Lecture note

Paddy cultivation

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by

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Lecture notes have been prepared on the following topics:

- *Aggregate water balances for basinwide planning*
- *Case study: Kok River Basin*
- *Case study: Lower Mekong Basin*
- *Environmental management*
- *Floods and drought*
- *Glossary*
- *Good governance strategies (example from Thailand)*
- *Internet applications in river basin management*
- *Paddy cultivation*
- *Poverty alleviation*
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- *Strategies for natural resources and environmental management (example from Thailand)*
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- *UTM coordinates*
- *Water demand management*
- *Water resource economics*
- *Water user associations*

Each note is intended as a quick introduction of a subject prepared for professional practitioners who are specialists in other subjects.

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Suggestions and comments are most welcome!

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Contents

Glossary

Aerobic: With access to free oxygen (O_2)

Beri-beri: A lethal disease caused by lack of thiamine (vitamin B1). The relation between the disease and the diet was established in 1889 in Jakarta by Christiaan Eijkman (who observed chicken eating either brown or white rice) and confirmed in 1907 in Kuala Lumpur by William Fletcher (based on experiments with asylum inmates). Hereby, it was known as a fact that people eating white rice (and white rice only) would inevitably get beri-beri, and that they would recover if they shifted to brown rice - but it was not understood why. Vitamin B1 - the first vitamin to be discovered - was identified in brown rice in 1912 by Casimir Funk

Bran: Outer, thin ('pericarp' and 'skin') layers of the grain, removed during the milling process (to process brown rice into white rice). Bran contains carbohydrates (starch), protein, fat, vitamins, minerals, and fibre. Removing the bran reduces the nutritional value of rice

Paddy (with husk) | Brown rice (with bran layers) | White rice (milled rice or polished rice)

Brown rice is rice that is un-milled or lightly milled, so that the bran remains [1]

Cadmium in rice is the main contributor to the human intake of cadmium in Asian countries [2]. Cadmium can be supplied to the paddy fields by wastewater, sludge, phosphate fertilizer, and sometimes by mine tailings

Command area: The area that can receive water via an irrigation scheme

Crop intensity: The part of an area that is actually cultivated. If the whole area is cultivated in the wet season, and half of it is cultivated in the dry season (due to water shortage), the crop intensity becomes 150 %.

Crop water requirement: The amount of water required for cultivation of a crop, as available to the crop in the field where it grows (mm/day, mm/ month or mm/crop). The crop requirement equals the evapotranspiration of the crop in question. The crop requirement is supplied by rainfall, soil moisture variation and irrigation. Irrigation water requirement (in FAO terminology) is the part of the crop requirement that is not supplied by rainfall or by soil moisture variation

Demand management: Intervention in order to reduce the consumption of water, in order to meet a water shortage, or a shortage of funds for infrastructural development, or to improve the water efficiency. Demand management can comprise improved operation and maintenance of distribution systems (including reduction of water losses), green taxes to reduce the demand, awareness campaigns to change consumer habits, introduction of new crops or cultivation routines, etc.

Demand satisfaction: The ratio between the water that is available (at the intake from a river or a gate of a reservoir) and the withdrawal demand, at a given time for a given purpose (for example a given crop and a given cultivation routine). The demand satisfaction is 100 percent if there is enough water to serve the demand

Drought: *'A period with an extraordinary water shortage'* (due to the rainfall being less than normal)

Efficiency: (1) The ratio between output (for example food or money) and input (for example land, water, labour, or energy); (2) the *'economic efficiency'* is the ratio between value generated and water used/allocated; (3) the *'scheme efficiency'* or the *'irrigation water efficiency'* is the ratio between the crop water requirement and the irrigation demand

Evapotranspiration:The loss of water from the ground to the atmosphere by evaporation and by transpiration (of plants). The rate is determined by the energy supply (by sunlight radiation), the

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1 Figure from Centre de coopération internationale en recherche agronomique pour le développement, CIRAD, http://www.cirad.fr

2 N Schouw and Jens Chr. Tjell (2003)

wind speed, and the moisture of the air. Potential evapotranspiration is the capacity of the atmosphere to remove water from the ground, if water is abundantly available. Reference evapotranspiration (ET_O) is the evapotranspiration of a well-defined vegetation cover, measured by a standard routine, and used for calculating the evapotranspiration for a given crop during its cultivation cycle (by multiplication with a time-varying crop coefficient) (Nesbitt July 2003)

FAO: United Nations Food and Agriculture Organization

Husk (or chaff): The outer cover of a grain of paddy, removed by thrashing and winnowing. Can be used for fuel (but contains little energy and a lot of ash)

Irrigable area: The area that can actually be irrigated with a specific (present or future) infrastructure (disregarding the finite availability of water)

Irrigation: Artificial supply of water (other than rainwater) for cultivation, from groundwater, or by diversion of surface water, or by distribution or retention of flood water, or from a storage tank or reservoir. FAO makes a distinction between 5 possible sources of irrigation water: Surface water, renewable groundwater, fossil water, treated wastewater and desalinated water. Please compare with *'water-managed area'*

Irrigation demand (or withdrawal demand for irrigation): The required gross amount of water needed to be abstracted (from the river or reservoir) to cultivate a crop (mm/month or mm/ crop). Irrigation demand = crop requirement, plus the return flow from the field to the river, plus miscellaneous losses (distribution, conveyance, and percolation out of the root zone)

Losses of water: At scheme level, losses take place via evaporation, seepage, percolation, and release of return flows; but at the basin level, the *'lost'* volumes can often be utilized at a different time and place

Manageable water resources (according to FAO Aquastat): The part of the water resources which is considered to be available for development under specific economic and environmental conditions. This figure considers factors such as the dependability of the flow, extractable groundwater, minimum flow required for non consumptive use, etc. Also called water development potential

Moisture content: Paddy is best milled with a moisture content of 14% [3]. Many rice buyers apply an upper limit of 12-12.5 % for milled rice. The official upper limit for Thai Hom Mali rice is 14 %

Paddy: (1) a field where lowland (wet) rice is grown; (2) rice in its husk (also called rough rice)

Parboiled rice is soaked, cooked and dried before it is milled. As compared with ordinary white rice, the milling efficiency is higher. Parboiled rice has a different taste and texture, and needs a somewhat longer cooking time. Some countries have a traditional preference for parboiled rice

Percolation, seepage: Flow through a porous material. Some authors distinguish between seepage *('horizontal'* leakage through a bund) and percolation *('vertical'* leakage through the soil layers to the groundwater)

Precipitation: Rainfall and snow reaching the ground

Puddling (of paddy fields): Softening (by various operations) of the top soil layer before transplanting, at the same time levelling the soil surface and destroying weeds, while maintaining a low permeability of the sub-soil (to reduce percolation losses)

Rice species: Rice (Oryza) is one of around 600 members of the grass (Poacea) family of plants. Two species (of about 22) are cultivated. Oryza glaberrima (African rice) is native to Sub-Saharan Africa, where it was domesticated in the upper Niger River Basin some 2-3,000 years ago. Oryza sativa, (Asian rice), domesticated 10-15,000 years ago, is by far the prevalent cultivated species. It has thousands of varieties, covering a

[3] IRRI website, http://www.knowledgebank.irri.org/grainQuality_loband/module_3/02.htm

broad span of properties. Long-grain rice (indicas) and short-grain rice (japonicas) are groups of varieties. Well-known varieties are (the aromatic) basmati rice (from India and Pakistan) and (the aromatic) Thai jasmine rice (Thai Hom Mali)

