
- identify the implications of these scenarios in terms of service and performance objectives, design, management, operation, institutions, financing, environment and biodiversity, and multiple uses;
- re-appraise present policies, strategies, programmes and intervention models, and make recommendations for new strategies and directions and concrete action.

A field trip to an irrigation system (the Cu Chi system) was organized with specific programmes to explore different issues (environment and multifunctionality, irrigation management and operation, and farming systems). It was hoped that the field trip would lead to new issues being fed into the workshop process and also allow the participants to gain perspective from being face-to-face with a functioning irrigation system.

Evaluation of previous recommendations

Prior to the workshop, a questionnaire based on an inventory of 50 relevant recommendations at six regional and global events (the FAO 1996 expert consultation on modernization of irrigation schemes, the fifth international ITIS network meeting in India 1998, World Water Vision 2000, the first and second Southeast Asia water forums (2002 and 2005), the INPIM/FAO IMT Email conference) was prepared and sent to the participants, who were asked whether these recommendations had been implemented or not implemented, effective or not effective, and to provide additional comments. The purpose of this exercise was to inform the workshop process by identifying effective recommendations, considering the non-effectiveness of certain recommendations, and understanding why certain recommendations had not been implemented.

Drivers and typology

To support the discussion of evolution scenarios and strategic responses, the workshop produced a typology of the large rice-based irrigation systems in the region, and identified drivers of change. It was thought initially that a typology reflecting both technical characteristics of the schemes and their socio-economic context would be necessary, as different drivers would apply or the same drivers would apply differently to different classes of systems, and that possible objectives and strategic responses would also differ from class to class. The object of the typology was also to guide the subsequent steps of the workshop process towards the production of scenarios/strategies/recommendations as specific/practical as possible.

Evolution scenario and strategic responses

Considering the effect of different drivers, strategies and policies for all different classes of systems, the workshop, divided into working groups, and developed and synthesized likely evolution scenarios for each class.

The workshop then identified the implications of these scenarios in terms of service and performance objectives, design, management, operation, institutions, financing, environment and biodiversity, and multiple use. It also re-appraised present policies, strategies, programmes and intervention models, and made recommendations for new strategies and directions and concrete action.

For this, the workshop divided into multidisciplinary working groups, each reviewing and preparing recommendations relevant to a specific theme:

- Financing and multifunctionality.
- Design and operation.
- Management and institutions.
- New irrigation systems.

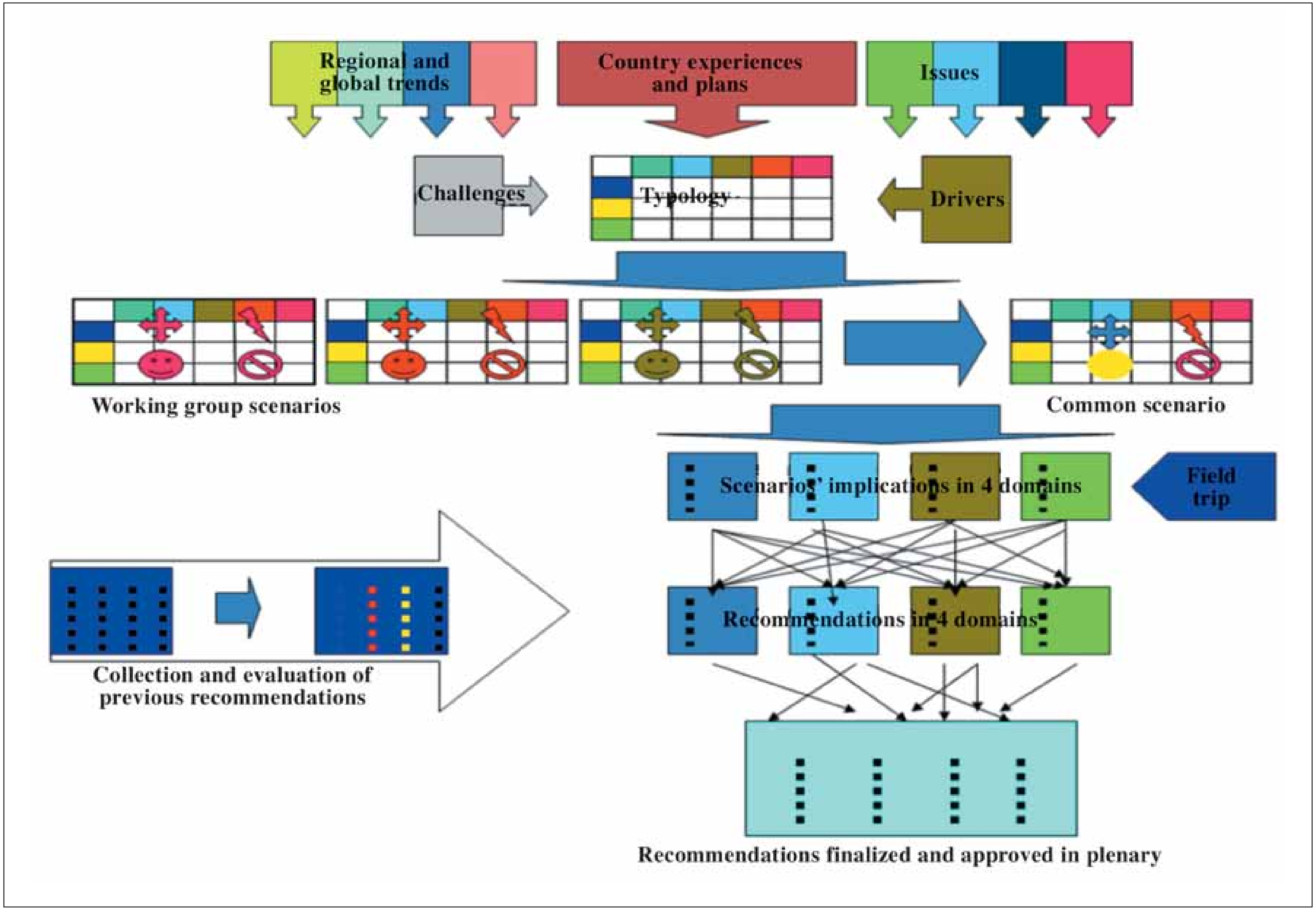


Figure 1. The workshop process

An important consideration in the design of the scenarios was that the implications in each domain should be shared among the working groups and recommendations harmonized in a common framework, so that the workshop as a whole would develop a set of consistent and mutually supportive recommendations. Intermediate briefing and discussions steps were thus planned in the process, and all recommendations were discussed, finalized and approved in plenary by all participants.

The process is summarized and presented in Figure 1.

2. Regional trends and challenges

Between 40 and 90 percent of the population of Southeast is engaged in agriculture or related industries, even though the contribution to GDP is between 10 and 60 percent only. Rice cultivation dominates cropping patterns in much of the irrigated agricultural lands. Large irrigation systems in the region are thus characterized by rice and indeed were mainly constructed to support rice production during the monsoon season and also provide irrigation to grow a second dry-season rice crop. Rice is recognized as a relatively low-value commodity, but attempts to promote crop diversification in the systems have often failed to provide viable alternatives for substantial numbers of farmers, whereas in traditionally non-irrigated areas diverse crop mixes and innovative land and water management strategies seem to be opening new possibilities for higher value agricultural products.

The specific characteristics of the systems and the evolution of rice consumption and the economics of rice production present additional challenges which these systems will need to face in the future. Although rice consumption per capita is decreasing and is expected to further decrease in the region, rice is still the main staple food for the people of Southeast Asia and total demand will continue to increase. For centuries, rice has been the most important source of food, employment and income for the rural people in Asia. Increases in rice production over the last 50 years have played a major role in achieving food security and alleviating malnutrition and poverty, especially through lowering the rice price. However, the green revolution has largely bypassed the unfavourable drought-, flood-, and salinity-prone areas where nearly 700 million people depend on rice production. Sustained rapid economic growth and urbanization in Asia will continue to increase the feminization of agriculture and reduce the availability of labour for rice cultivation, driving the need for high yielding production technologies with lower labour requirement.

Rice is unique in its ability to grow and yield in a wide range of agro-ecological conditions, from flooded lowlands to drought prone uplands, and from humid tropical to cool temperate climates. Rice is a semi-aquatic plant and yield declines as the soil dries below saturation. Therefore rice is grown under ponded water culture (lowland rice) where possible, accounting for about 90 percent of world rice production. Contrary to popular misconceptions, when grown under flooded conditions, rice has similar transpiration efficiency to other cereals. Nonetheless, lowland rice fields lose large amounts of water by seepage, percolation, run-off and evaporation from the water surface, and therefore require up to two to three times more water than other cereals. Much of these outflows is captured and reused downstream, and is not a true loss from rice-based systems. Nevertheless, conversion of lowland rice fields to other more profitable crops or uses, including aquaculture, is an increasing trend.

The productivity of irrigated rice systems is threatened by increasing water scarcity induced by sectoral competition and climate change (although there is no systematic inventory or quantification of the nature, extent or severity of water scarcity in rice-growing areas, and its likely impact on productivity). Meanwhile, the rainfed and unfavourable rice ecosystems experience multiple abiotic stresses such as drought, salinity/sodicity and uncontrolled flooding.

Lowland rice ecosystems have both beneficial and negative environmental externalities and unique ecosystem services which will be affected by increasing water scarcity. Compared with other cereals, lowland rice is a heavy emitter of methane and ammonia and a low emitter of nitrous oxide. However, lowland rice fields are responsible for less than 10 percent of total global methane emissions. Lowland rice fields behave as artificial wetlands in their capacity to remove nitrogen and phosphorus from contaminated surface waters. Nitrate leaching from flooded rice fields is usually negligible. Biocide use in Asian rice systems is generally low and the biocides used degrade rapidly. However, the biocides are often extremely toxic and their negative human health impact is large. Flooded rice can increase the risk of salinization and waterlogging in poorly drained areas by raising groundwater levels. Non-rice food ecosystem services provided by the lowland rice landscape can be significant, particularly for the poorest segments of the rural population. Non-food ecosystem services provided by the lowland rice landscape, such as cultural aspects, groundwater recharge, control of soil erosion, flood mitigation and sustenance of a rich biodiversity, including unique and endangered species, are equally often overlooked. The multiple uses and functions of rice landscapes are often ignored in integrated water resources management discussions, policy reform and institutional setups and need to be better valued.

Previous development and policies have been successful globally in assuring the food security of the populations of Southeast Asia, but with a continued slump in the price of cereal commodities, the benefit has increasingly been to urban populations and landless farmers and rice producers have been squeezed. Meeting the future demand for rice and reducing poverty will require: increasing resource productivity in irrigated, rainfed and unfavourable ecosystems; reducing production costs and labour requirements; improving the management of water resources in the face of declining availability; and developing technologies and strategies to cope with the likely impacts of climate change, including increased incidence of extreme events. Increasing water scarcity in many areas will change the dominantly flooded systems to more aerobic systems, bringing new challenges for increasing productivity while minimizing associated negative externalities and maintaining beneficial ecosystem services (multifunctionality) of rice-based systems.

There is however still scope to greatly increase rice productivity in unfavourable regions by developing rice varieties that are drought-, salt- or submergence-resistant, but there is less scope to further increase yield potential of current high-yielding (inbred or hybrid) varieties grown under non-stressed conditions. However, a yield gap, which has been closed in East Asia, still persists in Southeast Asia. Yield potential of modern high-yielding varieties has stagnated during the last two decades, with the exception of the development of hybrid rice. Research provides a range of options to increase the water productivity of rice with respect to evapotranspiration by manipulating early crop vigour, leaf waxiness and transpiration efficiency, and to improve nutrition quality, and these need to be combined with other successful traits, including those that impart drought tolerance. With proper investments, varieties can be developed with 50 to 100 percent increase in yield potential in rainfed lowlands and drought- and flood-prone areas within ten years.

There is also great scope to develop and deploy integrated technologies to increase rice productivity and lower production costs in the face of water scarcity, but more research is needed on real water savings, long-term sustainability and environmental impacts. Technologies that integrate components of management with varietal improvement can bridge the yield gap in well-defined target environments. The water balance of rice fields under such technologies should be quantified to identify water savings at field and system scales. Several water-saving technologies are being developed for water-short irrigated environments. The sustainability and environmental impacts of many newly developed technologies are however not well understood. In rainfed and drought- and flood-prone environments, technologies should aim at reducing abiotic stress intensities, enhancing survival and robustness of the crop to withstand stress, and stabilizing yields.

3. Irrigation evolution in Southeast Asia (and China)

The evolution of irrigation in Southeast Asia has shown both convergence and divergence during the past decade. Although software upgrading, mainly through management transfer, institutional reform, strengthening of governance and participation, were highlighted in all countries, different countries took different actions to upgrade hardware systems.

Indonesia, Philippines and Thailand have focused on upgrading the software of existing systems to better exploit their potential, combined with small-scale irrigation development. Indonesia has highlighted institutional strengthening and interagency coordination; the Philippines has conducted policy innovations, such as “no payment no irrigation”; and Thailand has adopted participatory irrigation management.

Cambodia, China and Malaysia have seen a return of large irrigation investment and irrigation modernization has been initiated through joint efforts on both software and hardware systems. Cambodia gained support from external donors and conducted more than 20 participatory irrigation management and development projects that included both infrastructure rehabilitation and institutional reform. China spent US$4 billion on implementing a national large-scale irrigation rehabilitation programme. Malaysia increased investment to upgrade large irrigation systems in eight rice granary areas.

In Lao PDR, Myanmar and Viet Nam, significant irrigation development is underway, including various models, large and small, gravity and pumping, surface water and groundwater, mainly focused on hardware construction. Software systems are also gearing in at a comparatively slow pace. From 1997 to 2004, the irrigation area in Lao PDR increased by 140 percent. Myanmar carried out the most significant irrigation development in its history from 1995 to 2005 with the total irrigation area increasing by about 700 000 ha, mostly focused on reservoir systems. Viet Nam started modern irrigation development in 1975 and from 1988 to 1994 the irrigation expansion rate reached 4.58 percent per year, and is still expanding strongly. Pumping irrigation plays an important role in Viet Nam and accounts for 26 percent of its total irrigation area.

By the end of last century, the irrigated area in Southeast Asia reached 18 million ha, of which 80 percent is for rice cultivation, and 40 percent is irrigated by large-scale systems. Large irrigation systems have become the most important supporting systems to food security and rural development. Despite these great achievements, there was a general consensus that these large rice irrigation systems had not lived up to expectations because of the poor institutional setting and the system design, degraded infrastructure, poor management and stagnation in the face of rapid agriculture and water sector change. Farmers and field operators have adjusted and freed themselves from the constraints by exploiting groundwater, recycling water from drains and canals, changing cropping patterns, and adjusting the timing of water release. These changes have taken advantage of new and cheap pumping technologies and government subsidies and may be further challenged by increasing energy prices.

Different countries have set up different strategies, programmes and goals to meet the new requirement and challenges. The Royal Irrigation Department of Thailand has reviewed its water vision to focus on supplying sufficient water to support agricultural production, raising farmers incomes and sustaining economic development. A national strategy has been formulated to improve irrigation efficiency and water management in existing systems while expanding new small and medium systems. Relevant activities on participatory management, conjunctive water use, water disaster mitigation and environmental protection have been initiated. A national training programme was also developed with support from FAO. The Department of Irrigation and Drainage (DID) of Malaysia is pursuing the national modernization strategy centered on the rice granary systems and has established a structured and elaborate programme to improve system performance and service quality. In Viet Nam, investment projects funded by the World Bank and the Asian Development Bank include large irrigation modernization components based on similar concepts of service orientation. In China, the government has targeted that during the next 25 years, when the country’s population grows from the current 1.3 billion to a peak of 1.6 billion, the agriculture sector should maintain national food security (95 percent self-sufficiency rate) with zero water consumption increase. Hence a nationwide water saving programme is now under way through legal, institutional, physical, technical and managerial options. Modernization of large rice irrigation systems is one of the core components: China is now implementing more than 200 large schemes.

Despite some optimistic achievements, overall progress of the 1996 modernization agenda has remained relatively modest. Constraints remain: The concepts of irrigation modernization are not fully understood and properly adopted – in some cases, they have been used to continue to obtain funding for rehabilitation, operation and maintenance, or further capital-intensive interventions; policy changes have little impact since they are based on a poor understanding of basin and system efficiencies; reformed institutions do not capture the complexity of the hydrological cycle and the multiple functions of irrigation systems and service relationships between different levels of management; in most countries, PIM/IMT has made very modest progress in improving system productivity and raising the cost recovery rate; the differences between stated policies and actual practices are generally large; significant underinvestment in operation and maintenance and poor management continue to be the norm rather than the exception; in general, the performance of large irrigation systems in Southeast Asia continues to be low in terms of control, water productivity, yields, and quality of service delivery to farmers. It is therefore necessary to identify the main drivers of change, a typology of large rice-based irrigation systems, and likely scenarios for evolution and suitable options.

4. Systems typology and drivers of change

The workshop adopted the following typology for the large rice-based systems in Southeast Asia:

	Technical criteria	Main characteristics (and examples)
1	Reservoir-backed, gravity fed irrigation systems	Water is stored in large reservoirs, distributed via a canal network to the fields mainly by gravity (Zhanghe system, Dau Tieng, UPRIIS)
2	Off-river diversion irrigation systems	Water level in the rivers is raised by dam so that water can be distributed via a canal network to the fields (SCRIS, Philippines)
3	Off-river pump irrigation systems	Water is pumped into a canal network, to be distributed to the fields (northern part of Viet Nam)
4	Integrated water management systems in the deltas	Low lying deltas, consisting of a series of multi-functional canal networks (water supply, drainage, transport) and water management structure (salinity control) and a mosaic of small irrigation systems (tidal or pump)
5	Conjunctive groundwater-surface water system	Both gravity fed surface irrigation and groundwater pumping
Additional criteria	Urban-rural irrigation systems	Near or including cities or industrialized centres, steep competition for water and labour (Cu Chi, Zhanghe, Mangat)

Various national or subnational contexts of agriculture in the region were identified. Major implications in terms of goals and strategies were identified for each of these contexts.

National and subnational stage	Economic and agriculture situation	Strategy and policy
Focus is outside agriculture; Post-agriculture/advanced	Highly diversified agriculture; resources competition; high environmental concern; diets shifting; need to conserve certain level of food production capacity; on the way to diversification	Reduce/decommission rice irrigation areas; specialization; improve water productivity; protect environment and water quality; government investment for modernization
Agricultural export main focus Intermediate/transition	Quick demographic transition; further improvement of food security; need to stabilize rice production; rice exporting for foreign exchange earnings+C6; rely on rice production	Stabilization and modest development of rice irrigation areas; development of small systems; increase financial self-sufficiency; further water resources development
Agriculture main focus Low developed/early economy	Urgent need for food security; possess comparative advantage; few alternatives	Further rice irrigation expansion; strong government financial support; external assistance

Major drivers affecting irrigation water management were found to be:

Common drivers
• Food security: national-regional-household • Poverty alleviation/regional development • Increasing concern for environmental protection and ecosystem management • Issues of energy and other chemical inputs • Climate change (coastal impact – risk for rainfed agriculture).
Nation specific
• Development stage that sets the exporting/importing strategy • National budget support/constraints – O&M cost reduction (may be a constraint) • Institutional reforms: Regional autonomy – decentralization • Agriculture and water management policy • Migration rural/agri-urban population balance.
Other drivers for change
• Equity of distribution including gender concerns • Multiple purpose nature of service from reservoirs • Market diversification and integration (need for crop diversity) • Pressure on water resource: scarcity, water quality and competing uses of water • Reclaiming land.
Management related objectives/drivers
• Cost-effectiveness of O&M and management • More responsive, transparent and participatory management • More flexible water delivery systems • Accounting for multiple uses of water • Water on demand (removing technical constraints) • Technology: availability of low cost pumps.
Accompanying supports (enabling conditions)/drivers:
• Strategies of the World Bank and Asian Development Bank for management/rehabilitation projects • Capacity building in water infrastructure management and service oriented management, in modernization and development.

5. Evolution scenarios and strategic responses

Considering the effect of different drivers, strategies and policies for all five types of systems in the three contexts/stages, the workshop developed likely evolution scenarios. There is a general trend for countries to move from economies with an important agricultural sector towards economies with a focus outside agriculture. It is expected that such a trend will remain in the future. More specifically, and differentiated by the economic context, the following implications are expected for the various types of large scale irrigation schemes:

Reservoir gravity schemes

Because of the high costs of building large dams, these schemes are too expensive to develop for rice only in countries with economies that focus on agriculture. However, these countries can plan reservoir schemes for the future, because it is feasible to develop such schemes for countries that focus on agricultural export. These countries should anticipate non-agriculture uses. Optimizing the multiple uses of reservoir schemes will be a priority for those countries that focus their economy outside of the agricultural sector. Apart from water for agriculture, these uses may include water for the environment, recreation, energy and water for cities.

Off-river gravity schemes

Off-river gravity schemes are cheaper than other type of schemes and it is therefore to be expected that countries with early developing economies will invest in such schemes (partly because of lack of alternatives). Because of the low reliability of these schemes, countries with intermediate economies will try to improve the performance by modernizing them taking into account their inherent limitations. Countries with post-agriculture economies will probably reduce these types of schemes by converting them to other types like off-river pumping schemes or introduce conjunctive use of surface water and groundwater. Other options are converting the rice schemes to different type of crops or land use.

Off-river pumping schemes

Off-river pumping schemes with subsidized operation and maintenance will probably be an affordable investment for economies with a focus on developing agriculture. These types of schemes will not likely be extended in the other types of economies because of the high energy costs involved by growing a water intensive crop like rice. For economies with a focus outside agriculture crop diversification will be promoted and rice will be phased out.

Conjunctive schemes

Because of their high flexibility, these systems are popular with farmers who can afford pumps, and it is therefore likely that these schemes will expand in all types of economy. In the poorer economies only a few rich farmers will be able to afford pumps but in the richer economies pumps are already being used by many farmers. By pumping groundwater, farmers can react quicker to demands from the market. Because of increasing energy costs, the pumped groundwater will be mainly used for cash crops rather than for rice.

Integrated management of deltas

Integrated management of river deltas is especially important for economies with urbanization that takes place in the deltas. Early developing economies that rely on developing agriculture do not yet have high levels of urbanization and will develop river deltas for paddy cultivation. Export oriented and post-agriculture economies have to deal with urbanization through optimizing multiple use of water. Issues that have to be taken into consideration are peri-urban agriculture, protection of the environment and increased control of drainage.

In conclusion, for countries that rely heavily on developing the agricultural sector, it is still economically justified to further invest in water resources development and expand and intensify existing rice schemes. In intermediate and post-agriculture economies, trends in agricultural development will shift towards:

- modernization of existing large-scale schemes;
- smaller irrigation systems that rely on conjunctive use of river and groundwater;
- integrated management of river deltas, taking into consideration water for all sectors.

For these types of economy it is important that the irrigation schemes will be adapted in such a way that they can accommodate crop diversification.

A synthesis of the outputs of the different working groups is provided in Table 1.

6. Group recommendations

The participants split into four thematic working groups to formulate recommendations respectively according to the four themes:

1) Financing and multiple roles.
2) Design and operation.
3) Management and institutions.
4) New irrigation systems.

Each group took into consideration the review of previous recommendations, their effectiveness and implementation.

The workshop followed an iterative process whereby the thematic groups reported and were able to comment on the work of the other groups, in order to ensure consistency and cross-fertilization of recommendations pertaining to all four themes. The final recommendations were finally presented and amended in plenary and adopted by the whole workshop.

Financing and multiple roles

1) Modernization should aim to secure reliable, equitable and predictable water supply and be responsive to the individual needs of farmers where possible. Trust farmers to respond to such a water supply, e.g. through conjunctive water use.
2) Water-delivery systems need to be flexible (technically and institutionally) to deliver water for multiple uses (agriculture, environment, city, industry, energy generation), from entire river basins down to (within) large irrigation systems.
3) Financing (capital and O&M) of irrigation systems needs to progressively move from subsidies to market-based incentives, and public-private cost-sharing mechanisms, as economies evolve (early -> transitional -> post-agriculture).
4) "Early economies" should anticipate, "transitional economies" should plan for, and "post-agriculture economies" should harmonize (social, cultural, institutional, and policy) water management for different ecosystem services within irrigation areas and catchment areas.

Management and institutions

1) Southeast Asian governments should invest in making irrigation management more professional through the establishment of continuous in-service training focused on operational management:
   - training of today's graduates who are tomorrow's managers;
   - training at all professional levels within irrigation systems across all relevant disciplines;
   - overseas secondment of irrigation managers within the region and in higher-income countries; and
   - practical training for farmer organizations/WUAs/federations.
2) The irrigation sector in Southeast Asia should operationalize and mandate a suite of assessment and performance measures to continually upgrade and compare the effectiveness of service provision and the management of negative externalities, such as environmental impacts:
   - RAP;
   - benchmarking;
   - introduction of service-related performance for irrigation service provider staff;
   - public accountability – balance sheets; and
   - improve and sustain monitoring, data collection and processing and management for improved service provision.
3) Existing participatory irrigation management (PIM) approaches in the region should be diagnosed, and successful approaches and their contexts identified and replicated. A key focus of initiatives to implement participatory management and management transfer should be on:
   - minimizing the transaction costs relative to actual benefits of participation;
   - creating incentives for participation and compliance of the irrigation service providers;
   - self-financing arrangements;

- functional water user associations and federations, with clear rights responsibilities and programmes of action in both management and local investment; and
- improving the service delivery of WUAs and federations – support is required to realize this.

4) Propagandize! Take these messages to the governments.

Design and operation

1) A greater awareness of the operational deficiencies of large rice based irrigation systems exists since the last FAO consultation; given the present lack of expertise and the magnitude of the problem, there is a need to develop excellent water control engineering programmes in universities and engineering schools. Related to this is the establishment of national/regional centres of excellence for irrigation modernization.
2) Regional training programmes on modernization and the rapid appraisal process (RAP) specialized for different levels of the organization – senior managers, operations staff, designers/engineers – should be conducted. Before any new investment is put in place, RAPs should be carried out for a comprehensive diagnosis of the system, developing proper water management strategies, and benchmarking of existing and desired performance.
3) National design standards and operation manuals should be revised to take advantage of new knowledge in the irrigation sector and state-of-the-art technologies.
4) Pilot projects should be replicated to demonstrate modern technologies and learn from practical experience for a relatively small cost.
5) Make use of new donor lending instruments, e.g. adjustable programme loans (APL) (longer time periods are needed to design and implement modernization programmes; typical five-year loans are too short).

New large-scale irrigation projects

1) Before committing to new, large-scale irrigation developments a comprehensive options assessment should be made of the land and water existing use values and development options in that place. If a new, large-scale irrigation development is proposed, it should be examined by a wide-ranging feasibility analysis which is ecologically, physically, economically, politically, socially and culturally "logical". These different logics should all be used to guide analysis and debate when examining the feasibility of a project. This should take place before progressing into the formal, legal, often rigid and relatively narrow "impact assessment" process. CSIRO's 5-Way methodology and the World Commission on Dams' (WCD) guidelines, where relevant, are international references.
2) If a new, large-scale irrigation development is proposed, the design must recognize the inevitability of future demand changes and be flexible enough to take account of them. As economies improve and alter, land/water use and cropping systems will change. Therefore the function/service of the irrigation will change. From the initial stage of the development of an irrigation project, it is important to visualize the trajectory of how these changes might occur (e.g. from rice-focused production to more diversified enterprises).
3) Large-scale irrigation projects, as with any others, should be planned, built and operated within a governance regime that embodies social justice ethics, is transparent, and participatory. Participation in irrigation governance should not be restricted to technical experts and bureaucrats, but should be open to representatives of affected communities and interest groups. The water rights and responsibilities of all stakeholders should be openly negotiated and established, with equity and sustainability being primary considerations. Management arrangements for a new project should include, from the beginning, credible representatives of different stakeholder groups.
4) If a new, large-scale irrigation development is proposed, it is essential to increase efforts to boost the capacity of local stakeholders playing many different roles. For example, local decision-makers need to be aware of the different options and feasibilities. Public authorities need to be skilled in designing

terms of reference and overseeing contracts. Local consulting firms and engineers are required to construct and then be locally available to support ongoing operation, maintenance and adjustment. User groups need to be aided to improve water use efficiency. Local civil society organizations and universities should be able to play roles in governance (e.g. monitoring compliance with negotiated protocols) and problem-solving. Supporting the development of this capacity needs to be factored into any new project.

5) In addition to the overall economic assessment, it is critical that an adequate financial strategy is put in place. The finance for complete construction must be ensured. Beyond construction, there must be a plausible strategy to ensure the availability of funds to meet full operation and maintenance costs, drawn from all project beneficiaries.

6) Irrigation projects do more than supply water. They become part of the ecosystem and may have major impacts, for example on groundwater hydrology. The year-round effects of a project on the hydrology and wider environment have to be assessed. As does the impact, whether positive or negative, on the livelihood of all affected peoples.

7. Workshop conclusions

The workshop generated the following major conclusions:

1. Although a greater awareness exists of the present deficiencies of the irrigation systems, knowledge does exist, efforts to develop tools have been substantial and effective, and efforts to develop capacities have been effective where implemented, very little successful modernization has taken place in Southeast Asia. In the present context and under future perspectives, modernization of the irrigation systems and their management to increase their flexibility and insert them into river basin management, taking into account the multiple functions of agricultural water management, is more required than ever. A fast pace of change is certain. Another certainty is that unless management adapts, the discrepancy between stated and actual policies will widen.
2. Compared to ten years ago, new layers of complexity have been added to our understanding of irrigation, from multiple use and social complexity, to multiple use, multiple ecosystem and livelihood functions, and agro-socio-economic-ecologic complexity.
3. To respond to this complexity, management needs to be professionalized and present institutional reform models need to be evaluated and overhauled to respond to new demands and characteristics of farmers. Capacity building of managers and of intermediate service providers will need to be substantially enhanced. Simplicity of operation and proper information will be required. Advances in supervisory control and data acquisition (SCADA) systems are being cautiously tested in a number of countries. The need to strengthen capacities also applies, critically, to consulting firms, and to the various components of civil society.
4. Evolution scenarios, objectives and strategic responses will vary greatly according to the types and socio-economic environments of the systems. Non-rice drivers will play an important role in their evolution.
5. Compared to recommendations made ten years ago, new recommendations can be characterized as: moving away from generation of both positive and negative externalities by accident and from development of autonomous farmers' responses by neglect, to explicit management of multiple roles and explicit recognition of farmers' service and other objectives, and of their contributions to overall efficiency and productivity, for instance by pumping, and of the costs thus incurred by them. They can also be characterized by the search for the most practical, economical options on where, how and at which levels (main system, intermediate distribution, farmers, conjunctive use, etc.) to locate improvements for service delivery.
6. The main focus will remain the improvement of performance of existing assets. New systems may be still developed in predominantly agrarian economies, in ecosystems with comparative advantages, but their planning and appraisal process should be reformed to adhere to improved water governance.

Introductory papers

Overview of large irrigation systems in Southeast Asia

Zhijun Chen[1]

Abstract

Most of the large irrigation systems in Southeast Asia have been designed for rice irrigation under supply-driven mode. Despite their huge contribution to agriculture production and local social and economic development, there has been a general consensus that these large rice irrigation systems have not lived up to expectations because of a legacy of poor institutional arrangements and system design, degraded infrastructure, poor management and stagnation in the face of rapid transformations of agriculture and pressure on their water supply. Population growth, economic development, urbanization and globalization have been and will continue to be the main drivers of changes in the agriculture and water sectors. Southeast Asia is expected to be the subregion where the greatest urban growth will occur over the next thirty years. Agriculture water use is facing more competition. In the meantime, diversification, commercialization and modernization of agriculture call for more flexible, high-quality, user-oriented water services. Large rice irrigation systems are facing multiple challenges.

During the past decades, responses have been made and initiatives have been taken by the international community, government departments and farmers on field water management improvement, institutional reform and governance strengthening, systems rehabilitation and irrigation modernization. So far the progress has been modest and, in general, the performance of large rice irrigation systems in Southeast Asia continues to be low in terms of control, water productivity, yields, and quality of service delivery to farmers. The differences between stated policies and actual practices are generally large. Significant underinvestment in operation and maintenance and poor management continue to be the norm rather than the exception. It is therefore necessary to review the experiences gained and the lessons learned, to analyze current strategies and programmes, and to propose further options.

This paper, first, reviews the historical evolution of irrigation and the current status and constraints of large rice irrigation systems in Southeast Asia; second, analyzes the changing trends of the agriculture and water sectors in Southeast Asia and their implications for large rice irrigation systems; third, discusses the responses and initiatives (both past and present) of government departments and the international community; fourth, evaluates the outcomes and constraints; and fifth, identifies issues to be addressed and options to be taken.

It is concluded that to meet the future challenges better, multiple options and systematic approaches are needed to transform large rice irrigation systems in Southeast Asia from supply-driven to demand-driven responsive systems, to improve their water service in terms of reliability, equity, flexibility and multiple use, and to enable farmers to boost agricultural and water productivity and be more responsive to market opportunities.

1. Large irrigation systems in Southeast Asia

Historical evolution

The development of large irrigation systems has a long history in Asia. The world-famous Dujiangyan irrigation system was built 2 000 years ago in present-day Sichuan Province of China, and it is still functioning with a current irrigated area of 670 000 ha. Pyu, located in present-day Myanmar during the sixth to eighth centuries AD, was one of the first kingdoms in Southeast Asia that established a complex irrigation system. Large-scale, state-centred antecedent irrigation systems in agrarian societies enabled food surpluses and released labour for other cultural activities and were associated with the formation of many of the early powerful kingdoms. Barker and Molle (2004) in their review of the development of modern Asian irrigation

[1] Water Resources Development and Conservation Officer, FAO Regional Office for Asia and the Pacific, Bangkok, Thailand; Zhijun.Chen@fao.org

distinguished three time periods in terms of their geopolitical significance: the Colonial Era (1850 to 1945), the Cold War Era (1946 to 1989) and the New Era of Globalization (1990 onward).

The Colonial Era was characterized by irrigation expansion by the colonial powers, mainly through river diversion, to control famine, unrest, or revolt and to extract surplus, such as the large rice expansion in Indonesia by the Dutch from 1900 to 1940, expansion of canals and paddy fields in Viet Nam from the 1860s to the 1930s, and the reclamation of the Irrawaddy delta in Myanmar. There are some exceptions: the Chao Phraya Delta in Thailand was reclaimed between 1850 and the mid-twentieth century in the absence of formal colonization; many irrigation advances in China that occurred centuries ago were not influenced by colonial programmes.

The Cold War Era was characterized by rapid irrigation expansion mainly through construction of dams, reservoirs and canal systems, and later on followed by public and privately financed groundwater exploitation. From 1950 to the late 1970s, 50 percent or more of the agricultural budget in many Asian countries was devoted to irrigation. From the 1970s to the 1980s, more than half of the World Bank spending for agriculture was for irrigation. In the late 1970s and early 1980s, lending for irrigation by the World Bank and ADB reached a peak of over one billion US dollars per year in constant 1980 dollars, but fell to less than half that level by the late 1980s because of the sharp drop of cereal grain prices in the mid-1980s, the rise of construction costs and the growing opposition of environmentalists.

The New Era of Globalization is characterized by the control and management of water for agricultural and non-agricultural uses. As water has become scarce as a result of growing demand, water pollution has been increasing, and yield gains in cereal production in most of Asia have slowed or leveled off, profits from cereal

Table 1. Evolution of publicly managed irrigation in South and Southeast Asia

Issues	Colonial Era (1850 to 1945)	Cold War Era (1946 to 1989)	New Era of Globalization (1990 onward)
Primary goals of national and international agencies (or colonial powers)	Famine protection Revenue Exports	Food security Control of the spread of communism	Livelihoods Protection of environment Global markets Exports
Defining events	Famines Suez Canal (1869)	Droughts (1965; 1972/73) Population growth	Grain price decline Global warming
Resource availability	Land/labour plentiful	Land becoming scarce	Water and labour becoming scarce
Hydro-economic stages	Construction	Construction/utilization	Utilization/allocation
Professional orientation of development	Civil engineers	Agricultural Engineers	Multi-disciplinary
Dominant irrigation development	River diversion Flood control Canalling of deltas	Storage dams Gravity irrigation	Pumps and wells
System design	Protect/supplement	Supply driven	Demand driven
System management	Hydraulic	Agriculture-based	Farmer-oriented
Crops	Cereals/cotton	Cereals/cotton	Diversified
Cropping intensity	One crop	Two crops	Multiple cropping
Factors affecting livelihoods	Subsistence farming Colonial surplus extraction	Increasing mobility and economic diversification	High economic diversification
Value of water	Low	Increasing	High
Environmental degradation	Low	Increasing	High

Source: Barker & Molle (2004).

grain prices have declined and Asian farm households rely increasingly on income from non-farm sources. The period of the rapid expansion of the irrigated area through either construction of surface irrigation systems or exploitation of groundwater has seemingly come to an end. Attention has turned to improving the management and performance of existing irrigation systems both to reduce the financial burden and to allow an increasing share of water to be diverted to non-agricultural uses.

The evolution of irrigation in Southeast Asia generally followed the regional path, but with varied paces and some diversification. The construction phase had reached a peak by the end of the 1970s in Indonesia, Malaysia, the Philippines, Thailand and China. After 1985, there was a significant decline in the rate of growth in these countries. But in recent years, irrigation investment has made a comeback in Malaysia, China and Thailand, mainly focused on large system rehabilitation and new small system development. In Cambodia, Lao PDR, Myanmar and Viet Nam there has been continued strong growth during the past two decades and various irrigation systems have been under design and construction.

