Coastal Adaptation and Resilience Planning Component

Final

Climate-Resilient Irrigation Guidance Paper

Cambodia Climate Change Alliance (CCCA)

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Climate-resilient irrigation

Guidance paper prepared by Coastal Adaptation and Resilience Planning (CARP) Component,
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Contents

Summary

The paper presents suggestions on climate-resilient irrigation in the specific context of the coastal climate adaptation needs in the CARP pilot area. It covers climate-related considerations of hydraulic feasibility; design; and operation. For each of these aspects, some thoughts are listed on guiding principles; suggestions and recommendations; and options for consideration (depending on the context).

Climate resilience will be supported) by the following measures:

- High over-all efficiencies of water-dependent production systems: High output and high value per m3 of water
- Adequate hydraulic feasibility; good design; and good operation
- Balance between water demand and raw water availability
- Limited reliance on pumping
- Adequate drainage
- As much storage as possible
- Good control of water allocation over time and within the scheme
- Limited losses, for the sake of flow capacity and scour control
- Predictable and reliable water allocation
- Good collaboration between the farmers
- Good access to information about the normal and actual weather
- Good knowledge about management options, covering both cultivation and water management

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A smooth formal collaboration and informal dialogue has been maintained with CCCA, sharing information, ideas and findings.

The Team sincerely thanks everyone who shared their time and knowledge, and looks forward with enthusiasm and confidence to a continued fruitful dialogue.

This Guidance has been developed based on a number of on-going activities conducted in 2012 to early 2013 and a number of persons have been involved in this or part of this work.

In addition, the following persons (listed by order of alphabet) kindly shared their information and provided data and ideas:

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Acronyms and abbreviations

CARDI:	Cambodia Agricultural Research and Development Institute
CARP:	Coastal Adaptation and Resilience Planning
CC:	Climate change
CR:	Climate resilience
DOA:	Department of Agriculture
DOE:	Department of Environment
DOWRAM:	Department of Water Resources and Meteorology
DRD:	Department of Rural Development
EIA:	Environmental impacts assessment
FWUC:	Farmers' water users community (water user group)
ha:	Hectare (10,000 m2)
MAFF:	Ministry of Agriculture, Forestry and Fisheries
MOE:	Ministry of Environment
MOWRAM:	Ministry of Water Resources and Meteorology
NAPA:	National Adaptation Programme of Action

1 Introduction

This paper is related to Outcome 2 of the CARP: *'Increased resilience of coastal communities and coastal ecosystem buffers to climate change and improved livelihoods'.*

Specifically, it is related to Output 2.8:

> *'Development of guidance for climate-resilient irrigation design'.*

The work is based on a literature study, and a series of consultations with government bodies, farmers, and resource persons in Preah Sihanouk, Koh Kong and Phnom Penh from mid 2012 till early 2013.

The paper presents suggestions in the specific context of the coastal climate adaptation needs in the CARP pilot area. It covers climate-related considerations of hydraulic feasibility; design; and operation.

The interested reader is referred to the comprehensive related literature, examples of which are listed at the end of the document.