Straw is used for animal feed, fuel, and fertilizer. Roughly, 2 tons of straw are produced for each ton of paddy [4]

Transplanting [5]: Traditional lowland cultivation often comprises sowing the rice in nursery beds, and transplanting the seedlings after a period of 12 days to 6 weeks. Transplanting requires intensive labour within a short period of the cropping calendar. Depending on site-specific conditions, this can give a higher yield (but a longer cultivation period, and hereby a higher risk of drought exposure), as compared with direct seeding (or broadcasting)

Virtual water: Water represented by a traded commodity (for example rice). (1 kg of milled rice may represent 3-6 m3 of water). (If so, for example, Thailand would export some 30 km3 of virtual water per year, represented by the country's rice export) [6]. The opinion is offered that this line of thinking is not entirely fruitful - the comparative value of the traded commodity may be quite different from the comparative value of the *'virtual water'*

Water-managed area (according to FAO): An area on which water, other than direct rainfall, is used for the purpose of agricultural production. The term irrigation refers to that part of the water managed areas that is equipped to provide water to the crops

White rice (or milled rice or polished rice): The inner rice grain, consisting mainly of starch. Milling increases the storage time and reduces the cooking time, but removes the protein, fibre, vitamins and minerals

Withdrawal demand: Same as irrigation demand

Yield (of rice): Production (in t/ha/crop or t/ha/year). In the Lower Mekong Basin, the annual yield is 1.9 t/ha/year (Cambodia 2000), 2.0 t/ha/year (NE Thailand 2001), 2.9 t/ha/year (Laos 1999) and 4.1 t/ha/year (Viet Nam, Mekong Delta 1999). In SE Asia, yields are higher in the dry season than in the wet season, because the solar radiation from the clear sky is higher in the dry season, even if the day length is shorter [7]

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4 A Koopmans and J Koppejan (January 1997)

5 Photo: YANMAR Agricultural Equipment Co., Ltd. (2003), http://www.yanmar.co.jp

6 The total export of virtual water from Thailand has been estimated at 47 km3/year (1995-99) (Hoekstra and Hung 2002)

7 H. Nesbitt (May 2003)

1 Introduction

The present note describes, at an introductory level, some water resources implications of paddy cultivation, in a Southeast Asian context.

The note draws heavily on Harry Nesbitt (July 2003): *Water used for agriculture in the Lower Mekong Basin*, report prepared for Mekong River Commission, Basin Development Plan.

Another example of an important publication is L. C. Guerra, S. I. Bhuiyan, T. P. Tuong, and R. Barker (1998): *Producing more rice with less water from irrigated systems*, SWIM paper 5, IWMI, Colombo.

For further reading, reference is made to the Internet.

> Please note that (in most cases), *numbers* in this note are examples only. Many numbers - be it crop water requirement, yield, percolation, return flow or whatever - are highly site-specific, and would be different from one place, one year and one cultivation technique to another place, another year, and another cultivation technique.

2 Basics

It is no coincidence that paddy cultivation is the main traditional livelihood in Southeast Asia. Rice is a unique crop in many ways, as shown in Table 1.

Table 1: Valuable properties of rice [8]

- Rice is the traditional stable food in Southeast Asia, and can assure food security (at the family level, as well as at the national level)
- Agriculture, and mainly paddy cultivation and related occupations, provides the livelihood for some 75 percent of the people living in the Lower Mekong Basin
- Rice can grow on soil types that are not well suited for other crops
- Rice can grow in areas that are waterlogged or inundated
- Rice can be stored for years
- The commercial demand of rice is relatively stable (but prices are low)
- Rice is relatively robust towards pests, and lowland rice is very robust towards weeds
- One crop of rice can be raised in 3-4 months, well within the period of the monsoon rainfall

Traditional Southeast-Asian cultivation systems comprise:

- Upland (or aerobic) rice, grown in dry fields;
- lowland (wet) (rainfed or irrigated) rice, grown in fields that are inundated for the major part of the cultivation period. Lowland rice can be transplanted or direct seeded; and
- deepwater/floating rice, growing in water depths between 0.5 m and 4-5 m.

Among these, lowland rice is by far the most important in terms of production and occupation.

Table 2: Transplanted rice [9]

Rice can be ***transplanted*** or ***direct seeded (or broadcast)***

Transplanted rice gives a higher yield, and a somewhat better control of the cultivation cycle (relative to the rainfall), because the transplanting can be postponed by some weeks, if need be.

In return, the maturation period is 5-7 days longer than for direct seeded rice - and the risk of faulty weather is related to the length of the cultivation period.

Transplanting is labour-intensive (around 10 person-days per hectare, or more)

Lowland rice does not grow well in stagnant water. Either, a slow flow must be maintained, or the field must be drained and re-flooded at intervals. This generates a *return flow* of excess water, of the same magnitude as the crop water requirement.

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8 H Nesbitt (July 2003) and MRC-BDP (Nov 2002)

9 After H Nesbitt (July 2003)

Regarding the water supply, there is a broad scale between fully irrigated and fully rainfed crops. In most cases, irrigated crops are partly rainfed. Supplementary irrigation (for example during the onset of the wet season) can be important for orderly cultivation, whereby it can represent a high added value per m3 of water used.

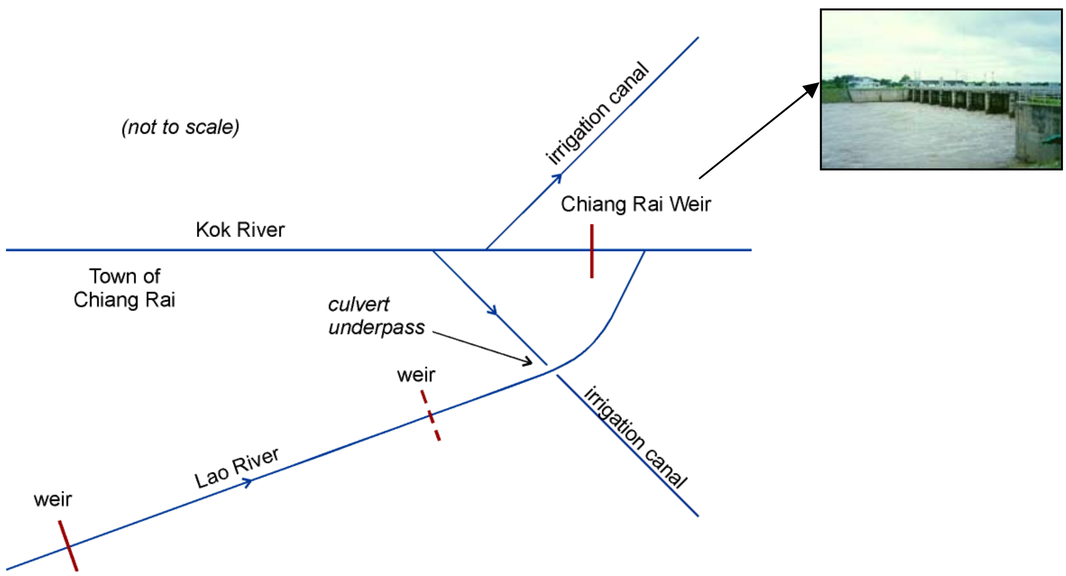
Irrigation can comprise a variety of operations, alone or in a combination:

- Storage of water in a reservoir;
- pumping (large-scale or small-scale) (from a river, lake, canal or reservoir);
- diversion of water from a river, by a control structure (weir), into a network of canals;
- retention of surface runoff (towards the end of the wet season), by dams, canals and gates; and
- retention of return flows from upstream paddy fields, by canals and gates.