Table 2. Annual growth in irrigated area in Asia and in the countries of its subregions, 1961–1999

Country or region	Average annual growth (%) in irrigated area		Share of total net irrigated area in Asia (total = 1.0) 1998
	1962–1985	1985–1998	
Asia	2.3	2.0	1.00
SEA I	2.2	1.3	0.07
SEA II	3.7	4.2	0.03
China	1.9	1.4	0.34

Notes: Calculations are based on three-year averages centred on the years shown.
SEA I = Indonesia, Malaysia, the Philippines and Thailand
SEA II = Cambodia, Lao PDR, Myanmar and Viet Nam
Source: Barker & Molle (2004).

Recent developments

During the past decade, irrigation evolution in Southeast Asia has shown both a general trend and diversification. The general trend is that software systems, including water management, system management, legislation, institutions, and participation have been highlighted in all countries. The diversification is that different group of countries have taken different actions on hardware systems corresponding to their specific resources conditions and agriculture and economic development requirements. In Indonesia, Philippines and Thailand the major focus has been the innovation in software systems of existing irrigation schemes for better exploiting their potential, with some small-scale irrigation system development. Indonesia has conducted a large-scale irrigation rehabilitation and development programme since the 1960s. Since that time, the government has focused on effective and efficient irrigation water management through increased reliance on institutional strengthening and effective interagency coordination. The Philippines has been continuously struggling to improve water availability, allocation, regulation and irrigation performance through irrigation sector reform and policy innovation such as “no payment no irrigation” (Domingo, 2005). Thailand has been driven by the recent increasing rice prices and by droughts to exploit better the potential of existing large irrigation schemes by adopting participatory irrigation management (PIM), changing irrigation schedules, combined with groundwater exploitation.

In Cambodia, China and Malaysia there has been a comeback of large irrigation investments, and the major focus has been on modernization of existing large irrigation systems through joint efforts addressing both software and hardware issues. In 2000, Cambodia adopted participatory irrigation management and development policy (PIMD), and has been focusing on its implementation since then. The policy requests irrigation management transfer from government to water users associations. A prerequisite for the successful transfer is proper physical upgrading before the transfer. In support of this policy, thirteen donors, mostly international funding agencies, including the Asian Development Bank (ADB), the European Union (EU) and the World Bank have conducted 20 projects on irrigation infrastructure rehabilitation, followed by management transfer and WUA empowerment.

Table 3. Irrigation in Indonesia in 1966 and 1989

Irrigation scheme	Java and Madura (ha)	Other islands (ha)	Total (ha)
Technical irrigation:			
1966	1 430 000	274 000	1 704 000
1989	1 977 000	724 725	2 701 765
Semi technical irrigation:			
1966	457 000	301 000	758 000
1989	393 295	878 177	1 271 472
Simple irrigation:			
1966	920 000	415 000	1 335 000
1989	399 620	446 928	846 549
Total			
1966	2 807 000	990 000	3 797 000
1989	2 769 955	2 049 830	4 819 785

Source: Country paper from Indonesia (in this publication).

The Chinese Government tackles water saving as "a revolutionary option". While conducting nationwide water legislation innovation, institutional reform and technological dissemination, the nationwide "water-saving rehabilitation of large-scale irrigation systems" was launched in 1996, aiming at upgrading all its 402 large irrigation systems (each with irrigation area larger than 20 000 ha) by year 2015 through policy innovation, infrastructure rehabilitation, institutional reform and technical evolution. From 1996 to 2003, around US$4 billion have been invested jointly by the central government and local governments, 2 million ha of irrigation area have been rehabilitated or developed, and water services on 4.66 million ha of irrigation areas have been improved. Total grain production capability in these areas has increased by 11 million tonnes whereas total irrigation water consumption has reduced by 12 billion m^3.

Malaysia emphasizes the agriculture sector as "the third engine of growth" in the national development agenda and has designated eight large irrigated rice production areas as the "rice granary areas" of Malaysia. In support of these, government investment for irrigation and drainage has boomed during the last decade and an irrigation modernization programme aiming at further improving irrigation infrastructures as well as addressing managerial, institutional and technological development has been formally established under the Seventh Malaysia Plan and is under implementation.

Table 4. Development expenditure for drainage and irrigation in Malaysia

Malaysia Plan	Period	Total agriculture (RM million)	Irrigation and drainage	
			Amount (RM million)	Percentage (%)
First Malaya Plan	1956–60	227.5	38.3	16.8
Second Malaya Plan	1961–65	467.9	108.5	23.2
First Malaysia Plan	1966–70	1 114.1	342.6	30.8
Second Malaysia Plan	1971–75	7 100.3	271.1	3.8
Third Malaysia Plan	1976–80	4 666.2	554.8	11.9
Fourth Malaysia Plan	1981–85	7 671.3	396.6	5.2
Fifth Malaysia Plan	1986–90	7 325.0	200.3	2.7
Sixth Malaysia Plan	1991–95	8 215.2	844.6	10.3
Seventh Malaysia Plan	1996–00	8 139.3	1 929.9	23.7
Eight Malaysia Plan	2001–05	7 860.0	2 170.2	27.6

Source: Country paper from Malaysia (in this publication).

In Lao PDR, Myanmar and Viet Nam, significant irrigation development is taking place with a variety of models: large-scale and small-scale, gravity and pumping, surface water and groundwater. The major focus has been on hardware construction. Software systems are also gaining attention, but somehow are gearing in at a slower pace. From 1997 to 2004, the irrigation area in Lao PDR increased by 140 percent through diversified water resources development, including weirs, reservoirs, pumping systems, diversion gates, traditional weirs and gabion dams. Some large reservoir systems are still at the design stage. In Myanmar, the most significant growth in irrigation, ever, happened during 1995 to 2005, with a net increase of about 700 000 ha, mostly in the form of reservoir systems. In Viet Nam, modern irrigation development stagnated until the reunification of the country in 1975. Early post-1975 growth was in small and medium irrigation schemes, whereas in the period 1985 to 1990, growth was concentrated on large irrigation and multipurpose schemes. The total irrigated area expanded at a rate of 2.9 percent/year in the period 1980 to 1987, whereas between 1988 and 1994 it was 4.58 percent/year. That trend is still continuing. Pumping irrigation plays an important role in Viet Nam and accounts for 26 percent of its total irrigation area.

Current status

From the early 1960s until the end of the twentieth century, the irrigated area in Southeast Asia doubled. The total irrigation area in this subregion reached about 18 million ha. Rice is the most important irrigated crop, accounting for 80 percent of all irrigated cropping areas. Taking southeast China into consideration, the percentage is about 75 percent. In Cambodia, rice represents 98 percent of irrigated crops. In Indonesia, Lao PDR, Malaysia, and the Philippines the percentages are higher than 80 percent.

In Malaysia, the Philippines and Thailand 102 large rice irrigation systems (larger than 10 000 ha) have been constructed, with about 3 million ha of total irrigation area, accounting for 44.4 percent of the total rice irrigation area in these three countries. In Indonesia, 3.2 million ha of rice field are irrigated by large rice irrigation systems (larger than 3 000 ha), accounting for 42 percent of the total rice irrigation area. China has 402 large-scale irrigation systems (larger than 20 000 ha), the total rice irrigation area accounts for 30 percent of the total national irrigation area (56 million ha); 5 300 medium-scale irrigation systems (between 667 ha to 20 000 ha) service an irrigation area representing 15.5 percent of the total national irrigation area. About 50 percent of these systems are rice-based. These large irrigation systems are the most important systems supporting food security and rural development. China concluded that its capacity to feed 22 percent of the world population with 9 percent of the world arable land was because it has 20 percent of world irrigation area, and the large-scale irrigation schemes are the bases of basic food production. Malaysia's eight granary rice irrigation areas cover only 36 percent of the total paddy fields, but produce 72 percent of the total national rice production.

Table 5. Irrigation development in Lao PDR 1997–2004

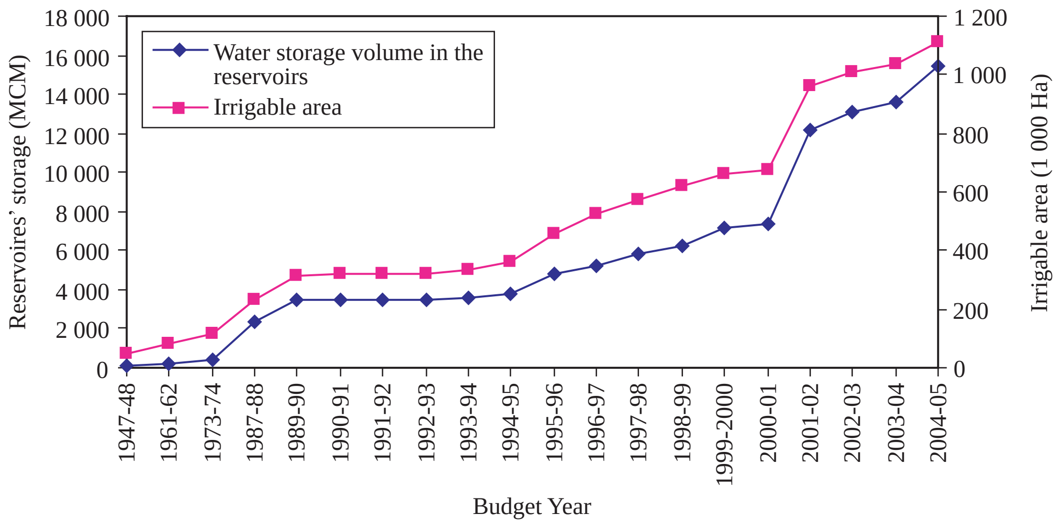
Year	Wet season (ha)		Dry season (ha)	
	Paddy field	Other crops	Paddy field	Other crops
1997	164 892	–	26 645	25 500
1998	216 892	–	53 130	30 930
1999	250 000	–	75 000	40 000
2000	280 000	–	100 000	100 000
2001/02	307 097	–	214 625	–
2003/04	310 360		215 000	

Source: Mr Ouanpasith Chounlamany, Ministry of Agriculture and Forestry, Lao PDR, 2005, personal communication.

Table 6. Rice irrigation in Southeast Asia (and China) in 2000

	Irrigated rice areas (1 000 ha)	All irrigated crops (1 000 ha)	Percentage of irrigated rice (%)	Equipped areas for irrigation (1 000 ha)	Cropping intensity (%)
Cambodia	313	319	98	269	119
Indonesia	5 505	6 575	84	4 428	148
Lao PDR	150	186	81	155	120
Malaysia	434	501	87	363	138
Myanmar	1 600	2 123	75	1 555	137
Philippines	1 810	2 067	88	1 550	133
Thailand	4 531	6 210	73	5 004	124
Viet Nam	2 550	4 300	75	3 300	129
China (southeast only)	29 621	40 405	73	23 295	173

Source: FAO AQUASTAT Database (2004).



Source: Country paper from Myanmar (in this publication).

Figure 1. Annual progress of reservoir water storage and irrigable area in Myanmar

Table 7. Large rice irrigation systems in some Southeast Asian countries (and China)

	Total equipped irrigation areas (1 000 ha)	Large irrigation system*		Percentage of large irrigation area in total irrigation area
		Number	Irrigation area (1 000 ha)	
Malaysia	363	4	166	45.7
Philippines	1 550	13	236.4	15.3
Thailand	5 004	85	2 668.2	53.3
Total	6 917	102	3 070.6	44.4
Indonesia	7 767		3 246	42
China	56 000	402	16 800	30

Note: Large irrigation system in Malaysia, Philippines and Thailand means larger than 10 000 ha.
Large irrigation system in China means larger than 20 000 ha.
Large irrigation system in Indonesia means larger than 3 000 ha.

Source: Country papers from Malaysia, Philippines and Thailand (in this publication).

Most of the large rice irrigation systems in Southeast Asia have been designed under a supply-driven mode. Despite their huge contribution to agriculture production and local social and economic development, there was a general consensus that these large rice irrigation systems had not lived up to expectations because of a legacy of poor institutional arrangement and system design, degraded infrastructure, poor management and stagnation in the face of rapid transformations of agriculture and pressure on their water supply. From 2000 to 2005, the FAO Regional Office for Asia and the Pacific conducted appraisals of a number of large rice irrigation systems in Indonesia, Malaysia, Philippines, Thailand and Viet Nam, and has identified some major constraints (Facon, 2005).

Institutional and administrative systems are generally top down. System planners, designers, managers and beneficiaries are not integrated in a systematic participatory approach. Design standards have not been changed for 20 to 30 years. Canal structure settings do not allow easy water control, measurement and system operation. Although most of these large irrigation systems were designed as multifunctional systems (municipalities, industrial customers), none of them has specific environmental targets. Recirculation of drainage is practised in a large number of schemes, but none is equipped with buffer or regulating reservoirs. Near-farm, and on-farm infrastructure is underdeveloped. System operation follows rigid seasonal schedules that lack flexibility. Field-level operators are poorly paid and their operation practices often differ from official rules and policies. Water supply from the main canals to the secondary canals and command areas is generally unreliable and inequitable. Effective monitoring and evaluation systems are not established or directly linked to operation. Managers do not have a proper estimation of system water balance and efficiency.

2. Future trends and requirements

2.1 Growing population calls for further development of irrigation

Southeast Asia is one of the most populated subregions, with about 522 million in 2002 and annual population growth of 2.1 percent. Nearly 33 percent of the total population lives in urban areas, and the urban population is further expected to increase by about 3 percent annually. Food security is still a major concern in this subregion. As indicated in Table 8, about 13 percent of the population in the developing countries of this subregion is undernourished. In Cambodia, Lao PDR, the Philippines, Thailand and Viet Nam, the proportions of the population undernourished are still above the global average. With the expected continuous population growth in the coming decades, food production in Southeast Asia needs to be increased. Irrigation is one of the major options to improve food security. Currently, irrigated agriculture is practised on 20 percent of all arable land and accounts for 40 percent of all crop production and almost 60 percent of cereal production in developing countries. FAO projects that from 2000 to 2030, to meet future food production demand, net global arable irrigated land needs to be expanded by 45 million ha. About 70 percent of the global expected increase in cereal production is attributed to irrigation. With abundant total water resources and lower development level, Southeast Asia is one of the subregions which have obvious irrigation development potential. For centuries, rice has been the most important source of food, employment and income for the rural people in Southeast Asia. Although rice consumption per capita is decreasing and is expected to decrease further, the special monsoon climate condition, the long heritage of social customs combined with the unique rice culture determine that rice is still the main staple food for the people of Southeast Asia and total demand will continue to increase. Rice irrigation in Southeast Asia is to be further expanded.

2.2 Increasing competition calls for more efficient water use

Southeast Asia has an average annual water resource of about 7 000 km^3, about 15 percent of the world's total. More than 90 percent of total freshwater withdrawals in the region go to agriculture, which is much higher than the global average of 70 percent. Currently, 18 percent of the harvested land in Southeast Asia is under irrigation. This rate is still low compared with the average level in Asia. Rice is a semi-aquatic plant, especially the lowland rice which accounts for about 90 percent of world rice production. The productivity of irrigated rice systems is threatened by competitive water use induced by rapid industrialization and urbanization. In China and Viet Nam, agriculture water withdrawal as a percentage of total national water withdrawal declined from 88.2 and 92.5, respectively, in 1990 to 67.7 and 68.1, respectively, in 2000. Overall, water competition from other sectors may not be a major concern in Southeast Asia, as actual consumptive use of water for irrigation is still expected to grow from 85.5 km^3 in 1995 to 91.9 km^3 in 2025, although more slowly than for other uses (Rosegrant *et al.*, 2002). Nevertheless, in certain circumstances, increased competition for water from industry, domestic use and the environment will be a constraint for farmers, especially near urban areas and in drought years. This is dramatically changing the way we value and utilize water and the way we mobilize and manage water resources. It is necessary to produce more food and agricultural products with less water while maintaining the multiple roles of the systems. Figure 2 shows the example of Zhanghe Reservoir near Wuhan in Hubei province of China. Over a 30-years period, water allocated to agriculture from this reservoir has declined steadily from 80 percent to less than 20 percent. By implementing water saving practices at both system and farm level, there has been only a modest decline in agricultural production in the 100 000 ha Zhanghe Irrigation District.

Table 8. Undernourished population in Southeast Asia (and other world regions)

Developing World / Region/subregion/country	Total population			Number of people undernourished			Proportion of undernourished in total population		
	1990–1992	1995–1997	2000–2002	1990–1992	1995–1997	2000–2002	1990–1992	1995–1997	2000–2002
	millions			millions			%		
Cambodia	10.1	11.8	13.5	4.3	5.2	4.4	43	44	33
Indonesia	185.2	200.1	214.3	16.4	11.2	12.6	9	6	6
Lao PDR	4.2	4.8	5.4	1.2	1.3	1.2	29	28	22
Malaysia	18.3	20.9	23.5	0.5	0.5	0.6	3	–	–
Myanmar	41.2	44.8	48.2	4.0	3.2	2.8	10	7	6
Philippines	62.5	69.9	77.1	16.2	16.3	17.2	26	23	22
Thailand	55.1	58.5	61.6	15.2	12.0	12.2	28	20	20
Viet Nam	67.5	74.0	79.2	20.6	16.7	14.7	31	23	19
Southeast Asia	**4 44.2**	**484.7**	**522.8**	**78.4**	**66.3**	**65.5**	**18**	**14**	**13**
South Asia	**1 125.3**	**1 242.7**	**1 363.3**	**291.3**	**287.3**	**301.1**	**26**	**23**	**22**
East Asia	**1 241.5**	**1 307.2**	**1 364.5**	**198.8**	**155.1**	**151.7**	**16**	**12**	**11**
Asia and the Pacific	**2 815.2**	**3 039.5**	**3 256.1**	**569.2**	**509.5**	**519.0**	**20**	**17**	**16**
Developing world total	**4 058.7**	**4 431.1**	**4 796.7**	**823.8**	**796.7**	**814.6**	**20**	**18**	**17**

Source: FAO (2005).

2.3 Diversified agriculture calls for user-oriented water service

During the past 20 years, the importance of trade has increased rapidly in Southeast Asia. The international trade in agriculture (the average of agricultural imports and exports) increased from 47 percent of agricultural GDP in 1981–1983 to 89 percent in 2001–2003 (Dawe, 2005). Global cereal grain prices declined to 50 percent of their levels in the previous three decades and continued to a historical low in 2001, but there has been a comeback in Thailand in recent years. The agricultural sector in Southeast Asia has shifted from traditional rice cultivation to more diversified and market-oriented crop cultivation. In China, from 1990 to 2003, the rice crop area declined by 6.6 million ha (19.8 percent) and the vegetable crop area increased by 11.6 million ha (183.3 percent) and the orchard area increased by 4.3 million ha (82.2 percent). In Malaysia, the national policy is to decrease self-sufficiency in rice from 80 to 65 percent in 2010. Diversified agriculture demands increased flexibility and reliability in water services.

Table 9. Irrigation water withdrawal in Southeast Asian countries (and China) in 2000

	Total renewable water resources (km^3)	Irrigation water requirements (km^3)	Water requirement ratio in percentages	Water withdrawal for agriculture (km^3)	Water withdrawal as percentage of renewable water resources
Cambodia	476.11	1.20	30	4.00	1
Indonesia	2 838	21.49	28	75.60	3
Lao PDR	333.55	0.81	30	2.70	1
Malaysia	580	1.68	30	5.60	1
Myanmar	1 045.601	9.79	30	32.64	3
Philippines	479	6.33	30	21.10	4
Thailand	409.944	24.83	30	82.75	20
Viet Nam	891.21	15.18	31	48.62	5
China	2 829.569	153.90	36	426.85	15

Source: FAO AQUASTAT Database (2004).

Table 10. Urbanization rates in Southeast Asia: 1961, 1990, and 2004

Country	1961	1990	2004
Cambodia	0.10	0.13	0.19
Indonesia	0.15	0.31	0.47
Lao PDR	0.08	0.15	0.21
Malaysia	0.27	0.50	0.65
Myanmar	0.19	0.25	0.30
Philippines	0.30	0.49	0.62
Thailand	0.20	0.29	0.32
Viet Nam	0.15	0.20	0.26

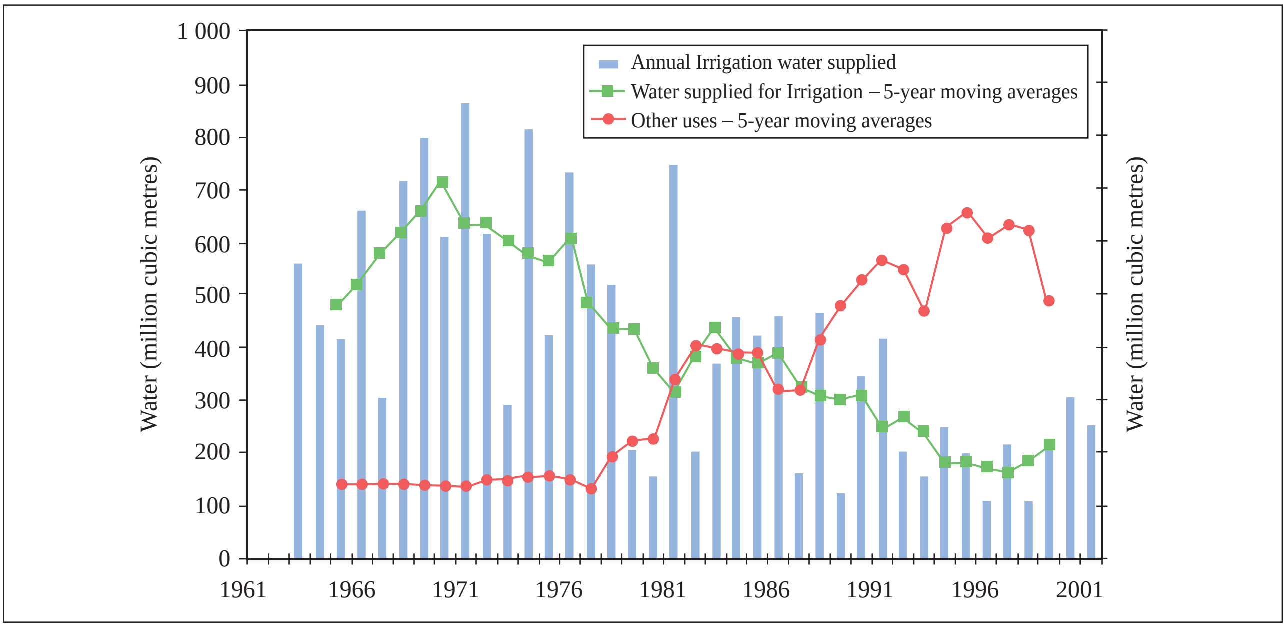
Source of raw data: FAO (2005).

2.4 Demographic transition calls for new system innovations

Sustained economic growth and urbanization in Southeast Asia have been accompanied by significant demographic transition. Large numbers of farmers emigrated from rural areas to urban areas. Populations in some Southeast Asian countries, such as Indonesia, Malaysia and the Philippines have decreased in the past ten years. About 100 million farmers in China move to city areas seasonally for short term jobs. In addition to intersectoral mobility and growth in urban areas, rural household economies have become more composite. Farm households are diversifying their income sources outside of agriculture. In some areas, the household income from agriculture is even lower than that from non-agricultural occupations. In Central Luzon, Philippines, for example, the percentage of household income from agriculture declined from 64 percent in 1985 to 40 percent in 1997 (Hossain, 2000). As young males are migrating to urban areas, farm households are becoming older and more likely to be headed by females. In Thailand, agricultural census data show that the proportion of farm households headed by women increased from 12 percent in 1978 to 27 percent in 2003. The same source shows that the percentage of farm household heads aged 55 and above increased from 25 percent in 1978 to 34 percent in 2003. This situation makes it difficult to hire labour and causes the price of labour in rural areas to increase. For example, agricultural wages in the Philippines, adjusted for inflation, were 60 percent higher in 2002 than in 1981. This has significant impact on irrigation design, construction and management. New innovations based on labour savings, low cost, high productivity and operation and management ease need to be adopted.

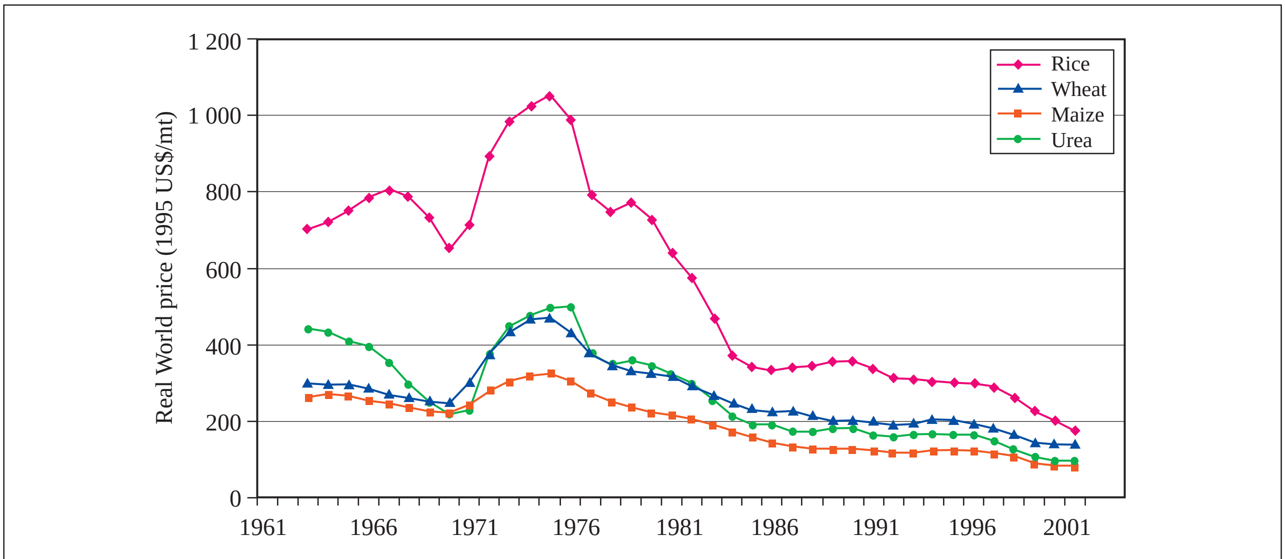
2.5 Sustainable development calls for integrated water resources management

Competitive water use and segmented water resources management has resulted in rapid degradation of rural watersheds and the regional environment. In China, 70 percent of waterbodies of major rivers are polluted; in Indonesia, the number of degraded river catchments increased from 22 in 1984 to 59 in 1998; in Thailand and Viet Nam, mangroves and coastal crops have been destroyed as a result of contamination by shrimp farms. Rice irrigation is also responsible for some environmental issues such as non-point source pollution by nitrates and pesticides, overdraft of groundwater which has resulted in salt water intrusion into coastal aquifers and land subsidence and the gradual sinking of major cities such as Bangkok and Jakarta. Moreover, some 1.4 million ha of agriculture area are salinized by irrigation in Indonesia, the Philippines, Thailand and Viet Nam, and another 6.7 million in China. Other irrigation-related environmental issues include waterlogging, the release of acid (e.g., in the Mekong) and the spread of vector-borne diseases. It is therefore important to merge large rice irrigation management into integrated river basin or watershed water resources management.



Source: Barker and Molle (2004).

Figure 2. Annual water allocations, 1965–1999: Zhanghe Irrigation Reservoir, China



Source: Barker and Molle (2004).

Figure 3. Real world prices (1995 US$ per metric tonne) for rice, wheat, maize and urea

Table 11. Population change in Southeast Asian countries and China (per 1 000 inhabitants)

	1990			1995			2000		
	Total	Rural	Agri.	Total	Rural	Agri.	Total	Rural	Agri.
Cambodia	10 437	9 077	3 650	12 158	10 315	4 214	13 810	11 307	4 764
Indonesia	188 260	127 192	45 285	203 038	125 808	47 940	217 131	120 465	49 957
Lao PDR	4 350	3 648	1 665	4 918	4 032	1 875	5 529	4 414	2 113
Malaysia	18 817	9 042	1 967	21 431	8 962	1 902	23 965	8 687	1 795
Myanmar	41 927	31 348	15 858	45 502	33 339	17 198	48 852	34 728	18 437
Philippines	63 989	31 382	11 320	71 337	31 452	12 045	78 580	31 265	12 688
Thailand	55 806	39 172	20 139	59 084	41 003	20 438	62 193	42 564	20 348
Viet Nam	68 901	54 476	24 827	75 070	57 775	26 686	80 278	60 003	28 227
China	1 189 560	840 223	499 280	1 249 499	831 635	508 201	1 302 307	808 094	510 950

Source: FAO AQUASTAT Database (2004).

2.6 Ongoing democratization calls for participatory approaches

The planning and management of irrigation systems has been, and is being, shaped by the ongoing political processes of democratization, which constantly redefine the relationships between the state and the citizenry and have a bearing on the conditions of access to resources (Barker and Molle, 2004). The age of globalization thus brings with it a pressure to blend the traditional top-down decision-making by the state with the growing empowerment of civil society. This can be witnessed, for example, in the development of Asian non-governmental organizations (NGOs), some of which have successfully opposed some large-scale developments.

3. Measures undertaken in the past and present

3.1 Past route

Initial efforts at improving large irrigation system performance in Southeast Asia to a large extent have been concentrated on on-farm water management. The achievements have been very modest since they are normally partial, segmented, and have had little impact on the overall performance of the systems. Recently, governance strengthening and institutional reform have been high on government agendas. The achievements have been modest still mainly because farmers have limited capacity and few incentives to take over the operation and management responsibilities of irrigation systems that are in poor physical condition, and to pay for poor water services; also because the reforms have remained partial, with optimistic assumptions about the willingness or capacity of bureaucracies to carry out the necessary changes. More recently, technical concerns have made a comeback. Major system rehabilitation has been carried out for large irrigation schemes. But these works normally followed the original designs and concepts, focused on improving the performance of canal irrigation systems by lining canals, encouraged greater farmer participation, called for water pricing, cost recovery, and irrigation management transfer, neglected the changing trends and new requirements of the agriculture and water sectors, and neglected system design, operation and water services issues. At the 1996 FAO regional expert consultation meeting on modernization of irrigation systems, a new definition of modernization of irrigation systems was coined to guide future understanding and efforts, namely, "Irrigation modernization is a process of technical and managerial upgrading (as opposed to mere rehabilitation) of irrigation schemes combined with institutional reforms, if required, with the objective to improve resources utilization (labour, water, economic resources, environmental resources) and water delivery services to farmers." Calls were made for systematic strategies to address institutional, physical and technical issues coherently through participatory approaches. Since then, numerous efforts have been taken and still are being taken by international communities and institutions and governments in Southeast Asia.

3.2 Recent responses and initiatives by FAO

FAO and the Land and Water Development Division have responded by developing, over recent years, in partnership with a number of international and national institutions, a series of technical and advocacy publications on the modernization of irrigation systems, tools for the appraisal and evaluation of the performance of irrigation systems, a suite of training materials and modules on the modernization of irrigation schemes, a regional training programme on irrigation modernization, a Website on the modernization of irrigation schemes, and has supported the efforts of national governments and agencies in the modernization of their irrigation sectors. The regional programme aims at disseminating modern concepts of service-oriented management of irrigation systems in member countries with a view to promoting the adoption of effective irrigation modernization strategies in support of agricultural modernization, improvement of water productivity, and integrated water resources management. The first training workshop under the programme was organized in Thailand in 2000, and since then India (Andhra Pradesh), Indonesia, Malaysia, Nepal, Pakistan, the Philippines, Thailand, Turkmenistan and Viet Nam, have benefited from the support of the regional training programme to organize national training workshops on irrigation modernization and benchmarking. More than 500 engineers and managers have been trained with support from the programme. The rapid appraisal process (RAP), introduced by FAO, has been adopted by the World Bank as one of the three elements of its holistic benchmarking methodology for irrigation systems.

3.3 Recent initiatives by governments and the international community

Although support from the international community in the form of investment in the irrigation sector has somewhat decreased in recent years, countries in Southeast Asia continue to have significant and ambitious programmes and objectives in the irrigation sector, particularly in terms of improving their large irrigation systems. For instance, the Royal Irrigation Department of Thailand has formulated a national strategy to improve irrigation efficiency and water management in existing systems while expanding new small-scale and medium-scale systems. Relevant activities on participatory management, conjunctive water use, water disaster mitigation and environmental protection have been initiated. A national training programme was also developed with support from FAO. The Department of Irrigation and Drainage (DID) of Malaysia is pursuing a national modernization strategy centred on the rice granary systems and has established a structured and elaborate programme to improve system performance and service quality. In Viet Nam, investment projects funded by the World Bank and the Asian Development Bank (ADB) include large irrigation modernization components based on similar concepts of service orientation. In China, the government has targeted that during the next 25 years, when national population grows from the current 1.3 billion to 1.6 billion, the agriculture sector should maintain national food security (95 percent self-sufficiency rate) with zero water consumption increase. Hence a nationwide water-saving programme is now under way based on legal, institutional, physical, technical and managerial options. The modernization of large rice irrigation systems is one of the core components and is now being implemented in more than 200 large schemes.

To summarize, all the efforts and initiatives that have been undertaken and that are being undertaken by government departments and the international community for the whole water sector have been focused on integrated water resources management and environmental issues through revising national water policies and strategies, establishing national water apex bodies and river basin organizations. For the irrigation subsector, the foci have been institutional reform through participatory irrigation management (PIM) and irrigation management transfer (IMT) to increase cost recovery and governance and adopting demand management to achieve improved performance through water pricing. Promotion of a private sector role and public-private partnerships in irrigation management and development have also been piloted. National policies have evolved from engineering expansion to food security, poverty alleviation, and related social objectives through multiple agriculture water use. An international programme on performance benchmarking in the irrigation and drainage sector is supported by FAO, the International Commission on Irrigation and Drainage (ICID), the International Programme for Technology and Research in Irrigation and Drainage (IPTRID), the International Water Management Institute (IWMI), and the World Bank.

3.4 Recent initiatives by rural communities and farmers

Farmers and system operators have adjusted to the challenges posed by the growing demand for water and new agricultural opportunities and constraints by exploiting groundwater, recycling water from drains and canals, changing cropping patterns, and adjusting the timing of water releases. These changes have taken advantage of new and cheap pumping technologies and government subsidies. Where system operations and management have not been proactively managing these changes, they have occurred nevertheless, with a growing dichotomy between official management and operating rules, and actual water management practices. Farmers still have little to say in general in the design and management of public irrigation schemes and in the definition of the service.

3.5 Outcomes and constraints

Some positive results have been achieved. In China, nationwide irrigation water use efficiency has been increased by around 10 percent during the past ten years. From 1980 to 2000, the total irrigation area in China increased by 6.7 million ha, the impoverished population in China reduced from 250 million to 29 million, while the total irrigation water use amount remained at about 350 billion m^3 and the share of irrigation water use in total national water use declined from 85 percent to 63 percent. In Myanmar, irrigation development in lower Myanmar has enabled the rice cultivation area to increase from 4.78 million ha in 1988 to 6.54 million ha in 2003. Thus, rice exports increased to one million tons in 2004 (Naing, 2005). Despite these positive examples, overall progress on the 1996 modernization agenda has remained relatively modest. Constraints still remain. The concepts of irrigation modernization are not well understood and adopted. In some cases, it is just a resort to continue to obtain funding for rehabilitation, operation and maintenance, or further capital-intensive interventions. Policy changes have little impact since they are based on a poor understanding of basin and system efficiencies. Reformed institutions do not capture the complexity of the hydrological cycle and the multifunctionality of the irrigation systems and service relationships between different levels of management. In most countries, PIM/IMT has made very modest progress on improving system productivity and raising cost recovery rates. The appraisals of large irrigation systems in Southeast Asia confirm that, in general, the performance of these systems continues to be low in terms of control, water productivity, yields, and quality of service delivery to farmers. The differences between stated policies and actual practices are generally large. Significant underinvestment in operation and maintenance and poor management continue to be the norm rather than the exception. Very frequently the actual system performance, particularly service delivery, is overestimated and therefore they lack the capacity to support and enable the proposed reforms. On the other hand, the actual performance of the systems in terms of overall water use efficiency may have been considerably underestimated and therefore, the potential gains in water savings may have been considerably exaggerated (Facon, 2005).

4. Issues and options

4.1 Issues to be addressed urgently

Typological classification Southeast Asia is a diverse subregion including least-developed countries, developing countries and almost-developed countries. Different social and economic development levels pose different requirements for irrigation systems, hence the need to identify different models and approaches. No one model fits all. Whereas some countries are advocating multiple uses of rice irrigation systems, the least developed countries may still be focusing on food security. To address food security issues, rice irrigation needs to be expanded. Principally, expansion should be in those areas where land, water and labour resources provide comparative advantages for rice cultivation. But there is still a series of questions that need to be answered: what kind of approach should be adopted? Should it be existing system modernization or new system expansion or some combination of the two? For new system expansion, what kind of model should be adopted — large systems or small systems, surface water or groundwater or conjunctive use, gravity or pumping? These issues shall be addressed through typological classification.

Water productivity This is a prerequisite to justifying continuous water allocation to rice irrigation in an increasingly competitive water environment. Contrary to popular misconceptions, when grown under flooded conditions, rice has similar transpiration efficiency to other cereals. Lowland rice fields lose large amounts of water by seepage, percolation, run-off and evaporation from the water surface, and therefore require up to two to three times more water than other cereals. Much of these outflows is captured and reused downstream, and is not a true loss from rice-based systems. However, as widely discovered, wastage and misuse of water resources do exist in many rice irrigation systems and could be avoided. So this is involves improving water management and usage while renewing the notions and evaluation methods of water use efficiency and productivity.

Irrigation service Agriculture diversification and demographic transition call for more flexible, reliable and equitable irrigation services and low-cost, labour-saving operations. Large rice irrigation systems are designed and constructed for rice irrigation, and operated following rigid schedules. They are not compatible with diversified and quick shifting cropping patterns. Because of large-scale and complicated engineering settings, the requirements of maintenance work are high. This will need joint efforts to modify system design, reform institutions, rehabilitate infrastructure, manage innovation and build capacity.