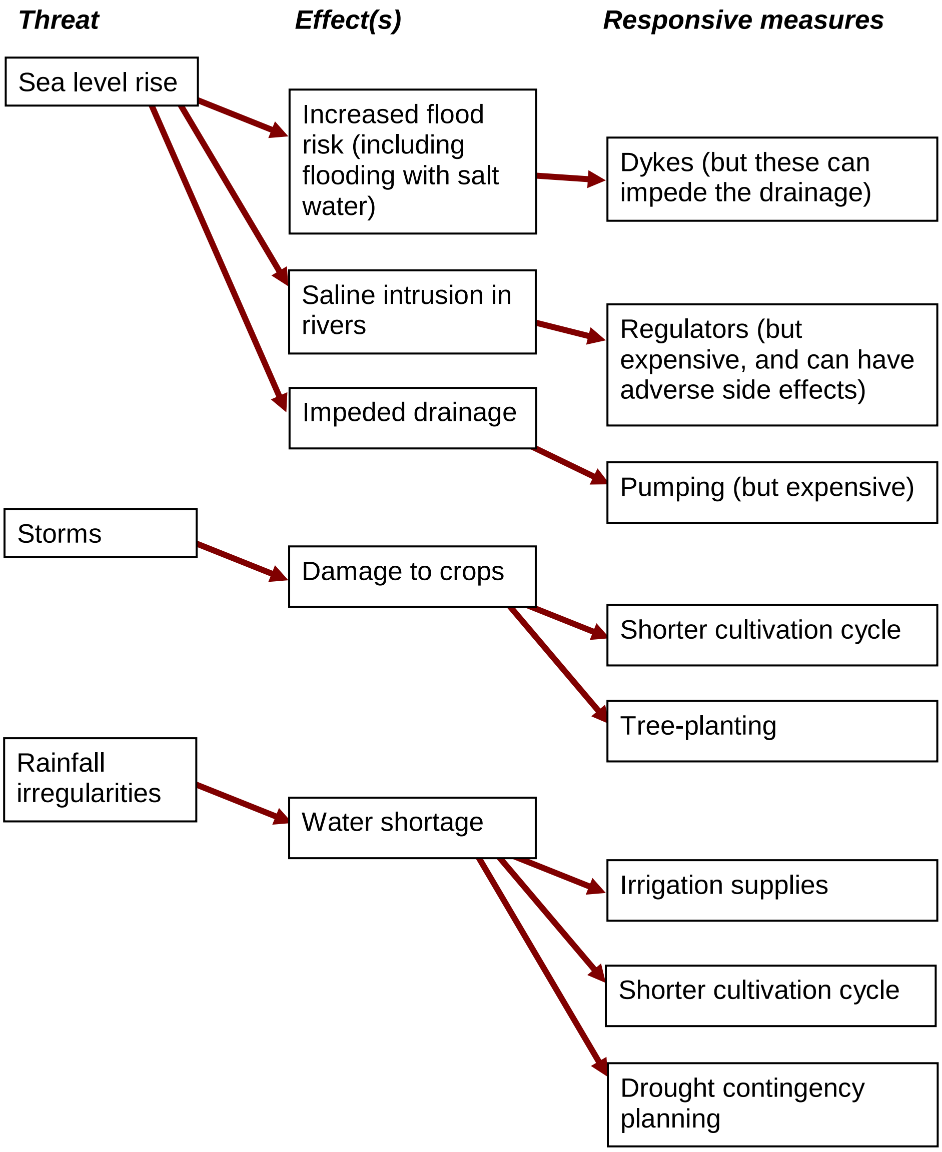
2 Climate-related concerns and options

2.1 Climate-related cause-effect relationships

In the coastal zone of Cambodia, the climate-related challenges within water availability for cultivation are already clearly visible. Climate change will amplify their significance, rather than introduce new cause-effect relationships. [1]

This is illustrated in the following figure. It must be noted that not all potential responsive measures are feasible: Some have adverse side effects; and some are simply too expensive. The threats are *seasonal.*

Figure 1: Climate-related challenges to irrigation



1 One exception is *drought,* which is a minor concern today, but which can become more serious in connection with a changed climate (as well as new cultivation systems that reach into drier parts of the year). As it is, the coastal zone is under-prepared for serious drought events

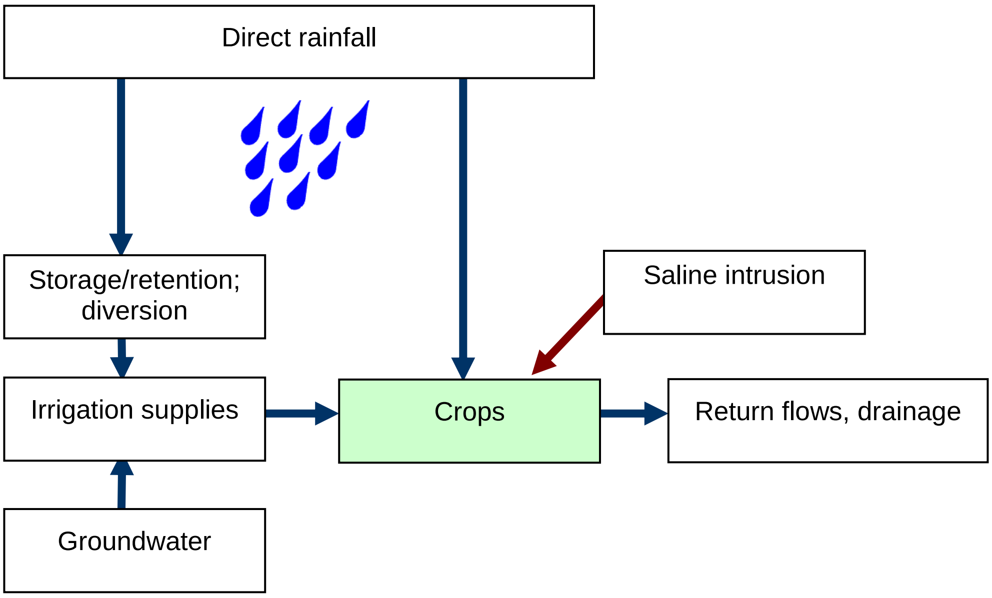
The climate-related concerns interact (and amplify) some other concerns in the coastal zone:

- Some low-lying areas (including the Prey Nob polders) are subsiding, presumable due to drainage; which interacts with sea level rise and amplifies its consequences to flood risk, saline intrusion and drainage.
- The traditional cultivation system is one rain-fed, long-term crop of rice per year. The yield is modest (around 2.6-2.7 t/ha)[2] and in some parts of the Prey Nob polder yields of 1.5 t/ha has been reported, and the land holdings are small. This makes it difficult for farmers to make ends meet, and imposes a need of upgraded technology (higher yield, and shorter duration, but possibly more than one crop per year). This can increase the exposure to seasonal, climate-related threats.
- Reclamation and landfill operations can affect the flood risk and drainage.

2.2 Resilience

Irrigation involves supply of water to the fields, by gravity or pumping. The water can be diverted from a river or canal, or drawn from a lake or a reservoir, or from the ground; or it can simply be retained at the place where the crop will be cultivated.

Figure 2: Water flows for cultivation



A good irrigation scheme is characterized by the *predictable availability of adequate water at the place and the time when the crops need it.* The scheme must be

2 Average for Preah Sihanouk and Koh Kong provinces

- hydraulically feasible (for example in terms of raw water availability);
- well designed (for example in terms of storage capacity, conveyance capacities and control structures); and
- well operated (for example in terms of water allocation within the scheme).

Also, the scheme should be *financially feasible* - meaning that the economic benefits exceed the operation and maintenance costs with a margin that makes it attractive to the farmers. [3]

A scheme with such characteristics will often have a good (or fair) climate resilience, because it intended for *'normal',* short- or medium-term weather irregularities. Unfortunately, many irrigation schemes in Cambodia are not hydraulically feasible, and/or not well designed, and/or not well operated. [4]

Climate change will mainly affect the hydraulic feasibility; the design (of new or upgraded schemes); and the operation (supported by data and knowledge).

Efficiency of production systems

One important general consideration is the efficiencies of water-dependent production systems: Output and value generated per m3 of water (as well as per working day, per ha of land, or per kWh of power consumed). In this respect, Cambodia lags behind Thailand and Viet Nam, and there is an attractive scope for upgrading. This is for several good reasons - one being that *efficient production systems are more resilient than less efficient ones.* Also, good efficiencies support sustainable resource utilization.

This is not only a matter of higher volumes. Quality plays a role along with quantity. Some low-yield rice varieties can have a higher value than high-yield ones (for example the Thai hom mali rice).

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3 Ideally, the scheme should also be *economically feasible* - meaning that the economic benefits exceed the total (capital + operation and maintenance) costs. This is achieved for few schemes in Cambodia, where the capital costs are conventionally disregarded

4 A study by Cambodian Center for Study and Development in Agriculture (CEDAC) in 2008 covered 13 major rice-growing provinces (about 90 percent of the total current rice cultivated areas of Cambodia). There were more than 2000 irrigation schemes in this area. However, only 7% were considered to be *'functional',* 34% were *'partly functional',* while the rest was *'out of function'*

3 Hydraulic feasibility of irrigation infrastructure

3.1 Significance

Hydraulic feasibility is the basic requirement for any investment in irrigation infrastructure. If a scheme is not hydraulically feasible, it is not likely to generate economic and social benefits. On the contrary, it can be a waste of money, and, at worst, positively harmful to resource management and cultivation.

In Cambodia, there are frequent examples of schemes that are not hydraulically feasible, particularly among the many schemes built under Pol Pot (1975-79).

The hydraulic feasibility includes the balance between water demand and availability (for existing and future cultivation systems), possibly related to storage capacity. The raw water availability is a key consideration. A hydraulically feasible irrigation system is able to deliver a *predictable and reliable* amount of water, reflecting the raw water availability and the storage and conveyance capacity. A feasibility analysis must be based on knowledge (or realistic assumptions) about the over-all, *'reliable'* water availability (which can for example be *'the water available in 4 out of 5 years').*

In this connection, it must be kept in mind that *future cultivation systems will be visibly different from today's.* One rainfed, low-yield crop per year with a small land holding does not allow for a sustainable livelihood.