Groundwater irrigation is hardly economically feasible for paddy cultivation, due to high operation costs and low value produced. To some extent, however, the same can be said about surface water irrigation, unless weather conditions and the topography are favourable.

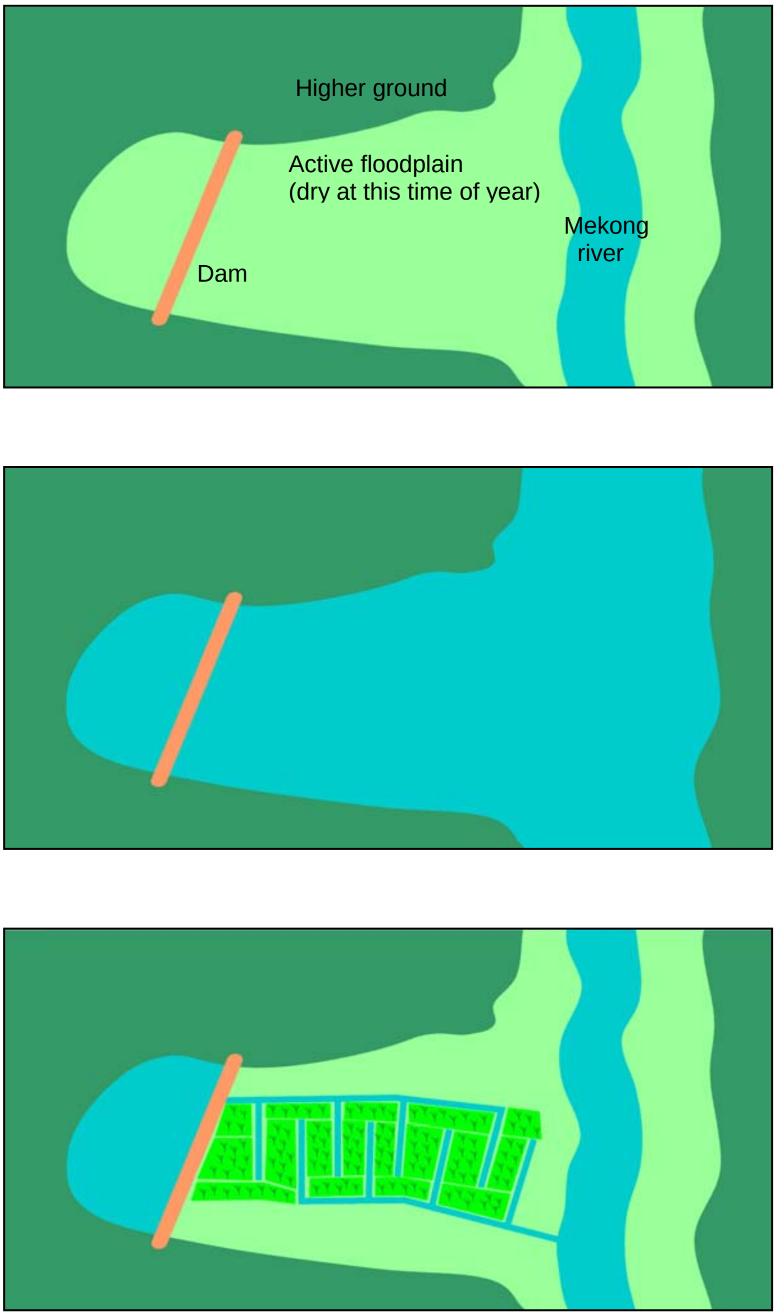
Operation of irrigation schemes can be complex, and sometimes very much so. Good operation is supported by thorough professional insight, access to historical data, real-time data and reliable forecasts.

Figure 1: Example of a diversion scheme: The Chiang Rai Weir, North Thailand [10]



[10] MRC and OEPP (Oct 2000)

Figure 2: Example of a retention scheme, typical for the flood plains of Cambodia [11]



End of the dry season
(April-May)

Peak of the flood season
(September) - the entire
active flood plain is flooded

One crop of paddy is
cultivated from
October/November to
January/March

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[11] Strongly simplified diagramme, illustrating the 800 ha Chruy Chek irrigation scheme, Trean commune, Kompong Siem district, Kampong Cham province, Cambodia (visited in May and December 2004)

Typical processing operations are shown in Figure 3. After an allocation (of around 1 percent) for seeds, post-harvest losses (including drying) and milling, 1 kg paddy leaves 0.5 - 0.6 kg milled rice. (So it is important to distinguish between paddy and milled rice!) An example is shown in Table 3 below.

Figure 3: Rice processing

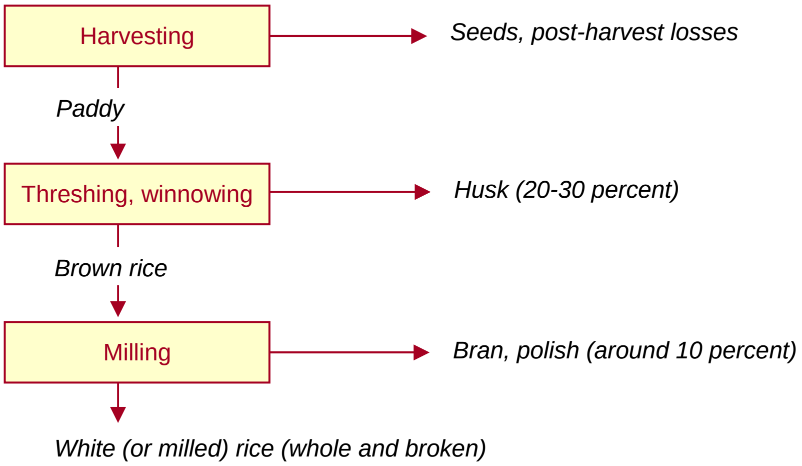


Table 3: Rice production and food balance (example, Cambodia 2000-2001) [12]

Total paddy production	4,026,000	t	100	percent
Seed and post-harvest losses	684,000	t	17	percent
Balance: Paddy available	3,342,000	t	83	percent
Milled rice available	2,072,000	t	51	percent
Population, persons	13,100,000	persons		
Total rice requirement, at 151 kg/person/year	1,981,000	t		
Surplus rice production	91,000	t		