Environmental protection The hard part is how to incorporate irrigation water management into integrated river basin water resources management to develop integrated strategies, systematic approaches and practical technologies to minimize their negative externalities while maintaining and further developing their positive externalities. Also, there may be a need to balance the needs of food security and multiple functions in the least developed countries.

Participatory management Large irrigation systems are normally designed for multiple uses with complicated facilities, and they cover large areas. They require higher technical and management qualifications for management staff and need broad coordination in system operation and management. Some systems cover several counties, provinces and even areas larger than a small country. For these systems, participatory management should have different modalities from those adopted in small community systems that are mostly advocated by the international community. Since farmers have limited capacity to manage and operate the main systems, and technical agencies and government may continue to play important roles in system management. Participatory approaches for democratic decision-making are needed, but suitable options need to be carefully identified.

4.2 Options proposed by experts and institutions

Policy innovation

- Align and harmonize water and irrigation policies with agricultural and environmental policies and integrate them into overall socio-economic development policies; better understand and recognize the multifunctionalities of rice irrigation systems.
- Incorporate concepts and principles of irrigation modernization into upgrading of existing irrigation systems and development of new irrigation systems.
- Target systems goals at the total productivity of rice-based livelihood systems while continuously highlighting poverty alleviation and food security.
- Develop strategic planning and management approaches with a service orientation to support irrigation modernization strategies.
- Adopt participatory planning and design processes to better incorporate farmers’ needs into system management goals.
- Further decentralize authorities and responsibilities from irrigation bureaucracies to system managers and farmers’ organizations to enhance the clarity of operation policies, ease the involvement of farmers or WUAs in decision-making, and facilitate the establishment of incentive structures for farmers and employees.
- Enforce appropriate policy and make institutional arrangements for conjunctive management of ground and surface water to enable rational resource planning.

Institutional reform

- Develop new frameworks that can manage the complexity of the hydrological cycle, the multiple roles of irrigation systems and deliver irrigation and drainage service to farmers in a responsive, accountable and efficient manner.
- Adopt business approaches to tailor the institution to deliver specific performance goals in addition to governance and representation goals, and to improve service orientation and accountability, to move towards decentralized management, and reflect the diversity of stakeholders and water uses.
- Change models of farmers' organizations to professionalized institutions that can provide new ranges of delivery and other services and reduce transaction costs for farmers, as labour costs are increasing and labour and management shortages are to be further expected.
- Overhaul public management institutions by means of financial autonomy, incorporation, professionalization, public-private partnerships, privatization and transfer to farmers' organizations.
- Create irrigation authorities' accountability and water users' responsibilities through the establishment of water rights for individuals or WUAs, or through suitable amendment of existing irrigation acts; develop service attitude of government agencies.
- Establish enabling legislation and enforcement capabilities, which would allow WUAs to operate in a businesses model.

Management improvement

- Develop systematic approaches and methods to incorporate irrigation system management into integrated river basin water resources management.
- Formulate explicit water management objectives for different levels (farm, irrigation system, river basin and national level).
- Develop a systematic approach, procedures and methods to improve system water control, water services equity, reliability and flexibility.

Financial support

- Mobilize public funds to support the transformation of systems and institutions towards more agile and better performing systems.
- Shift investment policy from being rice-centric to being rice-aware.
- Establish new financial instruments to cover not only O&M but also upgrading of management and infrastructure assets at all levels of agricultural water management.
- Provide investment to drainage, tools and data for decision-making at both national and system level.

Technical evolution

- Improve system design by adopting conjunctive use of surface and groundwater, recirculation of drainage, buffer reservoirs at appropriate levels in the systems, improved design of control structures, operation and ordering procedures, piping of near-farm delivery, proper drainage systems and intensification of irrigation system management.
- Revise irrigation design standards, conduct irrigation modernization capacity building.
- Conduct research on water-saving irrigation technologies, their real water savings, long-term sustainability and environmental impacts.
- Introduce information and control technology and software for remote monitoring of spills, drains, and flow rates at major offtakes as a basis for the establishment of feedback mechanisms, as well as for a better understanding of the water balance of the systems.

- Disseminate technologies and study new options for flexible canal lining.
- Develop methods and tools for volumetric measurement and pricing.
- Develop methods and tools for evaluation and pricing of multifunctionalities of rice irrigation systems.

International cooperation

- Disseminate technology and share information among line organizations, country institutions and governments, especially on interactions between design standards, operation strategies, service level and water pricing.
- Seek international assistance from funding agencies for technical evolution, institutional innovation and engineering construction and upgrading.

5. Conclusions

Most of the large rice irrigation systems in Southeast Asia have been designed for rice irrigation under a supply-driven mode. Despite their huge contribution to agriculture production and local social and economic development, there is a general consensus that these large rice irrigation systems have not lived up to expectations because of a legacy of poor institutional arrangements and system design, degraded infrastructure, poor management and stagnation in the face of rapid transformations of agriculture and pressures on their water supply.

Population growth, economic development, urbanization and globalization have been and will continue to be the main drivers of changes in the agriculture and water sectors. Southeast Asia is expected to be the subregion where the greatest urban growth will occur over the next thirty years. Agriculture water use is facing more competition from other sectors. In the meantime, diversification, commercialization and modernization of agriculture calls for more flexible, high-quality, user-oriented water services. Large rice irrigation systems are facing multiple challenges. The preferred option is irrigation modernization through participatory approaches.

Responses have been made and initiatives have been taken by national governments, the international community and farmers on various aspects of field water-management improvement, institutional reform and governance strengthening, irrigation rehabilitation and system modernization. Modest outcomes have been achieved, but some major constraints remain: the concepts of irrigation modernization are not fully understood and properly adopted; policy changes have little impact; PIM/IMT has made very modest progress; the performance of these systems continues to be low in terms of control, water productivity, yields, and quality of service delivery to farmers; the differences between stated policies and actual practices are generally large; significant underinvestment in operation and maintenance and poor management continue to be the norm rather than the exception.

To respond better to the previous shortcomings and to meet the new challenges, multiple options and systematic approaches are needed in terms of strategy, institutions, financing, technology and international cooperation to transform large rice irrigation systems in Southeast Asia from supply-driven to demand-driven responsive systems, to improve their water service in terms of reliability, equity and flexibility and multiple uses, to enable farmers to boost agricultural and water productivity, to be more responsive to market opportunities and to contribute to environmental sustainability.

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Comprehensive assessment of water management in agriculture: rice and water — the livelihood of Asia

Coordinating lead author: Boumar B.A.M.

Lead authors: Barker R., Humphreys E., Tuong T.P.

Contributors[2]: Atlin G.N., Balasubramanian V., Barry G., Bennett J., Dawe D., Dittert K., Facon T., Fujimoto N., Gupta R.K., Haefele S.M., Heong K.L., Hosen Y., Ismail A.M., Johnson D., Johnson S., Khan S., Lin Shan, Masih I., Matsuno Y., Pandey S., Paris T.R., Peng S., Thiyagarajan T.M., Wassman R.

Executive summary and key messages

Overall message. To sustain the livelihoods of rice farmers and meet the food needs of growing populations in the face of increasing water scarcity and abiotic stresses, low cost technologies that increase production and water productivity at field and system scales, and that minimize negative environmental externalities and maintain ecosystem services, need to be developed and adopted.

Rice is the most important food and biggest agricultural water user in the world. Dramatic changes are occurring in the biophysical and socio-economic environment under which rice is produced. In the face of increasing resource constraints — land, labour, and water — new technologies and management practices must continue to be adopted to sustain the livelihood of rice farmers in irrigated, rainfed, and unfavourable ecosystems and to meet the food needs of a growing population. Particular attention must be given to practices that increase water productivity and protect the environment. We need a better understanding of the interactions between field, irrigation system, and landscape level and of the various ecosystem services of rice-based landscapes to meet both agricultural and environmental development objectives.

Submessage 1. Rice is the main staple food for three billion people, 90 percent of whom live in Asia.

For centuries, rice has been the most important source of food, employment and income for the rural people in Asia. The concept of a *rice culture* gives meaning to rice beyond its role as a food item. Increases in rice production over the last 50 years have played a major role in achieving food security and alleviating malnutrition and poverty, especially through lowering the rice price. However, the green revolution has largely bypassed the unfavourable drought-, flood-, and salinity-prone areas where nearly 700 million people depend on rice production. Sustained rapid economic growth and urbanization in Asia will continue to increase the feminization of agriculture and reduce the availability of labour for rice cultivation, driving the need for high-yielding production technologies with lower labor requirement.

Submessage 2. Rice grows in a wide range of environmental conditions and is productive in many situations where other crops would fail.

Rice is unique in its ability to grow and yield in a wide range of agro-ecological conditions, from flooded lowlands to drought prone uplands, and from humid tropical to cool temperate climates. Although rice is adapted to water logging, deep water decreases productivity and complete submergence can be lethal. Rice is a semi-aquatic plant and yield declines as the soil dries below saturation. Therefore, rice is grown under ponded water culture (lowland rice) where possible, accounting for about 90 percent of world rice production. Contrary to popular misconceptions, when grown under flooded conditions, rice has similar transpiration efficiency to other cereals. Nonetheless, lowland rice fields lose large amounts of water by seepage, percolation, runoff and evaporation from the water surface, and therefore require up to two to three times more water than other cereals. However, much of these outflows is captured and reused downstream, and is not a true loss from rice-based systems.

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2 Authors as of August 2005. In subsequent versions of the paper, new authors will be recognized who contribute substantially to revision of the text.

Submessage 3. The productivity of irrigated rice systems is threatened by increasing water scarcity, whereas that of rainfed and drought- and flood-prone environments is affected by a complex of abiotic stresses.

The highly-productive irrigated rice ecosystem receives 17 to 28 percent of the world's developed fresh water resources and provides cheap food for urban and rural landless rice consumers. Many large-scale irrigation systems are in poor condition and poorly managed. Groundwater pumping has increased tremendously relative to surface irrigation and overdraft has become a serious problem in the semi-arid regions. Water scarcity is increasing in some regions because of competition with urban and industrial users, and because of climate change. There is no systematic inventory or quantification of the nature, extent or severity of water scarcity in rice-growing areas, and its likely impact on productivity. The rainfed and unfavourable rice ecosystems experience multiple abiotic stresses such as drought, salinity/sodicity and uncontrolled flooding.

Submessage 4. Lowland rice ecosystems have both beneficial and negative environmental externalities and unique ecosystem services (multifunctionality) which will be affected by increasing water scarcity.

Compared with other cereals, lowland rice is a heavy emitter of methane and ammonia and a low emitter of nitrous oxide. However, lowland rice fields are responsible for less than 10 percent of total global methane emissions. Lowland rice fields behave as artificial wetlands in their capacity to remove nitrogen and phosphorus from contaminated surface waters. Nitrate leaching from flooded rice fields is usually negligible. Compared with temperate non-flooded crops, biocide use in Asian rice systems is generally low and the biocides used degrade rapidly. However, the biocides are often extremely toxic and their negative human health impact is large. Flooded rice can increase the risk of salinization and water logging in poorly drained areas by raising groundwater levels. Conversely, it can be used to reclaim saline and saline/sodic soils by leaching salts from the rootzone. Often overlooked are non-food ecosystem services provided by the lowland rice landscape, such as cultural aspects, groundwater recharge, control of soil erosion, flood mitigation and sustenance of a rich biodiversity, including unique and endangered species. The multiple uses and functions of rice landscapes need to be valued.

Submessage 5. More rice needs to be produced, at low cost, in the face of increasing water scarcity and a complex of abiotic stresses, while protecting the environment and safeguarding the ecosystem services (multifunctions) of rice-based ecosystems.

Meeting future rice demand and reducing poverty will require: increasing resource productivity in irrigated, rainfed and unfavourable ecosystems; reducing production costs and labour requirements; improving the management of water resources in the face of declining availability; and development of technologies and strategies to cope with the likely impacts of climate change, including increased incidence of extreme events. Increasing water scarcity in many areas will change the dominantly flooded systems to more aerobic systems, bringing new challenges for increasing productivity while minimizing associated negative externalities and maintaining beneficial ecosystem services (multifunctionality) of rice-based systems.

Submessage 6. There is scope to greatly increase rice productivity in unfavourable regions by developing rice varieties that are drought-, salt- or submergence-resistant, but there is little scope to further increase yield potential of current high-yielding (inbred or hybrid) varieties grown under non-stressed conditions.

Yield potential of modern high-yielding varieties has stagnated during the last two decades, with the exception of the development of hybrid rice. Transforming rice from C3 into C4 may increase the yield potential, but there is no consensus about its feasibility. Theoretically, there are a range of options to increase the water productivity of rice with respect to evapotranspiration by manipulating early crop vigour, leaf waxiness and transpiration efficiency, but these have not yet been explored. Traits that improve nutritious quality need to be combined with other successful traits, including those that impart drought tolerance. With proper investments, varieties can be developed with 50 to 100 percent increase in yield potential in rainfed lowlands and drought- and flood-prone areas within ten years. Genetic engineering tools can accelerate the development of these new varieties. Management technologies will also need to be developed and adopted to achieve the potential gains offered by the new varieties.

Submessage 7. There is great scope to develop and deploy integrated technologies to increase rice productivity and lower production costs in the face of water scarcity, but more research is needed on real water savings, long-term sustainability and environmental impacts.

Technologies that integrate components of management with varietal improvement can bridge the yield gap in well-defined target environments. The water balance of rice fields under such technologies should be quantified to identify water savings at field and system scales. Several water saving technologies are being developed for water-short irrigated environments which need to be further explored in participatory research. Integrated development of varieties and management practices is required to optimize yields in these environments. The sustainability and environmental impacts of many newly developed technologies are not well understood. In rainfed and drought- and flood-prone environments, technologies should aim at reducing abiotic stress intensities, enhancing survival and robustness of the crop to withstand stress, and stabilizing yields.

Submessage 8. More understanding is needed of scale effects and rice ecosystem services (multifunctionality) to develop specific improvement options, especially for irrigated ecosystems.

Many generic options to improve irrigation systems or the productivity of rainfed and unfavourable agro-ecosystems apply to rice-based systems as well. However, irrigated rice systems are characterized by large volumes of water flows, and more insight is needed on current water reuse and on system-level impacts of adoption of field-level water-saving technologies. More systematic evaluations are needed to understand the water balance dynamics and productivity of water at various scales of the irrigation system. More case studies are needed to identify local or region-specific characteristics of ecosystem services. Management practices need to be developed to sustain and enhance the ecosystem services of rice landscapes.

Submessage 9. Appropriate incentives and policies are needed to steer the improvement of water use in rice-based ecosystems.

Proposed policies, institutions and incentives to increase the efficiency and equity of water use in agriculture in general apply to rice-based systems as well. These include water pricing, tradable water rights, water markets, virtual trade, increasing the role of the private sector in operation and management, and general rural development strategies. A particular characteristic of rice-based cropping systems is that holdings are small and that some policies, such as volumetric pricing, should better be targeted at groups of farmers rather than at individual farmers. With the growing scarcity of labour and water, the development and dissemination of labour- and water-saving practices and drought-tolerant rice varieties are priority areas for research.

Trends and conditions

1. The role of rice in food security and poverty alleviation

Rice production

Rice is eaten by about three billion people and is the staple food of the largest number of people on earth. Ninety percent of the world’s rice is produced and consumed in Asia, where it accounts for more than half of the agricultural harvested area in many countries and for 20 to 40 percent of total caloric intake. An important political objective in most rice-growing countries is to achieve self-sufficiency in rice production and maintain price stability through domestic procurement and adjustment of stocks. The international trade in rice is only some 5 percent compared with 18 percent for wheat and 11 percent for maize. The growth in rice production over the last 40 years has kept pace with the tremendous growth in population in Asia and now stands at about 550 to 600 million tonnes annually. The average per capita rice production is about 18 percent higher than it was in the mid-1960s. This increase in rice production was largely a result of expansion of the irrigated area and increase in yield (t ha^{-1}) of irrigated rice.

Rice production and poverty alleviation

The surplus rice produced in the irrigated systems contributes to food security and helps to alleviate the poverty of an increasing urban population. The increased production from irrigated rice (the green revolution) was the result of a combination of the development of high-yielding varieties, expansion of the irrigated area and increased inputs such as water, fertilizer, and pesticides. High yield potential was achieved through increased harvest index, dwarfing and lodging resistance. Over the years, short growth duration (allowing multiple-cropping) and resistance to major pests and diseases were incorporated into the high-yielding varieties. Access to irrigation substantially reduced the probability of living in poverty. However, the main driving force in poverty reduction was the decline in the rice price that resulted from the increase in rice production. The world rice price now is just 25 percent of its level in the early 1980s and national prices show a similar trend. Rice farmers have borne the brunt of lower prices whereas rice consumers, particularly low income consumers, have been the major beneficiaries. In particular, the urban labouring class, the rural landless, and the small and marginal producers (being net consumers) benefit from the low rice price.

Though the green revolution was successful in dramatically increasing yields in favourable, irrigated ecosystems, it largely bypassed the unfavourable drought-, flood-, and salinity-prone areas. Nearly 700 million people are dependent on rice production in these environments, mainly in South and Southeast Asia. Countries and regions with a large proportion of rainfed areas have a relatively high incidence of poverty. These rainfed areas now constitute the major hunger and poverty hotspots of the world. Raising the productivity of major staples such as rice is critical to addressing hunger and poverty in these areas.

The Asian rice culture and economy

For centuries, rice has been the main staple food in most parts of Asia and has been the most important source of employment and income for rural people. It is currently estimated that rice is grown on some 250 million farms in Asia, most of them family-owned with average size varying from less than 0.5 to 4 ha. Much rice is used for home consumption and the marketed ratio for rice is small. In Asian countries, the rice production system is also highly valued because of its strong links to culture, rural communities, natural resources and the environment. Rice affects daily life in many ways and the concept of a *rice culture* gives meaning to rice beyond its role as an item of production and consumption. There are many traditional festivals and religious practices associated with rice cultivation. Many old kingdoms as well as small communities have been founded on the construction of irrigation facilities to stabilize rice production. The decline in these hydraulic societies is often associated with the inability to manage water resources.

As of the last century, Asia is becoming more urbanized. At the same time, the distinction between rural and urban is becoming blurred and households increasingly have representation in both worlds. In 1950, 17 percent of the Asian population was urban. This share is now 40 percent and will exceed 50 percent by 2025. With the decline in the rice price, farmers who once depended largely on their income from rice now earn half or more of their income from non-rice sources, including non-farm sources. For example, between 1985 and 1997, among a sample of Central Luzon rice farmers, income from rice declined from 48 to 35 percent. A similar decline occurred in Thailand.

As economies develop, the rural sector undergoes major changes. The younger members, particularly the males, leave rural areas in search of jobs in urban areas or overseas, sending remittances to their rural homes. In many instances the rural economy is becoming more feminized and aging. The feminization of agriculture is likely to continue to increase.

Labor demand from the expanded industrial and service sectors has increased wages. Farm employment is less desirable and it is harder to find labour at peak periods for key operations such as transplanting, weeding, and harvesting. With rising wages and labour shortages, mechanization is becoming more prevalent for both land preparation and harvesting, especially in the irrigated areas. Farmers are shifting from hand weeding to the use of herbicides, and from transplanting to direct seeding. As of the late 1990s it is estimated that one-fifth of the area in Asia is direct seeded, and it is expected that this proportion will increase in the future.

2. Rice ecology and hydrology

Rice ecology

Rice is unique among the major food crops in its ability to grow in a wide range of hydrological situations, soil types and climates. Depending on the hydrology of where rice is grown, the rice environment can be classified broadly into irrigated rice, rainfed or unfavourable ecosystems. Irrigated lowland rice is grown in bunded fields with assured irrigation for one or more crops per year. Usually, farmers try to maintain 5 to 10 cm of water (floodwater) on the field. Worldwide, there are about 79 million ha of irrigated lowland rice. Rainfed lowland rice is grown in bunded fields that are flooded with rainwater for at least part of the cropping season to water depths that exceed 100 cm for no more than ten days. Worldwide, there are about 54 million ha of rainfed lowland rice. In both irrigated and rainfed lowlands, fields are predominantly puddled with transplanting as the conventional method of crop establishment. In flood-prone ecosystems, the fields suffer periodically from excess water and uncontrolled, deep flooding. About 11 to 14 million ha worldwide are flood-prone lowlands. Upland rice is grown under dryland conditions without irrigation and without puddling, and is grown on some 14 million ha.

In many rice production areas, rice is grown as a monoculture with two crops per year. However, significant areas of rice are also grown in rotation with a range of non-rice crops, including about 15 to 20 million ha of rice-wheat systems, much of which is irrigated. In such systems, the preferred cultural practices for rice are often antagonistic to the preferred practices for the non-rice crops, and vice versa.

The rice plant

Cultivated rice evolved from a semi-aquatic, perennial ancestor, and rice evolved separately from other *Graminae* before grasses moved from the forest floor to more open habitats. The wetland ancestry of rice is reflected in a number of morphological and physiological characteristics that are unique among crop species. Key differences between rice and other cereals include shoot and root anatomy, water loss patterns, and growth responses to soil water status drier than saturation.

Rice is extremely sensitive to water shortage. When soil water content drops below saturation, growth and yield formation are affected, mainly through reduced leaf surface area, photosynthesis rate and sink size. In rainfed systems, drought stress can occur at any time during the growing season, and is especially damaging immediately before and during flowering. There is little relationship between tolerance to stress at the vegetative and reproductive stages. Genetic analysis of traits related to drought tolerance in rice indicate that grain yield under drought stress in rice is a complex trait affected by many genes. No genes for tolerance to either reproductive- or vegetative-stage stress with effects large enough to be useful in breeding have yet been identified. Screening for drought tolerance is complicated by the intermittent occurrence of natural stress, and by the strong relationship between plant phenology and sensitivity to stress.

Although rice is adapted to water logging, complete submergence can be lethal. The effect of flash-flooding varies depending on growth stage. Germination is highly sensitive to flooding. Short-term flooding hastens the plant’s energy depletion and increases mortality. Tall plants tend to lodge when the water level recedes resulting in additional yield losses and poor grain quality. Under long-term flooding, genotypes need to be able to elongate fast to keep their leaves exposed above water surface. Productivity of this system is low because of the high energy required for shoot elongation. Most existing rice cultivars are seriously damaged if they are completely submerged for more than three days. Progress through breeding has been slow because of the complexity of tolerance where many traits are involved, and the complexity of the environment where more than one stress is prevailing.

Rice is a salt-sensitive crop with a threshold of about 2 to 3 dS m^{-1}. Salt stress affects rice through osmotic stress, salt toxicity and nutrient imbalances. Tolerance to salt stress in rice is complex and varies with the stage of development. Rice is most sensitive to salinity during the reproductive and early seedling stages. Tolerance at one stage does not correlate with tolerance at another stage, and traits essential for tolerance at one stage are different from those at another stage. These suggest the need for incorporating traits/genes associated with tolerance at different stages. Because of this complexity and the many traits involved, progress in breeding for salt tolerance has been relatively slow. Also, salinity typically occurs in association with other soil-related stresses or temporary tidal submergence.

Water use and water productivity

About 90 percent of the world's rice production is harvested from so-called lowland (or paddy) rice fields. Traditionally, lowland rice is raised in a seedbed and then transplanted into a main field which is kept under continuous or intermittent ponded water conditions. Land preparation consists of soaking, ploughing and puddling (*i.e.*, harrowing or rotivating under shallow submerged conditions). Puddling is done for weed control and to reduce soil permeability and percolation losses, and eases field leveling and transplanting.

Water for lowland rice is needed for land preparation and to match seepage, percolation and evapotranspiration outflows during crop growth. The soil is ponded for soaking prior to puddling and transplanting, and is usually kept ponded until shortly before harvest. Seepage is the lateral subsurface flow of water and percolation is the down flow of water below the rootzone. Typical combined values for seepage and percolation vary from 1 to 5 mm d^{-1} in heavy clay soils to 25 to 30 mm d^{-1} in sandy and sandy loam soils. Evaporation occurs from the ponded water layer or from the surface of the soil and transpiration is the process by which plants take up water from the soil and release it into the air as vapour. Typical combined evaporation and transpiration rates of rice fields in the tropics are 4 to 5 mm d^{-1} in the wet season and 6 to 7 mm d^{-1} in the dry season, but can be as high as 15 mm d^{-1} in subtropical regions prior to the onset of the monsoon. Over-bund flow (or surface runoff) is the spillover when water depths rise above the paddy bunds.

Transpiration rates of lowland rice crops are the same order of magnitude as many other cereals, but the evaporation flows from soil or the ponded water layer are higher. The modern rice varieties, when grown under well-watered conditions, can have similar transpiration efficiency (water productivity with respect to transpiration) to other C3 cereals such as wheat, at about 2 kg grain m^{-3} water transpired.

The few available data indicate that water productivity of rice with respect to evapotranspiration is similar to that of wheat, ranging from 0.6 to 1.6 kg grain m^{-3} of evapotranspired water, mean 1.1 kg grain m^{-3}. For maize, being a C4 crop, the values tend to be higher, ranging from 1.1 to 2.7 kg grain m^{-3} water, mean 1.8 kg grain m^{-3}. However, total water inputs to rice fields (rainfall plus irrigation) are up to two to three times more than for other cereals. Total seasonal water inputs to rice fields vary from as little as 400 to 600 mm in heavy clay soils with shallow groundwater tables, to more than 2 000 mm in coarse textured (sandy or loamy) soils with deep groundwater tables. Around 1 300 mm seems to be a typical average value for irrigated rice in Asia. Values of water productivity with respect to total water input range from 0.2 to 1.2 kg grain m^{-3} water, with 0.4 as average value. Non-productive outflows of water by run-off, seepage and percolation are about 25 to 50 percent of all water input in heavy soils with shallow water tables, and 50 to 85 percent in coarse textured soils with deep water tables. Though seepage and percolation are losses at the field level, they are often captured and re-used downstream and do not necessarily lead to true water depletion at the irrigation area or basin scales. The proportion and magnitude of unrecoverable losses by seepage and percolation from rice fields is generally not known.

3. Rice ecosystems

The irrigated ecosystem

Irrigated rice provides 75 percent of the world's rice production. The green revolution led to a rapid increase in productivity especially in irrigated areas during the 1960–80s. Country-average irrigated rice yields in Asia now range from 3 to 9 t ha^{-1}, with an overall average of about 5 t ha^{-1}. Irrigated rice receives 17 to 28 percent of the world's developed fresh water resource. Approximately 56 percent of the total world irrigated area is in Asia, where rice accounts for 40 to 46 percent of the net irrigated area. In Southeast Asia, rice occupies 64 to 83 percent of the irrigated area, in East Asia 46 to 52 percent, and in South Asia 30 to 35 percent. Irrigated rice is mostly grown with supplementary irrigation in the wet season, and is entirely reliant on irrigation in the dry season. Irrigated wet-season rice is grown predominantly in the subtropical regions of north and central China and the northwest Indo-Gangetic Plain of India and Pakistan, and is highly dependent on irrigation. Dry season irrigated rice is concentrated in south China, south and east India and Bangladesh. The proportion of the rice area that is irrigated (excluding China where essentially all rice is irrigated) increased substantially from the late l970s (35 percent) to the mid-1990s (44 percent). This occurred because of an increase in the irrigated area coupled with a large decline in upland and deep water rice cultivation. The growth in the total irrigated area in Asia has slowed in the past decade and is projected to increase at less than 1 percent per year between 1995 and 2020. Lower rice prices, poor performance and high construction costs of irrigation systems, and environmental protests over large dam construction are major factors behind this decline in growth rate. Large parts of the increase in irrigated area of Asia since 1980 are not being planted to rice. For example, 45 percent of the gross irrigated area in India was cropped to rice in 1960, but by 1992 this had fallen to 30 percent.

Irrigated rice production has only recently moved into non-traditional rice growing areas, on relatively permeable soils, in the northwest Indo-Gangetic Plain. Between the middle of 1960 and the late 1980s, the area, yield and total production of rice increased rapidly as a result of the introduction of high yielding varieties, increased use of chemical fertilizers, assured irrigation via public investment in irrigation systems and private investment in groundwater pumping, and favourable policies (subsidies for inputs and minimum price support schemes for grain). However, there are now grave concerns about the sustainability of irrigated rice production at current levels in this region because of rapidly falling groundwater levels and the need to reduce the large fiscal costs associated with government policies that promote rice production.

Shifting comparative advantage in rice production

The comparative advantage in rice production is shifting within Asia. Before World War II, the delta regions (Bangladesh, Cambodia, eastern India, Myanmar, Thailand, Viet Nam) held the comparative advantage in rice production and were the main sources of rice exports. However, the early beneficiaries of the green revolution technology were those areas where, with the construction of reservoir storage, it was possible to irrigate two crops of rice, and the northwest Indo-Gangetic Plain where private groundwater pumping expanded rapidly. For political reasons and/or because of the inability to manage floods, the deltas initially were unable to take advantage of the new rice technologies. However, over the past 15 to 20 years, the delta areas have regained the comparative advantage with the aid of low-cost pump technology. During this period, the delta regions have shown the most rapid growth in rice production and exports. With the improved water control provided by pumps, the delta regions have been able to shift out of deep water and floating rice by planting one crop before and one after the floods. In short, rice production is gaining in those regions with plentiful water supply and cheap labour relative to those areas of water scarcity.

Irrigation water supply infrastructure

The growing role of the private sector in managing ground and surface water irrigation is changing the incentives to manage water. Much of the existing surface irrigation infrastructure in Asia has been designed for supplementary irrigation of rice during the rainy season. Large systems are publicly managed in a supply-driven mode without accountability to users. They are generally in a poor condition because of insufficient maintenance, and provide poor control and service to farmers. Design standards and operation have not changed in many countries for 20 to 30 years: they are a cause of poor performance and have not responded to changes in farming systems and farmers' service requirements, and their extension into the dry season. In gravity systems water is either priced well below operation and maintenance costs or not priced at all. The general response from the public sector has been their rehabilitation, transfer of the burden of maintenance costs to farmers, and substantial investments in rigid canal lining, with dubious results.

A very important trend is the tremendous increase in irrigation with groundwater pumping in the semi-arid regions of Asia since the 1960s (e.g. the northwest Indo-Gangetic Plain and the North Central Plain of China). More recently, there has been a rapid growth in the use of pumps in the monsoon areas. The use of pumps has facilitated diversification from rice to higher value crops. With privately owned systems the users pay for the cost of fuel and maintenance with the exception that electricity is subsidized in some areas (such as the Indo-Gangetic Plain). Users who pay the cost of pumping have an incentive to minimize costs by managing water carefully.

Water scarcity in the irrigated ecosystem

Though water scarcity is increasing worldwide, there is no systematic inventory, definition or quantification of water scarcity in rice growing areas. It has been estimated that by 2025, 15 to 20 million ha of irrigated rice will suffer some degree of water scarcity. Water scarcity is most pronounced in the semi arid regions of the Indian subcontinent where 15 000 million ha of rice are grown mostly in the wet season. In parts of the northwest Indo-Gangetic Plain and the Yellow River Plain, long surplus producers of cereals, heavy pumping of groundwater is rapidly lowering water tables. Even in many monsoon areas such as India's Cauvary Delta and Thailand's Chao Phraya Delta, there is heavy competition for water among states and sectors, particularly in the dry season. Individual case studies also suggest local hotspots of water scarcity, even in areas generally not considered water scarce.

Two typical cases of water scarcity can be defined. In some irrigated rice areas, there may be sufficient water for farmers to practise flooded rice culture. Tail end parts of irrigation systems or regions with falling groundwater tables are examples of areas where farmers may not have access to sufficient water to grow continuously flooded rice. The challenge in this case is to devise strategies to assist farmers to cope with water scarcity. In the second case, there may be adequate water where the farmer is (e.g. upstream part of an irrigation system), but inadequate water elsewhere in the system or the catchment, or there may be increasing demands from non-agricultural sectors of society (e.g. cities, industry) that result in partial or complete withdrawal of water resources from irrigation systems. In this case, the challenge is to have strategies for farmers to reduce water input, to "save" water to divert it to somewhere else or for use by other sectors.

Coping with water scarcity or reducing water inputs will require changing from flooded to more aerobic rice cultural systems and to irrigation systems that are more responsive to the needs of farmers. Changed water management will affect many aspects of crop management, productivity, and the environmental impacts of rice-based systems.

The rainfed and unfavourable ecosystems

The rainfed and unfavourable rice ecosystems (including upland, flood-prone and saline environments) account for about 45 percent of the total rice area and produce 25 percent of the world's rice. The rainfed and unfavourable rice ecosystems experience multiple abiotic stresses. Approximately 25 million ha of rainfed rice are frequently affected by drought, the largest, most frequently and severely affected areas being eastern India (about 20 million ha) and northeastern Thailand and Lao PDR (7 million ha). About 15 million ha of rice land are frequently damaged by submergence in South and Southeast Asia and tropical Africa. Further constraints arise from the widespread incidence of problem soils. Salinity and/or sodicity are most widespread (>10 million ha) in coastal areas, where salinity is predominant, and in inland areas, where both salinity and alkalinity are major problems and often coexist.

The abiotic stresses of rice-based rainfed lowlands are characterized by high levels of uncertainty, particularly for timing, duration and intensity because of the unpredictability of rainfall and/or flooding. Most rainfed lowlands are characterized by small to medium topographic differences that have important consequences for water availability, soil fertility, flooding risk, and extent of soil-borne abiotic stresses. Most of the management options for rice were developed for irrigated ecosystems with a reliable supply of water. The unpredictability of rainfall in rainfed ecosystems often results in field conditions that are too dry or too wet. Besides imposing abiotic stresses on crop growth, these conditions also prevent timely and effective critical management operations such as land preparation, transplanting, weed control, and fertilizer application. If such operations are delayed or skipped, large yield losses often ensue, even though the plants have not suffered physiological water stress.

Because of diverse stresses, productivity growth in rainfed areas has been slow and average rice yield is currently some 2 t ha^{-1}. Research efforts to increase yields and yield stability in rainfed environments have been limited; specific research issues for rainfed rice have been extensively discussed only in the recent past. Thanks to these recent efforts, rice research for rainfed lowlands has been intensified and was more successful during the last decade. Together with socio-economic developments, this has contributed to considerable improvements in rainfed systems. Important changes include much-improved access to markets for inputs (inorganic fertilizer, agrochemicals), more opportunities for off-farm income, improved varieties, (partial) mechanization, and better access to information.

4. Environmental conditions

Air pollution

Rice stubble burning causes serious air pollution, affecting human health, in the mechanized rice-wheat systems of the northwest Indo-Gangetic Plain where the majority of the rice is harvested by combine harvester. Approximately 10 million tonnes of rice straw are burnt in the small state of Punjab, India, alone. Burning is promoted by the lack of economic uses for rice straw, the loss of wheat yield with delayed planting, and the lack of suitable machinery for direct drilling into rice stubbles. In contrast, burning of wheat straw is a major source of air pollution in rice-wheat systems in China where the turn around time between wheat harvest and rice planting is small. Policies banning stubble burning were recently introduced in Punjab, India and Sichuan, China, although the policies have not yet been legislated in India, and implementation will be difficult there until recently-developed technologies for direct drilling into rice stubble are proven and adopted.

Ammonia losses from lowland rice fields are estimated to account for 20 percent of all mineral N fertilizer applied, or about 2.4 Tg NH_3-N per year. The magnitude of ammonia volatilization largely depends on climatic conditions and method of application. In tropical regions, ammonia losses can reach up to 54 percent of all applied mineral N fertilizer, while emissions are generally negligible from direct-seeded rice culture in temperate regions where the majority of the fertilizer is applied prior to flooding. Volatilization of ammonia reduces the efficiency of N fertilization and increases input costs. Through aerial translocation, it can also lead to unintended N inputs into neighbouring sensitive natural ecosystems, potentially resulting in their degradation and loss of biodiversity.

Greenhouse gases

In the early 1980s, it was estimated that lowland rice fields emitted more than 50 Tg methane per year, or about 10 percent of global methane emissions. Recent measurements, however, show that many rice fields emit substantially less than those investigated in the early 1980s, especially in northern India and China. Also, methane emissions have actually decreased since the early 1980s because of changes in rice production systems such as the decrease in organic inputs. At the same time, techniques for upscaling of greenhouse gas emissions have improved greatly. Current estimates of annual methane emissions from rice fields are in the range of 10 to 30 Tg. The magnitude and pattern of methane emissions from rice fields is mainly determined by water regime and organic inputs, and to a lesser extent by soil type, weather, management of tillage, residues and fertilizers, and rice cultivar. Flooding of the soil is a prerequisite for sustained emissions of methane. Mid-season drainage, a common irrigation practice adopted in major rice growing regions of China and Japan, greatly reduces methane emissions. Similarly, rice environments with an insecure supply of water, namely rainfed rice fields, have a lower emission potential than irrigated rice. Organic manure generally enhances methane emissions.

Few accurate assessments have been made of emissions of nitrous oxide from rice fields. Emissions are primarily affected by the availability of mineral N in the soil and by soil water status, and are stimulated by the transitions between anaerobic (waterlogged) and aerobic conditions. Constant flooding generally implies relatively low emissions with the notable exception of the phase immediately after N fertilizer application. In irrigated rice fields the bulk of nitrous oxide emissions occur during fallow periods. Cumulative nitrous oxide production during the pre-rice fallow and the rice crop is 1 to 7 percent of applied N.

Crop production *per se* is neither considered a source nor a sink of carbon dioxide, because the carbon stored during crop growth is ultimately released after harvest through decomposition and/or burning of crop residues and through consumption of the produce. However, lowland rice culture increases the soil carbon content, and rice production can result in the net sequestration of carbon. The amount of sequestration is difficult to quantify, and the contribution of rice cultivation to the global carbon dioxide budget is unknown.

Soil and water pollution

Changes in water quality associated with lowland rice production may be positive or negative depending on the quality of the incoming water and rice cultural practices. The quality of the water leaving rice fields may be improved as a result of the capacity of the soil to hold contaminants such as heavy metals, and its ability to transform organic contaminants and trap sediments. A lowland rice field behaves as an artificial wetland in its capacity to remove nitrogen and phosphorus.