3.2 Guiding principles

- Adopt a ***basin-wide, IWRM-based perspective***[5] on water availability assessments. Storage capacity upstream can improve conditions downstream (including water availability and salinity control). The over-all water allocation must provide a balance between demand for irrigation and other off-stream and in-stream demands of water - including domestic demands, livestock, and preservation of wetlands and other aquatic habitats. Many of these water uses generate a much higher value per m3 that paddy cultivation.

- Conduct a ***climate assessment*** (of opportunities and risks) before deciding on any major investment. Please refer to Appendix E for an elaboration.

- ***New technology*** can be attractive, but should be introduced with due caution, considering the risk of unexpected adverse side effects. Learn from others, and apply a step-wise approach if possible.

- ***Groundwater*** should be regarded with caution, particularly in low-lying areas near the coast, where there is a risk of saline intrusion. In more elevated parts, groundwater may serve marginal demands, such as small-scale cultivation and livestock. Groundwater should not be used in areas in risk of land subsidence.

5 IWRM = integrated water resources management

Looking beyond the hydraulic feasibility, an eye must be kept on the ***social implications*** of irrigation development. Water management 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.

Is an EIA required?

The *Sub-decree on Environmental Impact Assessment Process* was passed by the Council of Ministers on August 11, 1999. (Presently an EIA law is being prepared).

According to the decree, an EIA is required for (among others)

- Land covered by forest: ≥ 500 ha
- Agriculture and agro-industrial land: ≥ 10,000 ha
- Flooded and coastal forests: All sizes
- Irrigation systems: ≥ 5,000 ha
- Drainage systems: ≥ 5,000 ha

3.3 Suggestions and recommendations

- Avoid expensive infrastructure in ***flood-prone areas.***
- ***Drought mitigation plans*** should be prepared. Here, the coastal zone can learn from Cambodia's inland provinces.
- Include the ***soil quality*** in the feasibility assessment. Rice is unique because it can grow almost anywhere. Is the soil suited for crops other than rice? If *'yes',* it will add to the feasibility of the scheme. If *'no'* - can something be done about it?
- Caution is warranted regarding the feasibility of ***schemes that only provide supplementary wet season irrigation*** (for a single crop per year).

3.4 Options for consideration

- ***Tree planting*** (to break the wind) can also reduce the evaporation and hereby the irrigation demand
- Consider ***remote storage*** (far from the fields) with an open mind. Transport of water over long distances does not need to be prohibitively expensive if it can proceed by gravity.
- Consider the scope for a small ***agricultural research & extension station*** (if none is already available nearby). Cultivation technology (and particularly innovative technology) can be quite site-specific. The same is the case for pest control and drought mitigation - experience from elsewhere is valuable, but well-informed site-specific guidance is indispensable.

- Consider the ***land ownership structure,*** and how to preserve a supportive land ownership structure.

3.5 Technicalities

General

In Cambodia, *'irrigation'* is almost synonymous with *'irrigation of paddy fields'.* This is for good reasons: Rice provides food security, a major concern within living memory, and is presently developing into a major export commodity. [6] On the other hand, rice requires a lot of water (if grown in paddy fields) and provides a modest value per m3 of water. [7] [8] Other crops, such as fruit trees, vegetables or spices can provide an attractive value per m3 of water and may be considered as supplements to the rice cultivation, possibly occupying small areas. Examples include sugarcane, water melon, onion, maize and banana. *Livestock* is another option.

The hydraulic feasibility considers the *balance between demand and (potential) supply of water.* This balance is critical to the hydraulic feasibility of an irrigation scheme. It should be considered with an open mind, given the high water demand of paddy cultivation. A scheme that is not feasible for paddy cultivation could be feasible for other production systems. Ask questions such as *'what can be done with this amount of water?'* rather than *'do we have enough water for a second crop of rice?'* There could be interesting answers to the first question, even if the answer to the second question is a clear *'no'.*

The table and figure below illustrate the seasonal variation of the irrigation demand, indicating that in this example, irrigation supplies are needed in half of the year (from November to April) (with a crop demand of 0.6 l/s/ha and a rainfall reliability of 4 out of 5 years). With the same assumptions, the crop requirement plus losses balances the annual rainfall within a margin of 65 mm/year - so that there could be enough water for 2 or 3 crops per year if only the water could be stored.