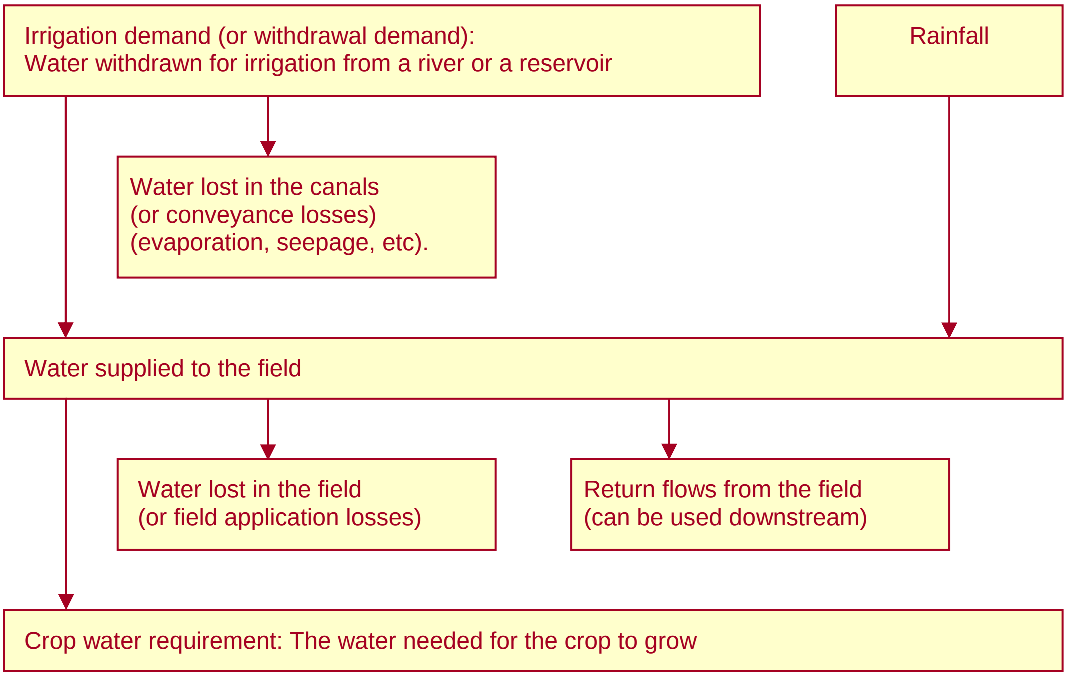
[12] CNMC-BDP (Aug 2003)

3 Water utilization

Water balance

A basic water balance is shown below for paddy irrigation based on surface water.

Figure 4: Water balance for paddy cultivation



Due to the losses, the irrigation demand is much higher than the crop water requirement. It is seen, however, that much of the water that is '*lost*' goes to groundwater recharge or can be used for other purposes downstream.

Both the crop water requirement and the rainfall depend on the location. The crop water requirement varies during the cultivation period, and the rainfall varies with an annual cycle. Therefore, the water balance is made on a monthly or daily basis for the entire cultivation period. A suitable basic unit is mm/day.

The crop water requirement can be determined by experiments at agricultural field stations, or it can be calculated from a reference evapotranspiration by a method available on FAO's website.

For over-all water resources management purposes it is convenient to know the irrigation demand for an entire crop, expressed in mm/crop or m3/crop/ha. Obviously, this value depends on the time, place and duration of the actual cultivation period, and it will highly depend on how much of the crop requirement that is served by irrigation and how much by rainfall.

Water efficiencies

The *scheme efficiency* is the over-all ratio between the water needed by the crop and the water that needs to be withdrawn for irrigated cultivation [13]. Scheme efficiencies are often low in places where water is by tradition abundantly available.

The *conveyance efficiency* (the extent to which the water reaches its destination) depends on whether the canal is lined, and on the canal length and soil type. Also, the state of maintenance is important.

The *field application efficiency* for irrigated paddy cultivation depends on the system layout, the management of the system, and the skills and coordination between the farmers.

Table 4: Examples of efficiencies

Conveyance efficiency [14], lined canals earthen canals	Ec	95 % 60-90 %
Field application efficiency, paddy [15]	Ea	60-65 %
Scheme (or over-all) efficiency (paddy) [16]	Ec * Ea	30 %
Return flow (paddy) (in % of irrigation demand) [17]		30 %
Please note that these figures are examples only!		

Irrigation demand and crop requirement

In an example from Thailand, the crop requirement was determined to 3.6 and 5.0 mm/day for rainfed and irrigated rice, respectively [18]. Assuming a 120 days cultivation period, this equals 4,300 - 6,100 m3/crop/ha.

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13 The efficiency is the part of the water that is used for its intended purpose. If a scheme efficiency is 30 % it means that 30 % of the water is used by the crops, while 70 % is lost on the way to the crops or are subsequently released as return flows

14 Drainage and Irrigation Department, Penang, Malaysia (website read October 2004): http://agrolink.moa.my/did/didpenang/pengairan/irr_eff.htm

15 (same)

16 Nesbitt (July 2003) Table 11, quoting FAOSTAT data for Cambodia, Laos, Thailand and Viet Nam. The same value was used in MRC and OEPP (Oct 2000)

17 MRC and OEPP (Oct 2000)

18 Panya Polsan et. al (July 2004)

Table 5: Consumptive water use in traditional (wet) rice systems

Land preparation	150 - 250	mm/crop	Restoring soil moisture, ploughing and puddling
Evapotranspiration	500 - 1200 4 - 10	mm/crop mm/day	Crop requirement
Seepage and percolation	200 -700 2 - 6	mm/crop mm/day	Maintaining water pounding
Mid-season drainage	50 - 100	mm/crop	Refilling after drainage
Total Average over a 120 days cultivation period	900 - 2250 7.5 - 20	mm/crop mm/day	Total water utilization from rainfall + irrigation, excluding return flows
Source: FAO (2004a)			

In comparison, the following figures are from Royal Irrigation Department in Thailand [19]:

Crop requirement, dry season rice:	6-7 mm/day
Percolation (depending on soil type):	1-3 mm/day
Total (crop requirement + percolation):	8-10 mm/day

According to the figures in Table 6 (which are more or less typical for Southeast Asia), it is required to withdraw around *3.3 m3 of water for each m3 needed by the crops* - in the absence of rainfall:

Table 6: Irrigation demand and crop water requirement

Irrigation demand (withdrawal from river or reservoir):	100 percent
Available to serve the crop water requirement:	30 percent
Return flows:	30 percent
Various losses:	40 percent

Water used per kg rice

As shown by the following examples, it requires a lot of water to produce rice - in particular where the traditional cultivation systems are based on abundance of water. As a rule of thumb, it requires *5 m3 of water to produce 1 kg of rice.*

For a given crop at a given time and place, the yield depends on many factors, including the continuous water supply, the crop variety, weed management, and the use of fertilizer. Within limits, each kilogram of nitrogen fertilizer can produce 10–15 kg more rice [20]. Assume a specific crop water requirement of (for example) around 4 m3/kg paddy (Table 7). If so, *1 kg of fertilizer can replace 40-60 m3 of water.*

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19 Osot Charnvej (Oct 1999)

20 Guerra, Bhuiyan, Tuong and Barker (1998)

In the Mekong Delta, the irrigation demand (for fully irrigated paddy) has been reported at 1 l/s/ha[21] or 8.6 mm/day.

The yield of (dry season) rice is 5.0 t/ha [22]. Assuming a 120 days cultivation period, this is *2.1 m3 of water per kg dry season paddy rice.*

Assuming post-harvest losses of 10 percent and a milling rate of 65 percent, this becomes ***3.5 m3 of water per kg milled rice.***

In Northeast Thailand, the irrigation demand (for fully irrigated paddy) has been reported at 12,000 m3/ha/crop [23] (or 1,200 mm/crop or 10 mm/day).

The yield of (dry season) rice is 3.3 t/ha[24]. This is *3.6 m3 of water per kg dry season paddy rice.*

Assuming post-harvest losses of 10 percent and a milling rate of 65 percent, this becomes ***6.2 m3 of water per kg milled rice.***

Table7: Specific crop water requirements (Example, Thailand 1999) [25]

Banana	970 m3/ton
Groundnut	1880 m3/ton
Maize	780 m3/ton
Soybean	3050 m3/ton
Sugarcane	200 m3/ton
Watermelon	270 m3/ton
Onion (dry)	490 m3/ton
Rice	4050 m3/ton

Note: *Various irrigation losses not included*
Post-harvest losses are not included

Record yields - *'China cultivates record high-yield super rice'*

Chinese agronomists have cultivated a new species of 'super rice,' the Super Rice II YOU 28, with average yield reaching a record high of 18,400 kilograms per hectare.