Nitrate leaching from flooded rice fields is normally negligible because of rapid denitrification under anaerobic conditions. Ammonium, the predominant form of mineral nitrogen in saturated soils, usually has a very low mobility in soil. However, high nitrogen pollution of freshwaters can be found in lowland rice growing regions where fertilizer rates are excessively high, for example in Jiangsu province in China. Nitrogen transfer from wetland rice fields to freshwaters by direct flow of dissolved nitrogen in floodwater through runoff/drainage warrants more attention.

In traditional rice systems, relatively few herbicides are used as puddling, transplanting and ponding water are effective weed control measures. In Asian rice systems in general, biocide (herbicides, pesticides, insecticides, etc.) use is small in terms of dosage and number of applications, and the chemicals degrade more rapidly in tropical flooded conditions than in temperate non-flooded conditions of non-rice crops. However, the negative human health impact of biocides is large and overwhelms the impact on the rice ecosystem and the environment. Since lowland rice fields are closely linked with the hydrologic cycle of basins, there is a high risk of discharge of biocides and their toxic metabolites to waterbodies. The potential for water pollution by biocides is greatly affected by field water management. Different water regimes result in different pests and weeds, and therefore require different amounts and types of biocides. Residual biocides interact differently with soil under different water regimes. The recent success of integrated pest management has reduced the use of biocides in some Asian countries such as Indonesia and Viet Nam. Studies on the impact of drainage waters from rice systems on downstream flora and fauna and ecosystem function are lacking.

Percolating water from lowland rice fields usually raises the water table. Where the groundwater is saline, this can salinize the rootzone of non-rice crops in the area, and cause waterlogging and salinity in lower areas in the landscape, such as in parts of the northwest Indo-Gangetic Plain. On the other hand, flooded rice can be used in combination with adequate drainage to leach accumulated salts out of the rootzone, as in parts of northern China, and to reclaim sodic soils when used in combination with gypsum as in parts of the northwest Indo-Gangetic Plain.

Farming on acid sulphate soils, which is common in the deltas of Southeast Asia, entails the risk of leaching pollutants to adjacent areas. The leaching process is especially intense under upland crops that are often grown on raised beds to avoid flooding. These leachates can adversely affect rice production through low pH and high aluminum concentrations, as observed in the Mekong Delta. Flooded rice can also be grown on acid sulphate soils, and leachates from rice fields are less harmful (having higher pH and lower aluminum levels) than those from upland crops.

Ecosystem services (multifunctionality)

The lowland rice landscape provides many ecosystem services which have been receiving increased recognition under the term "multifunctionality". In East Asian countries/areas like Japan, Republic of Korea, Taiwan Province of China multifunctionality has become a focal issue in agricultural policy in the context of international trade negotiations. Because market forces alone are not sufficient to induce farmers to produce non-food benefits, several countries argue that they must be able to promote these beneficial outcomes without interference from the international trade bodies. However, few studies of ecosystem services of rice landscapes have been conducted to date. These few studies indicate that the multifunctional aspects vary with infrastructural, regional, climatic, social, cultural, and economic conditions. Examples of commodity functions beside the production of rice are the raising of fish in rice fields, ponds or canals, and the tending of ducks in stubble fields. Frogs and snails are collected for consumption in some countries. The non-commodity outputs, or externalities, from rice production can be both positive and negative.

Bunded rice fields may increase the water storage capacity of catchments and river basins, lower the peak flow of rivers, and increase groundwater flow. For example, in 1999 and 2000, 20 percent of the floodwater in the lower Mekong River Basin was estimated to be stored temporarily in upstream rice fields. The many irrigation canals and reservoirs associated with the lowland rice landscape have a similar buffering function. Other possible services of bunded rice fields and terraces include the prevention of land subsidence, soil erosion and landslides. Percolation from rice fields, canals and storage reservoirs recharges groundwater systems. Such recharge may also provide a means of sharing water equitably among farmers who can pump from shallow aquifers at relatively low cost rather than suffer from inequitably shared or poorly managed surface irrigation systems.

Flooded rice fields and irrigation channels form a comprehensive water network, which, together with their contiguous dry land, provides a complex mosaic of landscapes. Surveys show that rice-based ecosystems sustain a rich biodiversity, including unique as well as threatened species, and also enhance biodiversity in urban and peri-urban areas. In Asia, lowland rice fields are valued for their scenic beauty. In parts of the USA, such as California, rice fields are ponded in winter and used to provide habitat for ducks and other water birds for recreational hunting. Climate mitigation by rice fields has been recognized as a function in peri-urban areas where paddy and urban land are intermingled. This function is attributed to relatively high evapotranspiration rates resulting in reduced ambient temperature of the surrounding area in the summer, and in lateral heat emission from the waterbody in winter.

5. The challenges

Food security and poverty alleviation

The future demand for rice is a function of population growth and income-driven consumption characteristics. The population growth rate in Asia today stands at about 1 percent per year. As incomes rise, particularly in urban areas, per capita rice consumption declines. At the national level, per capita demand for rice is declining not only in East Asia (Japan, Republic of Korea, and Taiwan Province of China) but also in Malaysia and Thailand. Overall, however, the demand for rice is still growing, though at a lower rate than previously. In the mid-1990s, it was estimated that total rice production would need to increase to 750 million tonnes by 2025 and to 875 million tonnes by 2050 to meet the (changing) food demand of the growing population and to eliminate hunger among the 600 million poor in different parts of Asia. This increase in food production has to be realized with declining water, land and labour resources, and probably under increasing incidence of abiotic stresses. The challenge is to find ways to increase the productivity of scarce resources to achieve growth in total resource (factor) productivity so that future food needs can be met.

Besides quantity, the quality of rice is becoming increasingly important. More-affluent rice consumers become more discriminative with respect to taste, texture and other quality attributes. In poor rural areas, increasing the nutritional quality of rice (iron, zinc, provitamins) can help alleviate malnutrition and improve health.

Despite advances in poverty alleviation in the past few decades, absolute numbers in poverty have declined very little, especially in South Asia. Therefore, a major challenge is not only to produce more rice, but to produce it more cheaply so that the livelihoods of rice farmers can be sustained while feeding the poor. However, low rice prices threaten the livelihoods of rice farmers, the very segment of the population which helped to alleviate poverty. Therefore, costs of production need to be decreased so that both producers and consumers benefit. Lowering the cost of production has to be achieved in the face of rising wages, and the aging and feminization of rural populations. In many instances women's role in agriculture will shift from unpaid labourers to farm managers.

Increasing productivity and protecting the environment of irrigated ecosystems

Productivity of the irrigated ecosystems needs to increase to provide sufficient cheap rice for urban and rural net food consumers. In some of the major rice-producing countries in Asia, such as Bangladesh, the Philippines, and Thailand, there is still a large gap between actual and potential yields, and efforts need to be directed at adoption of improved crop management technologies. In other countries, such as China, Japan and Republic of Korea, the yield gap is closing and efforts are needed to increase yield potential. Increased yield and increased total production mean that with current cultural practices more water will be needed to meet the increased evapotranspiration requirements. With increasing water shortage, this means that the water productivity of rice needs to increase.

Irrigated rice culture has been practised for thousands of years in various parts of Asia. This fact, together with the findings of 30 long-term continuous cropping experiments at 24 sites in Asia, suggests that irrigated lowland rice productivity is relatively sustainable, given an assured water supply. However, water shortage endangers the sustainability of lowland rice production, and may increase negative externalities. There are indications that soil-borne diseases (e.g. nematodes, root aphids) and micro-nutrient disorders are more serious threats in non-flooded than in flooded rice systems. Whereas methane emissions will decrease and nitrous oxide emissions increase under non-flooded conditions, the net greenhouse gas impact is currently unknown. Less ammonia volatilization is expected under non-flooded conditions, but more nitrogen will be present in the form of nitrate, and this nitrate may be prone to leaching or denitrification upon flood irrigation. Submergence is a key component for the relatively high carbon sequestration capacity of lowland rice fields. Although direct evidence from converted paddy fields is still missing, it is likely that growing rice with less water or conversion to non-rice crops will reduce soil carbon. This change in soil organic matter will be accompanied by changes in the microbial community, shifting from predominately anaerobic to aerobic organisms. It is not clear if or how these changes will affect soil fertility. Flooded rice has both fewer total weeds and a different weed spectrum than rice that is not permanently flooded. It is expected that water shortages will lead to increased herbicide use, as well as different types of herbicides. The challenge is to develop weed management practices that reduce the reliance on herbicides. With less water, the amounts and types of pests and diseases may change as well as predator-pest relationships. In particular, soil and root-borne diseases may increase under non-flooded soil conditions. The impacts of shifts in the use of pesticides cannot yet be predicted.

Managing water resources and irrigation infrastructures

As water becomes increasingly scarce, it must be managed as a scarce resource at farm, system, basin, and national levels. Most of the irrigation water for rice is supplied by state-operated large-scale surface irrigation systems that suffer from a legacy of poor design, degraded infrastructure, poor management, and stagnation. Currently, reformed institutions do not capture the complexities of the hydrological cycle, the multifunctionality of irrigation systems, and service relationships between different levels of management. The challenge is to transform these systems from supply-driven to demand-driven, responsive systems. Their financial, environmental, technical and service performances need to be improved to increase control, reliability, equity and flexibility. This will allow these systems to adapt to changing water allocations, and enable farmers to increase productivity, be more responsive to market opportunities, and adopt new and diversified water management practices. Improved system operation and service delivery can contribute significantly to alleviating waterlogging and salinization, but investment in drainage will be required in salt-affected areas. At the institutional level, the challenge is to develop new frameworks that can manage the complexity of the hydrological cycle, the multiple roles of irrigation systems, and deliver irrigation and drainage services to farmers in an accountable and efficient manner. At the policy level, the challenge is to harmonize water and irrigation policies with agricultural and environmental policies and integrate them into overall socio-economic development policies through strategic planning and management at national policy, river basin and irrigation system levels.

Increasing productivity and protecting the environments of rainfed and unfavourable ecosystems

The productivity of the rainfed and unfavourable ecosystems needs to increase to alleviate poverty and achieve food security for the rural poor. There is a lack of flexible crop and natural resource management techniques to cope with the complexity of the abiotic stresses in these environments. The high variability of rainfed environments exposes farmers to higher risk of losing their inputs. Furthermore, although the adoption of new varieties can be fast, the adoption of new crop and natural resource management techniques is usually slow. They often consist of different elements and farmers need time to familiarize themselves with them and become receptive to them. Although adaptive and participative research in farmers' fields was identified as the most promising approach, clear concepts and methods are neither available nor practised in current research activities. How to transmit the targeted "conditional recommendations" to farmers is a challenge rarely addressed. Simple decision support tools for farmers could assist such site-specific management technologies, but most existing and successful tools address favourable environments. Increased flexibility will also be necessary to help farmers cope with changing and more extreme weather conditions. These could be a result of global climate change and will affect rainfed environments more strongly than irrigated systems.

Another major challenge is to avoid the potential negative environmental consequences of intensification. Agrochemicals are important ingredients of intensified systems but their use must be optimized to minimize harmful effects on the environment and human health. Possibly because rainfed systems are generally perceived as "natural", rice growing environments where no or few agrochemicals are used and traditional varieties dominate, little research has focused on sustainability issues. Emission of methane from rainfed systems was found to be comparatively small, but nitrate accumulation in aerobic phases might contribute to considerable emission of nitrous oxide. Intensification through increased fertilizer use, cropping intensity, and changes in methods of crop establishment will affect such processes considerably. Increased productivity initially based on better varieties and subsequently on (unbalanced) inorganic fertilizer and reduced organic fertilizer use changes nutrient balances and increases the mining of soil nutrients. Reports of quickly emerging, severe nutrient deficiencies after intensification testify that rainfed systems are comparatively fragile because of frequently low natural soil fertility and low buffering capacity.

Climate change

Climate change is expected to increase the frequency of extreme events, such as storms, droughts in dry areas, and heavy rainfall and rainfall intensity in monsoon climates, which will increase the incidence of flooding in low-lying and poorly-drained areas. Sea level rises are expected to increase flood risk and salinity intrusion in delta areas. Rice ecosystems are especially prone to increased salinity intrusion and flooding because of their widespread occurrence in low-lying deltas and inlands. Despite the benefits of elevated CO_2, climate change will reduce yields in most major rice producing regions as a result of higher temperatures, and possibly because of increased UV-B radiation and increased storm damage. Recently, yield reduction in rice has been correlated with increased night-time temperatures. Higher temperatures will reduce crop water use efficiency because of lower biomass production and higher transpiration.

Valuing the ecosystem services of rice landscapes

It has become common to view the supply of environmental attributes and other non-commodity outputs as secondary factors in the pursuit of traditional policy objectives, such as food security and income support. If addressed at all, the focus is likely to be on a single environmental attribute. However, an approach that treats environmental aims and the production of non-commodity outputs as subsidiary factors is an outdated policy paradigm. Although methodologies exist to measure and estimate various services of agricultural systems, quantifying and valuing the positive and negative externalities still present a major problem. The types, magnitudes and values of the ecosystem services often vary geographically, and accurate estimates must be based on regional or local data. In many countries, relevant data at the appropriate geographic level are not available. Furthermore, there is a potential for the erroneous estimate of multifunctional outputs because of double counting, failure to recognize interactions among the outputs, and failure to consider the potential outputs from other uses of the land.

6. Response options

6.1 Varietal improvement

The complete sequencing of the rice genome is expected to accelerate the discovery and exploitation of useful genes in breeding programmes for all ecosystems. However, to enhance identification and adoption of superior varieties, farmers' needs, preferences, and opinions should be taken into account in the selection process, e.g. via farmer-participatory variety selection.

Varietal improvements in irrigated systems

The key factors in the success of the green revolution varieties were increased harvest index and short duration while maintaining yield potential. However, there are no indications that these factors can be further exploited to significantly increase the yield potential of inbred varieties under fully irrigated conditions in the future. For example, since the introduction of IR8, the yield potential of semi-dwarf tropical *indica* inbred rice varieties has stagnated at about 10 t ha^{-1}. The yield potential of longer-duration temperate *japonica* varieties is around 14 t ha^{-1}. Significant yield improvement has recently come mainly from the development of hybrid rice, which has increased yield potential by 5 to 15 percent over inbred varieties in the same ecosystem. Transforming the C3 rice plant into a C4 plant by genetic engineering could be a long-term approach for increasing rice yield potential.

The reduced growth duration of modern high-yielding rice varieties has reduced total outflows of evaporation, seepage and percolation from rice crops. The combined effect is that these varieties have a water productivity with respect to total inputs (irrigation, rainfall) that is three times that of traditional varieties grown under a similar water management regime. The higher harvest index contributed to increased water productivity through higher grain yield per unit water transpired or applied. As for yield potential, there appears to be little scope for further increasing water productivity by further reduction in growth duration or increased harvest index under fully irrigated conditions.

Traditional breeding programmes for irrigated environments have been selected under conditions of continuously ponded water. With increasing water scarcity in irrigated systems, breeding programmes should also include selection under conditions of water saving technologies such as alternate wetting and drying or aerobic cultivation (see below). Some success has been recorded with the development of high-yielding aerobic rice varieties in northern China. Breeding programmes for water-short conditions should focus on maintaining harvest index, seedling survival, and early vigour. A variety of breeding strategies can be explored to increase water productivity with respect to evapotranspiration, such as early vigour to reduce soil evaporation, weed suppression to reduce weed transpiration, and increased waxiness of leaves to reduce non-stomatal transpiration. The modern, improved *japonica* varieties have higher transpiration use efficiencies than the older *indica* varieties, suggesting that significant variation exists for this trait in rice germplasm. The potential for exploiting this trait, however, has not been investigated. Transforming rice into a C4 plant could potentially also increase water productivity, though no evaluation of the effectiveness of such an approach has been made.

Varietal improvements for tolerance to abiotic stresses

For drought conditions, most progress so far has come from the development of short-duration varieties that escape drought at the end of the rainy season. But recently, substantial genetic variability for grain yield under drought stress has been documented and demonstrated to be a moderately heritable trait, with repeatabilities similar to those of yield in non-stress environments. New breeding approaches and improved screening methods are advancing the development of drought-tolerant varieties and need to be expanded to national programmes.

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. However, fast progress is being made with the development of submergence tolerant lines using marker-assisted selection. A first major *quantitative trait loci* (QTL) was fine-mapped, and markers were developed and successfully used to transfer this QTL into a popular rainfed lowland variety. Efforts are currently ongoing to transfer this QTL into other lowland rice varieties. For deepwater areas, some breeding progress has been made and a few new lines with reasonable yield and grain quality have been released. Recently, three main QTLs 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.

Despite its high 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 percent 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, appear very promising. A major QTL was recently mapped and marker-assisted backcrossing is currently being used to incorporate this QTL into popular varieties that are sensitive to salt stress.

Building on this, improved modern-type varieties with an increase in yield potential of about 1 t ha^{-1} should become increasingly available and widespread in drought-, flood- and salinity-prone rice areas within the next ten years. A careful characterization of target areas will be essential for developing effective varieties and management technologies.

Varietal improvement for tolerance to climate change

Preliminary results suggest that there is genotypic variation in the sensitivity to warm night temperature. If this is true, there is a possibility to develop rice varieties that are insensitive to warm night temperature through plant breeding. Moderately large genetic variation in the tolerance to high-temperature-induced spikelet sterility exists among rice genotypes. Selection of rice varieties that flower early in the morning can be an effective way to avoid high-temperature-induced spikelet sterility. Therefore, both tolerance and avoidance mechanisms can be used in breeding varieties that yield well under extremely high temperature. Significant intraspecific variation in yield response with a doubling of current CO_2 levels has been observed in rice. The CO_2 responsive characteristics of older cultivars could, potentially, be incorporated as factors in future varietal selection to maximize the beneficial effect of carbon fertilization.

6.2 Quality improvement

A growing trend in breeding is the effort to increase not only crop yield potential, but also the nutritional value of the food derived from the crop. To alleviate malnutrition, a particular emphasis is to increase the micronutrient density of the edible portions, with specific focus on increasing provitamin A carotenoid, iron, and zinc contents. It still remains to be seen, however, whether these contents can actually be increased in the endosperm as opposed to the bran, to make a significant impact on human health and nutrition, given the almost universal compulsion to eat polished rice. The efforts to increase nutritional value are not expected to have any effect on the water relations of the crop. To drive the adoption of these new varieties, the successful traits will need to be combined with other successful traits, including those that impart drought tolerance. This is especially pertinent as the major target farmers and consumers for more nutritious rice are located in the most disadvantaged zones (rainfed and unfavourable environments), both in terms of poverty and crop production resources.

7. Field management to increase yield and water productivity

Water-saving technologies and holistic approaches for irrigated ecosystems

A suite of so-called “water-saving technologies” exists, or is being developed, to assist farmers to cope with various degrees of water scarcity in irrigated ecosystems. These water saving technologies increase water productivity with respect to total water inputs (rainfall, irrigation), mainly by reducing seepage and percolation flows, and to a lesser extent by reducing evaporation. General measures such as land leveling, farm channels, good puddling and bund maintenance improve water control and reduce seepage and percolation outflows. Minimizing the turnaround time between wet land preparation and transplanting can be accomplished by the adoption of community seed beds or adoption of direct seeding. Direct dry seeding can increase the effective use of rainfall and reduce irrigation needs. Mechanical soil compaction can reduce percolation flows in certain soil types. Chemical evaporation suppressants have been tested in flooded rice fields but financial and environmental impacts have not been assessed. Water management techniques such as saturated soil culture and alternate wetting and drying, can reduce field water application by 15 to 20 percent without significant impact on yield. Alternate wetting and drying has been widely adopted throughout China and can now be considered the common practice of lowland rice production. In the system of aerobic rice, specially adapted "aerobic rice varieties" are grown under dryland conditions just like other cereals such as wheat, with or without supplemental irrigation. Currently, yields of aerobic rice systems can be up to 20 to 30 percent lower than continuously flooded systems with conventional lowland varieties, while water inputs can be reduced by 30 to 50 percent. In aerobic rice systems, resource-conserving technologies, as practised in upland non rice crops, become available to rice farmers as well, such as mulching, zero tillage and minimum tillage. Growing rice under aerobic conditions on raised beds shows promise but is still in its infancy with many challenges to be overcome, including micronutrient deficiencies, biotic stresses, yield sustainability and identification of optimum irrigation management where limited irrigation water is available. The development of management technologies needs to be integrated with characterization of the water-short target environments and the selection or breeding of appropriate varieties for target environments. The example of aerobic rice is a case in point.

Increasingly, technologies that aim to close the gap between actual (farmers') yields and yield potential need to apply holistic approaches that integrate various components of crop, soil and water management. Other examples are the system of rice intensification (SRI), site-specific nutrient management and integrated crop management. Depending on baseline conditions, yield increases of 10 to 100 percent have been reported with these technologies. Though water flows have hardly been studied in these integrated yield-improving technologies, it is likely that yield increases are accompanied by relative increases in transpiration, and by relative decreases in evaporation, seepage and percolation. In terms of water savings, any agronomic practices that increase harvest index will result in more grains per unit water transpired and hence increased crop water productivity. The system of rice intensification includes the water saving practice of alternate wetting and drying and has been shown to decrease water inputs at the field level. The appropriateness of each (integrated) technology or system depends on the nature and severity of water scarcity, farmers' current practices, soil properties, and hydrological boundary conditions (groundwater table depth, rainfall). The attractiveness of the technologies depends on profitability, risk perception and ease of adoption by farmers. The technologies need to be carefully targeted and widely tested and improved using farmer participatory approaches.

Sustainability and environmental protection under water scarcity

While relatively 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 type, amount, timing and method of application of organic and inorganic N fertilizers, water management and crop residue management on the one hand, and yields and yield sustainability, greenhouse gas emissions and pathways of N losses on the other. The effectiveness of fertilizer management technologies such as site-specific nutrient management, leaf color chart, slow-release fertilizers, and deep placement, need to be evaluated under various conditions of water scarcity from saturated soil to alternate wetting and drying to fully aerobic soil conditions. Little is known about changing pest dynamics when field conditions change from water-abundant conditions to water-short conditions. Under increasing aerobic soil conditions, pest and disease management technologies used for dryland crops may become relevant for rice. Technologies based on integrated pest management need to be tested under water-short conditions. The development of appropriate crop rotations needs attention.

Increasing productivity in the rainfed and unfavourable ecosystems

The development of varieties that are tolerant to abiotic stresses will have considerable impact on many unfavourable environments. Input-responsive varieties, shorter duration, and reduced risk increase the incentive to use external inputs and to intensify the cropping system. Adjusted management technologies will be needed to make the best and most efficient use of the possibilities offered by the new varieties. These technologies should aim at reducing stress intensity, enhancing survival and robustness of the crop to withstand stress and stabilize yields, and avoiding stress occurrence at sensitive crop stages. Because of the complexity of the systems to be targeted, very close cooperation between breeders, agronomists, social scientists, and farmers will be necessary to produce relevant results.

For the drought-prone rainfed lowlands, two promising technologies are direct seeding and improved nutrient management. Direct seeding potentially offers better use of early-season rainfall, better drought tolerance as a result of better root development, lower risk from late season droughts, better use of indigenous soil N supplies, and an increased chance for a second crop after rice. Site- and season-specific nutrient recommendations can reduce nutrient losses and chemical pollution of the environment by allowing for the natural soil fertility and the likely field water supply, combined with an appropriate rice variety. Both technologies have already enabled substantial productivity increases in some more favourable rainfed systems. In Indonesia (Lombok), the introduction of short-duration and input-responsive varieties with direct seeding and the use of inorganic fertilizer increased and stabilized yields in the *gogorancah* system. In Lao PDR, rainfed lowlands contributed considerably to achieving self-sufficiency in rice within a decade after the introduction of improved varieties and crop management. Similar successes should be feasible in drought-prone lowlands in eastern India. Smaller and slower progress characterizes more unfavourable environments, but while yields and cropping intensity have been almost stagnant in most irrigated systems for the past two decades, they started to increase faster in rainfed systems about twenty years ago. Technologies based on integrated pest management should also be further explored for the drought-prone lowlands.

In the submergence-prone environments, the combination of new submergence tolerant varieties with adapted crop management and nutrient management can improve seedling and plant survival as well as the ability to recover after submergence. Seedlings enriched in nutrients, particularly zinc and phosphorus, and possibly silicon, have greater chances of survival because they have enhanced growth and accumulated higher carbohydrate reserves. Application of certain nutrients after the recession of flood water also helps in faster recovery, better tillering and higher grain yield.

Because the ponded water leaches accumulated salts from the topsoil, lowland rice is the only cereal cropping system that has been recommended as a desalinization crop. Soil amendments, particularly gypsum, assist in reclaiming salt-affected soils but require large investment. New approaches involving the use of farmyard manure, pressmud from industrial waste, and tolerant varieties can help reduce the need for gypsum by more than 50 percent. The integration of tolerant varieties with specific nursery management, crop and nutrient management strategies are needed to enhance crop survival and productivity, mitigate salt stress and improve soil quality.

Lowering cost of production and labor requirements

Many integrated crop management practices aim not only to increase yield, but also to increase the efficiency of resource inputs, thereby lowering the cost of production. Where irrigation water is supplied by pumping, water-saving technologies reduce water inputs, pumping costs and energy consumption. Whether this actually increases profitability depends on the yield obtained and the relative price of rice and water/pumping. Reducing the frequency of irrigation reduces the labour use for irrigation. On the other had, when fields are not continuously flooded, weed infestation may increase and more labour or herbicides may be required. The system of rice intensification has relatively high labour requirements and abandonment of the system has been reported in its country of origin, Madagascar. Conversely, the adoption of labour-saving practices can impact on the way in which water is used. For example, studies in the Philippines and Malaysia show substantial irrigation water savings with dry (direct) seeding. However, it is not clear whether changing to direct seeding will save water everywhere. Dry seeding and aerobic rice technologies offer possibilities for mechanization of farm operations such as seeding, weed control and combine-harvesting (which is easier on firm dry land than on lowland soil that may still be relatively wet). So far, however, few studies have reported the trade-offs between reduced inputs (e.g. water, labour, energy) and impacts on yield, and more effort is needed to identify win-win (e.g. more profitable, more convenient to the farmer) situations. With increasing feminization of the rural labour force, women need to be involved in the development of suitable production technologies.

8. Options at the landscape level

Irrigation systems

Rice irrigation systems are characterized by large volumes of water in circulation through surface drainage, seepage and percolation from the flooded rice fields. In many systems in low-lying deltas or flood plains with impeded drainage, the continuous percolation of water has elevated groundwater tables close to the soil surface. Water-saving technologies at the field level mainly reduce seepage and percolation flows from the field. Because these flows can often be recaptured downstream, they may not contribute to water savings at higher spatial scales such as the irrigation system. Recent studies of rice-based irrigation systems in China, the Philippines and Sri Lanka indicated that irrigation efficiency improves with increased area of spatial domain because of the reuse of water. In some situations, reducing percolation from rice 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. On the other hand, lowering of the groundwater table may reduce direct evaporation from the groundwater, which is a true water-saving since it reduces a non-beneficial depletion flow. Evaporation may also be reduced from rice fields using water-saving technologies. Alternate wetting and drying has been found to reduce evaporation by 0 to 30 percent, compared with reductions of 50 to 75 percent in aerobic rice. Overall, there is still very little understanding of the potential impacts of adopting field-level water-saving technologies on the water dynamics, water balance and water productivity of irrigation systems as a whole.

More systematic evaluations are needed to understand the water balance dynamics and productivity of water at various scales of the irrigation system. Application of new concepts of irrigation efficiency that take into account the return flows (irrigation water run-off and percolation that re-enters the water supply to fields), are needed in designing interventions for improving total water use efficiency at the system scale. It is important to select the appropriate set of water balance and water productivity indicators, specify the spatial domain of interest and the interactions (agrohydrological, socio-economic and environmental) across spatial and temporal scales among the users of water. A system's approach is essential to determine water balance related objectives and water management strategies to achieve them. These strategies should aim at improving water control, equity, reliability and flexibility of service to allow farmers to make choices of crop and water management. Major options for improving irrigation systems include conjunctive use of surface and groundwater, recirculation of drainage, buffer reservoirs at appropriate levels in the systems, improved design of control structures, investment in drainage, operation and ordering procedures and intensification of irrigation system management. The gap is in capacity building of the irrigation profession at large and a critical required action is the revision of design standards.

Rainfed and unfavourable environments

There are many interventions at the landscape level that are effective in alleviating field-level abiotic stresses, and in increasing land and water productivity in rainfed and unfavourable environments. On-farm water harvesting is an effective means of reducing risk and increasing productivity in drought-prone rainfed environments. The development of reservoirs and canal networks to store fresh water from rain or rivers before they become saline can help extend the growing season in saline coastal areas and can substantially improve productivity. The main constraints to technology adoption are related to socio-economic and organizational issues. Therefore, increased use of this option seems to be more dependent on local decision-makers and national governments than on any other factor.

Water management through large-scale construction of coastal embankments and sluices has been reasonably successful in preventing seawater intrusion in many deltaic coastal areas, substantially reducing soil salinity in the wet season. Coastal embankments have increased rice yields in coastal Bangladesh by more than 200 percent in 20 years. The technology also opens up the possibility of growing high yielding, modern rice varieties in these areas, as in the coastal areas of the Mekong Delta, Viet Nam. However, water needs to be managed judiciously to avert undesirable long-term environmental consequences and local conflicts with other water users, especially the landless poor who depend on brackish water fisheries for their livelihoods.

Ecosystem services (multifunctionality)

The concept of ecosystem services, or multifunctionality, was conceived to give recognition to the environmental attributes of crop production such as rice production. More recently the interest in multifunctionality has taken on a policy emphasis as governments, particularly in East Asia, seek to provide a rationale for farm subsidies. However, as we move to an era of scarcity and increasing competition for water, greater emphasis needs to be given to both positive and negative externalities of water in rice-based landscapes. This will require greater emphasis on appropriate data collection to facilitate the estimation of ecosystem services. 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. Finally, agricultural policies should be implemented that explicitly consider the multiple outputs of rice production.

9. Creating incentives for improved water management

Farm and village level

For farmers who are already directly confronted by water scarcity, further incentives to improve water management may not be necessary — the cost of acquiring water is sufficient incentive. For example, many farmers using pump irrigation already face a positive marginal cost every time they irrigate their fields. On the other hand, where gravity flow irrigation is provided free to farmers, or at low fixed fees, or where electricity for pumping is subsidized, farmers lack incentives to manage water carefully. This is not a problem where water is locally abundant. However, in many cases, water is abundant upstream but scarce downstream (for either farm uses or non-farm uses) and the lack of incentives to save water upstream becomes a problem. One option is to volumetrically price water. However, the majority of the world's rice is grown on small farms and the cost of volumetrically pricing at the farm level is prohibitive. In this situation, it is possible to volumetrically price to the village or irrigation association. The savings may be retained by the village or association or rationed among users.

Allocation among sectors

Where there is sufficient demand for water from the industrial and domestic sectors, water is often allocated out of agriculture by administrative fiat. Administered prices or tradable water rights may provide an incentive for reallocation of water at the irrigation system or basin level. The incentive for irrigation managers to reallocate water can impose scarcity at the farm level and encourages farmers to adopt water-saving practices, technologies, or cropping systems.

Virtual water

Other solutions to water scarcity skirt the difficult problems of raising prices, instituting a system of legal rights, or administratively restricting water allocations. One of the most promising is trade in "virtual water". This involves trading commodities where the production is relatively water intensive (e.g. rice) instead of trading water itself for which transportation costs are usually prohibitive. In the world rice economy this already happens to an important extent. The water-scarce Middle East is one of the biggest rice importing regions of the world. Mainland Southeast Asia (Myanmar, south China, Thailand and Viet Nam) has an abundance of water resources, and rice exports from these countries can help alleviate water shortages in other countries. But international trade is still restricted, and much more trade in virtual water could profitably occur.

Public and private sector

There is a growing interest in irrigation management transfer, and governments are attempting to transfer management and some of the financial burden for operation and maintenance of irrigation systems to water user groups. Meanwhile there has been a rapid private sector increase in pumps and tubewells, much of it within surface irrigation systems. There is a need to integrate the management of surface and groundwater resources to avoid overexploitation, equitable access to water, and to ensure that users have the flexibility to shift from rice to high-value crops. Given the financial constraints facing the public sector in many economies, it may well be that in the future the private sector will play a stronger role in operation and maintenance, and water users will pay private sector entities for services delivered.

Rural development

We have emphasized the challenges caused by urbanization: the ageing and feminization of the agricultural sector. Nevertheless, close to half of the labour force and the majority of the poor remain in rural areas. Fostering rural development requires investment in rural infrastructure (roads, electricity, communications, and irrigation) and in human capital (education and health). Such investments will result in employment and income gains in the rural non-agricultural sector strengthening the demand for both agricultural and industrial products.

New priorities for research

With the decline in funding for research, those areas with potential for increasing production must be carefully targeted. Scientists disagree on the potential for increasing production in the irrigated as opposed to the rainfed areas. However, the need for production increase is clear in both the irrigated and rainfed areas. Gains in production in the past have typically come from increasing area and land productivity (yield). However, as other resources have become scarce, productivity must be examined in a broader context. Reflecting the growing scarcity of labour and water, development and dissemination of labour-saving and water-saving management practices and drought-tolerant rice varieties are priority areas for research.

Key trends affecting agricultural water resources management in Southeast Asia

David Dawe[3]

1. Introduction

In a market economy, the most important function of agriculture is to provide food for people. Consumer demand is thus an important driver of agriculture. Tastes and preferences obviously vary from country to country and even between provinces or states within a country. Nevertheless, incomes permitting, consumers the world over have shown a nearly universal desire for a varied diet. If farmers cannot produce the variety that private consumers want at reasonable prices, then agriculture is doomed to stagnation, and it will ultimately be unable to provide a sustainable living to farmers. Of course, it is possible for farmers to produce what the government wants (instead of what consumers want) for some period of time, but government demand and subsidies are not likely to be sustainable. For example, after many years of farm subsidies, the New Zealand Government was eventually forced to abandon them in 1984 in order to avoid a fiscal crisis.

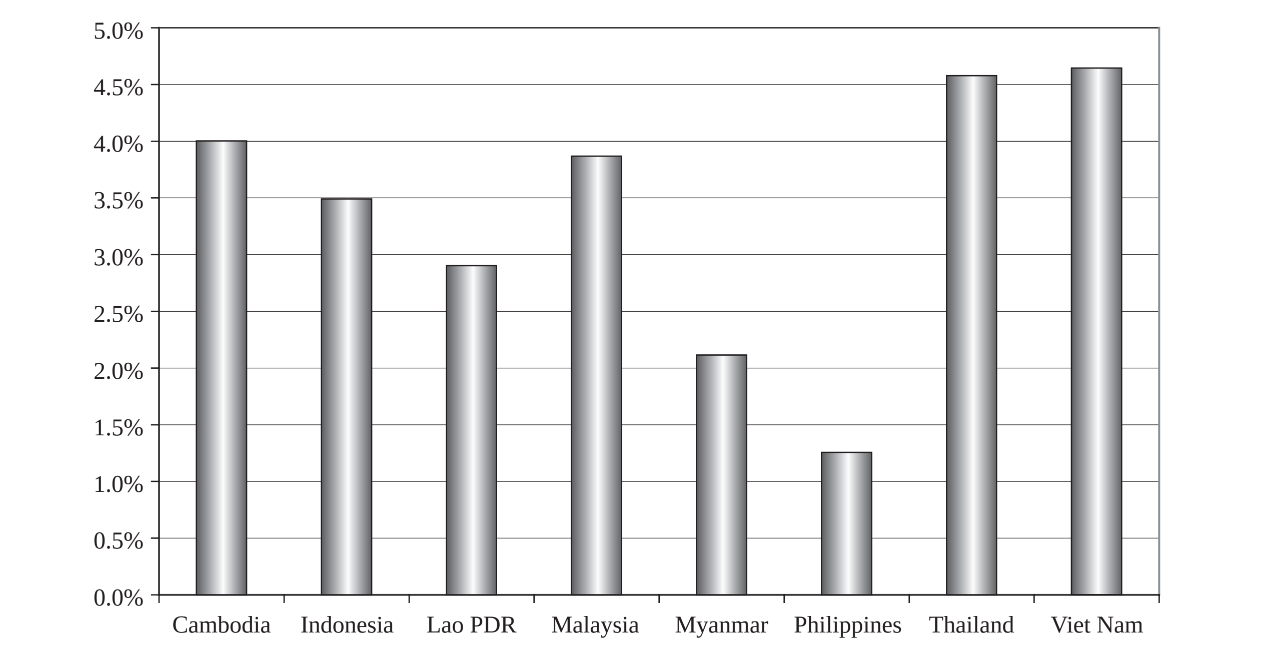
Whereas consumers want to diversify their diets, the vast majority of farmers want to leave agriculture altogether whenever it is possible. They want to leave agriculture in order to escape the drudgery of farm labour and to have a chance at earning the higher incomes that are possible in non-agricultural work. There are not many farmers in Asia whose ambition it is to have their children continue to work in the fields. Farmers understand that in the economy of the future, it will not be enough simply to own one or two hectares of land. In other words, if land is the only asset one possesses in addition to the physical power of the body, it will be impossible to escape poverty.

Economic growth is the most important factor that determines whether or not consumers and farmers can satisfy these desires. Fortunately, despite the financial crisis that gripped the region in 1997, economic growth has been quite rapid in most of Southeast Asia during the past 40 years or more (Figure 1). These rates of growth cumulate strongly over long periods of time. For example, per capita GDP in Thailand, after adjusting for inflation, was nearly seven times higher in 2003 than it was in 1960.