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6 Cambodia exported more than 200,000 t of milled rice in 2012 (according to the Minister of Agriculture, quoted in Cambodia Daily 17 January 2013)

7 Traditional paddy cultivation requires several m3 of water per t of milled rice

8 An alternative cultivation technology, the *'System of Rice Intensification (SRI)',* requires much les water. It has been tested in Cambodia, with good results, but is labour-intensive and may therefore not replace the traditional paddy cultivation (unless perhaps as a second crop on small areas, or as an option in drought contingency planning)

Table 1: Crop demands and irrigation supplies (example, illustrating paddy cultivation)

Month	Rainfall	Rainfall, adjusted	Crop requirement and losses	Irrigation demand
	mm	*mm*	*mm*	*mm*
	1)	*2)*	*3)*	*4)*
J	4	3	148	145
F	3	3	134	131
M	10	8	148	140
A	80	64	143	79
M	186	149	148	-1
J	425	340	143	-197
J	358	286	148	-138
A	425	340	148	-197
S	359	287	143	-139
O	208	167	148	-19
N	36	28	143	115
D	2	2	148	146

Notes:

1) Reliable (4 out of 5 years) rainfall in Sihanoukville (see Appendix B)

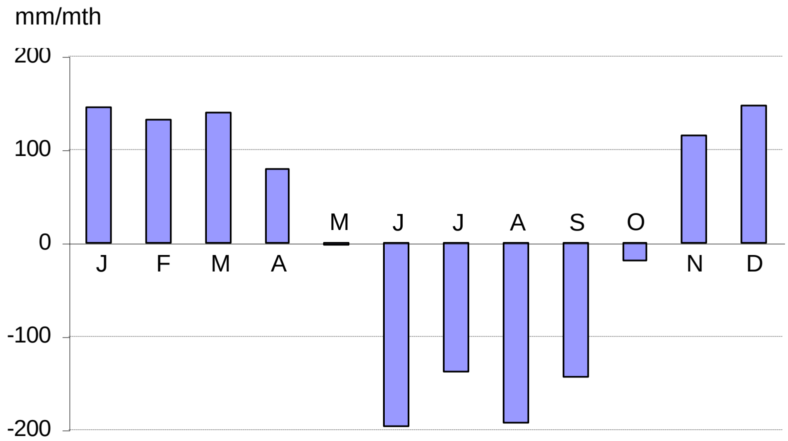
2) = 1) minus 20 percent (because the rainfall in Sihanoukville is higher than in most other parts of the coastal zone) (see Appendix B)

3) Estimated at 0.6 l/s/ha (5 mm/day) including losses as an average over a 5-months cultivation period

4) = 3) minus 2)

For a real analysis, site-specific estimates should be used, and the time increment should be less than a month

Figure 3: Seasonal irrigation demand



Values are indicative examples taken from the table above

Approach [9]

Hydraulic feasibility assessment can comprise

- hydrological analysis of general water availability;
- assessment of the adequacy of the available water as compared with the intended use (service area and cultivation cycles);
- conceptual design and capacity assessment of structural components;
- assessment of hydraulic risks and side effects and related mitigation options: Flood risk, erosion, siltation, and connectivity; and
- identification of present and future competing uses, in-stream and off-stream, and upstream as well as downstream

Regarding approach and level of effort, a distinction can be made between

- rehabilitation of existing schemes;
- capacity expansion of existing schemes; and
- new schemes.

Rehabilitation

One key question is: *'Has this scheme ever functioned well'?*

If *'yes',* until when, and what happened to cause that it does not function well any longer? Typical answers could be lack of maintenance, or a healthy concept with a wrong design, such as inadequate flow capacity of structures, so that they became affected by siltation and/or erosion, or a healthy scheme with a suitable design but poor construction quality, so that structures have been damaged in the course of time.

If *'no',* the reason why should be investigated. There are many examples that schemes that have never functioned well should never have been built in the first place. On the other hand, there may be some obvious explanation (like faulty design of an otherwise healthy scheme) that can be remedied

That a scheme has worked well in the past is an indication of its feasibility, but not a proof. The reason(s) that it does not work well any longer can be prohibitive - like a permanent upstream diversion, or an irreversible change of the planform of the river network. A truly feasible scheme would normally be preserved at the initiative of the water users, at their own cost, if they agree to its usefulness.