The figure broke the records set in 2004 of 18,300 kilograms per hectare, setting a new world record, said Shi Changjun, leader of the super rice acceptance test.

Experts from the China Rice Research Institute, Yunnan Agricultural University and the Yunnan Provincial Academy of Agriculture conducted on-the-spot acceptance check over harvest of the super rice.

The new species of high-yield hybrid rice was sown in March, planted in May and harvested on September 10 in Taoyuan Village, Yongsheng County of south China's Yunnan Province, with fertility period lasting 192 days.

Source: Xinhua, quoting People's Daily Online, September 12, 2005

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21 Nesbitt (July 2003) p. 33

22 MRC-BDP (Nov 2002) p. 18, 1999 data from Viet Nam General Statistical Office

23 Nesbitt (July 2003) p. 33

24 MRC-BDP (Nov 2002) p. 17, 2001 data from Thailand National Statistics Office

25 Hoekstra and Hung (2002), Appendix III, pp. 3, 6, 9, 12

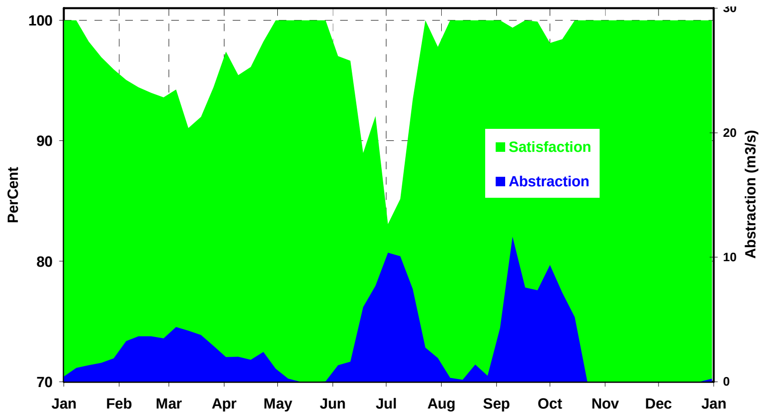
Demand satisfaction

Demand satisfaction is a measure to illustrate the amount of water needed for serving the full demand.

The following figure is an example from Kok River Basin in North Thailand. The wet season is from May to October, with the highest rainfall in July and August. Surprisingly, at the first glance, *the month with the lowest demand satisfaction is July, in the middle of the wet season* (where water is required for land preparation for the main rice crop, which will be harvested in November).

In this area, the irrigation demand is higher in the wet season than in the dry season, because the crop intensity is low in the dry season - the farmers cultivate their land in harmony with the water availability. When asked, they will reply that they don't need irrigation water in the dry season, because they don't cultivate their fields in that part of the year.

Figure 5: Demand satisfaction (example from Kok River Basin, North Thailand) [26]



Water quality

Like other water-dependent production systems, paddy cultivation requires a certain quality standard of the consumed water on the one hand, and represents a certain environmental pressure on the other.

Production systems based on paddy cultivation in combination with paddy field fisheries can be economically attractive - the income from the fish can exceed the income from the cultivation - but require water that is uncontaminated to a standard where fish can survive.

Example from Thailand (2003 figures) [27]

Import of fertilizers:	3,840,000 tonnes/year
Import of pesticides:	50,331 tonnes /year

(These figures relate to the entire agricultural sector of Thailand, which comprises a variety of crops other than rice)

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26 MRC and OEPP (Oct 2000)

27 Thailand National Economic and Social Development Board, quoted in Bangkok Post 14 November 2004, p. 3

If the irrigation tailwater carry *'hard'* pollutants (like bio-accumulating and slowly decaying pesticide residuals), the consequences to the fisheries sector and the public health can be severe.

Paddy cultivation in itself is robust to pesticide residues in the irrigation water, but is sensitive to salinity, which is a problem in downstream areas of the river basin that are exposed to sea water intrusion.

4 Water resources management

General

A fruitful distinction can be made between

- *basin level* management, for a river basin or sub-basin; and
- *scheme level* management (or system level management), for a single irrigation scheme.

These two levels differ widely in terms of agenda, management options, and needs of knowledge and data.

Also, the water balances are different at the two levels. At the basin level, percolation losses and return flows at the scheme level are (typically) not *'losses'* but rather *'re-allocations'*.

- The third level of management, the *farm level*, is not covered by this lecture note.

Basin level management

The purpose of water resources management at the basin level is to establish and maintain some harmony between (1) the over-all water availability and (2) the potential demand of water.

This exercise must be carried out in time and space. That there is enough water on the average is of little practical interest. In the Lower Mekong Basin, the average water availability is 19 m3/person/day, or 7,100 m3/person/year [28], but still, there are severe seasonal water shortages - and a strong need of water resources management.

For a given area, the availability is largely determined by the rainfall (and by large-scale storage facilities), while the demand is determined by the crops, the cultivation routines, and the applied technology. The availability and the demand are linked by prevailing, traditional production system modalities, but are otherwise largely unrelated.

The irrigation demand may be the largest item in the budget in terms of volume, but not in terms of significance. The domestic demand is much smaller in terms of volume, but much higher in terms of significance. In terms of value generated, paddy irrigation comes low on a long list of industrial and agricultural water uses.

A balance must be maintained between consumptive (or *'off-stream')* water uses and non-consumptive (or *'in-stream'* water uses). The former comprise domestic, industrial and agricultural demands. The latter represent the needs of the fisheries and navigation sectors, as well as the ecological demand of water (to maintain a desired state of aquatic and floodplain ecosystems and other wetlands). Hydropower reservoirs fall somewhat in between, but are important, as they can re-distribute the water availability over the year.

In some rivers, for example the Mekong, the lower parts are only slightly elevated above sea level, and with no control structures to keep the saline sea water out. If so, a certain minimum flow must be maintained to prevent saline intrusion.