In addition to rapid income growth, urbanization is also proceeding rapidly (Table 1). It appears to be proceeding more rapidly in insular Southeast Asia (Myanmar, Indonesia, Malaysia, and the Philippines) than in mainland Southeast Asia (Cambodia, Lao PDR, Myanmar, Thailand, and Viet Nam). As urbanization proceeds and job opportunities outside of agriculture expand, farms will need to become more commercially oriented in order to supply food to people who no longer work or live on farms. As consumer demand for convenience increases, agro-industries will develop to create more highly processed food, and farmers will need to pay more attention to quality in order to sell their output.

In addition to affecting consumer demand for food, and farmers' occupational choices, economic growth and urbanization also profoundly affect the supply of water available for agricultural use, because of rapid growth in demand for water for industrial, household, and environmental purposes. The objective of this paper is to explore what considerations agricultural water managers will need to take into account in order to effectively deliver services to farmers and society, given the rapidly changing world around them that is being created by economic growth and urbanization. The first section will explore the nature of three key macro trends — the declining relative importance of agriculture, changes in consumer food demand, and increased trade. The second section will discuss the implications of these macro trends for farm households and irrigation system managers.

[3] Senior Food Systems Economist, Food and Agriculture Organization, Regional Office for Asia and the Pacific, Bangkok, Thailand.



Notes: Because of lack of data availability, growth rates were calculated for shorter periods as follows: Cambodia (1993 to 2003), Lao PDR and Viet Nam (1984 to 2003), Myanmar (1960 to 2001).
Source of raw data: World Bank (2005).

Figure 1. Average annual growth rates of per capita GDP, 1960 to 2003

Table 1. Urbanization rates in Southeast Asia, 1961, 1990, and 2004

Country	1961	1990	2004
Brunei Darussalam	0.44	0.66	0.77
Cambodia	0.10	0.13	0.19
Indonesia	0.15	0.31	0.47
Lao PDR	0.08	0.15	0.21
Malaysia	0.27	0.50	0.65
Myanmar	0.19	0.25	0.30
Philippines	0.30	0.49	0.62
Thailand	0.20	0.29	0.32
Viet Nam	0.15	0.20	0.26

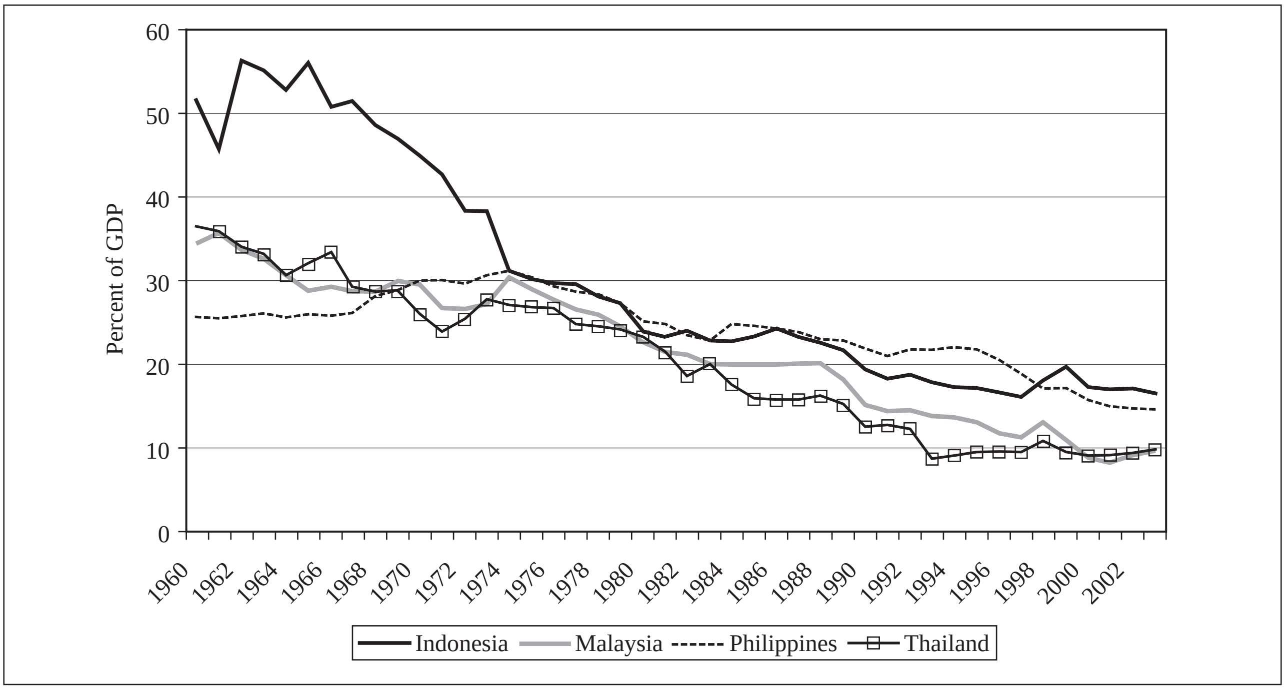
Source of raw data: FAO (2005).

2. Key macro trends driving Southeast Asian agriculture

2.1 The declining relative importance of agriculture

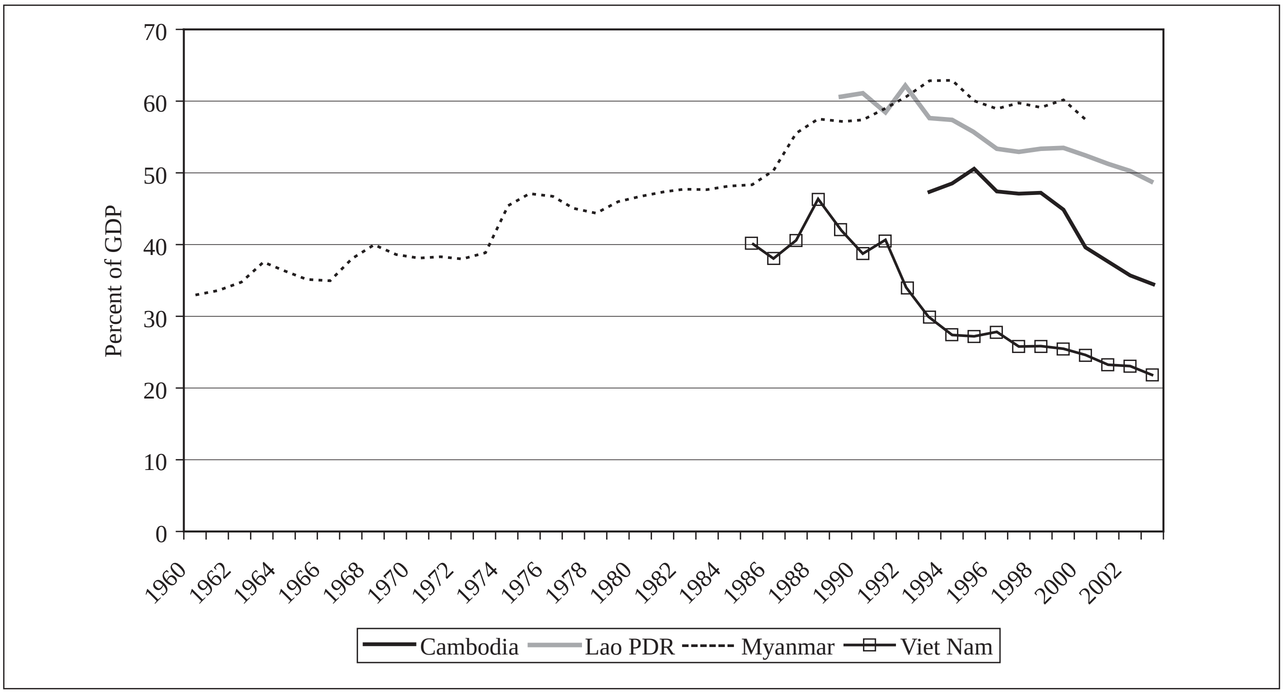
Along with the economic growth noted above, the importance of agriculture to national economies, measured as a percentage of GDP, has consistently declined (Figures 2a and 2b). The share of agriculture in the labour force, although greater than the share of agriculture in GDP, is also declining (Figures 3a and 3b). This decline in the relative importance of agriculture is not unique to Southeast Asia — it is a fundamental feature of what is known as the structural transformation in economic development, and it has occurred in all countries around the world that have experienced economic growth.

This structural transformation does not mean that the agricultural sector has contracted. Indeed, the agricultural sector has grown substantially in Southeast Asia since at least as far back as 1960. For example, the value of agricultural output in Thailand is nearly five times as large today as it was in 1960. In both Indonesia and the Philippines, it is more than three times as large. However, its growth has been less rapid than that of the industrial and service sectors, so its *relative* importance has declined.



Source of raw data: World Bank (2005).

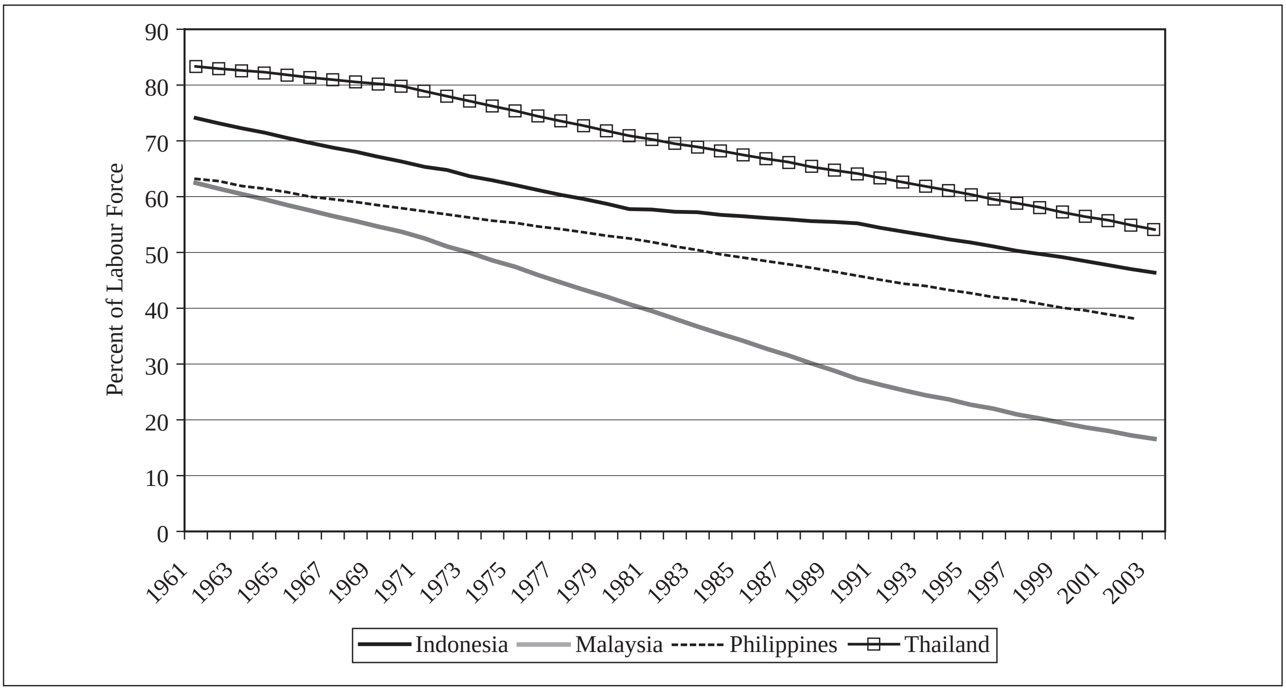
Figure 2a. Agriculture's share in GDP, 1960 to 2003



Source of raw data: World Bank (2005).

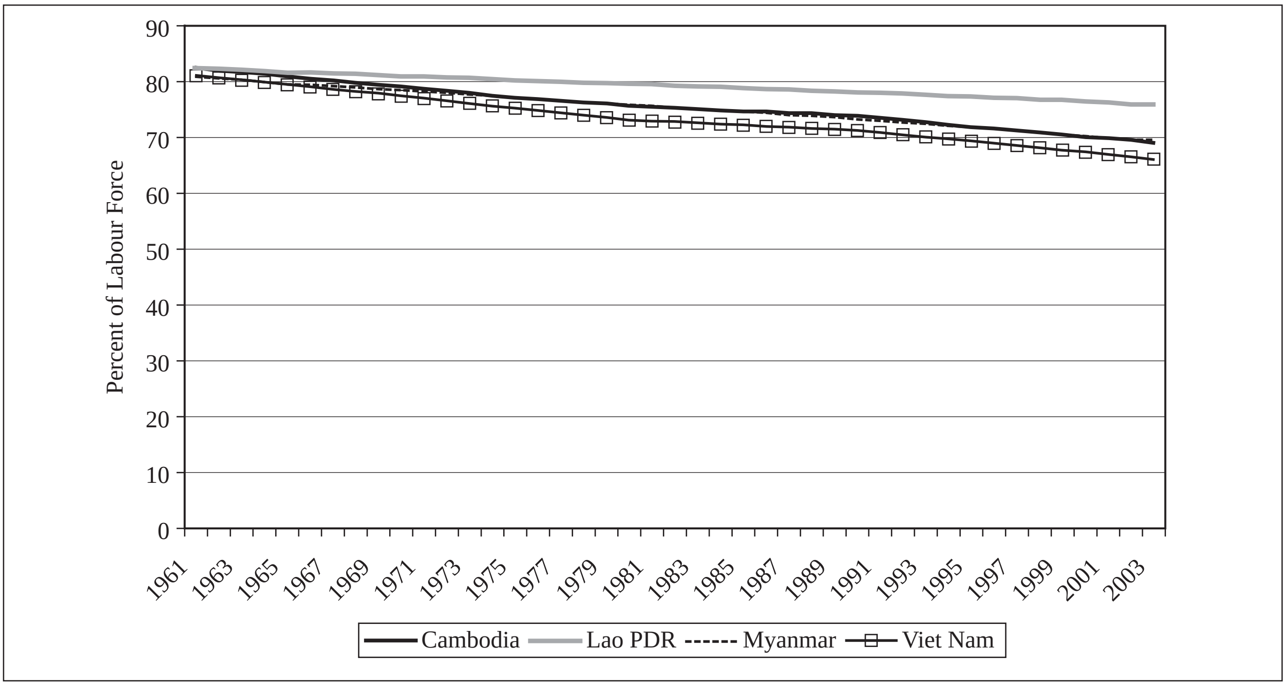
Figure 2b. Agriculture's share in GDP, 1960 to 2003

The decline in relative importance suggests that agriculture will receive a diminishing share of government resources, as indeed it should. This may or may not mean a decline in absolute levels of funding, because economic growth can make the pie bigger for everyone. But regardless of whether government support to agriculture increases, declines or remains roughly constant, agriculture remains a key sector of the economy. It still comprises anywhere from 10 percent of the economy (in Malaysia and Thailand) to nearly 50 percent in Lao PDR. Given this importance, continued agricultural growth is critical for the overall health of the economy and for poverty alleviation. But it will be a challenge to maintain this growth and services to farmers in the face of shifting budget priorities.



Source of raw data: FAO (2005).

Figure 3a. Agriculture's share in the labour force, 1961 to 2003



Source of raw data: FAO (2005).

Figure 3b. Agriculture's share in the labour force, 1961 to 2003

2.2 Consumer food demand is changing

Income growth leads to many changes in diets. For example, Bennett's Law states that the proportion of starchy staple foods (grains, roots and tubers) in total calories declines as income increases (Timmer *et al.*, 1983). This decline has occurred in all countries in Southeast Asia during the past twenty years (Table 2; FAO, 2004).

Table 2. Percentage of calories coming from starchy staples, 1979–82 and 2000–02

Country	1979–82	2000–02
Cambodia	88	78
Indonesia	75	70
Lao PDR	86	77
Malaysia	52	47
Myanmar	80	73
Philippines	59	56
Thailand	67	50
Viet Nam	84	72

Source of raw data: FAO (2005).

Within the category of starchy staples, diversification also occurs with increases in income. For example, in southern India, the importance of rice is declining as consumption shifts toward wheat. But, in northern India, where wheat is the traditional staple, demand is shifting from wheat to rice (Pingali and Khwaja, 2004). A similar trend is taking place in northern and southern China. In Southeast Asia, where rice is the staple food and wheat is not even grown, a shift from rice to wheat has been taking place in several countries. The process is well underway in Indonesia, Malaysia, the Philippines and Thailand, is just starting in Viet Nam, but has not yet begun in Cambodia, Lao PDR and Myanmar (Figure 4). Some of the shift from rice to wheat products may also be a result of increased convenience in terms of less preparation time, which is important as populations become more urbanized.

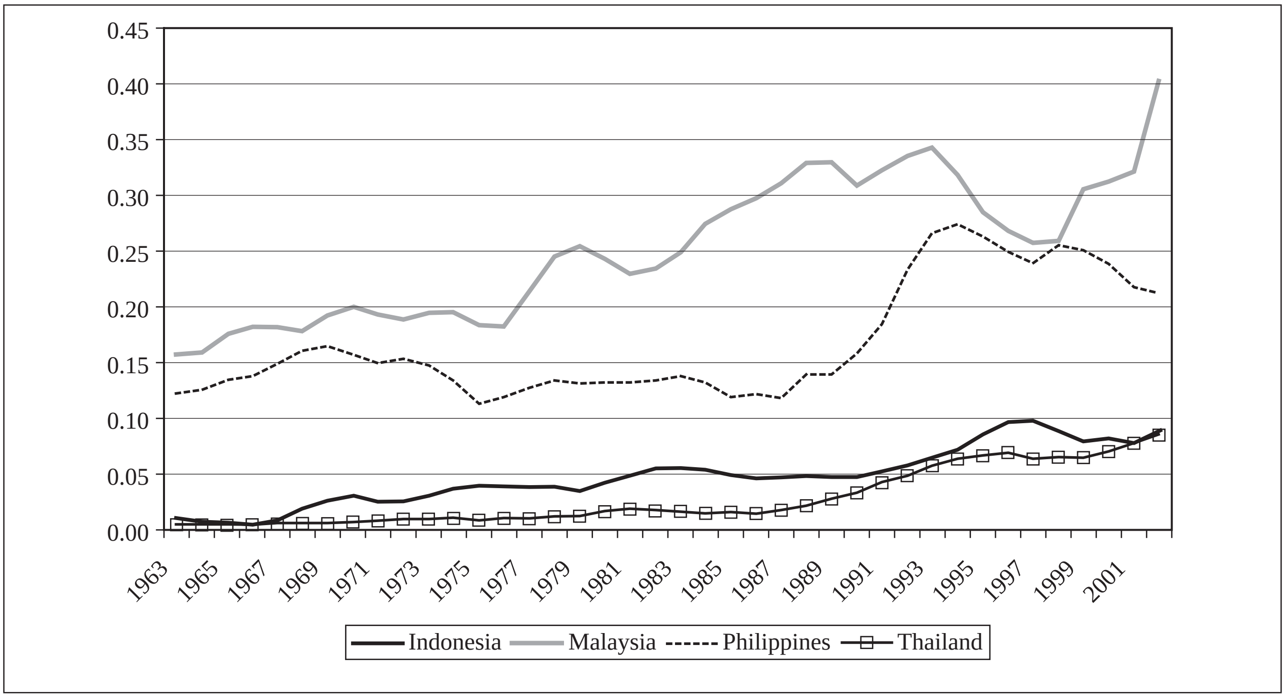


Figure 4. Calories from wheat relative to calories from rice (percent), lagged three year moving average, 1963 to 2003

The shift toward wheat and away from rice in Southeast Asia is because of demand shifts for both rice and wheat. First, per capita demand for rice has stagnated in most countries, and has sharply declined in Malaysia and Thailand, the two wealthiest economies in the region. The only factor now sustaining growth in rice demand in Southeast Asia is population growth, but this is slowing in most of the region. Second, per capita consumption of wheat has increased strongly since the middle of the 1980s, when world market wheat prices began to fall to very low levels. Ignoring the years of the world food crisis (when prices were very high), world wheat prices averaged approximately US$367 per tonne (in 2004 dollars) from 1957 to 1981. Just four years later, by 1985, prices had declined to US$238 per tonne, and they remained in the vicinity of US$200 per tonne for most of the next decade, before they fell again to current levels of about US$150 per tonne. This decline in prices made wheat much more affordable to the people of Southeast Asia, accelerating a process that would have occurred anyway, eventually. For example, Malaysian wheat consumption has been on an increasing trend for at least the past forty years, well before the fall in wheat prices or the beginning of globalization. Indeed, the increase in wheat consumption during the past two decades occurred even while the world price of wheat increased relative to the world price for rice by a substantial margin (i.e. world rice prices declined even faster than world wheat prices).

Despite the shift away from rice and towards wheat, rice will remain the staple food for the foreseeable future in Southeast Asia. Even in Japan, where income levels are much higher than in Southeast Asia, rice still provides considerably more calories than wheat. Nevertheless, rice will not be a source of dynamic consumer demand in the region, and wheat cannot be grown profitably in Southeast Asia. Thus, farmers will need to explore alternative crops to meet consumer demand.

During the past twenty years, there has been a sharp increase in consumption of fats also. For Southeast Asia as a whole, average daily fat consumption increased from 29 grams in 1975 to 54 grams by 2002, with all countries experiencing increases. Much of the increased consumption has come from animal products, but a large proportion also has come from vegetable oils (animal products supplied 30 percent of fat in 2002, compared to 28 percent in 1975). The percentage of calories in the diet coming from fat also has increased substantially since 1980 in most countries in the region, although levels remain well below the 37 percent observed in the United States. It is an open question how far this trend will continue. For example, it reached a peak of 33 percent in Malaysia in 1990, but has declined since then to a level of 26 percent. In Japan, the percentage is 28 percent, much below levels in Australia (39 percent) and New Zealand (32 percent). Thus, it is not clear that Asian diets will become as fatty as those in Western countries. However, it does seem likely that fat intake will continue to rise in Southeast Asia for some time to come, as the current percentage of calories coming from fat in the region is just 18 percent.

Protein consumption also increased substantially from 1975 to 2002, from 46 to 63 grams per capita per day. Again, all countries in the region experienced increases. The percentage of protein that comes from animal sources increased from 23 percent to 27 percent since 1986.

2.3 Increasing domestic and international trade

Whereas the agricultural sector in general will need to become more diversified to meet demand, individual farms and regions may become increasingly specialized in particular crops. Trade, both domestic and international, will thus play a greater role in supplying consumers. Indeed, the importance of trade has increased rapidly in Southeast Asia during the past 20 years. International trade in agriculture (the average of agricultural imports and exports) increased from 47 percent of agricultural GDP in 1981–83 to 89 percent in 2001–2003.

Although data on domestic trade flows are not as readily available, the available literature shows that domestic markets have become more integrated. This is not surprising given the massive increases in domestic communications and transportation infrastructure (Rashid *et al.*, 2005). Even for an export-oriented crop like oil palm in Indonesia, nearly one-third of the massive increase in production since 1970 has been used for domestic supply, which usually involves transportation from producing areas, e.g. Sumatra, to consumption areas on Java.

3. Implications for farm households and irrigation system managers

3.1 Crop diversification and competition for water

Within agriculture, staple crops are becoming less important because of changing demand and downward trends in rice prices on the world market. For example, Isvilanonda *et al.* (2000) conducted repeat surveys of three villages in the province of Suphan Buri in the Central Plain of Thailand in 1987 and 1998. They report that the percentage of farmers that exclusively planted non-rice crops increased from 1 percent in 1987 to 17 percent in 1998. A similar, but smaller, change occurred in Khon Kaen Province in the Northeast. For Southeast Asia as a whole, the share of agricultural cropped area planted to starchy staples (rice, coarse grains, roots and tubers) declined 15 percentage points (from 70.6 percent of total area to 55.5 percent) between 1961 and 2004. Thus, farmers will increasingly demand irrigation that is more flexible (e.g. suitable to crops other than rice and cereals).

For the many farmers who continue to plant rice (rice still accounts for 43 percent of total cropped area in Southeast Asia), more reliable irrigation may be needed to prevent plant stress in the face of increased competition for water use from other sectors. On average, competition from other sectors may not be a major problem in Southeast Asia. Actual consumptive use of water for irrigation is expected to grow more slowly than for other uses, but it is still expected to grow, not shrink (from 85.5 km^3 in 1995 to 91.9 km^3 in 2025; see Table 4.6 in Rosegrant *et al.*, 2002). Nevertheless, in certain circumstances, increased competition for water from industry and households will be a constraint for farmers. This competition will be particularly acute near urban areas and in years of drought (caused, for example, by El Niño).

Farmer demand for increased flexibility and reliability in water deliveries has contributed to the spread of pump irrigation, as has the increased availability and lower prices of such pumps, many of which come from two concentrated industry clusters in China, one in Zhejiang and the other in Fujian (Huang, 2004). In Viet Nam, the number of pumps more than quadrupled in just 11 years (1988 to 1999), from 124 thousand to nearly 800 thousand. Pumps are especially common in southern Viet Nam (Viet Nam General Statistical Office, 2000). Similar trends have been documented for Bangladesh. In the Philippines, approximately 23 percent of rice farms now use pumps to access water, either from subsoil reservoirs, drainage canals, or natural creeks and rivers. Among these three sources, groundwater is the most important (Dawe, 2005). The increased prevalence of pump irrigation is creating challenges for surface water managers to manage water conjunctively.

3.2 Labour scarcity and the increasing importance of non-farm income

In parallel with trends in the macro economy, farm households throughout Asia are diversifying their income sources outside of agriculture. Hossain *et al.* (2000a) report that the percentage of household income coming from agriculture in Central Luzon, Philippines, declined from 64 percent in 1985 to 40 percent in 1997. In Bangladesh, the share of rural household income coming from agriculture declined from 63 percent in 1987/88 to 54 percent in 1994/95 (Hossain *et al.*, 2000b).[4]

Labour scarcity is increasing in most of Asia, making it more difficult to hire farm labour. For example, agricultural wages in the Philippines, adjusted for inflation, were 60 percent higher in 2002 than in 1981. Fan *et al.* (1999) show data for India that rural real wages were 63 percent higher in 1993 than in 1970. Sombilla and Hossain (1999) show similar trends for Thailand and Bangladesh. Thus, although demands for flexible and reliable irrigation increase, farmers will be less willing to devote their own scarce time to manage irrigation (because of the increased importance of non-agricultural income in their livelihoods noted above) and will find it difficult to hire labourers to do it for them. Increased labour scarcity and the increased importance of non-agricultural income to rural livelihoods have deep implications for the design of schemes (e.g. participatory irrigation management and irrigation management transfer) to devolve managerial and financial responsibility for irrigation systems. Although governments have fiscal incentives to devolve such management, it is not clear that rural households have incentives to spend the time required to manage these systems effectively. This problem may account for the fact that studies of participatory irrigation management (PIM) and irrigation management transfer (IMT) have typically been unable to demonstrate gains in efficiency as a result of the new management system (e.g. Vermillion, 1997).

[4] Bangladesh is obviously not part of Southeast Asia. However, the trends affecting South Asia are similar to those affecting Southeast Asia. Because of a scarcity of data on some of the important trends, this paper on occasion cites data from South Asian countries for illustrative purposes.

An alternative institutional arrangement that shows some promise is described and assessed in Wang et al. (2003). In some irrigation systems in China, surface water management for a village (or other unit) is contracted to a single individual, the water manager. Farmers in the village pay water fees based on historical averages of how much water they have used, and these fees are given to the water manager. This system gives no incentives for farmers to conserve water. On the other hand, the irrigation manager is required to pay only for the water delivered to the village. If the water delivered to the village is below historical norms, then the water manager can keep the difference, generating incentives for the water manager to conserve water without reducing deliveries so much that farmers demand his replacement. Using multivariate statistical analysis, the authors found that systems where water managers have these types of incentives use less water, after controlling for a variety of other influences. This is an emerging institutional form in China, and it is not clear how widely it has spread. It is very similar to a system of water rights (Rosegrant and Binswanger, 1994), but instead of vesting such rights legally in each farmer (which might be very expensive when farm sizes are small, the rights are vested in the community, which can then temporarily assign them to individuals. Such institutional innovation has the potential to be very effective at conserving water (Dawe, 2005).

3.3 Land consolidation, aging, and feminization

Increased commercialization and specialization, along with migration to urban areas, is likely to result in land consolidation and larger farm sizes in the future. Such consolidation might make it easier to manage irrigation water deliveries, but it should be noted that the process is proceeding slowly. For example, even in Japan, a relatively wealthy country where one might expect the process to be most advanced, average farm size has increased from 0.99 hectares in 1956 to 1.59 hectares in 2003 (raw data from MAFF, 2004). This represents a cumulative increase of about 60 percent, which seems large, but in absolute terms the increase of 0.6 hectares in nearly half a century seems quite small. The situation is similar in the Republic of Korea, where average farm sizes have been steadily increasing from 1970 (0.88 hectares) until 2002 (1.46 hectares; Fan and Chan-Kang, 2003).

Land consolidation is already underway in some parts of Southeast Asia. In the Muda Irrigation System in Malaysia, many groups of farmers have contracted out operations of their farms to others, who then manage the farms as a block. Here, although there has not been large scale transfer of ownership because of land laws, management consolidation is being achieved.

Farm sizes in Thailand at the national level are still declining, according to the most recent data from the 2003 Agricultural Census.[5] But in some dynamic agricultural areas of the country, such as Suphan Buri Province in the Central Plain about 150 kilometres north of Bangkok, average farm sizes increased from 3.8 hectares in 1993 to 4.0 hectares in 2003. This is not a large increase, but it is an increase nonetheless, and it is likely the beginning of further consolidation. The total number of farm holdings declined by 11.5 percent, as many small farmers moved to non-farm employment, either in Bangkok or rural areas. Although some of the land formerly farmed by these households is no longer used for agricultural purposes (total agricultural area fell 6.6 percent), many households are now renting out their land to other farmers — the percentage of medium-size holdings (those between 6 and 22 hectares) that are rented in is now 41 percent, compared to just 23 percent in 1993 (the proportion of land rented in increased in all size classes).

Small farms in Suphan Buri increased their reliance on vegetables, livestock and fish during this period — the percentage of small farms engaged in these activities increased from 3 percent to 11 percent during those ten years. On the other hand, medium-size farms became more reliant on rice. Specialization in rice has been facilitated by the availability of water that has allowed farms to greatly intensify cropping — the percentage of rice farms growing two or more crops of rice in a year increased from 12 percent in 1987 to 53 percent in 1998 (Isvilanonda *et al.*, 2000). Both types of farms are becoming more commercial (all rice production on medium-size farms is marketed outside the home), with each specializing in a different type of activity. This illustrates how the farming sector as a whole is diversifying, but certain classes of farms are specializing.

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[5] Unless otherwise specified, all data in this paragraph and the two succeeding paragraphs come from various agricultural census publications in Thailand (National Statistical Office of Thailand, 1993 and 2003).

Farm households are also becoming older and more likely to be headed by females as young males migrate to urban areas for job opportunities. In Thailand, agricultural census data show that the proportion of farm households headed by women increased from 12 percent in 1978 to 27 percent in 2003. The same source shows that the percentage of farm household heads aged 55 and above increased from 25 percent in 1978 to 34 percent in 2003. This is not particularly surprising, as those who migrate from farms to cities in search of jobs are most likely to be young males (de Haan, 1999). These trends show that the clientele for water managers is already different from what it was in the past, and these trends are likely to continue in the future. Different clients are likely to mean that different strategies will be required to meet their needs.

4. Summary and conclusions

Compared to most other regions in the world, Southeast Asia is relatively rich in water resources. Nevertheless, the declining importance of agriculture and expanding populations mean that there will be increasing pressure to manage agricultural water resources more carefully. Improved incentives, institutions and technologies will be crucial to these efforts.

Because of crop diversification, farmers will increasingly demand irrigation that is more flexible (e.g. suitable for crops other than rice and cereals). For the many farmers who continue to plant rice, more reliable irrigation may be needed to prevent plant stress in the face of increased competition for water use from other sectors. The increased prevalence of pump irrigation is a response to these demands (Barker and Molle, 2004), and it is creating challenges for surface water managers to manage water conjunctively.

While demands for flexible and reliable irrigation increase, farmers will be less willing to devote their own scarce time to manage irrigation, because of the increased importance of non-agricultural income in their livelihoods, and will find it difficult to hire labourers to do it for them because of increasing labour scarcity and wages. This suggests that institutions that rely on substantial inputs of labour and time may experience difficulties, and new institutions that more directly confront the issue of incentives for individuals may have an important role to play in improved water management.

The clientele for water managers is already different from what it was in the past, and it will continue to change in the future. On average, the farmers of tomorrow will be older, more balanced in terms of gender, and will operate larger farms, although this latter characteristic will take longer to realize. Different clients mean that different strategies will be required to meet their needs.

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Ecosystems, livelihoods and governance in large-scale Southeast Asian irrigation

John Dore, David Blake, Madhusudan Bhattarai

The World Conservation Union (IUCN)
Asia Regional Water and Wetlands Programme, Bangkok, Thailand
iucnasiawater@iucnt.org

1. Introduction

IUCN should be a constructive change agent for more sustainable development, with a dual focus on ecosystems and livelihoods. In a world where governance is changing from a purely state-centric construct, the Union's structure is well positioned to have more impact, now and in the future, giving extra space for both state and non-state actors to engage in political processes.

Many of us in the secretariat, in Asia and elsewhere, are particularly committed to water-related issues, which are increasingly prominent in Asia and world affairs. IUCN is a water actor in many different domains, such as: water infrastructure decision-making, flow regime negotiations, wetlands conservation, wetlands livelihoods, hydropower governance, irrigated agriculture, groundwater use, local adaptation to the impact of climate change and climate variability.

The IUCN Asia water team is committed to:

- *water for nature* — healthy ecosystems, especially rivers, lakes, wetlands, forests, fisheries, mountains;
- *water for people* — increasing livelihood opportunities and ensuring food security and sanitation as well as water's contribution to spirituality; and
- *water for development* — sustainable national and regional development, especially employment, energy, transport, industry.

In Asia, the regional and national water team members have working relationships with state water-related players, local civil society organizations, and other international actors. There is much more to do, but the IUCN secretariat is committed to working with members and partners to improve the way in which we use water. This is the context within which we were pleased to accept an invitation to join the symposium organized by FAO in Ho Chi Minh, Viet Nam, 26 to 28 October 2005. As this brief written contribution was prepared after the event, we take the opportunity to congratulate FAO on their successful convening of a constructive, knowledge-sharing event.

2. Irrigation development

Southeast Asia

The growth of public funded and state-controlled large irrigation systems since the early twentieth century in Asia has been characterized by large water management projects that have harnessed rivers through the construction of dams, diversion structures, and canal systems. In the latter half of the twentieth century, the spread of irrigation technology has accelerated through state-sponsored large-scale irrigation and a greater emphasis on large dams for storage of river water. Irrigated areas worldwide increased from 40 million hectares in 1900 to ~100 million hectares by 1950 and then rapidly expanded further to ~280 million ha by 2000 (WCD, 2000). Most of this expansion in irrigated area took place in Asia. The irrigated area in Asia expanded from 65 million ha in 1950 to over 220 million ha in 2000. Asia now accounts for about 60 percent of the global irrigated area, about 60 percent of the global population, and about 90 percent of world rice production and 90 percent of global rice consumption (Maclean *et al.*, 2002). In Southeast Asia the irrigated area has doubled between 1960 and 2000, from 9 million hectares in 1960 to about 18 million hectares in 2000. In Southeast Asia, rice is far and away the most important irrigated crop, accounting for on an average of 80 percent of irrigated cropping areas in the region, but as high as 98 percent in the case of Cambodia (see paper by Zhen in these proceedings).

A significant change in many countries has been the shift to have more multidisciplinary professional teams involved from the early stages of projects when developing irrigation systems. This is necessary if the mistakes of the past are to be avoided in the future.

Thailand

There are many examples in Thailand of irrigation systems that have been operating relatively successfully for a long period of time. However, an example of a poorly conceived and implemented project is the Khong-Chi-Mun (KCM) water diversion project, from which some lessons can be drawn.

The KCM project was originally planned to divert 6 850 million cubic metres of water annually from the Khong (Mekong) River by pumping and distributing it through a series of canals, aqueducts and storage reservoirs across vast areas of Northeast Thailand for irrigation. The projected cost of the project was over US$11 billion in 1992, and was to have taken 42 years to complete over three phases. Since the late 1980s, successive governments and senior politicians promoted the KCM project as a solution to the twin problems of water shortage and poverty in the Northeast, by utilizing the “wasted” waters of the Mekong to irrigate a target area of 4.98 million rai (7 970 km^2) of rainfed agricultural land in the Mun-Chi Basins which feed the Khong. The project was first approved in 1989 and the Department of Energy Promotion and Development (DEDP), under the Ministry of Science, Technology and Environment was assigned responsibility.

Despite the completion of at least 12 dams along the Mun and Chi Rivers by the late 1990s, the KCM project has never met more than a fraction of its irrigation targets and some dams, like the Rasi Salai Dam in Sisaket Province were abandoned altogether, because of unpredicted environmental impacts and land conflicts which created social unrest and protests by local villagers and NGOs. Of particular concern was the rapid spread of salinization of water and farmland, rendering it unsuitable for agriculture and the loss of riparian forest to permanent flooding from reservoirs. Fisheries also declined precipitously around the same period, as the river was steadily fragmented from its mouth (Pak Mun) upstream. Although the KCM project has now been shelved since the dissolution of DEDP, the rationale and desire to complete a large pan-Isaan irrigation project is still alive, as evidenced by the recent re-rise (and fall) of interest in the northeast component of the so-called Thailand water grid mega-project.

The major food-bowl of present-day Thailand is the Chao Phraya Delta which has essentially been fully developed for irrigation, in a process spanning several hundred years since the Ayutthaya period (1350–1767), up to the present. The Upper Delta is supplied by a diversion dam at Chai Nat, whose water supply is partly dependent on the controlled release of waters from large storage dams upstream, such as the Bhumipol and Sirikit Dams. The Delta is the most populous part of Thailand and includes the capital Bangkok, with its associated industries and seat of political power, which compete with agricultural and domestic uses for a limited water supply. Most of the Delta has in the past been given over to double-cropping or even triple-cropping rice, although some parts are devoted almost exclusively to intensive vegetable or fruit tree cultivation, e.g. Damnoen Saduak to the west of Bangkok. It is estimated that during the dry season (January to June), when demand reaches its peak, available water supply is on average just above half the potential demand. The delta is marked by extreme hydraulic connectivity, which creates a high level of interactions and competition between the various users and actors, as well as its upstream water sources, and between surface and groundwater.