Schemes that have never worked well must be considered with due diligence with respect to hydraulic feasibility.

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9 The remainder of this chapter has been extracted from MOWRAM (December 2007)

Capacity expansion

Capacity expansion of existing schemes, whether functional or not, can sometimes be an attractive development option. Also in this case, the basic water availability is a key criterion for hydraulic feasibility.

New schemes

With the possible exemption of small schemes, less than 200/400 ha, a particular scrutiny is recommended in case of new schemes.

This is for the simple reason that in many parts of Cambodia, the areas best suited for cultivation and irrigation are already cultivated and irrigated.

Feasibility criteria

The hydraulic feasibility criteria are

1. Harmony between availability and demand of water
2. Acceptable hydraulic risks and side effects
3. Realistic operation requirements

The hydraulic feasibility criteria are not adequate for over-all feasibility of a scheme. This requires in addition that economic and social benefits exceed the economic and social costs, and that environmental consequences are acceptable.

A reference may be made to a groundbreaking study by Halcrow (back in 1993-94), which applied the following ranking criteria for rehabilitation of irrigation systems: [10]

- Projects expected to have high tangible net economic benefits (for example projects with highly suitable soils and enough water for double cropping);
- existing successful systems to be rehabilitated or improved;
- low cost investments which would yield significant benefits (for example flood recession projects); and
- social rehabilitation or poverty alleviation projects.

Water being adequate for double cropping will highly increase the value as compared with schemes that provide supplementary wet season irrigation only. While supplementary wet season irrigation represents the highest value generated per m3 of water, the economic benefits are reduced because the infrastructure is used in a part of the time only, and possibly not even once per year.

In the *'Inventory and analysis of existing systems'* under the same study priorities for rehabilitation were based on the following criteria:

- Good yields at present;

10 Halcrow (December 2003)

- good soils; and
- farmer interest.

These characteristics are not directly related to the hydraulic feasibility, but particular attention may be paid where a scheme is characterized by low yields, poor soils, or lack of farmer interest.

4 Design of irrigation infrastructure

4.1 Significance

A good design is a precondition for convenient operation and for achieving a good efficiency. Critical design aspects in connection with climate adaptation include

- storage capacity;
- control of flow rates and water allocation within the command area;
- flood resilience;
- drainage; and
- salinity control (in affected areas).

In comparison, the conveyance capacities are less sensitive.

4.2 Guiding principles

- The ***storage capacity*** should be enhanced in all practical ways - including storage in canals and idle lands, if possible.
- In the coastal zone, the design must consider ***salinity control and drainage*** as well as water supplies.
- Canals can serve the double purpose of ***water supply and drainage*** - but this is less than ideal, because the required instantaneous drainage flow capacity can be much larger than the required instantaneous flow capacity for water supplies.
- Provide ***facilities for flow control*** to allow for a functional water allocation within the irrigated area.
- Provide adequate flow capacity of regulators and other structures (such as bridges) in order to ***prevent scour.*** Consider scour protection at exposed locations. Improve the design of existing structures that cause scour.
- Consider the ***passage of fish*** when blocking a flow channel with a dam or a regulator. Fish ladders or by-passes can work (occasionally but not always) but are expensive and require a diversion of water. Sometimes, regulators can be operated in ways that allow migrating fish to pass in a

part of the year. Protect fish against birds (and kids!) in places around structures where they are particularly vulnerable.

4.3 Suggestions and recommendations

- Try to ***balance excavation volumes and landfill volumes*** (like it is done in the traditional *barays).*

- Divide the command area into ***sections*** (or *'compartments'),* to allow for orderly cultivation of a part of the area in case of water shortage or saline intrusion.

- ***Concrete lining*** of distribution canals will reduce the seepage losses and prevent or reduce scour during peak flows (for example related to floods). Also, concrete canals occupy less land, and regulators are much easier to build.

- Dams should be provided with ***spillways*** (most dams from the Pol Pot period are not). Provide excess capacity, or allow for subsequent capacity upgrading.

- ***Pumping*** should be applied to high-value crops only, due to the high costs (or in connection with drought mitigation, where a short period of pumping may save the crop).

- Provide ***simple network diagrams*** with command area details, regulators, and conveyance and storage capacities.