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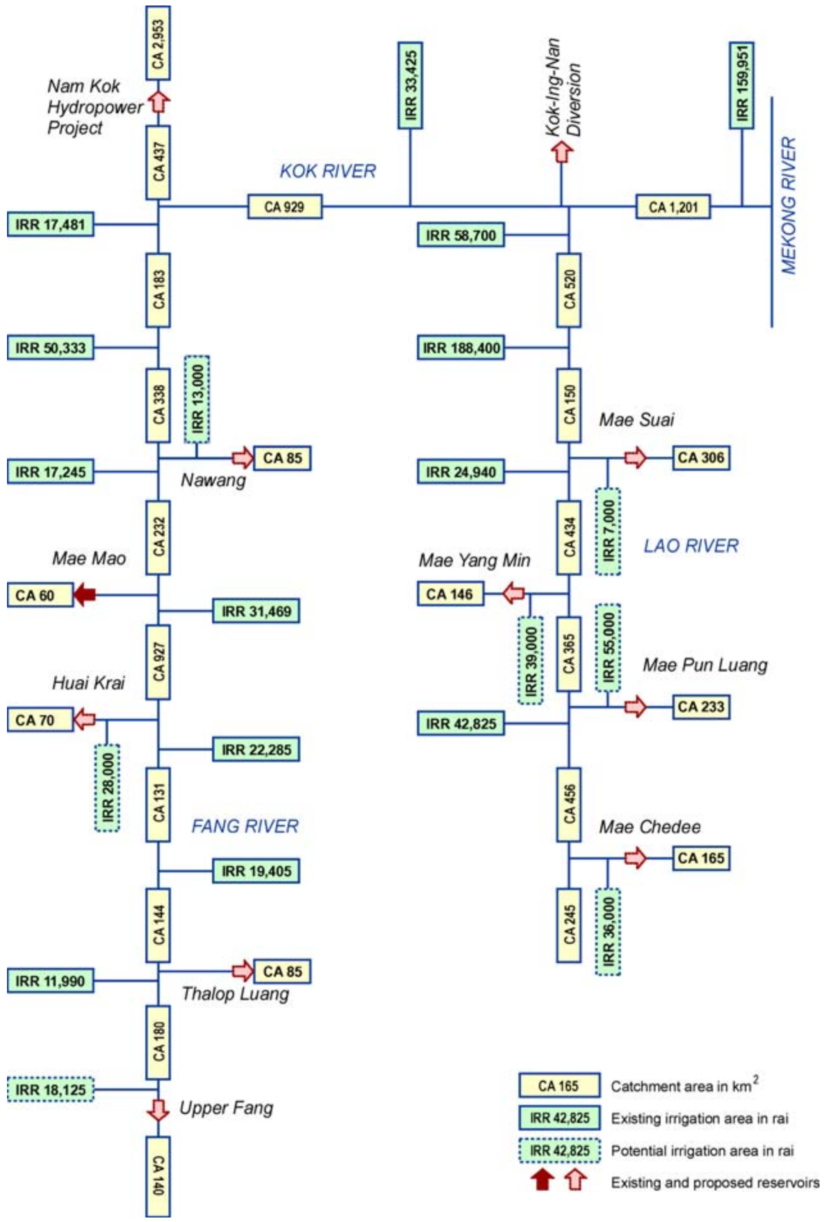
[28] MRC (July 2003)

For planning purposes and feasibility analyses, knowledge is required about the over-all, *'reliable'* water availability (which can for example be *'the water available in 4 out of 5 years').*

At the basin level, the return flows are not really losses - quite often, they can be used further downstream in the basin, at a later time. Similarly, percolation is regarded as groundwater recharge, rather than a loss. Still, these flows must be taken into account, since they need to be removed from the river or the reservoir in the first place.

Figure 6: Example of water management infrastructure involving reservoirs and diversions. Kok River Basin, North Thailand [29] [30]



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29 MRC and OEPP (Oct 2000)

30 1 rai = 1600 m2

Figure 7: Satellite view of Tonle Sap (Cambodia) and the Mekong Delta

The Vietnamese part of the Mekong Delta produces 50% of the national rice yield and 90% of the exported value [31].

48 % of the area is irrigated. The hydraulic infrastructure is comprehensive and complex, providing irrigation water, flood protection, and salinity control.

The low-lying Delta is exposed to intrusion of saline sea water, and a certain minimum flow is required to maintain the freshwater regime [32]. The required minimum flow is not much less than the annual monthly minimum flow of around 1,630 m3/s (or 2.1 l/s/km2 catchment area) [33].

Knowledge about the water availability is much more accessible and much more accurate than knowledge about the future, potential demand, which can vary within a broad range, depending on crops and cultivation techniques.

Water management at the basin level is not always based on win-win-solutions. Development initiatives that benefit some people in some areas can have adverse consequences to other people living in adjacent areas. Many irrigation schemes with an undisputed over-all positive 'bottom line' can deprive some people of land and/or water.

Scheme level management

The purpose of scheme level management is to serve the crop water requirement.

Scheme level management requires

- real-time information about storage volumes and/or river stages and/or flow rates;
- good forecasts of rainfall and river stage over as long a period of time as possible;
- knowledge about normal rainfall and stage, and typical variation intervals, as a function of time; and
- knowledge about optimal and critical crop requirements.

In some places, scheme level management can also comprise operational protection against floods, or operational protection against salt water intrusion, by means of control gates or flow regulation.

An important feature of scheme level management is the coordination among the water users. This must take place either in a close dialogue, or by the water users themselves (depending on

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[31] Data from 2000, VNMC (May 2003), p. 8

[32] Nedeco (Feb 1993)

[33] January 1964 - May 1974, data published in the Lower Mekong Hydrologic Yearbooks

the complexity of the scheme, its size, and other circumstances). In any case, the skills of the water users, and the collaboration between them, are crucial to successful management.

Criteria for successful scheme level management are :

1. Adequate basic technical and financial feasibility ('sustainability') of the enterprise. A scheme must be practical and profitable, otherwise it will fail - no matter how well it is managed;
2. roles understood and accepted by everyone involved. This requires in turn (i) that the roles are well-defined and transparent, and (ii) that the enterprise is supported by the stakeholders;
3. an adequate information flow - managerial, technical and financial - between the involved parties, so that good and timely decisions can be made; and
4. adequate managerial skills available as required with each decision-making body. This can be supported (i) by training; and (ii) by avoiding overly complicated management routines.

As a matter of curiosity, it can be noted that paddy cultivation is seldom financially sustainable, if depreciation of construction costs are taken into account, due to the marginal added value.

A life-long education process of everybody involved can highly support a sustainable scheme level management.

5 The development agenda

Technological aspects

Scientific research related to rice cultivation is carried out by International Rice Research Institute (IRRI), International Water Management Institute (IWMI), and many other international and national research centres and programmes. FAO maintains a major knowledge base and develops tools for agricultural management and related water resources management. Please refer to the Internet for (much) more information.

Current research comprises issues such as [34]

- higher yield (tons per ha)
- increased water efficiency (tons per m3)
- increased nutrient efficiency (tons per ton fertilizer used)
- improved drought tolerance
- integrated pest management

Golden rice [35]

Recent breakthroughs in scientific technology have made it possible to enhance the nutritional value of rice through modifying the genetic code.

The best-known example of this technology is *'golden rice',* which contains carotenoids (precursors to vitamin A) from daffodil genes.

Yield gaps [36]

The yield gap is the (often significant) difference between an actual and a potential yield. A distinction can be made between (1) the gap between the potential theoretical yield and the experiment station yield; (2) the gap between the experiment station yield and the potential farm yield; and (3) the gap between the potential and the actual farm yield.

Factors causing yield gaps include

1. Biophysical: climate/weather, soils, water, pest pressure, weeds.
2. Technical/management: tillage, variety/seed selection, water, nutrients, weeds, pests, and post-harvest management.
3. Socio-economic: socio-economic status, farmer's traditions and knowledge, family size, household income/expenses/investment.
4. Institutional/policy: government policy, rice prices, credit, input supply, land tenure, market, research, development, extension.
5. Technology transfer and linkages: the competence and facilities of extension staff; integration among research, development and extension; farmers' resistance to new technology; knowledge and skills; weak linkages among public, private and non-governmental extension staffs.

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[34] Cantrell and Hettel (2004)

[35] FAO (2003b)

[36] FAO (2003c)

Social and economic aspects

In Southeast Asia, paddy cultivation is of decisive importance in terms of employment and food security. It is not a very profitable livelihood, however:

- In NE Thailand (1996/97), the net profit of paddy cultivation was estimated from *minus 49 to plus 21 USD/ha/crop* for irrigated HYV rice in the wet and dry season, respectively, and at *minus 44 USD/ha/crop* for the traditional wet season rainfed local variety rice (family labour valued at 2.5 USD/day). [37]
- In Cambodia, the net profit of paddy cultivation was estimated at *2 USD/ha/crop* for rainfed wet season rice and *2 USD/ha/crop* for irrigated dry season rice (family labour valued at 1 USD/day). [38]

Example from Thailand [39]

The average income of people in the farm sector (2002) was two times lower than in non-farm sectors, and 3.8 times lower than the income of skilled labour workers. Most of the 6.2 million people living below the poverty line were in the farm sector.