A recent study which took a political ecological approach (Molle, 2005) argued that the evolution of the Chao Phraya Delta has not been a linear process where technical change has allowed ever-increasing control of nature and development. Rather, the analysis argued that water use and further development has been highly politicized. Access to water has been constantly challenged and redefined, as old and new actors and interest groups have competed to obtain benefits. So also has it been with KCM.

These examples serve to remind us that the irrigation development must take into account ecosystems, livelihoods and governance. The next section offers some thoughts on these topics.

3. Ecosystems, livelihoods and governance

3.1 Ecosystems

Irrigation systems are made up of several components, e.g. reservoir, supply canals and irrigated fields that are artificial wetland ecosystems, often modifying or replacing earlier natural or semi-natural wetland ecosystems in the process of agricultural intensification and land conversion. Because of a poor understanding of the multifunctional uses of wetland ecosystems, these are often neglected in water management. A turn towards greater ecosystem consideration would seek to *"strike a balance between benefiting from the natural resources available from an ecosystem's components and processes, while maintaining an ecosystem's ability to provide these at a sustainable level"* (Pirot *et al.*, 2000).

For example, where floodplain ecosystems exist in Southeast Asia, they are often associated with highly productive fisheries, which are dependent on natural flows and flood-drought cycles for their continued productivity. The best example in the region is the lower Mekong Basin, which is estimated to support a "wild" fishery yield of more than million tonnes per annum, which has been valued at US$1.2 billion (Sverdrup-Jensen, 2002). Upstream dams and impoundments in the Mekong Basin tend — as elsewhere — to impact negatively on wild fisheries because of flow alteration, nutrient capture, changes in water quality, loss of critical habitat, and blockage of fish migration routes.

In the lower Mekong Basin, there is finally an increasing interest in considering the needs of the wild fishery when considering further intensification of agriculture, energy production, and water flow regime changes.

To do so requires informed negotiations about how humans will intervene in natural flow regimes. Some toolbooks which aim to help different actors prepare for such negotiations have been prepared by IUCN, and may be of interest to the irrigation community assembled in Ho Chi Minh: "VALUE — Counting ecosystems as water infrastructure" (Emerton and Bos, 2004), "FLOW — The essentials of environmental flows" (Dyson *et al.*, 2003), and NEGOTIATE (forthcoming).[6]

The point is to bring the ecosystems more explicitly into consideration, or take an "ecosystem approach" (Shepherd, 2004). In so doing, the full range of benefits and costs associated with irrigation systems are more likely to be taken into account.

3.2 Livelihood issues

Properly addressing the livelihoods perspectives of all the stakeholders in water allocation decisions, including construction and management of large irrigation projects, is critical since most irrigation projects are designed and justified in the name of poverty alleviation and food security. Therefore, irrigation projects should not jeopardize the livelihoods of any segment of society.

In the past decade or so, more and more bilateral donor institutions and development organizations have recognized the need to include sustainable livelihoods approaches (SLA) as an integral part of their work programmes and policy for addressing poverty reduction. SLA emphasizes understanding the vulnerability context and the organizational and institutional environment within which poor people draw upon assets of different types — human social, natural, physical, financial — to try and meet their needs (Scoones, 1998; Deardon *et al.*, 2002).

SLA approaches provide a framework for fully taking into account the range of policy issues relevant to the poor early in the project planning cycle.

[6] VALUE, FLOW, NEGOTIATE (and others such as CHANGE, PAY, RULE and SHARE) are toolbooks in the IUCN Water and Nature Initiative series, and are downloadable from www.iucn.org/water

3.3 Governance issues

By water governance we mean the ways in which society shares power and negotiates with respect to decisions about how water resources are to be developed and used, and the distribution of benefits and involuntary risks from doing so. This includes the full spectrum of influences from shaping agendas and deliberating options through the design of institutions and laws, through the way these are implemented in the practices of day-to-day management of water. Governance is therefore not the privy of the state or confined to a particular scale or arena but emerges from the interactions between state, business and not-for-profit actors and their institutions at multiple scales (Lebel and Dore, 2005).

Southeast Asia has a long tradition of run-of-river farmer-managed irrigation schemes, and an even longer tradition of rainfed agriculture. More recently, large-scale schemes have been developed, and many more are being promoted and planned by state agencies. On the whole, much of this planning and construction takes place with minimal public information and consultation.

Governance analysis examines the rationales and processes for decisions about large-scale water infrastructure developments, such as large-scale irrigation schemes. These may, for example, involve interbasin diversions and the construction of storage dams, or be more about shifting responsibilities for water allocation or operations. Elsewhere, we are focusing our analytical work on the "re-packaged" different elements of the Thailand water grid and the irrigation works planned in northwest Cambodia (around Battambang), and northeast Cambodia (around Stoeng Treng), recognizing that there may be local, national and crossborder impacts. Through our analysis and engagement we expect to be able to get behind the discourses and document the beneficiaries of this "new water". In doing so we also hope that such large regional water projects receive wide public scrutiny and are part of public debates and negotiations within and among countries.

4. Reflections and recommendations

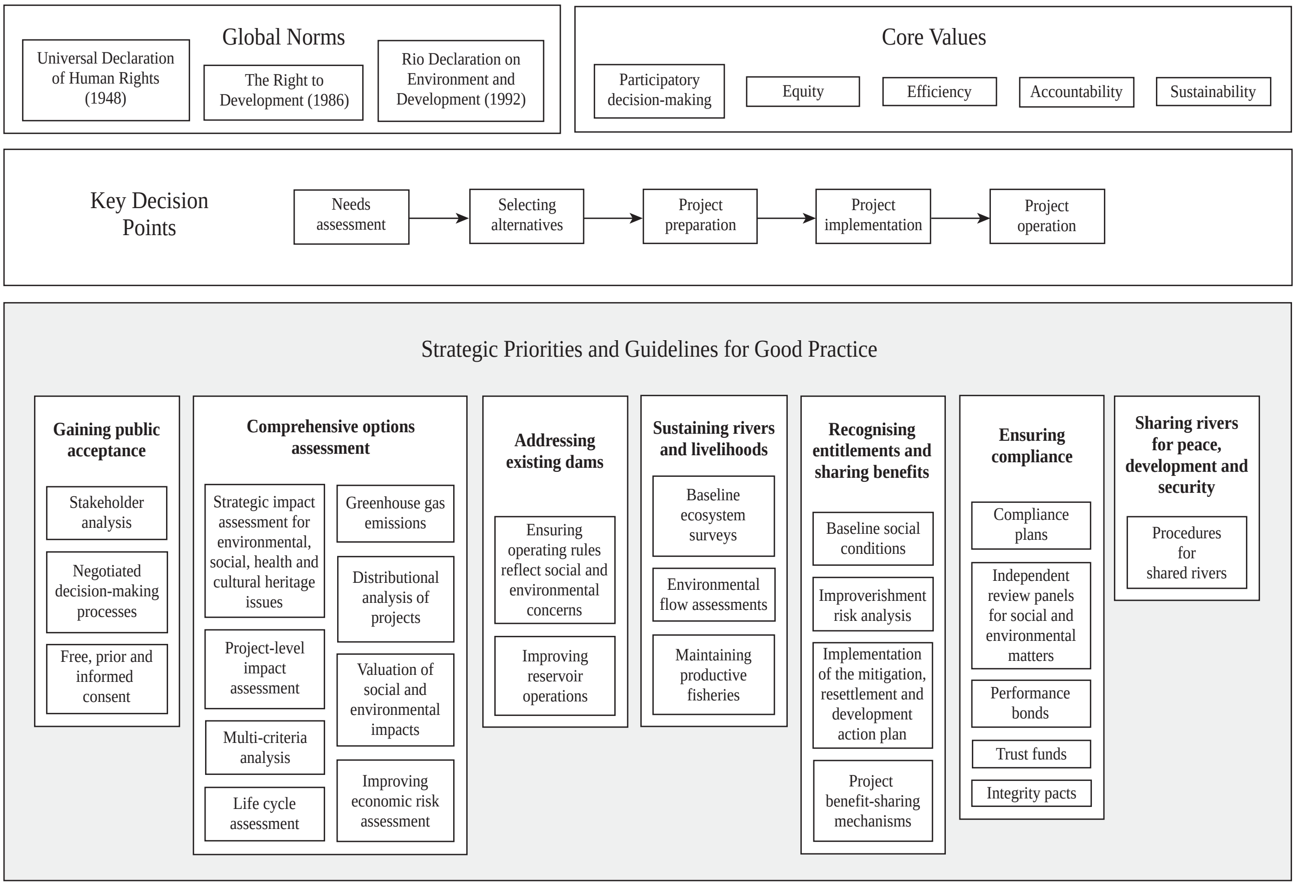
New systems are being constructed, and existing systems modernized, in the developing countries of Southeast Asia, and so there is an urgent need to learn from past lessons and apply current best practice to ensure better outcomes and sustainability of the systems in the future. The following recommendations, generated in working groups at the Ho Chi Minh symposium, were offered for the consideration of those with an influence on irrigation design, construction and operation.

Comprehensive options and feasibility assessment

W*orkshop recommendation: Before committing to new, large-scale irrigation developments, a comprehensive options assessment should be made of the land and water existing use values and development options in that place. If a new, large-scale irrigation development is proposed, it should be examined by a wide-ranging feasibility analysis which is ecologically, physically, economically, politically, socially and culturally "logical". These different logics should all be used to guide analysis and debate when examining the feasibility of a project. This should take place before progressing into the formal, legal, often rigid and relatively narrow "impact assessment" process. CSIRO's 5-Way methodology and the WCD's guidelines, where relevant, are international references.*

CSIRO is an Australian science organization. The CSIRO 5-Way feasibility assessment methodology asks new projects to prove themselves as acceptable in five different ways: ecologically logical, physically logical (e.g. good engineering); economically logical (e.g. have the potential to provide financial benefit to society); politically logical; and socially logical. Of course, there will be different opinions as to what is logical or sensible in any place. Ideally these differences would be shared in the public domain and proponents of various views would be enabled to make their arguments.

WCD refers to the World Commission on Dams (WCD, 2000) which sought to undertake a global review of the development effectiveness of large dams, and assessments of alternatives. It wanted to create a framework for options assessment and decision making processes. It also wanted to identify internationally acceptable criteria and guidelines for planning, designing, construction, operation, monitoring and decommissioning of



Source: CMU-USER summary extract from WCD report (Dore *et al.*, 2004).

Figure 1. WCD framework for decision-making

dams. The commissioners produced a “consensus” report, a negotiated opinion, which was launched in a blaze of publicity in 2000.

Anticipate future changes

Workshop recommendation: If a new, large-scale irrigation development is proposed, the design must recognize and be flexible enough to take account of the inevitability of future demand changes. As economies improve and alter, land/water use and cropping systems will change. Therefore the function/service of the irrigation will change. From the initial stage of the development of an irrigation project, it is important to visualize the trajectory of how these changes might occur, e.g. from rice-focused production to more diversified enterprises.

This recommendation is a reminder that any comprehensive options assessment should also take into account possible futures.

Governance, water rights and responsibilities

Workshop recommendation: Large-scale irrigation projects, as with any others, should be planned, built and operated within a governance regime that embodies social justice ethics, is transparent, and participatory. Participation in irrigation governance should not be restricted to technical experts and bureaucrats, but should be open to representatives of affected communities and interest groups. The water rights and responsibilities of all stakeholders should be openly negotiated and established, with equity and sustainability being primary considerations. Management arrangements for a new project should include, from the beginning, credible representatives of different stakeholder groups.

This recommendation is a reminder that — in WCD parlance — there are global norms and some core values which should guide action.

Local capacity development

Workshop recommendation: If a new, large-scale irrigation development is proposed, it is essential to increase efforts to boost the capacity of local stakeholders playing many different roles. For example, local decision-makers need to be aware of the different options and feasibilities. Public authorities need to be skilled in designing terms of reference and overseeing contracts. Local consulting firms and engineers are required to construct and then be locally available to support ongoing operation, maintenance and adjustment. User groups need to be aided to improve water use efficiency. Local civil society organizations and universities should be able to play roles in governance, e.g. monitoring compliance with negotiated protocols and problem-solving. Supporting the development of this capacity needs to be factored into any new project.

Some of the discussants at the Workshop were very critical of past examples where local people and their institutions had not been factored into large-scale irrigation development and operation in ways that could have ensured more efficient management.

Finance

Workshop recommendation: In addition to the overall economic assessment, it is critical that an adequate financial strategy is put in place. The finance for complete construction must be ensured. Beyond construction, there must be a plausible strategy to ensure the availability of funds to meet full operation and maintenance costs, drawn from all project beneficiaries.

It is easy to see why this recommendation emerged. An over-emphasis in the past on anticipated net present value (NPV) or internal rate of return (IRR) and an under-emphasis on cash availability has left many schemes unable to be properly constructed, operated or maintained.

Monitoring impact on ecosystem and livelihoods

Workshop recommendation: Irrigation projects do more than supply water. They become part of the ecosystem and may have major impacts, for example on groundwater hydrology. The year-round effect of a project on the hydrology and wider environment have to be assessed; so does the impact, whether positive or negative, on the livelihood of all affected peoples.

This final recommendation of the Ho Chi Minh subgroup deliberating about new, large-scale schemes reflects a recognition that reductionist approaches in the past have led to insufficient analysis of the impact of large-scale schemes on nature and human development.

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Country papers

Large rice-based irrigation systems in Cambodia

Chan Sinath[1]

1. Introduction

Cambodia is bordered by Thailand in the west and by Lao PDR and Thailand in the north, by Viet Nam in the east and by the Gulf of Thailand in the south. The total land area of Cambodia is 181 035 km^2, consisting of 24 provinces, including two municipalities and 172 districts. The forest area comprises 67 percent of the country, equal to 12.1 million ha. The cultivated area is approximately 21 percent, equal to 3.78 million ha (Table 1). The rice cultivated area in 1999 amounted to 2.08 million ha or 91.2 percent of the total cultivated area (Table 2).

Table 1. Irrigated agriculture and land uses in Cambodia

Land Use Group	Area (ha)
Natural Area	
Forest	**12 300 200**
1. Mainly evergreen forest	
a. *Broad leafed forest*	6 283 400
• Dense broad leafed forest	4 816 000
• Flood evergreen forest	361 700
• Mangrove forest	61 400
• Mosaic of evergreen or deciduous forest and secondary vegetal formations	528 900
• Mosaic of flooded forest, swampy vegetation, fallow land	157 200
• Secondary vegetal formations	358 200
b. *Pine forest (P. merkusii)*	9 800
2. Deciduous forest	6 007 000
Other vegetation	**1 529 200**
• Thickets	95 600
• Scrub, brushwood	102 600
• Grass savannah	129 000
• Grassland susceptible to flooding	822 900
• Swampy vegetation	379 100
Cultivated area	**3 785 000**
• Paddy field	1 377 100
• Paddy field with palm trees	1 309 200
• Mosaic of upland crops and secondary vegetal formations	839 400
• Mosaic of field crops and fruit garden/rural area in the lowlands	174 400
• Plantation (rubber)	84 900
Other land uses	**539 100**
• Bare land and sandy banks	51 500
• Open water areas, rivers	487 600
Total	**18 153 500**

Source: Statistics of the Irrigated Agriculture Department, MOWRAM.

[1] Deputy Director General for Technical Affairs, Ministry of Water Resources and Meteorology (MOWRAM), Cambodia.

Table 2. Rice cultivated areas by rice ecosystems and calendar

Rice Type	Harvested Area (ha)	Sow	Harvest	Yield (t/ha)	Production (t)
I. Wet season					
1. Upland	48 138	May	October	1.4	67 393.2
2. Rainfed lowland:					
• early	371 553	May	end October	1.6	594 484.8
• medium	838 237	May/June	December	1.8	1 508 827
• late	529 495	June/July	January	1.7	900 141.5
3. Deepwater	56 569	April/May	Feb./March	1.3	73 539.7
II. Dry season					
• Irrigated and Recession	233 000	Jan./Feb. December	April February	3.04	708 320
Total	**2 076 992**				**3 852 706.2**

Source: Statistics of the Irrigated Agriculture Department, MOWRAM.

The country's current population is 13 million, which has been growing at an annual rate of 2.8 percent with a population density of 51 persons per km^2. It is notable that there is a sex imbalance, undoubtedly because of two decades of conflict: 52.2 percent of the population comprises females, and there is a high proportion of youth. The current per capita GDP of US$290 is considered one of the lowest in the world. The agriculture sector in Cambodia has been the top earner of the national economy contributing about 45 percent of the GDP in 1994 and accounting for 75 percent of employed persons. Cambodia is a typical rice producing and exporting country with favourable natural conditions for paddy cultivation.

Thirty-six percent of the population is estimated to be below the poverty line now and the overall goal of the Royal Government of Cambodia (RGC) is poverty eradication through socio-economic development. Strategies for the attainment of this goal focus on, among other things, improved access to public services, the provision of safe drinking water supplies and sanitation, particularly in rural areas, improved infrastructure (especially irrigation systems) and increased agricultural productivity to achieve food security (in particular, large rice cultivation based on irrigation systems). The water sector makes an important contribution to the country's development in a number of ways.

- Irrigation contributes to agriculture, and to the achievement of food security, poverty reduction and socio-economic development.
- Water supply and sanitation meet the needs of the urban and rural populations, as well as their health requirements, and contribute to the achievement of better living standards.
- Drainage and sewerage contribute to better health and living standards.
- The goal of hydropower development is socio-economic development.
- Inland navigation serves to move goods and passengers from one place to another, and to facilitate tourism.
- Water contributes to the livelihood and food supply of the population by providing fish, animal protein and aquatic plants.

2. Objectives

Specific objectives of this paper are to:

1. provide information on the large rice-based irrigation systems;
2. review agriculture development and water resources management;
3. identify the needs for large rice-based irrigation systems;

4. identify measures already undertaken and being undertaken in the water sector for large rice-based irrigation systems; and
5. identify the tools and means for sustaining management of large rice-based irrigation systems.

3. Agricultural development and water resources management

Soil and agronomy

The soils in many irrigation systems, particularly the more successful recession cropping systems, are suitable for rice (especially large rice cultivation) but not for other crops. Generally, the limitation for other crops arises because of poor drainage or flooding. In these areas it is, therefore, unlikely that substantial areas of diversified cropping will be possible.

There are also good soils for both rice and other crops in areas away from the Mekong/Tonle Sap/Bassac flood plains. The development of these areas will generally involve new water storage to enhance water resources and allow double cropping. The cultivation of non-rice crops in these areas would improve the economics of irrigation development projects, providing that the market conditions allow the sale of cash crops at reasonable and predictable prices.

Cropping patterns and yields

There are three irrigated and three non-irrigated cropping patterns practised in Cambodia, and the irrigated cropping is almost exclusively for rice. The irrigated cropping patterns are:

- **Wet season lowland rice with supplementary irrigation** — This cropping pattern is where water is abstracted from watercourses or taken from dams to irrigate when rainfall is low.
- **Dry season lowland rice with irrigation** — Generally, under this system land is also used for wet season production with supplementary irrigation, but limited water resources and poor infrastructure mean the area cropped is small.
- **Flood recession rice** — This cropping pattern exists near the Mekong, Tonle Sap and Bassac systems as well as within some reservoirs, and relies on natural flooding to water the fields.

The remaining non-irrigated cropping patterns are:

- **Rainfed lowland rice** — This is the dominant cropping pattern in Cambodia. Land is prepared and planted in May to early June. The varieties are tolerant to the drier conditions typical from late June to August, but there is significant risk of crop failure in dry years. Also, it is not uncommon for there to be insufficient rain to plant in May and June.
- **Deep water floating rice** — This pattern is practised around the Tonle Sap Lake using varieties that can grow quickly enough to float above the rising flood water.
- **Upland rice** — This is grown in small areas of sloping land in the north and northeast of Cambodia and is not irrigated.

Average rice yields in Cambodia are only about 2 tonnes/ha. However, in special project areas where water control and agricultural practices are enhanced, rice yields can be 3.0 to 3.5 tonnes/ha. Conversely, rainfed yields may be as low as 0.7 to 0.8 tonnes/ha and crop failures as a result of inadequate rainfall are frequent.

Some 86 percent of Cambodia lies within the catchments of the Mekong River. Rising in China, the river passes through or borders Myanmar, Lao PDR, Thailand and Viet Nam before discharging to the South China Sea. With a drainage area of 810 000 km^2 and a total length of 4 425 km, the Mekong is one of the major rivers of the world. The mean annual discharge entering Cambodia is in excess of 300 000 million m^3, and it is estimated that with the contributions of downstream tributaries some 500 000 m^3 discharge to the sea annually (Table 3).

Table 3. Hydrological characteristics of Mekong River tributaries

Tributary	Catchment (km^2)	Annual (million m^3)	Discharge (m^3/s)	Annual runoff (mm)	Natural low flow (m^3/s)
Se Kong	28 500	32 200	1 368	1 310	40
Se San	17 100	17 300	547	1 010	28
Sre Pok	29 450	29 800	942	1 010	118
Prek Preah	1 510	760	24	505	3
Prek Krieng	2 450	1 240	29	505	5
Prek Kanpi	1 150	580	18	505	2
Prek Te	4 170	2 530	80	610	10
Preg Chhlong	5 750	2 910	92	505	3
Stung Chinit	4 130	1 360	43	330	3
Stung Sen	14 000	6 190	196	440	8
Stung Staung	1 900	840	27	440	1
Stung Chickreng	1 030	450	14	440	1
Stung Streng	3 210	1 140	36	355	1
Stung Sisophon	4 310	1 900	60	440	2
St. Mongol Borey	2 700	1 980	63	730	3
Stung Battambang	2 135	1 960	62	920	3
Stung Pursat	4 480	1 660	52	370	1
Prek Thnot	5 050	1 560	49	310	1
Mekong at Kratie	646 000	441 600	13 974	680	1 750

Source: Mekong River Commission, 1994.

An important feature of the Mekong system in Cambodia is the Tonle Sap. During the wet season, as the water level in the Mekong rises, the flow in the Tonle Sap River draining the lake to the Mekong reverses and the lake fills, reducing the discharge downstream of Phnom Penh. By September/October, the level of the lake may have risen by 3 to 4 metres and the area extended to 10 500 km^2. As the level of the Mekong falls, the water starts draining back, enhancing downstream dry season flows, and the lake eventually shrinks to about 2 600 km^2 and less than 2 m in depth in the dry season. The annual rise in the Mekong causes extensive flooding downstream of Phnom Penh.

Climate

The climate of Cambodia is a tropical monsoon climate which has two seasons: a wet season, from May to October, resulting from the southwest monsoon, and a dry season, from November to April, resulting from the northwest monsoon. Usually, the wet season is disrupted by a short dry spell during two weeks in July or August. The annual average rainfall is 1 200 to 1 500 mm and the annual average air temperature 21 to 35°C. The relative humidity ranges from 65 to 70 percent in January and February to 85 to 90 percent in August and September. The annual evaporation is 2 000 to 2 200 mm, being highest in March or April at 200 to 240 mm/month, and the lowest in September or October at 12 to 150 mm/month. The monthly average evapotranspiration is 90 mm during the wet season to 120 mm for the dry season.

4. The needs of irrigation systems for large rice cultivation in Cambodia

The Royal Government of Cambodia (RGC) determined that producing more water for irrigated agriculture was important as it would help meet the needs of the government's priority areas for poverty alleviation and economic growth by enabling an increase in the production of irrigated agriculture products for commercialization. Previously, the government's proposals for public sector investment allocated about 22 percent of projected investment funds to the irrigation sector, but today the government has allocated about 35 percent of the total national budget to the irrigation sector for producing more water for agriculture.

The objective of the government's investment in irrigation is to increase the total agricultural production, in particular in the large rice cultivation areas. When Cambodia has enough water for agriculture, the production may be raised by increasing yields and double cropping. Broader development objectives in the irrigation sector are economic growth and poverty alleviation. The above objectives can be achieved by enhancing and the country's reservoirs, by catchment area planning, and by institutional strengthening.

5. Irrigation development in Cambodia at present

Following independence, between 1953 and 1960, eleven major schemes were undertaken with the assistance of the United States of America, including partial rehabilitation of the Baval reservoir, damaged during World War II, and of a number of other schemes built during the French colonial period. New projects included 13 000 ha of irrigation based on the largest of the Angkor reservoirs, Barai Occidental, and more than 50 colmatage canals in Kandal and Kompong Cham, bringing the area served to some 17 000 ha. With completion of these projects, the area under formal irrigation amounted to 74 000 ha.

The first stage (5 000 ha) of the multipurpose Prek Thnot project in Kompong Speu was started in the late 1960s. The project included construction of a dam to provide ultimately year-round irrigation of 70 000 ha, but with the start of the war, was left unfinished.

Events during the Khmer Rouge regime (1975–1979) period have had a major impact on agricultural systems throughout Cambodia. Recognizing the importance of irrigation, the government organized the construction of diversion works, bunded reservoirs and other structures, supplying a rectangular grid of canals across a large part of the rainfed area. Up until now, the irrigated areas comprise 407 000 ha (Table 4). Table 5 identifies the means used to reach the irrigated areas. Table 6 presents a classification of the principal rice soils of Cambodia.

Table 4. Total rice harvested and irrigated areas

Province	Harvested Area, 1 000 ha			Irrigated Area 1 000 ha
	Wet Season	Dry Season	Total	
Banteay Mean Chey	140.2	0.3	140.5	36
Siem Reap	181.08	10.0	191.08	25.5
Preah Vihear	16.911	–	16.911	0.3
Stung Treng	13.466	–	13.466	0.8
Ratanakiri	17.618	–	17.618	0.2
Mondulkiri	6.180	–	6.180	0.2
Kratie	20.617	6.0	26.617	12
Kompong Thom	99.164	1.8	100.964	37
Battambang	168.571	1.2	169.771	52
Pursat	71.950	0.1	72.05	26
Kompong Chhnang	83.066	9.9	92.966	22
Kompong Cham	167.243	30.0	197.243	30
Svay Rieng	162.318	9.0	171.318	20
Prey Veng	240.225	57.0	297.225	40
Kandal	42.674	45.0	87.674	20
Takeo	173.131	58.0	231.131	40
Kompong Speu	84.303	1.0	85.303	22
Koh Kong	7.272	–	7.272	0.6
Kompot	133.107	2.5	135.607	19.3
Kompong Som	9.5	–	9.5	
Phnom Penh	5.396	1.2	6.596	3.1
Total	**1 843.992**	**233**	**2 076.992**	**407**

Source: Statistics of the Irrigated Agriculture Department, MOWRAM.

Table 5. Implemented irrigation methods of Cambodia

Method	Irrigated Area, ha	
	Wet season	Dry season
Gravity	87 800	119 700
Pump station	19 350	23 650
Mobile pump	73 850	47 850
Traditional lift	23 000	11 800
Total	**204 000**	**203 000**

Source: Statistics of the Irrigated Agriculture Department, MOWRAM.

Table 6. Principal rice soils of Cambodia

Group	Soil type	Area (ha)
Young alluvial soils	Alluvials	1 706 400
	Lacustrine alluvials	1 037 300
	Brown alluvial	276 000
Leached acid soils on old alluvium	Alluvials	included above
Poorly drained lowland soils	Cultural hydromorphics	1 289 600
	Grey hydromorphics	1 725 200
Imperfectly drained lowland soils	Brown hydromorphics	670 100
Acid sulphate soils	Alluvials	278 200

Source: Statistics of the Irrigated Agriculture Department, MOWRAM.

An inventory of irrigation systems carried out between 1993 and 1994 by the Mekong Secretariat listed some 950 schemes totaling 310 000 ha in the country (Appendix A). In rainfed lowland systems, the distinction between irrigated and rainfed area is not, however, well-defined; although not supplied through a formal distribution system, much of the rainfed crop receives water additional to direct precipitation. Irrigation of crops other than rice is largely confined to gardens.

In the wet season, supplementary irrigation may be through direct run-of-river diversion, pumping or by release of stored surplus run-off. In the dry season, when in the majority of rivers there is little flow, irrigation is only possible from storage, or by lifting water, either by pumping or by traditional methods, from residual flows, floodwater or, on a small-scale, from groundwater. Pumping from the dry season flows from canals and streams connected to the Mekong or Bassac Rivers is becoming a popular and productive dry season farming system in Takeo and Prey Veng Provinces.

Development opportunities

Gravity irrigation: The development options for irrigation offering the greatest scope for extensive development in Cambodia are exploitation of the abundant wet season river and stream flows to provide supplementary irrigation for the wet season rice crop, and provision of storage facilities to allow carryover for wet season run-off or flood water for irrigation in the dry season. At the other extreme, the areas which can be supplied from the smaller streams may be only a few hectares. In the dry season, flows, where they occur, are sufficient to irrigate only a minimal area. Gravity diversion has low operating costs and reduced reliance on mechanical equipment which, unless properly maintained, is prone to breakdown. Where channels are incised, however, diversion structures may be needed to gain command. There is also a need to safely pass flood flows, which can be very much larger than the flows which can be usefully diverted.

Pump stations: Pumped abstraction is appropriate where provision of the work necessary for gravity diversion would not be practical, or in terms of the quantity diverted, excessively costly. However, experience in Cambodia with fixed pump schemes has been disappointing, for a number of reasons, including: inadequate water source or siltation; over-dimensioning or over-sophistication of the pump; use of fuel-inefficient

Soviet-designed pumps; technically unsound irrigation schemes; and lack of maintenance. Pumped schemes are vulnerable to poor maintenance. Whereas capital costs of pumped abstraction tend to be less than for gravity diversion, annual operation and maintenance costs are significantly higher: about US$80/ha/year for pump schemes as against US$20 to 25/ha/year for gravity irrigation schemes in the case of Cambodia.

Mobile pumps: Averaging 3 hp, mobile pumps are used during the wet season to supply supplementary irrigation water from a convenient source to small areas of adjacent land that are out of command. In the dry season, they provide water for irrigation of the recession crop, where they are replacing traditional pedal pumps and scoops. They are used to a lesser extent to provide water from residual river flows and water stored in canals for irrigation of a second crop on the terrace lands, and for irrigating vegetable and fruit gardens.

Shallow bunded reservoirs: Storage for wet season supplementary and dry season irrigation is provided by bunded reservoirs storing water at a depth of 1 to 3 m. There are 2 800 such reservoirs countrywide. The water stored may be derived either from upstream runoff or from impoundment of flood water from rivers. In the wet season, reservoirs commanding terrace lands, as well as providing storage, serve also as diversion structures. The area supplied is reported as 200 000 ha in the wet season, and 65 000 ha in the dry season. Dry season irrigated areas generally range from 20 to 30 ha, to several thousand hectares, with the large areas being flood recession areas.

Colmatage canals: The colmatage or warping canals are cut to bring silt laden floodwater to the low-lying land behind the levees of the Mekong and Bassac Rivers. Set at a relatively high level, the canals are closed off from the river by a temporary bund until mid-August to allow harvesting of the previous season's crop. The canals are then filled on the rising flood land and, when the flood recedes, water is retained at the level of the canal, allowing recession cropping. In some cases, a head gate is provided, allowing water to be retained at a higher level. Recession crops are grown on the lower land. The canals also serve an important fishery function as they permit passage of broodstock on to the flood plain.

Development process

Irrigation and drainage — To expand the irrigated area from 20 percent to 50 percent of the total cultivated area by the year 2010 (it is possible to expand it a further 1 667 300 ha after that) so as to enhance rural food security and income generation MOWRAM needs to do the following:

- rehabilitate existing irrigation schemes;
- develop appropriate irrigation technologies;
- develop all-scale gravity irrigation systems;
- improve and expand areas covered by medium and large irrigation systems as the institutional capacity for planning, construction and implementation of PIMD of such systems is enhanced;
- enhance FWUCs participation in the design, construction, operation and management of hydraulic infrastructure; and
- promote private sector involvement in the construction of hydraulic infrastructure.

Control and abatement/reduction of the effects of floods and other hazards — To prevent damage to large rice cultivation that may occur from floods, drought, watershed degradation, erosion and sedimentation, and to protect aquatic and fish resources, it is necessary to:

- control floods and reduce their effects;
- improve weather forecasts to ensure timely warning of natural occurrences such as typhoons, floods and drought;
- prevent watershed degradation, erosion and sedimentation;
- protect fish stocks; and
- cooperate and exchange information with other riparian countries of the Mekong Basin.

Policy, legal and institutional strategies — To realize integrated water resources management and development (IWRMD) it is necessary to:

- formulate and adopt a policy for the water sector as a whole;
- formulate a comprehensive legal framework for the water sector institutions;
- strengthen the database and information system of MOWRAM to facilitate the integrated management of water quantity and quality and to determine the balance between the supply and the demand;
- strengthen the capacity of MOWRAM staff both at the central and at decentralized levels; and
- disseminate information on water resources through public meetings, radio broadcasts and printed materials (leaflets, posters, etc.).

6. Tools and means for sustaining the large rice-based irrigation system

6.1 Reform to facilitate participatory irrigation management and development (PIMD)

The former Director-General of Irrigation, Hydrology and Meteorology established a national policy, called *Circular No. 1 on the implementation policy for sustainable irrigation systems*. This was done without testing and development as, at that time, there were no financial resources to do these things. In 1999, the Ministry of Water Resources and Meteorology (MOWRAM) was established and the Ministry collected all the reactions to Circular No. 1 from farmers and NGOs, and then organized two workshops (a regional workshop in Battambang for the northwest provinces and a national workshop in Phnom Penh). The purpose of these workshops was to explore the participants' ideas and experiences of participatory irrigation management and sustainable development in the irrigation sector and to develop Circular No. 1 and another two documents that supported Circular No.1. Later, MOWRAM established a steering committee that included all concerned technical senior officers of MOWRAM as its members. The steering committee was chaired by the Under Secretary of State of MOWRAM. The steering committee carefully reviewed the appendix attached to Circular No. 1, and the two supporting documents to improve transparency and to ensure they were suitable for dissemination to all related stakeholders. After that, these documents were submitted to the Minister of MOWRAM for official endorsement and for approval to create Prakash (Declaration) 306. Currently, the Prakash 306 has been endorsed, approved, issued and used for the formation of farmer water user communities (FWUCs).

FWUCs are to be established to manage irrigation schemes. They will be empowered to collect an irrigation service fee (ISF) to cover the cost of service delivery and operation and maintenance. Circular No. 1 states that the FWUC is intended to:

- bring together farmers who are farming land in an irrigated area and form a group for facilitating the supply of irrigation water to them;
- supply adequate water for irrigation to the members;
- acquire the knowledge of management, maintenance and operation of the irrigation system as well as financial affairs;
- increase the yields and seasonal cropping; and
- facilitate support from the government (intervention when they meet obstacles and marketing problems).

Circular No. 1 also states that the management committee of each of the FWUCs has the following responsibilities:

- preparing a work plan for the FWUC;
- formulating statutes (constitution), contracts and internal regulations of the community;

- maintaining the irrigation system in good condition to enable the provision of irrigation for the whole season;
- managing and distributing water to all members;
- strengthening the use, management, and improvement of the irrigation system in an efficient manner;
- resolving problems occurring within the community; and
- collecting the irrigation service fee (ISF) as determined by the community.

6.2 Institutional framework for adopting participatory irrigation management and development (PIMD)

In order to ensure effective adoption and implementation of this PIMD policy, it is essential that the following organizations are formed and gain the capacity to perform the roles described below.

FWUCs

The FWUCs are to be a legal corporate bodies of farmer water users who share the use of water and take responsibility for drainage of water within a single irrigation system. The FWUC will be responsible for operating, maintaining, rehabilitating and financing the overall management of the irrigation system. Before a new irrigation system is developed, an FWUC will be established to guide the process of development.

All water users of an irrigation system will be required to become members of the FWUC and will be required to pay irrigation service fees of a sufficient amount so as to finance the proper maintenance of the irrigation system and to ensure sustained functionality of the infrastructure. Irrigation systems with sub-units such as tertiary blocks that consist of several farmers may form FWUC groups as small primary units within the FWUC. Larger irrigation systems may form three or more levels within the FWUC. In all cases, there should be a scheme-level FWUC to ensure the principle of *one irrigation system, one system of management*.

6.3. Irrigation management transfer, agreement and provisions of support services to FWUCs

Once the FWUC has been legally established and registered with a statute, by-laws and elected leaders, the FWUC support team will provide further intensive on-the-job training and monitoring for one irrigation season. During this period the FWUC will prepare, approve and implement an irrigation service plan. After this season the FWUC support team and FWUC officers will prepare an official document that is an agreement between the provincial government (represented by the governor), the FWUC (represented by its elected officers) and the village government (represented by the village leader).

This agreement will describe the responsibilities and tasks of the FWUC, roles and tasks of the provincial and district government (for capacity building, regulation and provision of support services), procedures for dispute resolution, protocol for external relations of the FWUC and an official acknowledgement of the authority of the FWUC. Ownership of large irrigation structures at the headworks or main canals of large-scale irrigation systems, which have been built with manufactured materials by the government, will not be transferred to the FWUC. In these cases, it is only the rights to operate, use and maintain these structures that will be transferred to the FWUC. In all other cases, ownership of irrigation infrastructure will be transferred to the FWUC (as mutually agreed by the FWUC and government).

After the irrigation management transfer or certification of management authority agreement has been signed by the parties concerned, all future technical, financial or managerial services provided to the FWUC must be provided on the basis of the principle of partnership, which is realized through formal agreements, cost sharing and mechanisms to ensure accountability between parties to the agreement. After the irrigation management transfer or certification of management authority agreement is signed, any government staff assigned to the system will either be transferred to other assignments or will be deputed to the FWUC to continue irrigation management functions under the supervision of the FWUC (only by agreement with the FWUC).

Information on irrigation systems in Cambodia

National irrigation management agency: **Ministry of Water Resource and Meteorology (MOWRAM)**

General information on irrigation systems in Cambodia				
Physical scale of rice-based irrigation system	**<500 ha**	**500 to 5 000 ha**	**>5 000 ha**	**All scales**
Number of systems	300	350	300	950
Annual water diversion (MCM)				
% of agriculture water use				95
% of domestic water use				4
% of other water use				1
Designed irrigation area (ha)				
Effective irrigation area (ha)				
Rice irrigation area (ha)				407 000 ha
Vegetable and orchard area (ha)				
Other crops irrigation area (ha)				
No. of beneficiaries — farmers				11 million
No. of beneficiaries — city residents				2 million
Wetland areas supported (ha)				2.5 million

Information on the largest rice-based irrigation system	
Name	**Kamping Pouy**
Location	Bannon District, Battambang Province
Construction period	1966–1977
Designed irrigation area	30 000 ha
Functional irrigation area	12 000 ha
Annual water diversion (MCM)	
% of agriculture water use	95
% of domestic water use	4
% of other water use	1
Rice irrigation area (ha)	20 000 ha
Vegetable and orchard area (ha)	5 000 ha
Other crops irrigation area (ha)	5 000 ha
Water supply per ha of irrigated rice field	13 000 m^3
Output (US$) per m^3 of water supply	
No. of beneficiaries — farmers	40 000
No. of beneficiaries — city residents	10 000
Wetland areas supported (ha)	40 000

Present performance of large rice-based irrigation systems in Indonesia

Dwi Kristianto and A. Tommy M. Sitompul

1. Background information on large rice-based irrigation systems

Irrigation has been practised in Indonesia for hundreds of years; yet current irrigation management is still encumbered by several problems, mostly related to the disparity between the modern concept of irrigation management and the traditional practice of the rural population.

As in many other developing countries, Indonesia's irrigation development plan has been based primarily on a pragmatic technological approach. As a result, the far more difficult problems of long-term implementation and appropriate water management at farm level have been neglected.

With Indonesia being an agrarian-based country, irrigated agriculture has always been highly important for its development and has been a priority in the Indonesian Government's five-year development plans from 1969 to 1994 (REPELITA 1 to REPELITA 5). Figure 1 shows that in the 1970s farming still dominated the island of Java, though the plans have tried to expand farming to other islands.

Figure 1. Map of Indonesia and plot utilization

The government's irrigation programme consisted of rehabilitating existing irrigation systems and developing new irrigation systems. Within about sixteen years (1969 to 1985), a significant addition to the existing irrigation areas in Indonesia had been achieved. Table 1 presents a comparison between irrigation areas before and after the rehabilitation and new development programme within the period of 1966 to 1989.

From the figures presented in Table 1, it is evident that besides new irrigation development, much of the simple irrigation was transformed to technical irrigation. The irrigation profiles also changed significantly between 1985 and 2005, as shown in Annex 1. The figures show the latest irrigation profiles in terms of classifications of system type (technical, semi-technical and simple), service area (<1 000 ha, 1 000 ha to 3 000 ha, >3 000 ha), and management responsibilities (district, province, and national responsibility).

Table 1. Irrigation in Indonesia in 1966 and 1989

Irrigation Scheme	Java and Madura (ha)	Other islands (ha)	Total (ha)
Technical irrigation:			
1966	1 430 000	274 000	1 704 000
1989	1 977 000	724 725	2 701 765
Semi technical irrigation:			
1966	457 000	301 000	758 000
1989	393 295	878 177	1 271 472
Simple irrigation			
1966	920 000	415 000	1 335 000
1989	399 620	446 928	846 549
Total			
1966	2 807 000	990 000	3 797 000
1989	2 769 955	2 049 830	4 819 785

Source: Gany (1993).

Irrigation areas less than 1 000 ha are considered small irrigation areas and are the responsibility of the district authorities. Irrigation areas in the range 1 000 to 3 000 ha (medium size) and transdistrict irrigation areas are the responsibility of the provincial authorities. Irrigation areas greater than 3 000 ha and transprovince irrigation areas are the responsibility of the national government. The management responsibility covers primary and secondary systems, whereas the tertiary systems are the responsibility of water users associations.

In line with the irrigation reform agenda, the government set the goal of effective and efficient irrigation water management and irrigation performance became an important indicator of an irrigation system’s success. However, as irrigation reform is still under way, irrigation systems have not been nationally evaluated and current performance figures are not yet available.

However, a performance evaluation was carried out in 2004 for five irrigation areas: Guguk Rantau (West Sumatra); Mandika (South Kalimantan); Kasinggolan (North Sulawesi); Sesaat (West Nusa Tenggara) and Panewon (East Java). The performance figures for these irrigation areas are presented in Table 2.

Table 2. Evaluation of irrigation performance

Aspect and weight / Irrigation area (province)	Water delivery	Irrig. facilities	Irrig. mgt.	Organi-zation	Farming	Total (category)
	30%	27%	18%	15%	10%	
Guguk Rantau (West Sumatra)	67	87	80	100	95	82.49 (GOOD)
Mandika (South Sulawesi)	49	93	54	100	76	72.13 (GOOD)
Kasinggolan (North Sulawesi)	90	73	55	78	48	73.11 (GOOD)
Sesaat (West Nusa Tenggara)	55	63	89	86	93	76.23 (GOOD)
Penewon (East Java)	70	100	81	88	99	85.68 (GOOD)

Source: DGWR (2004).

Another study was conducted in Yogyakarta by Arif (2004) using "fuzzy logical analysis". According to Arif (2004), of the 12 irrigation areas evaluated in Yogyakarta, i.e. Pengasih, Mejing, Donomulyo, Penjalin, Simo, Papah, Karang Ploso, Blawong, Sapon, Pendowo, Pijenan and Kali Bawang, only one irrigation system fell within the "good" category, whereas the others were within the "moderately good" category. Thus, from the two studies, it can be concluded somewhat crudely that irrigation performance in Indonesia tends to be in the "moderately good" category.

The government policy in irrigation is to achieve effective and efficient irrigation management through increased reliance on institutional strengthening and effective interagency coordination. Among the approaches that are being pursued to attain sustainable irrigation operation and maintenance, at least four have received high priority:

(1) encouraging a sense of belonging, of participation and of responsibility;
(2) increasing the sources of funding needed for more reliable operation and maintenance;
(3) a judicious programming, budgeting, and control system with systematic financial control; and
(4) a special maintenance programme.

Besides attaining a sufficient supply of food, irrigation development also aims to promote rural development through developing agricultural commodities. Some irrigation developments were intended to support the country's transmigration programme in Kalimantan and Sulawesi etc.

2. Trend of agriculture development and water resources management

Present irrigation projects in Indonesia, with a few exceptions, are all aimed at increasing food supplies through extending and intensifying rice cultivation, whereas elsewhere in the world, irrigation mostly has been intended to support commercial farming commodities. Yet agricultural in Indonesia also plays a very important role in the economy of the country.

According to Gany (1993), in the 1950s to early 1960s the rate of growth of Indonesia's agricultural production was the slowest amongst the Asian countries, even slower than many countries in Africa and Latin America.

By the 1970s, however, a remarkable acceleration in agricultural development started in Indonesia. The increased role of agriculture in the economy was even more striking against the background of remarkable improvements in international trade. As shown in Table 3, in 1973 the agricultural sector contributed about 40 percent of the gross domestic product. However the trend decreased to 23.33 percent in 1987, 24.07 percent in 1988 and 23.45 percent in 1989.

Table 3. Comparison of gross domestic product of Indonesia for selected years

Economic sector	Gross domestic product						
	1939 (%)	1960 (%)	1963 (%)	1973 (%)	1987 (%)*	1988 (%)*	1989 (%)*
Agriculture	61	54	52	41	23.33	24.07	23.45
Industry	15	8	9	9	13.83	12.08	13.06
Mining	–	4	4	9	16.95	18.49	18.33
Others	24	34	35	41	45.89	45.36	45.16

Source: Gany (1993).
* Central Bureau of Statistics (1990).

In the same period, however, about 65 percent of Indonesian citizens were directly engaged in agricultural activities (with a slight reduction in the following years). This indicates that the per capita income from the agricultural sector was relatively low compared to the non-agricultural sectors.

These conditions have stimulated a change in how people view agricultural activities. In some regions, especially Java and some other provinces, there is a trend for young people in particular to view agricultural activities somewhat negatively. This is a consequence of the low market price for agricultural commodities, especially rice.

Working in industry is preferable for them as they feel they will earn a secure income even if it is at the minimum rate. Rural to urban migration is also common in many places and as a result only elderly people are active in agriculture.

According to the government regulation concerning irrigation, farmers can, with some exceptions based on national food demand, choose to cultivate any agricultural commodity. This means farmers can choose to cultivate high value agricultural commodities.

As an agrarian country, a good income from agricultural activities is very important and is something expected by Indonesians. However, it is not easy to realize and needs comprehensive measures to be taken including market price interventions and arrangements to ensure that the price is sufficient to enable farmers to earn a profit. The farmers themselves have to adopt modern agricultural practices (including irrigation modernization) and a market orientation.

Given the current economic conditions, including the frequent industrial layoffs, the government should promote agricultural activities to absorb the young labour force whose dream of earning money from working in urban industries is becoming more and more difficult to realize. Irrigation water should be managed democratically with the aim being effective, efficient and sustainable irrigation. It is easier when the reservoir water is used exclusively for agricultural purposes. Where the reservoirs serve other purposes, an agreement should be made to give priority of water allocation to irrigation.

On the other hand, as most of the water delivery systems have been designed for single uses, they need to be adapted for multiple uses. The increasing competition for water from the urban, agricultural, industrial and environmental sectors will require comprehensive improvement of water management. Integrated water resources management should therefore be introduced along with irrigation modernization.

3. New requirements for large rice-based irrigation systems

Most water delivery systems in Indonesia are designed for agricultural purposes and the water allocation mechanisms rarely change. If irrigation water is to be managed democratically, effectively, efficiently and sustainably, then comprehensive improvements will be needed to all components of the system to enhance system operation and management.

The most likely problems to arise as a result of current conditions are problems concerning sustainability and conflict of interest. Increasing competition over water from the urban, agricultural, industrial and environmental water sectors will occur everywhere. Addressing these problems will require the redesign of the irrigation infrastructure, including its appurtenance structures and management. We can identify at least four areas which need to be addressed:

(1) Infrastructure readiness

Water should be reliably distributed to all water users. The water conveyance systems, the measurement structures, the regulatory structures should be able to ensure reliable water allocations. Supporting technologies will be required, i.e. prediction method of dependable water, operation method, and standard operation procedures. As accountability is also important, the infrastructure should be calibrated, especially the measurement structures.

(2) Management readiness

The management, including institutional arrangements, should be able to manage and run the system as appropriately as possible. All management personnel should clearly understand their jobs and responsibilities.

Human resources capability and an established system of management are the keys to success. The management should also be able to anticipate changing situations, conditions and policies and have an understanding of conflict management.

(3) Financial improvement

Sufficient financial support will enable the management plan to be implemented as envisaged. Management should be able to generate funds from the water users.

(4) Policy

National and regional policies should support efforts to achieve effective, efficient and sustainable irrigation.

Many district authorities do not make irrigation a high enough priority. They focus first on other infrastructures such as roads and buildings. Moreover, land conversion from farm land to housing and industrial estates is still occurring in many places.

4. Measures undertaken to ensure reliability of water allocation

Improving irrigation infrastructures through rehabilitation, upgrading and special maintenance are measures that should be undertaken to ensure reliability of water allocation. The limited budget available for these measures results in long delays in making the infrastructure technically reliable and ready.

Management improvement measures are faced with late regeneration programmes and human resources development is not well-prepared. In this time frame the number of irrigation engineers retiring is greater than the number of new irrigation engineers replacing them. As a result, the regeneration work can not be done properly. There is a gap of expertise between the senior engineers who are about to retire and the junior engineers who are not yet ready to replace them. Training and education programmes need to be conducted.

Participatory irrigation management can be introduced to the farmers to generate a sense of belonging, of participation and of responsibility. This will result in farmers being willing to pay an irrigation service fee. There are now 47 648 WUA in Indonesia. Establishing water users associations (WUA) at the systems where they are still absent should become a national programme. After their establishment, a strengthening programme addressing organizational, technical, administrative, farming and financial issues should be introduced.

5. Case study of Tarum irrigation system

Tarum irrigation system is within Jatiluhur Multipurpose Scheme. The scheme is intended for electricity, industry, tourism, irrigation and domestic use. As shown in Figure 2, the Tarum irrigation system consists of three subsystems namely West Tarum canal (WTC), North Tarum canal (NTC) and East Tarum canal (ETC). The service area of West Tarum canal is 68 000 ha, whereas the North Tarum canal is 78 000 ha and the East Tarum canal is 90 000 ha. Apart from conveying water for irrigation, the West Tarum canal also supplies domestic water for Jakarta. Figure 3 shows the distribution structure and a tertiary canal.

With regard to large rice-based irrigation system performance, the Tarum irrigation system is facing classical problems. However, the problems seem to be getting more and more complicated.

(1) Land conversion

Land conversion from irrigated paddy fields to industrial estates and housing has transformed thousands of hectares of potentially irrigated paddy field within the service area of Tarum irrigation system (Figure 4). The farmland area has been reduced, but on the other hand a significant additional regional income can be generated from tax payments from the industries that have located there. This fast growing industrialization has in turn stimulated a process of urbanization and the need for housing is increasing.

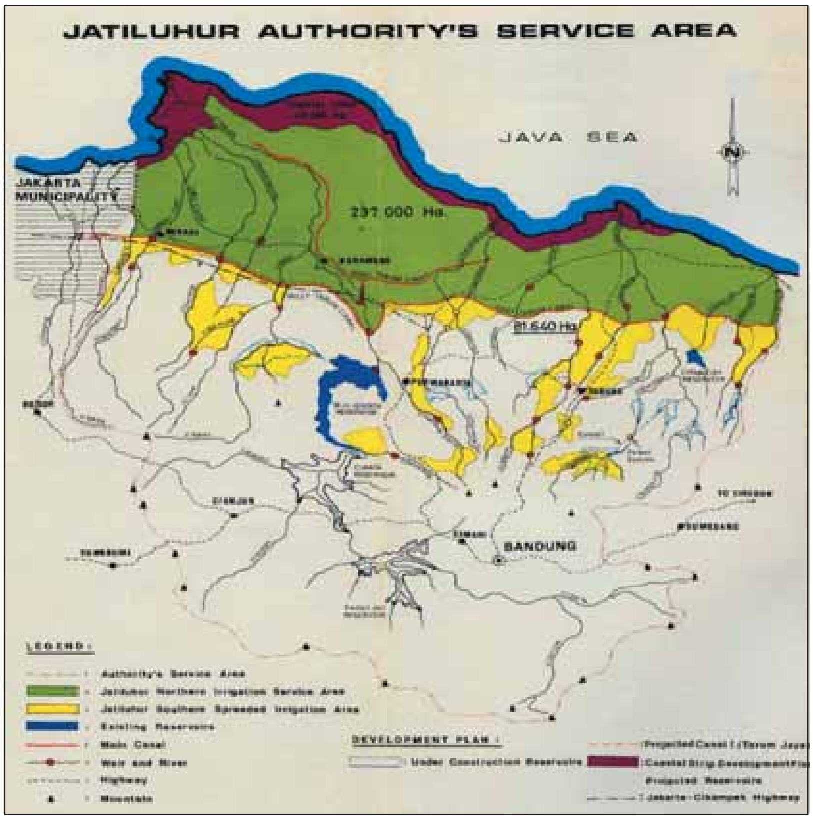

Figure 2. Map of Jatiluhur

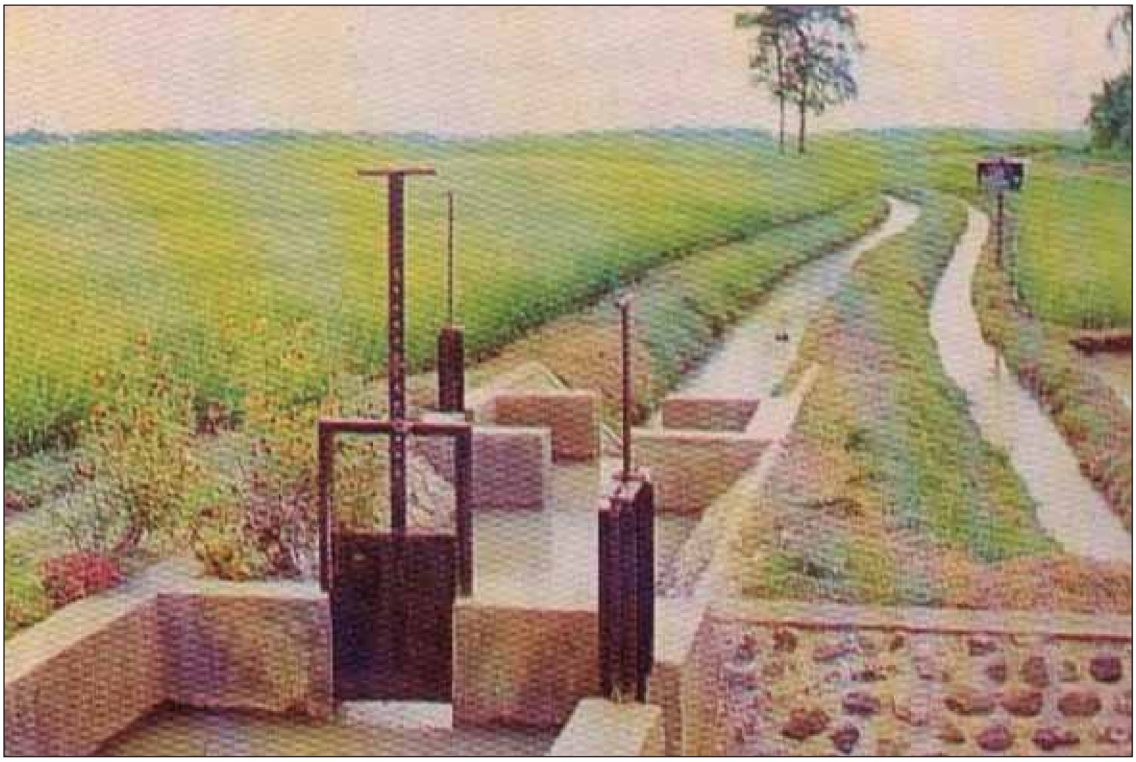

Figure 3. Distribution structure and tertiary canal

Figure 4. Farm land waiting to be converted to housing or industries

(2) Conflict of interest

All water users want to be given first priority for water delivery.

(3) Environment

Waste from industries and housing often result in environmental deterioration.

(4) Reducing services capacity

The main reason for the reduction in services capacity is the limited budget allocation. Proper operation and maintenance are being hindered by lack of funds. As a result, one can readily observe sedimentation in the canals, weeding in the unlined canals (as shown in Figure 5) and structural deterioration. The end result is that irrigation water is flowing below the required discharge rate.

Figure 5. Weeds in unlined canal

6. Conclusions

- Large rice-based irrigation systems in Indonesia play an important role in providing part of the national food supply for domestic consumption.
- The performance of most irrigation system in Indonesia tends to be in the "moderately good" category.
- Meeting the challenges of the next 25 years will require comprehensive improvements, i.e. structural, institutional, management, cultural and policy.
- Marketing mechanisms for agricultural commodities need to be reformed.
- Market oriented agricultural commodities need to be introduced.
- A sense of participation, of belonging and of responsibility needs to be generated.
- Farmers' traditional mindset needs to be replaced by a more advanced or modern mindset.

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Annex 1. Information on irrigation systems in Indonesia

National irrigation management Agency: **Department of Water Resources, Ministry of Public Works**

General information on irrigation systems				
Physical scale of rice-based irrigation systems	**<10 000 ha**	**10 000 to 100 000 ha**	**>100 000 ha**	**All scales**
Number of systems			1	
Annual water diversion (MCM)			7.5 billion m^3/year	
% of agriculture water use			6 500 million (86.7%)	
% of domestic water use			626 million (8.3%)	
% of other water use			5.0%	
Designed irrigation area (ha)			304 724 ha	
Effective irrigation area (ha)			242 585 ha	
Rice irrigation area (ha)			231 105 ha*	
Vegetable and orchard area (ha)			46 226 ha	
Other crops irrigation area (ha)			–	
No. of beneficiaries — farmers			4 806 million	
No. of beneficiaries — city residents			5 590 million	
Wetland areas supported (ha)			200 ha	

* Palawija

Information on the largest rice-based irrigation system	
Name	**Jatiluhur irrigation scheme**
Location	Subang, Bekasi, Karawang, Purwakarta, Indramayu (West Java)
Construction period	1957–1967
Designed irrigation area	Technical irrigation system
Functional irrigation area	Rice
Annual water diversion (MCM)	7.5 billion m^3/year
% of agriculture water use	6 500 million m^3/year (86.7%)
% of domestic water use	626 million m^3/year (8.3%)
% of other water use	5%
Rice irrigation area (ha)	231 105 ha
Vegetable and orchard area (ha)	46 266 ha
Other crops irrigation area (ha)	–
Water supply per ha of irrigated rice field	13 165 m^3/ha/season
Output (US$) per m^3 of water supply	US$0.0075 (Rp. 75)
No. of beneficiaries — farmers	4 806 million
No. of beneficiaries — city residents	5 990 million
Wetland areas supported (ha)	200 ha

Résumé of irrigation area in Indonesia by province

No.	PROVINCE	<1 000 ha				(1 000 to 3 000) ha				>3 000 ha				TOTAL	Total Area >3 000 & Trans Prov.
		FULLY KAB/KOTA	TRANS KAB/KOTA	TRANS PROV.	TOTAL	FULLY KAB/KOTA	TRANS KAB/KOTA	TRANS PROP	TOTAL	FULLY KAB/KOTA	TRANS KAB/KOTA	TRANS PROP	TOTAL		
1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**	**15**	**16 = 5 + 9 + 11 + 12 + 13**
1	**NANGGROE ACEH DARUSSALAM***	186 608	306	0	186 914	74 376	3 138	0	77 514	112 953	20 260	0	133 213	397 641	133 213
2	**NOTH SUMATRA***	206 948	3 865	0	210 813	128 088	2 846	0	130 934	88 646	6 300	0	94 946	436 693	94 946
3	*WEST SUMATRA*	157 205.91	6 275.00	0	163 481	32 633	0	0	32 633	74 570	3 193	0	77 763	273 877	77 763
4	**RIAU***	64 386	0	0	64 386	168 315	0	0	168 315	61 558	0	0	61 558	294 259	61 558
5	**JAMBI***	19 401	0	0	19 401	19 733	0	0	19 733	172 338	0	0	172 338	211 472	172 338
6	**SOUTH SUMATERA***	53 159	0	0	53 159	85 091	0	0	85 091	539 153	0	0	539 153	677 403	539 153
7	*BENGKULU*	45 451	0	0	45 451	12 733	514	0	13 247	18 657	0	0	18 657	77 355	18 657
8	**LAMPUNG***	122 458	250	0	122 708	20 559	3 601	0	24 160	111 506	94 547	8 100	214 153	361 021	214 153
9	**KEPULAUAN BANGKA BELITUNG***	8 240	0	0	8 240	8 595	0	0	8 595	3 108	0	0	3 108	19 943	3 108
10	**WEST JAVA***	97 339	6 964	947	105 250	64 339	8 720	0	73 059	47 701	114 136	242 523	404 360	582 669	405 307
11	**CENTRAL JAVA T***	456 069	21 787	1 189	479 045	61 553	25 682	61	87 296	131 431	145 885	49 204	326 520	892 861	327 770
12	**YOGYAKARTA S.P.***	39 382	4 541	40	43 964	14 716	0	0	14 716	0	5 158	0	5 158	63 838	5 198
13	**EAST JAVA***	434 401	22 271	537	457 209	144 833	20 341	0	165 174	142 870	142 094	0	284 964	907 347	285 501
14	**BANTEN***	87 075	1 359	0	88 434	13 673	5 442	0	19 115	14 560	51 104	0	65 664	173 213	65 664
15	*BALI*	64 893	0	0	64 893	7 450	0	0	7 450	0	0	0	0	72 343	0
16	*WEST NUSA TENGGARA*	82 833	0	0	82 833	56 625	0	0	56 625	33 802	0	0	33 802	173 260	33 802
17	*EAST NUSA TENGGARA*	29 631	0	0	29 631	37 353	0	0	37 353	36 071	0	0	36 071	103 055	36 071
18	**WEST KALIMANTAN***	107 325	0	0	107 325	77 766	0	0	77 766	119 680	0	0	119 680	304 771	119 680
19	**CENTRAL KALIMANTAN***	71 108	0	0	71 108	99 168	0	0	99 168	68 602	0	11 531	80 133	250 409	80 133
20	**SOUTH KALIMANTAN***	120 050	0	0	120 050	93 425	0	0	93 425	115 063	0	0	115 063	328 538	115 063

No.	PROVINCE	<1 000 ha				(1 000 to 3 000) ha				>3 000 ha				TOTAL	Total Area >3 000 & Trans Prov.
		FULLY KAB/KOTA	TRANS KAB/KOTA	TRANS PROV.	TOTAL	FULLY KAB/KOTA	TRANS KAB/KOTA	TRANS PROP	TOTAL	FULLY KAB/KOTA	TRANS KAB/KOTA	TRANS PROP	TOTAL		
1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**	**15**	**16 = 5 + 9 + 11 + 12 + 13**
21	**EAST KALIMANTAN***	39 891	0	0	39 891	38 766	0	0	38 766	4 000	0	0	4 000	82 657	4 000
22	**NORTH SULAWESI***	31 532	0	824	32 356	11 866	0	0	1 866	13 181	0	0	13 181	57 403	14 005
23	*GORONTALO*	7 838	425	0	8 263	5 545.54	2 263.00	0	7 809	0	0	0	0	16 072	0
24	**CENTRAL SULAWESI***	52 728	0	0	52 728	34 139	0	0	34 139	17 568	0	0	17 568	104 435	17 568
25	**SOUTHEAST SULAWESI***	27 768	0	0	27 768	32 303	0	0	32 303	22 671	0	0	22 671	82 742	22 671
26	**SOUTH SULAWESI***	227 741	0	0	227 741	99 502	5 016	0	104 518	285 032	51 977	0	337 009	669 268	337 009
27	**WEST SULAWESI***	28 210	0	5 500	33 710	2 800	0	0	2 800	40 082	0	0	40 082	76 592	45 582
28	**MALUKU***	7 499	0	0	7 499	37 157	0	0	37 157	12 500	0	0	12 500	57 156	12 500
29	*NORTH MALUKU*	4 802.43	0	0	4 802	3 708.40	0	0	3 708	0	0	0	0	8 511	0
30	*PAPUA*	1 700	0	0	1 700	4 700	0	0	4 700	3 450	0	0	3 450	9 850	3 450
	TOTAL	**2 883 673**	**68 043**	**9 037**	**2 960 753**	**1 491 511**	**77 563**	**61**	**1 569 135**	**2 290 753**	**634 654**	**311 358**	**3 236 765**	**7 766 653**	**3 245 863**

Note: Old data (26 Jan. 2005).

* Revised data.

Central Java --> revised data need further checking; Yogyakarta --> Kab. Sleman need confirmation.

Source: Directorate of Water Resources Utility (2005).

Large rice-based irrigation systems in Lao PDR

Phalasack Pheddara[2]

1. Background information on large rice-based irrigation systems

Lao PDR is located in the heart of peninsular Indochina. It is located between 14 to 23 degrees north latitude and 100 to 108 degrees east longitude. It is a landlocked country and shares a 505 km border with China to the north, 435 km border with Cambodia to the south, 2 069 km border with Viet Nam to the east, a 1 835 km border with Thailand to the west, and a 236 km border with Myanmar to the northwest. The country stretches 1 700 km from north to south, with an east-west width of over 500 km at its widest point and only 140 km at the narrowest point. The Lao PDR covers a total of 236 800 square kilometres. Most of the country is mountainous and thickly forested and the Mekong River forms a large part of the western boundary with Thailand.

The government of Lao PDR began decentralizing control and encouraging private enterprise in 1986. The results, starting from an extremely low base, were striking — growth averaged 6 percent between 1988 and 2004. Agriculture accounts for half of GDP and provides 80 percent of total employment.

The economy will continue to benefit from international assistance and from new foreign investment. The major contribution from various sectors to the GDP of Lao PDR is: agriculture 49.5 percent, industry 27.5 percent, and services 23 percent (2004 estimates).

Lao PDR's significant natural resources, proximity to large external markets, and potentially strategic position for trade are unexploited assets.

Agriculture has been a relatively dynamic sector with increases in cultivated land and yields for rice and maize as well as increasing production of cattle, pigs and chickens. Over the past twenty years paddy yields have doubled.

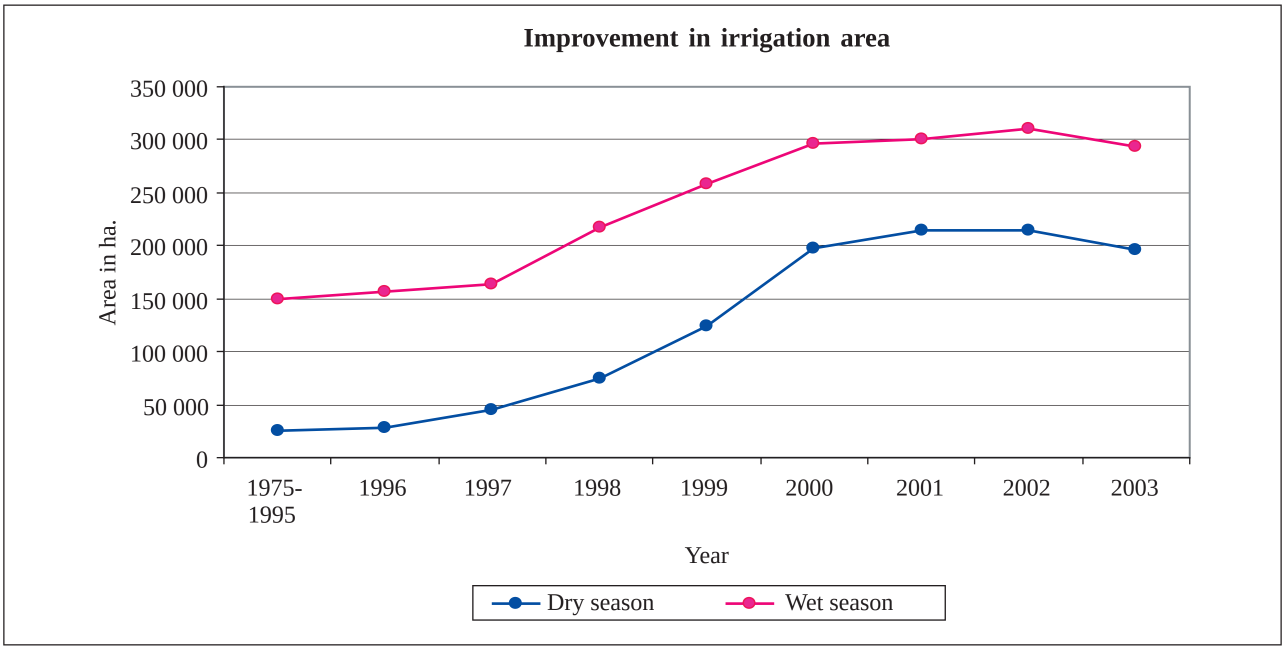
Lao PDR has three types of agricultural production: low land irrigated, low land non-irrigated, and upland slash and burn agriculture. The government has an explicit goal of increasing the amount of irrigated land and decreasing slash and burn agriculture. The country has many small rivers and agriculture lands are irrigated by river water.

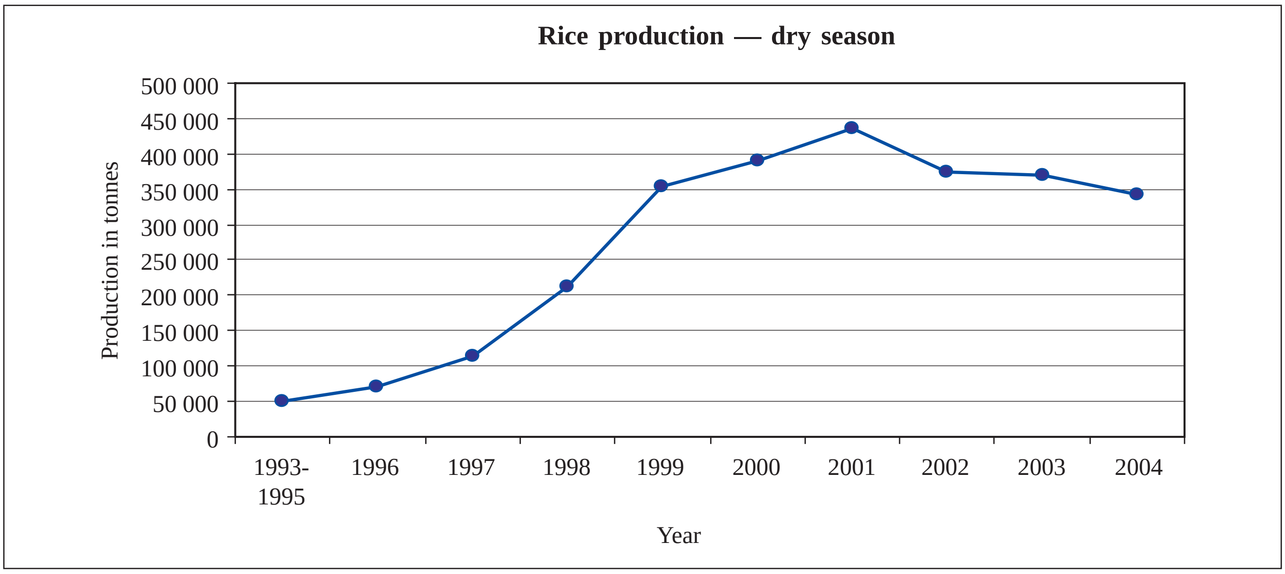
Pumps are used to take water from rivers to the fields. The level difference of water in the river between maximum and minimum is 10 to 12 metres. Pump sets are installed in a float which requires low investment and is easy to maintain.

Rice is the predominant crop and a staple food. Principal non-rice crops include cardamom — sometimes considered a forestry product — coffee, tea, corn, cotton, fruit, mung beans, peanuts, soybeans, sugarcane, sweet potatoes, tobacco, and vegetables. The only crop produced for export in substantial quantities is coffee. The total area planted with these crops is small relative to the area planted to rice. Although the increase in part reflects the drop in rice production during the drought years, it also demonstrates some success in the government's push toward crop diversification. Despite increasing agricultural output, however, Lao PDR is still an importer of food.

The Department of Irrigation (DOI) is under the Ministry of Agriculture. DOI is involved in developing and implementing irrigation systems in all the provinces of Lao PDR. All the existing irrigation systems in the country are implemented by DOI and were handed over to farmers' communities for operation and management (O&M). DOI is guiding the farmers toward the effective utilization of water, based on the amount of water needed for each crop.

[2] Director, Operation and Maintenance Division, Department of Irrigation, Lao PDR.





In the past, the country used to import rice from neighbouring countries to meet the domestic requirement but achieved self-sufficiency in rice production in 2000. Rice cultivation in the dry season has gone up to 436 000 tonnes from 50 000 tonnes in 1995. Dry season irrigated area has gone from 25 000 ha in 1995 up to 210 000 ha in 2002.

At present, Lao PDR has two crops in a year. Dry season crops are mainly dependent on pumping irrigation and reservoirs.

Wet season crops are mainly dependent on nature and irrigation systems are used as a supplementary source of water. Natural calamities like floods affect agriculture fields in the wet season.

The government of Lao PDR carried out major development activities from 1996 till 2000 but could not continue because of lack of funds. The government is encouraging the farmers to cultivate alternative crops after they have sufficient rice. This will help to reduce poverty and will improve the lives of the farmers.

The thematic approach to irrigation set down in the government strategy is based on the following policies:

(i) allocation and provision of water on a sustainable basis for agroforestry systems in the uplands and for existing and new agricultural areas in the lowlands;
(ii) diversification of water resources for irrigation and management for sustainable use;
(iii) improvement of water resource-based productivity;
(iv) improvement of the maintenance of irrigation systems and strengthening of O&M arrangements;
(v) maintenance of watersheds and mitigation of environmental degradation;
(vi) alleviation of rural poverty; and
(vii) acceleration of cash crop production for export, and for import substitution.

The national strategy related these policies to outputs through specific strategies and programmes. The specific strategies are to:

(i) continue to focus investment on the most economically viable irrigation systems and to consolidate and expand irrigation areas;
(ii) continue to strengthen community participation and initiative in project planning, works and maintenance;
(iii) encourage beneficiary financing in development and in O&M of irrigation systems;
(iv) strengthen farmer driven extension focus on cash crops, marketing and improve market access; and
(v) target rural development on “focal sites” within watersheds/river basins.

Programmes and priorities resulting from these strategies are:

(i) water resources use planning for sustainable irrigation development and management;
(ii) improvement of irrigation technology through the use of various irrigation innovations;
(iii) continued promotion of irrigation management transfer and of community managed irrigation programmes which include active participation in planning construction and O&M; and
(iv) consolidation and expansion of training programmes for farming communities and farmers in irrigation system management in O&M, watershed preservation, and improved and diversified farming systems.

The expected outputs identified by the national strategy are:

(i) major consolidation and expansion of community-managed small-scale irrigation systems;
(ii) accelerated increases in upland farming systems diversification, particularly in dry season irrigated agriculture;
(iii) full irrigation management transfer to local communities; and
(iv) sustainable irrigation systems where management and operational costs are borne by the irrigator farmers.