Slow progress [towards sustainable agriculture] was attributed to lack of land ownership documents, lack of water, lack of labour, lack of investment, and debt.

Farmers themselves also lacked the *'inspiration',* patience and diligence to succeed.

A farmer who wants to shift from paddy to other crops faces various obstacles, including the following:

- Whether the soil is suited for other crops;
- new needs of capital, technology and knowledge (and hereby, perhaps, new dependencies on suppliers);
- whether the alternative crops require more fertilizer and more pesticides (and hereby additional expenses, occupational safety risks, and pollution that can impede local fisheries and cause other harm);
- unfamiliar (and possibly risky) distribution and marketing systems (and hereby, perhaps, new dependencies on buyers); and
- social risks in general - illness in the family, natural disasters - and how to cover them.

Between them, these obstacles can point towards *contract farming*, with its variety of pros and cons. Also, the obstacles can point towards *land ownership concentration.*

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[37] Harry Nesbitt (July 2003)

[38] MAFF (September 2002)

[39] Thailand National Economic and Social Development Board, quoted in Bangkok Post 14 November 2004, p. 3

Management aspects

At the basin level, water-related management can be supported by developments towards:

- Supportive water allocation within the basin, and, possibly, among basins (subject to careful analysis of benefits and side effects);
- coordinated operational flow management of retention, release, and diversion of water, using existing or new infrastructure;
- coordinated, basin-level flood and drought preparedness, including forecast services and contingency planning;
- coordinated hydropower development in a multi-disciplinary perspective (subject to careful analysis of benefits and side effects);
- salinity control measures (that can reduce the required minimum flow while protecting downstream irrigation systems and ecosystems) (subject to careful analysis of benefits and side effects);
- coordinated, basin-level groundwater management (mapping, protection, regulation, monitoring) (to prevent contamination and assure prudent utilization);
- coordinated, basin-level morphological management (to protect infrastructure, waterways and ecosystems);
- awareness of the proper use of fertilizers and pesticides, with supportive regulation;
- coordinated management of wetlands and headwater areas;
- support in many ways to a partial crop diversification, combining paddy with other crops (and/or livestock and/or fish cultivation) (for example learning from experience achieved in Thailand, Viet Nam and elsewhere);
- support in many ways to enhancing the water efficiency and the economic efficiency of the primary production (involving extension services and bridging institutions);
- support in many ways to enhancing the added value of the primary production (within post-processing, distribution and marketing); and
- networking and knowledge-sharing among river basin organizations.

At the scheme level, water-related management of paddy cultivation can be supported by development comprising:

- Making operational data and information readily available;
- scheme-level flood and drought preparedness and contingency planning;
- networking and knowledge-sharing between scheme operators and water users;
- credit facilities for investment and disaster mitigation; and
- awareness of technological opportunities within crops, cultivation routines, water management and soil management.

The over-all water efficiency and the economic efficiency of water utilization can be enhanced by general measures such as

- Supportive land ownership structure;

- de-centralization of ownership and decision-making, as practical from case to case (considering the size of the scheme; its technological complexity; water sharing with other schemes; and various other site-specific circumstances);
- scientific research, international networking, bridging institutions and extension services;
- broad capacity-building; and
- holistic development of farming, post-processing, distribution and marketing (for example learning from experience achieved in Thailand and elsewhere).

Social risk management is an important companion to water management. Without one, the other can fail, or initial achievements can eventually become undermined. This can happen if intended beneficiaries of an irrigation development lose their land due to floods, drought, crop or livestock diseases, illness in the family, market failure, or other social shocks.

CGIAR (Consultative Group on International Agricultural Research)

Three CGIAR research centers focus on rice research: (i) The International Rice Research Institute (IRRI) in the Philippines; (ii) the West Africa Rice Development Association (WARDA) in Cote d'Ivoire; and (iii) the Centro Internacional de Agricultura Tropical (CIAT) in Colombia.

IRRI operates an award winning website dedicated to rice called the Rice Web (http://www.riceweb.org). This is a compendium of facts and figures from the world of rice.

The three research centers collaborate to improve yield potential , to develop hybrid rice for the tropics, to improve nitrogen use efficiency in rainfed systems, and to combat pests, diseases, and weeds.

Source: http://www.cgiar.org/impact/research/rice.html

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Appendix A: Statistics

Top producers (2003/04 data from US Department of Agriculture)

1	China	118,000,000 t
2	India	89,000,000 t
3	Indonesia	33,300,000 t
4	Bangladesh	26,000,000 t
5	Vietnam	21,000,000 t
6	Thailand	17,800,000 t
7	Burma	10,440,000 t
8	Philippines	8,500,000 t
9	Brazil	7,300,000 t
10	Japan	7,100,000 t

Top producers per capita (2003/04 data from US Department of Agriculture)

1	Thailand	277 kg/person
2	Vietnam	257 kg/person
3	Burma	246 kg/person
4	Bangladesh	188 kg/person
5	Indonesia	142 kg/person
6	Philippines	100 kg/person
7	South Korea	93 kg/person
8	China	92 kg/person
9	India	85 kg/person
10	Japan	56 kg/person

Top exporters (2003/04 data from US Department of Agriculture)

1	Thailand	8,000,000 t
2	Vietnam	4,000,000 t
3	India	3,000,000 t
4	United States	2,900,000 t
5	China	2,500,000 t
6	Pakistan	1,600,000 t
7	Uruguay	750,000 t
8	Egypt	700,000 t
9	Burma	500,000 t

Appendix B: Economy of paddy farming (example)

	The farmers income and expenses		***Adverse***	***Favourable***
			USD/ha/crop	*USD/ha/crop*
(1)	Sale of 3-5 t/ha/crop at 350-400 riel/kg paddy (0.09-0.10 USD/kg)		262.50	500.00
(2)	Seeds, 20-40 kg/ha/crop at 0.2 USD/kg		4.00	8.00
(3)	External labour, planting, 10 persons for 1 day/ha at 4500 riel/person/day		11.25	11.25
(4)	External labour, harvesting, 5 persons for 1 day/ha at 4500 riel/person/day		5.63	5.63
(5)	Fertiliser, 100-300 kg/ha/crop at 0.4 USD/kg		40.00	120.00
(6)	Pesticides, 3 times per crop, total 4 USD/ha/crop		4.00	4.00
(7)	Water fee, 50 kg paddy/ha/crop		4.38	5.00
(8)	Balance before own labour	= (1)-(2)-(3)-(4)-(5)-(6)-(7)	193.25	346.13
(9)	Own labour, 120 days/crop at 1 USD/day for 1-2 ha		120.00	60.00
(10)	Balance after own labour	= (8) - (9)	73.25	286.13
	Additional costs for groundwater irrigation by diesel pumps			
(11)	Depreciation of well & pump, 500 USD over 10 crops for 3-4 ha		16.67	12.50
(12)	Diesel, 90 days at 10 l/day at 0.5 USD/l for 3-4 ha		150.00	112.50
(13)	Water fee saved	= - (7)	-4.38	-5.00
(14)	Total additional costs	= (11) + (12) + (13)	162.29	120.00
(15)	Balance after own labour and irrigation costs	= (10) - (14)	-89.04	166.13