Fundamental to this national strategy for irrigation development are five national strategic plans. These plans, derived from the list of programmes outlined above focus on:

(i) water resources planning;
(ii) irrigation technology;
(iii) irrigation management transfer;
(iv) community managed irrigation; and
(v) training and extension.

The strategy focuses on community management of irrigation, irrigation management transfer, and consolidation of past achievements. Construction of new irrigation systems will be deferred until these stated priorities are attended to.

2. Trends of agriculture development and water resources management

Lao PDR appears to have an abundance of water. This abundance, be it real or perceived, has led to a somewhat cavalier attitude to the management of the resource. While key officials are aware of the need for resource management, there are higher development priorities for the country. The people of Lao PDR do not have far to look to see the problems that arise as a result of poor management of water resources. The neighbouring Northeast region of Thailand and Yunnan Province of China are two shining examples of the need for effective resource management.

Throughout the country, river and stream behaviour is changing as catchments are deforested with resulting degradation. Silt loads, particularly in the wet season are increasing and this is creating a problem in all subsectors using surface water. Suspended matter in the water creates a greater rate of component wear on pumps and turbines and increases filtration problems in any situation requiring clean water. Sedimentation of irrigation infrastructure provides an ongoing maintenance problem in an environment where attention to maintenance is not given a high priority. This is only part of the problem resulting from catchment degradation. Apart from the obvious localized problems resulting from catchment degradation, flow in all streams from minor streams to the Mekong River are being effected with increasingly lower dry season flows being experienced over a longer period of time. Wet season flows are becoming increasingly higher, with high flows experienced over a shorter period of time. Small streams which once ran year-round, although with low dry season flows, are now drying up during the dry season.

In Lao PDR, the indiscriminant use of water continues. Gravity fed irrigation schemes are designed for a headworks requirement of 4.5 litres per second per hectare. Elsewhere in the world, the figure adopted is 1.8 litres per second per hectare. It is easier to provide more water than to control water loss as a result of poor distribution infrastructure and poor management. In urban water supplies the percentage of non-revenue water is very high. In remote villages with piped water supplies gravity fed from springs, it is common to see faucets either full on, or removed from the standpipe. The water is not entirely wasted as it is then available for duck raising and other livestock and usually ends up in a communal pond. Apart from wasting the resource, a considerable sanitation problem is created in the meantime. Hydropower systems have been designed with scant attention to downstream users, although this lack of concern appears to be changing.

Little attention has been given to the exploitation of groundwater, however this is likely to change. In line with this change, an increasing need for groundwater investigation will be necessary both to maximize investments and to protect the resource. Experience in the adjoining Northeast region of Thailand, suggests that groundwater conditions in the flat areas of the southern provinces are likely to be complex and fragile. It is most important to avoid the problems experienced in this neighbouring region of Thailand, particularly with regard to salinity and diminishing availability.

Hydropower sales to Thailand are likely to increase considerably, and sales to Viet Nam are likely to commence as Lao PDR pursues its policy of pursuing export earnings in order to boost foreign exchange. In pursuit of the same goals it is likely that the sale of water to neighbouring Thailand will soon commence. The sale of water to Thailand need not involve the physical transfer of water. Instead, a holistic view of the Mekong River flow should be considered. Under the multilateral agreement framed by the Mekong River Commission, member countries have agreed on the amounts of water that each might withdraw from the Mekong River. Instead of physically transferring water from Lao PDR to Thailand, it would be sufficient for Lao PDR to reserve a certain flow from one of its prolific southern rivers and guarantee availability of an amount of water similar to what Thailand might extract elsewhere on the Mekong. In this manner, the amount of water available downstream in Cambodia and Viet Nam would be in line with the multilateral agreement. Thailand would pay Lao PDR for the water thus reserved without the cost of expensive infrastructure to physically transfer water from one country to the other. Thailand would extract water from the Mekong close to the point of requirement.

3. New requirements for large rice-based irrigation systems

New requirements for large rice-based irrigation systems are:

- studying potentials and identifying components and other measures that will help strengthen the potentials and functions of the projects;
- formulating others projects related to planning for organizational development, water management, land-use, production and marketing, etc. in relation to local and regional perspectives; and
- promoting the projects by means of building up people/local participation.

4. Case Study: Nam Suang irrigation project

Location

Nam Suang irrigation project is located about 42 km from Vientiane city, which covers the cultivated area of three districts namely:

- Naxaythong District (Vientiane City)
- Phonhong District (Vientiane Province)
- Thoulakhom District (Vientiane Province).

The project is bordered by the Nam Ngum River in the east and the Phouphanang mountain chain in the west.

Background/History

In order to implement the government's policy on rice self-sufficiency the following activities have been carried out:

- 1978–80: construction of dam, intake, temporary drain, and three km of main canal, using the government's budget and partly financed by SIDA, irrigated area of 84 ha;
- 1980–83: with assistance of former Soviet Union experts, re-study, survey and design for 4 500 ha;
- 1988: first construction of spillway on the temporary drain for emergency assistance DS 1988/1989, paddy of 300 ha (using government's budget);
- 1994: re-construction of spillway (using government's budget);
- 1996–98: Re-study using the existing structures and canal system to irrigate in dry season 3 500 ha and wet season 4 500 ha (using government's budget);
- 1998–2002: construction of main, secondary canals and related structures to serve an area of 2 350 ha (using government's budget);
- 2005: farmers participation for improvement of existing spillway and
- total investment up to 2005 is approximately US$20 million.

Storage capacity

- Maximum 91.28 MCM
- Minimum 34.20 MCM

Canals (rehabilitation needed)

- Total 72.0 km
- Main 27.0 km
- Secondary 45.0 km

Structures

- Total 55 structures
- Repair needed 35 structures

Organization

- No. of villages 15 villages
- No. of groups 11 groups

Members

- Permanent 960 members
- Temporary 380 members

Headwork, main and secondary canals are under the overall management of the Nam Suang Centre for Irrigation and Agriculture Development.

Financial

- ISF 125 000 Kip/ha
- VDF 150 kg (paddy)/ha
- Collection rate 65%

Justification

- Irrigation facilities already cover 4 500 ha;
- the present storage capacity is only for 2 350 ha (supply less than demand);
- poor canal system;
- poor water management (lack of management knowledge both project staff and farmers);
- poor management institutions, lax enforcement of regulation;
- depletion of the environment and biodiversity; and
- poor agriculture management (extension).

Rehabilitation/improvement programme

- review and study;
- watershed management;
- headwork and reservoir (dam, spillway, dike);
- canal system and structures;
- operation and maintenance;
- capacity building (staff & farmers); and
- extension services.

Budget requirement

Total US$5.98 million

- Bi-lateral assistance US$5.30 million
- Government contribution US$0.68 million
- Investment US$1 330 per ha

Expected outputs:

- irrigation system rehabilitated;
- rice production increased;
- crop diversified;
- watershed management improved;
- used for multipurposes;
- capacity built up;
- institutions strengthened;
- operation and maintenance improved; and
- extension.

Information on irrigation systems in Lao PDR

National irrigation management Agency: **Department of Irrigation (DOI)**

General information on irrigation systems				
Physical scale of rice-based irrigation systems	**<10 000 ha**	**10 000 to 100 000 ha**	**>100 000 ha**	**All scales**
Number of systems	24 000	0	0	24 000
Annual water diversion (MCM)	6 200	0	0	6 200
% of agriculture water use	97%	0	0	97%
% of domestic water use	2%	0	0	2%
% of other water use	0.5%	0	0	0.5%
Designed irrigation area (ha)	310 000	0	0	310 000
Effective irrigation area (ha)	214 000	0	0	214 000
Rice irrigation area (ha)	110 000	0	0	110 000
Vegetable and orchard area (ha)	80 000	0	0	80 000
Other crops irrigation area (ha)	24 000	0	0	24 000
No. of beneficiaries — farmers	300 000	0	0	300 000
No. of beneficiaries — city residents	1 200 000	0	0	1 200 000
Wetland areas supported (ha)	20 000	0	0	20 000

Information on the largest rice-based irrigation system	
Name	**Nam Suang Irrigation Project**
Location	Naxaythong District, Vientiane City
Construction period	1978–80
Designed irrigation area	4 500 ha
Functional irrigation area	2 350 ha
Annual water diversion (MCM)	62 MCM
% of agriculture water use	98%
% of domestic water use	1%
% of other water use	1% fish pond
Rice irrigation area (ha)	2 350
Vegetable and orchard area (ha)	50 ha
Other crops irrigation area (ha)	None
water supply per ha of irrigated rice field	DS 23 000 m^3; WS 10 000 m^3
Output (US$) per m^3 of water supply	12.5
No. of beneficiaries — farmers (family)	1 340
No. of beneficiaries — city residents (family)	3 000
Wetland areas supported (ha)	30

Irrigation systems in rice granary areas of Malaysia – challenges and the need for transformation

Mohd Abdul Nassir Bin Bidin and Natalia Puspa Dewi[3]

1. Background information on large rice-based irrigation systems

Malaysia covers an area of 336 000 sq. km and is located between 1 degree and 7 degrees north latitude and 100 degrees and 119 degrees east longitude. It consists of eleven states in the peninsular part of the country and the insular states of Sabah and Sarawak, which are separated by the South China Sea in the east. The total population is about 20 million and nearly 80 percent lives in the west side of the country.

The total land used for agriculture in Malaysia is about 22 percent. Townships, mining activities and other uses take up another 10 percent, leaving 68 percent under forest cover. Half of the agriculture lands are cultivated with perennial crops. The other half is taken up by annual crops, mixed horticulture, shifting cultivation and, to a much lesser extent, fishponds.

The total physical paddy area in Malaysia is estimated to be 598 483 hectares of which 379 469 hectares are located in Peninsular Malaysia with the remaining in Sabah and Sarawak. Wet paddy constitutes 85 percent of the total paddy area in the country and the remaining 15 percent consists of non-irrigated paddy areas, which include rainfed paddy fields, hill or upland paddy concentrated mainly in Sabah and Sarawak. In Peninsular Malaysia, 76 percent of the area is provided with extensive irrigation and drainage facilities whereas only 15 percent of the area in East Malaysia is irrigated. Most of the irrigated paddy areas in Peninsular Malaysia are located in the eight designated granary areas totalling approximately 212 000 hectares.

The remaining irrigated areas comprise 924 small irrigation schemes, 74 of which cover 28 000 hectares and are classified as mini granary areas. The location of granary and mini granary areas is given in Figure 1 and Figure 2.

Figure 1. Granary areas in Malaysia

[3] Ministry of Agriculture and Agro-based Industry Malaysia. Wisma Tani, Lot. 4G1, Presint 4, Level 4, Pusat Pentadbiran Kerajaan Persekutuan, 62624 Putra Jaya, Malaysia.

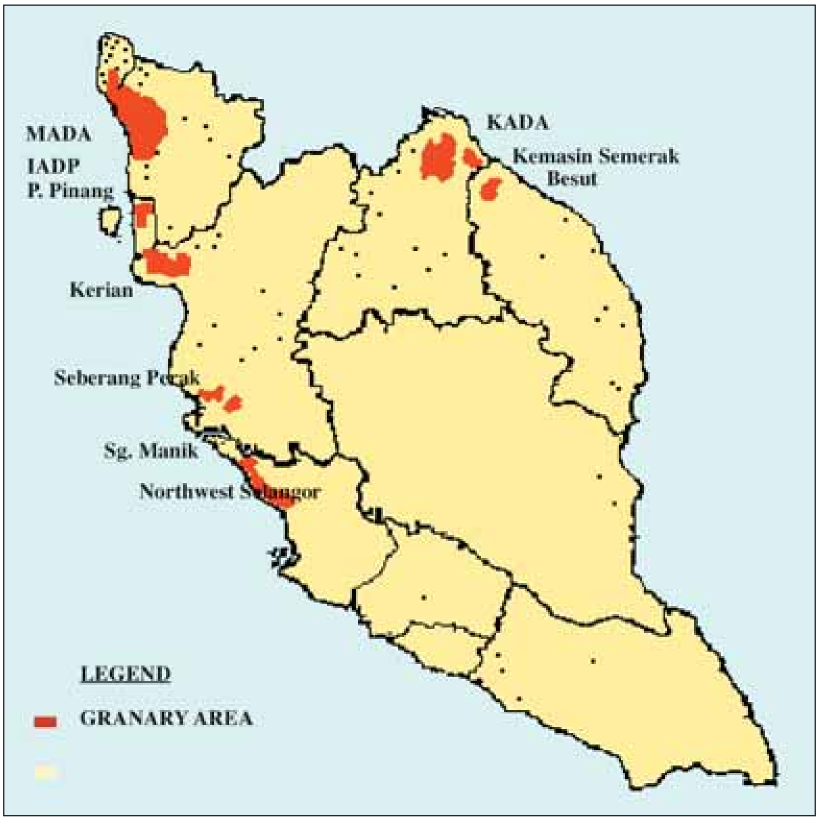


Figure 2. Mini granary areas of Malaysia

The paddy sector has been considered a strategic sector and has always been accorded special treatment by the Malaysian Government. These efforts reflected the concern of the government on issues relating to food security as well as other socio-economic considerations. As Malaysia faces a production deficit, rice is considered as a security commodity. Hence, the national policy is to maintain a prudent level of self-sufficiency at a minimum level of 65 percent.

In addition, support to the sector is justified to enhance the incomes of small paddy farmers, many of whom are poor. Government intervention is extensive — from production to distribution and marketing. Massive public investment in infrastructure development and support services is accorded to the industry. Price and fertilizer subsidies are among the various subsidies that help support the sector.

2. Trends of agriculture development and water resources management

2.1 Evolution of the agriculture sector

In the decades following independence, agriculture was the main earner for the country. The sector was the main contributor to the national economy and was the driving force behind the economic growth of the country. Agriculture was used to finance the development of the country and thus laid the foundation of its industrialization.

However, rapid industrialization during the last decade has led to the decline in the sector's relative contribution to national income, export earnings, employment and investment. The change in the country's economic policy brought forth issues and challenges in the agricultural sector, in particular acute labour shortages, limited availability of suitable land and the ever increasing cost of production arising from intersectoral competition for resources as well as intense competition in the global market resulting from trade liberalization.

The contribution of rice to the national economy is small and declining. The declining trend is largely a result of negligible gains in productivity, increases in production costs and decreasing profitability. Table 1 presents the contribution of agriculture sector in percentage of GDP from 1957 to 2004.

Table 1. Contribution of agriculture sector as percentage of GDP

1957	1970	1985	1995	2000	2003	2004
46%	30%	20.8%	13.9%	8.6%	9.4%	9.7%

- Late 1990s — significant change as a result of the financial crisis — agricultural exports enjoyed high prices during the crisis period.
- 1998 — GDP shrank to -5.1 percent, food and agri-business grew by 8.5 percent; high food import bill of RM12 billion.
- Critical review of existing agricultural policies leading to the formulation of the Third National Agricultural Policy (NAP3) in 1998 and the "MoA Inc." concept.

The agricultural sector had over those past decades contributed strongly to the country's economy, employment, social and political stability. Changes in policy to liberalize the agricultural sector and to stress industrialization in the second half of the 1980s saw the agricultural sector facing strong disadvantages in policy terms, thus losing its attractiveness in the competition for resources. The first National Agricultural Policy (NAP) was promulgated in the early 1980s to initiate liberalization of the agricultural sector. The policy stressed productivity and sustainable growth. The emphasis then was to continue with new land development and consolidation of economic farm sizes through *in situ* development. However, the rapid expansion of the manufacturing sector changed the relative importance of the agricultural sector. To address the issue of productivity, efficiency and competitiveness and to build linkages with other sectors of the economy, the second NAP (NAP2, 1992–2010) was introduced. Efforts to further liberalize the agricultural sector were intensified.

The rapid and sudden changes in the domestic and international economy highlighted the flaw in the national economic policy and the NAP formulation. NAP2 (1992–2010) lacked focus on priority areas of agricultural development, a plan of action and mechanisms for its implementation. To improve competitiveness as well as to ensure continuing growth of Malaysian agriculture, NAP3 (1998–2010) was then formulated. The aim is to ensure the maximization of income of the agricultural sector through efficient and optimal utilization of existing resources. Currently, the agriculture sector has been re-entrusted as an important sector "the third engine of growth" in the national development agenda.

2.2 Recent and future challenges

The rapidly changing national and international scenarios raised new issues and challenges for further development of the agricultural sector. One of the many challenges facing the agricultural sector is to improve the efficiency and effectiveness in the utilization of resources, land, water and labour. These challenges, if not adequately addressed, will definitely affect the agricultural sector's sustainability. There is a strong need to improve the agricultural sector delivery system all along the process and production chain. One of the functions and roles of irrigation and agricultural drainage is to bring about improvement in land, water and labour productivity.

Much of the country's arable land has been brought under cultivation. Further agricultural development will have to be developed vertically or on land that is marginal and requires expert handling and higher development cost. Ironically, the existence of substantial idle agricultural land and abandoned holdings is still an issue. It has been and remains a great challenge to resolve land issues.

Water use efficiency requires policy, infrastructural, institutional as well as managerial interference. Although too much water is a problem for agricultural production, water scarcity on the other hand can seriously affect agricultural production. It is a challenge in itself to promote water productivity and water use efficiency in the agricultural sector unless water can be considered as an economic good, which could be a reality in the future.

The issue of labour shortages has been tormenting the agricultural sector since the second half of the 1980s. Mechanization, however, is a well-known solution to the issue of labour productivity; but after twenty years the mechanization programme is still an issue. Currently, labour productivity in agriculture is only about 60 percent of the labour productivity in the manufacturing sector. The challenge is how to bring about mechanization to the whole chain of agricultural activities in the shortest time possible.

2.3 Infrastructure investment outlook

Farm investment in the form of irrigation canals, farm roads and other on-farm infrastructure has been instrumental in changing the paddy production situation in the country. The success of double cropping has been realized predominantly by the provision of irrigation facilities. Such facilities have been responsible for the achievement of an average of 180 percent cropping intensity for the eight rice-granary areas in the country.

The development of the irrigation infrastructure has been the sole responsibility of the government, even before independence, when a substantial amount of budget was allocated for the purpose as reflected in the First and Second Malaya Plans (1956–1960 and 1961–1965). In these, about 16.8 percent and 23.2 percent, respectively of the total budget for the agricultural sector were devoted for drainage and irrigation facilities (Table 3).

Table 2. Development expenditure for drainage and irrigation

Malaysia Plan	Period	Total agriculture (RM million)	Irrigation and drainage	
			Amount (RM million)	Percentage (%)
First Malaya Plan	1956–1960	227.5	38.3	16.8
Second Malaya Plan	1961–1965	467.9	108.5	23.2
First Malaysia Plan	1966–1970	1 114.1	342.6	30.8
Second Malaysia Plan	1971–1975	7 100.3	271.1	3.8
Third Malaysia Plan	1976–1980	4 666.2	554.8	11.9
Fourth Malaysia Plan	1981–1985	7 671.3	396.6	5.2
Fifth Malaysia Plan	1986–1990	7 325.0	200.3	2.7
Sixth Malaysia Plan	1991–1995	8 215.2	844.6	10.3
Seventh Malaysia Plan	1996–2000	8 139.3	1 929.9	23.7
Eighth Malaysia Plan	2001–2005	7 860.0	2 170.2	27.6

Source: National five-year development plans.

The pace continued in the First Malaysia Plan (1966–1970) where RM342.6 million was allocated for a similar purpose, which constituted about one third of the total agricultural development budget. It was during this period that the MADA irrigation scheme, the largest scheme in Malaysia, was constructed and completed in 1973. The allocation for drainage and irrigation was substantially reduced in the Second Malaysia Plan to the Fifth Malaysia Plan where the budget was reduced to less than 10 percent of the total for agriculture (except in the Third Malaysia Plan where it was 11.9 percent). Since the Sixth Malaysia Plan, the allocation had steadily increased to the current level of about 28 percent, an equivalent of RM2.17 billion, in the Eighth Malaysia Plan.

3. New requirements for large rice-based irrigation systems

3.1 The need for modernization

The most important factor to a sustainable agriculture sector is to remain competitive and be relevant in the context of national development. To remain competitive, the agriculture sector needs to go beyond the model of the earlier successes and must transform itself to enable an increase in its productivity as much as to match market demand in terms of quality and quantity. The agriculture sector must be transformed radically in terms of its processes, technology and culture. It must be able to quickly respond to the ever-changing needs in terms of quantity and quality while keeping pace with social and environmental needs. The immediate strategy is to modernize.

3.2 The need for irrigation infrastructural transformation

The recent trends in investment suggest that it is unlikely that the past high rates of infrastructural development for irrigated agriculture will continue. The main reason is the unfavourable economic outlook for new irrigated infrastructural projects. Rising capital costs, low returns on capital, problems of operation and maintenance, low efficiency of water use, low level of water charges and revenues, environmental impacts of dams and degradation of natural resources are reasons to suggest the slower growth for irrigated infrastructural development.

Future irrigation development will mainly be targeted at exploiting the full potential of increased cropping intensities and crop yields through rehabilitation, modernization and management review of existing irrigation systems. The main aims would be to ensure that irrigated agriculture is able to make a difference in the livelihoods of its beneficiaries through the provision of efficient delivery systems, paving opportunities for improving cost competitiveness as well as minimizing the investment risk of the sector.

3.3 The Need for technology and knowledge transformation

Knowledge and technology are the fundamentals of organizations of the future. The agricultural sector is no exception and it needs to move beyond the existing production system through a systematic process of information sharing and knowledge development. A new approach in the agricultural sector needs to be intensified and developed with concerted effort through collaborative national and international networks. Information sharing is a prerequisite in promoting efficient and quality decision-making. An effective delivery system is dependent on good decision-making, which in turn is based on quality data through a systematic information sharing mechanism. The online benchmarking information system is one good example of an information sharing mechanism.

The highest potential for change and growth in the agricultural sector is towards improving efficiency, effectiveness, quality and productivity of the sector through research and knowledge development. Knowledge in the agricultural sector is very much localized and locked within the individual farm community. The rapid appraisal process (RAP) is a knowledge development and sharing mechanism for irrigation system development.

Most of the knowledge in the agricultural sector is in the form of tacit knowledge — knowledge that is locked within the individual in the form of experience. The agriculture sector should make radical changes in its outlook towards knowledge by focusing on the process of converting tacit knowledge to explicit knowledge. The emphasis placed on tacit knowledge will give rise to a whole different view of an organization — not as a machine for processing information, but as a living organism that produces knowledge. It gives rise to a whole new view of how learning should be achieved — not only through the mind, but both body and mind.

4. Past and present measures

4.1 Performances of granary areas

Malaysia produces about 2.2 millions metric tonnes of paddy, 84 percent of which is produced in Peninsular Malaysia. The national average yield is about 3.2 metric tonne/ha, averaging 3.6 tonne/ha in Peninsular Malaysia against 1.6 metric tonne/ha and 3.2 metric tonne/ha in Sarawak and Sabah, respectively. A summary of the performance of the sector is depicted in Table 3. The eight main granaries consistently contribute about 70 percent of the national rice production. The MADA scheme on average contributes about 55 percent of total granary production, followed by KADA, Kerian-Sg. Manik and Barat Laut Selangor (each at about 10 percent), Pulau Pinang and Seberang Perak (each about 5 percent) and Besut and Kemasin Semerak (each about 1 percent).

Table 3. Planted area, production and yield of paddy, by main production area, 1985 to 2002

Region	1985			1990			1995			2002		
	Planted area	Production	Yield	Planted area	Production	Yield	Planted area	Production	Yield	Planted area	Production	Yield
	('000 ha)	('000 Mt)	(Mt/ha)	('000 ha)	('000 Mt)	(Mt/ha)	('000 ha)	('000 Mt)	(Mt /ha)	('000 ha)	('000 Mt)	(Mt/ha)
Peninsular Malaysia												
Main granary	**336.8**	**1 122.4**	**3.33**	**373.6**	**1 297.9**	**3.47**	**383.1**	**1 527.7**	**3.99**	**382.4**	**1 492.8**	**3.90**
• MADA	186.1	701.0	3.77	189.7	724.9	3.82	193.8	862.2	4.45	192.5	820.3	4.26
• KADA	37.9	108.2	2.85	46.3	163.7	3.54	51.7	181.2	3.50	47.2	121.4	2.58
• Kerian-Sg. Manik	47.2	144.1	3.05	51.1	128.7	2.51	48.6	163.0	3.35	56.8	174.2	3.07
• **Barat Laut Selangor**	34.2	97.4	2.85	35.7	142.0	3.98	35.6	146.7	4.12	37.2	177.1	4.76
• Pulau Pinang	16.0	31.7	1.98	21.8	35.9	1.65	19.3	62.7	3.25	17.4	80.04	4.60
• Seberang Perak	9.4	20.5	2.18	17.1	70.5	4.12	17.1	56.9	3.33	16.7	74.5	4.46
• Ketara	6.0	19.5	3.25	8.0	25.5	3.19	9.5	35.3	3.71	10.2	38.8	3.80
• Kemasin Semerak	–	–	–	3.9	6.5	1.67	7.5	19.7	2.63	4.4	6.4	1.47
The rest	118.9	332.4	2.80	120.4	326.9	2.72	113.4	310.6	2.74	126.3	359.2	2.84
Sub total	455.7	1 454.6	3.13	494	1 624.6	3.29	496.5	1 838.3	3.70	508.7	1 852.0	3.64
Sabah	38.0	79.1	2.08	54.8	94.8	1.73	53.1	143.5	2.70	42.7	137.0	3.21
Sarawak	161.2	211.7	1.31	131.8	165.6	1.26	123.1	145.4	1.18	127.1	208.4	1.64
Malaysia	**654.9**	**1 745.4**	**2.67**	**680.6**	**1 885.0**	**2.77**	**672.7**	**2 127.4**	**3.16**	**678.5**	**2 197.4**	**3.24**

In Malaysia, designating paddy production areas is one of the major strategies to enhance rice production. The eight granary areas comprise MADA, KADA, Kerian, Barat Laut, Seberang Perai, Seberang Perak, Ketara and Kemasin Semerak. These areas have been designated as permanent paddy producing areas to realize a minimum self-sufficiency level for rice of 65 percent. Currently they cover only 36 percent of the total physical paddy land but constitute 57 per cent of the total area planted and produce 72 percent of the total national rice production.

MADA is the largest rice granary area in Malaysia. Thus, the performance of MADA is extremely important as it influences the overall performance of the rice industry. During the 1982–2002 period, the planted area remained almost constant, between 96 000 to 97 000 ha for both the main and off-season. Average main season paddy yield fluctuated but was about 4 tonne/ha for most of the production periods. The growth rates in production were 1.9 percent and 4.6 percent per annum for the main and off-season respectively. However, the bulk of the growth was registered during the 1982–1990 period, against the more recent 1991–2002 period. In fact, in the main season of the period 1991–2002, there was negative growth, brought about by similar negative growth in planted area and productivity. The planted area grew by less than 1 percent for both seasons, with lower growth in the 1991–2002 period. Nevertheless, as a whole MADA could still be considered as a stable rice granary area. An overall negative growth in the main season is a cause of great concern though. Overall, the performance in the 1982–1990 period was better than that in the 1991–2002 period.

Past national agricultural policies (NAP) introduced various strategies to ensure sustainability of the paddy and rice industry. The current NAP3 (1998–2010) calls for the gradual but effective transformation of agriculture and includes measures to promote efficiency, competitiveness, and sustainability throughout the food value chain within the socio-political framework. For the paddy sector, the NAP3 outlines six major strategic thrusts toward ensuring the competitiveness of the rice industry. First is rationalizing resource use by designating the eight granary areas as permanent paddy producing areas. Commercial paddy production by the private sector will be promoted, especially in Sabah and Sarawak. Increasing efficiency and productivity is heavily emphasized. To ensure a competitive return from rice farming, large production units are supported.

4.2 Irrigation modernization

Irrigation modernization is an important step in Malaysia's next major effort towards upgrading irrigation services in the country. Under the Seventh Malaysia Plan, an irrigation modernization programme has been formally established, aiming at further improvement to the irrigation infrastructure, but addressing at the same time other aspects (managerial, institutional and technological development) that would support the targeted rice production with good stewardship over resource inputs including water, labour, finance and the environment. It is recognized that much effort is needed at farm level with respect to infield improvement, water delivery and management with higher precision, improved agricultural practices in crop varieties, seeding rate and fertilizer input, workability of farm machinery, farmers' organization and involvement, farm management efficiency, and pest, disease and weed control that are effective and environmentally friendly, etc.

In line with the policy of confining the future thrust in rice production to the eight designated granary areas, the irrigation modernization programme is focused on these areas. The irrigation modernization programme, especially the water management aspect, is geared towards improving the timeliness of activities and improved management productivity. The following key areas for improvement were studied and respective improvement plans formulated:

a) system infrastructure improvement;
b) infield infrastructure improvement;
c) water management improvement;
d) land consolidation;
e) acceleration of mechanized farming;
f) improvement of agriculture (farming practices);
g) strengthening of farmers' organizations; and
h) environmental management.

Each of these is elaborated on in the following sections.

4.2.1 System infrastructure improvement

The improvement plan for system infrastructure aims at ensuring adequacy in irrigation and drainage facilities in terms of capacity, delivery and drainage efficiencies and water control. Lining of canals and additional regulators are proposed. Drainage facilities have to be provided to improve machine workability. To facilitate modern mechanized farming, farm roads need to be upgraded, especially along tertiary canals.

4.2.2 Infield infrastructure improvement

Direct seeding is the way forward for paddy production in Malaysia and to support this the infield conditions must be able to facilitate good water level control and even distributions and timeliness of water application. It also should facilitate effective weed control. The infield infrastructure development comprises land leveling and construction of infield channels and control boxes. This will be a combined effort between the Department of Agriculture DOA (40 percent) and the private sector (60 percent). The Areal Farmers Organization (AFO) will be encouraged to undertake the work. Infield channel density target is 150 m/ha and two control boxes are proposed for each consolidated plot.

4.2.3 Modernization of water management system

The proposed water management system is being planned and will be operated with the aid of computers. Water level data for main and secondary canals together with rainfall data will be collected with telemetric facilities. A crop water requirement/water balance/hydrological model will be used to determine the amount of water available, required and being distributed.

4.2.4 Irrigation water management system (IWMS) and irrigation monitoring and feedback system (IMFS)

The IWMS is a computer model determining daily irrigation requirement and distribution and aims at effective use of irrigation water, better water management to support higher paddy production, as well as cost saving and labour saving in operation and management. It is proposed that the IMFS be integrated into the control station for each granary and so as to provide updated information on irrigation status and progress of farm activities so that the farmers can respond in good time to take the necessary preparatory steps and adhere to schedules. The system will also provide useful information to the O&M and agriculture extension field staff.

4.2.5 Irrigation performance assessment

As part of the operation of the modernized water management system, a standardized irrigation performance assessment is to be conducted based on three performance indicators namely relative water supply (RWS), cropping intensity (CI) and water productivity index (WPI). The proposed targets are: RWS at 1.65 (equivalent to 60 percent irrigation efficiency), CI at 190 percent, and WPI between 0.3 and 0.5 kg/m^3.

4.2.6 Land consolidation

Land consolidation aims at integrating adjacent lots to form one larger operating plot of 3 to 5 ha each through removal of field bunds. The proposed land consolidation requires intensive promotion to get the consensus of the land owners. Ideally, it should be performed concurrently with the infield infrastructure development works.

4.2.7 Acceleration of mechanical farming

Previously, major farming works such as the land preparation, harvesting and transportation were carried out rather efficiently using agricultural machines. However, other farming works like seeding, and fertilizer and chemical applications were mostly done manually or with "walking" machines. Such work efficiency is low and it is labour intensive and more costly. The recommended farm mechanization system for land preparation both for wet seeding and dry seeding is tractor plus rotavator.

4.2.8 Agriculture improvement

Cropping intensity

The granary areas have the potential for supporting paddy plant growth with a high yield of about 5 to 6 tonne/ha. In order to attain a stable double cropping with 190 percent cropping intensity, adherence to cropping schedule is important and water resources adequacy is crucial to meet this requirement.

Farming practices

Farm operations need to be practised in an optimal manner. This includes the land preparation method and procedure, amount and timing of fertilizer application, seeding rate, and weed, pest and disease control methodology. Precision water management is needed to maximize effectiveness of the above. The IMFS should serve well for smooth farming operations.

4.2.9 Strengthening of farmers' organization

Farmers' groupings are based on social/cultural background and are not that suitable for efficient operation of the irrigation water management system. Research confirmed the intended move by the Division of Irrigation and Agricultural Drainage and other agriculture agencies to reorganize the farmers according to irrigation system boundary. The main purpose of the reorganized farmers' groups, now widely referred to as water users groups (WUGs), is to implement proper water management in their respective areas. At the same time, the WUGs will also serve other farming functions such as farm mechanization, fertilizer management, pest/disease and weed control, and marketing. Farmers' understanding and cooperation are required for successful WUG development, and this plan should be implemented with seminars and training programmes using the facilities of the National Water Management Board.

4.2.10 Environmental management

Adverse impact on water quality in adjacent waterways is identified as the most critical environmental issue of the granary development. Therefore, a water quality monitoring system should be established to check the quality of drainage water from the paddy fields. Water sampling should be carried out in main drains in each granary area, and at pumping stations which recycle water for irrigation. When any excessive use of agrochemicals is detected, appropriate management actions must be administered immediately. The integrated pest management (IPM) of the Department of Agriculture promotes use of biological agents to control pests and weeds in agricultural practices as well as effective use of pesticides with readily decomposable chemicals.

4.3 Precision farming

Precision farming is currently generating interest in the rice granary areas after the successful application of micro-irrigation technology. In rice cultivation, precision farming also has the similar aim of applying the right amount of irrigation water at the right time and place. This indefinitely enhances the use of information technology in future irrigation water management and agricultural practices. Some examples of precision farming application in rice cultivation are soil and water mapping, yield prediction, evapotranspiration estimation using satellite data and GIS with the automation of water control and measurement facilities.

5. Further options to respond to the changing requirements

Radical structural transformation

The agricultural sector has to face many forces and challenges: political, social, technological, economic and, in the larger context, environmental forces. The performance of the agricultural sector greatly depends on its willingness and ability to cope with the changing environment. It must be able to change and adapt to the needs and demands of these forces with speed and agility.

In this respect, the agricultural sector must improve its system's flexibility, accountability and efficiency. That would then generate a system that would be effective and productive. This will in turn ensure quality and encourage investment. The way forward is to restructure the working mechanism in order to improve the delivery systems. Currently, the system is too heavy and bulky, making it inflexible, lacking in focus and slow in responding to changes. There are far too many agencies in the decision-making process and far too many levels to negotiate before a decision can be implemented. Utilization of resources is as a consequence inefficient and ineffective. There is a strong need to involve the beneficiaries in the decision-making mechanism as in the case of the involvement of WUGs in irrigation management.

The agricultural sector must undergo a radical transformation of the whole organizational structure in order to improve its delivery system. Recently, some restructuring was carried out but was not radical enough. In fact, to a certain degree, it further reinforced the old bureaucratic system. The latest restructuring, which involved the shifting of the Department of Irrigation and Drainage to another ministry and changing the name of the ministry to the Ministry of Agriculture and Agro-based Industries, is the kind of radical change needed by the agricultural sector to make it more focused.

Radical cultural and identity transformation

The agricultural sector has been recognized widely for its culture of subsidy, as the "poor man's sector", as being "traditional", "dirty", "rural", "inefficient", the "sunset industry". These negative stereotypes must go.

Cultural and identity transformation is definitely tough to achieve but could be most effective if successfully carried out. It requires a change of mind-set and effort from all parties. The way forward is to transform from within, meaning the people involved in the sector must be committed and proud to be involved in the agricultural industry. There is a need to promote a new image, which will gradually remove the old negative stereotype. A drive for a sector that is modern, productive, efficient, knowledge based with a slogan of "we feed the world" is just an example that can be taken up to start the change.

6. Conclusions

To remain competitive and relevant in the context of national development, the agriculture sector must transform itself to enable an increase in its productivity as much as to match market demand in terms of quality and quantity. In the current global environment, there is a need to go beyond the model of the earlier successes. The agriculture sector must be transformed radically in terms of its structure, processes, technology and culture, becoming a sector that is more customer focused, process centred, output driven and knowledge based.

Information on irrigation systems of Malaysia

National irrigation management agency: **Irrigation and Agricultural Drainage Division**

General information on irrigation systems				
Physical scale of rice-based irrigation systems	**<10 000 ha**	**10 000 to 100 000 ha**	**>100 000 ha**	**All scales**
Number of systems	4	4	–	8
Annual water diversion (MCM)	892	2 897	–	3 789
% of agriculture water use	95	95	–	95
% of domestic water use	5	5	–	5
% of other water use	–	–	–	–
Designed irrigation area (ha)	30 599	175 806	–	206 405
Effective irrigation area (ha)	26 624	165 999	–	192 623
Rice irrigation area (ha)	26 624	165 999	–	192 623
Vegetable and orchard area (ha)	–	–	–	–
Other crops irrigation area (ha)	–	–	–	–
No. of beneficiaries — farmers	24 577	186 875	–	211 452
No. of beneficiaries — city residents	nil	nil	–	nil
Wetland areas supported (ha)	nil	80 000	–	80 000

Information of the largest rice-based irrigation system	
Name	**Muda irrigation project (MADA)**
Location	State of Perlis and Kedah, Malaysia
Construction period	1965–1990
Designed irrigation area	97 257
Functional irrigation area	96 474
Annual water diversion (MCM)	908
% of agriculture water use	95
% of domestic water use	5
% of other water use	–
Rice irrigation area (ha)	96 474
Vegetable and orchard area (ha)	–
Other crops irrigation area (ha)	–
water supply per ha of irrigated rice field*	4 703 m^3
Output (US$) per m^3 of water supply	0.154
No. of beneficiaries — farmers	100 000
No. of beneficiaries — city residents	nil
Wetland areas supported (ha)	nil

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