Notes:

1 USD = 4000 riel

Data: 7 March Irrigation Scheme, Kampong Cham Province, Cambodia (October 2004)

This budget is made in the farmer's perspective, selling unmilled paddy at the farmgate (and with site-specific weather, soil conditions, crop varieties and cultivation routines)

To arrive at a 'true' economic budget, value generated downstream must be added, and price regulation (subsidies and taxes) removed

The 'favourable' budget assumes high yield and high use of fertiliser

The 'adverse' budget assumes low yield and low use of fertiliser

Typical farm size in this area is 1 ha (but some are several times bigger)

1 kg rice (ordinary quality) cost 1400-1600 riel (0.35 - 0.40 USD) in the markets in Phnom Penh (October 2004)

Please refer to MAFF (September 2002) for an in-depth analysis of the economy of paddy farming in Cambodia

Appendix C: The System for Rice Intensification (SRI) [40]

The SRI methodology was developed in the early 1980s by a Jesuit priest, Father Henri de Laulanié, who came to Madagascar from France in 1961 and spent the next (and last) 34 years of his life working with farmers to improve their agricultural systems.

As compared with traditional paddy cultivation systems, SRI can potentially provide a much higher yield while saving around 50 percent of water, both with traditional and new rice varieties, but with a higher input of labour. SRI has been implemented or tried in many countries, from case to case with positive, inconclusive or negative results.

SRI involves management of:

Rice plants: Seedlings are transplanted:

- very young - usually just 8-12 days old, with just two small leaves
- carefully and quickly to have minimum trauma to the roots
- singly, only one per hill instead of 3-4 together to avoid root competition
- widely spaced to encourage greater root and canopy growth
- in a square grid pattern, 25x25 cm or wider - 30x30 cm or 40x40 cm, even up to 50x50 cm with the best quality soil

Soil: This is kept moist but well-drained and aerated, with good structure and enough organic matter to support increased biological activity. The quality and health of the soil is the key to best production.

Water: Only a minimum of water is applied during the vegetative growth period, and then only a thin layer of water is maintained on the field during the flowering and grain filling stage. Alternatively, to save labour time, some farmers flood and drain (dry) their fields in 3-5 day cycles with good results. Best water management practices depend on soil type, labour availability and other factors, so farmers should experiment on how best to apply the principle of having moist but well-drained soil while thier rice plants are growing.

Nutrients: Soil nutrient supplies should be augmented, preferably with compost, made from any available biomass. Better quality compost such as with manure can give additional yield advantages. Chemical fertilizer can be used and gives better results than with no nutrient amendments, but it contributes less to good soil structure and active microbial communities in the rhizosphere than does organic matter. At least initially, nutrient amendments may not be necessary to achieve higher yields with the other SRI practices, but it is desirable to build up soil fertility over time. Rice-root exudation, greater with SRI, enhances soil fertility.

Weeds: Since weeds become a problem in fields that are not kept flooded, weeding is necessary at least once or twice, starting 10-12 days after transplanting, and preferably 3 or 4 times before the canopy closes. Using a rotary hoe -- a simple, inexpensive, mechanical push-weeder has the advantage of aerating the soil at the same time that weeds are eliminated. (They are left in the soil to decompose so their nutrients are not lost.) Additional weedings beyond two increase yield more than enough under most conditions to justify the added labour costs.

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[40] Source: The SRI section of Cornell Universty's website: http://ciifad.cornell.edu/sri/index.html

Appendix D [41]: Means for saving water and increasing the productivity of water

Increasing the productivity per unit of water consumed

- *Changing crop varieties* to new crop varieties that can provide increased yields for each unit of water consumed, or the same yields with fewer units of water consumed.
- *Crop substitution* by switching from high- to less-water-consuming crops, or switching to crops with higher economic or physical productivity per unit of water consumed.
- *Deficit, supplemental, or precision irrigation.* With sufficient water control, higher productivity can be achieved using irrigation strategies that increase the returns per unit of water consumed.
- *Improved water management* to provide better timing of supplies to reduce stress at critical crop growth stages leading to increased yields or by increasing water supply reliability so that farmers invest more in other agricultural inputs leading to higher output per unit of water.
- *Optimizing non-water inputs.* In association with irrigation strategies that increase the yield per unit of water consumed, agronomic practices such as land preparation and fertilization can increase the return per unit of water.

Reducing non-beneficial depletion

- *Lessening of non-beneficial evaporation* - by reducing:
  - evaporation from water applied to irrigated fields through specific irrigation technologies such as drip irrigation, or agronomic practices such as mulching, or changing crop planting dates to match periods of less-evaporative demand.
  - evaporation from fallow land, decreasing the area of free water surfaces, decreasing non- or less-beneficial vegetation and controlling weeds.
- *Reducing water flows to sinks* - by interventions that reduce irrecoverable deep percolation and surface runoff.
- *Minimizing salinization of return flows* - by minimizing flows through saline soils or through saline groundwater to reduce contamination of recoverable irrigation return flows.
- *Shunting polluted water to sinks* - to avoid the need to dilute with freshwater, saline or otherwise polluted water should be shunted directly to sinks.
- *Reusing return flows.*

Reallocating water among uses

- *Reallocating water from lower- to higher-value uses.* Reallocation will generally not result in any direct water savings, but it can dramatically increase the economic productivity of water. Because downstream commitments may change, reallocation of water can have serious legal, equity and other social considerations that must be addressed.

Tapping uncommitted outflows

- *Improving management of existing facilities* to obtain more beneficial use from existing water supplies. A number of policy, design, management and institutional interventions may allow for an expansion of irrigated area, increased cropping intensity or increased yields within the service areas. Possible interventions are reducing delivery requirements by improved application efficiency, water pricing, and improved allocation and distribution practices.
  - *Reusing return flows* through gravity and pump diversions to increase irrigated area.
  - *Adding storage facilities* so that more water is available for release during drier periods. Storage takes many forms including reservoir impoundments, groundwater aquifers, small tanks and ponds on farmers' fields.

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[41] Entire Appendix is quoted from Molden, Amarasinghe and Hussain (2001)

Appendix E [42]: Advice from Royal Irrigation Department

Varieties

- Use early varietes of local, photoperiod sensitive varieties. Local and photoperiod sensitive varieties are grouped as early variety (120 days) medium variety (150 days) and late variety (180 days)
- Use high yield varieties, the production can be doubled with the same amount of water consumption.

Growing season

- Cultivate in the rainy season and harvest at the end of the season.
- For non photoperiod sensitive varieties (110 to 120 days) the harvesting date should be planned at the end of rainy season in order to set the growing date.
- Cropping calendar should be planned suitable to wet and dry season.

Cultivation practice

- Good land preparation with smooth level of each field plot.
- Do not plough so deep that hard pan will be broken.
- Compact field boundary (dike) to avoid seepage loss.

Irrigation system

- Concrete lining in irrigation system.
- Construct on-farm system (extensive or intensive on-farm development work)

Water application and management

- Irrigate water according to crop water requirement
- Keep water level in paddy field about 6 cm deep
- Introduce rotation irrigation
- Stop irrigation in the tillering stage for some time. Besides, the water saving oxygen can also be brought the soil.
- Stop irrigation 20 days before harvesting.
- Introduce water user group and water fee.

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[42] Entire Appendix is quoted from Osot Charnvej (October 1999)