Figure 4: A fish ladder covered by a steel wire net

Photo from Kg Thom November 2006

Design basis

Key dimensions/characteristics of an irrigation scheme should be based on knowledge (or assumptions, when knowledge is imperfect) about the *'reliable'* water availability, flow rates and water levels.

Remember that *climate change* may well increase the intensity of extreme rainfalls and flow rates.

For water availability, it can be considered to serve the irrigation demand in *'4 out of 5 years'. '9 out of 10 years'* would be better but is in many cases significantly more costly, and with marginal additional benefits.

Canals and structures can be designed for a certain level of exceedence of rainfall, flow rates or water levels, selected with a view to the data quality and the consequences of an exceedence - the failure of a dam could be more serious (and costly) than a flooding of a paddy field. Select a high level for spillways - perhaps 50 years - and less for drains - and still less for conveyance canals.

Note

A *'20-years rainfall'* is ***not*** an event that happens once in 20 years. It is a rainfall level that is ***exceeded*** once in 20 years - on the average. So it is expected that once in 20 years there will be a rainfall higher than the 20-years level.

On the average, there will be five *'20-years rainfalls'* in a period of 100 years. And on the average, these events will have a level that is higher than the *'20-years rainfall'* (because each of them is equal to or higher than the 20-years level). (For example, there will be two 50-years rainfalls and one 100-years rainfall that contribute to the average).

A 20-years rainfall is not *'safe'.* The probability that a 20-years level is exceeded in any one year is 1/20 = 5 percent. And the probability that a 20-years level is exceeded in a period of 5 years is $1 - 0{,}95^5 = 0.23$ (or 23 percent)

4.4 Options for consideration

- Consider ***plastic pipes*** in reaches where flow regulation is not required (for example from upstream or central storage facilities to downstream or local storage facilities). (And protect against clogging)!

- Use ***mobile pumps*** as a supplement or alternative to gravity flow (or fixed pumps) where flow rates are moderate (for example for irrigation supplies at field level). They are versatile and can be allocated (and shared) as per demand.

4.5 Technicalities

As exemplified in many cases in Cambodia, hydraulic risks and side effects can from case to case comprise

- increased flood risk, due to a combination of factors - climate change, interacting with increased flow resistance (or inadequate conveyance capacity) imposed by hydraulic structures. This can, in turn, be caused by inadequate data and knowledge during the design
- upstream siltation, caused by unsupportive land use (perhaps deforestation), interacting with structures with an inadequate sediment (bed load) conveyance capacity (including reservoirs);
- downstream scour, erosion, and consequential accretion, caused by excessive flow velocities around structures; and
- related downstream morphological developments that can possibly shift the connectivity of the river network and the routing of flows, hereby affecting downstream water users, as well as fish migration.

These effects can be related and can amplify each other.

Use of groundwater can be considered for small-scale supplies, for example gardening or livestock. Cambodia has no strong tradition for groundwater utilization, and many farmers are sceptical. In low-lying areas near the coast, deep wells should be avoided, due to the risk of salinization - a risk that applies to shallow wells as well. Groundwater abstractions interact, so one well can undermine the performance (yield or salinity) of other wells in the area. Groundwater abstraction should be avoided if there is a risk of land subsidence.

Pumping is often indicated in places with a flat topography; but pumping is expensive, both in terms of capital and operation costs, and due caution is needed. The traditional self-powered water wheel (see photo below) is feasible under special circumstances only. Solar and wind-powered pumps are being tested on a pilot basis, but the jury is still out regarding their feasibility. Mobile diesel pumps (that can be allocated on demand) can be useful. Pumping should be considered only in case of small volumes, such as small fields and gardens. Full-scale paddy irrigation or drainage based on pumping is not feasible.

Figure 5: A traditional self-powered water wheel

Photo from Kg Chhnang, 2003

4.6 Scour protection

Scour is erosion around structures caused by turbulence. In rivers, streams and canals scour is also referred to as *leeside erosion,* occurring on the downstream side of structures. The level of turbulence (and hereby the scour) is related to the flow velocity (to the power of two) and the flow rate, so scour is very much a peak flow phenomenon.

Further downstream the turbulence dissipates and the flow loses its capacity to carry suspended sediments, which therefore settle. This causes siltation - which will reduce the flow capacity and increase the upstream flood risk - and sometimes impede fish migration.

Figure 6: Strong turbulence (and risk of scour) downstream of a structure

Photo from Kampot 16 Aug 2006 by Mr Sok Saing Im

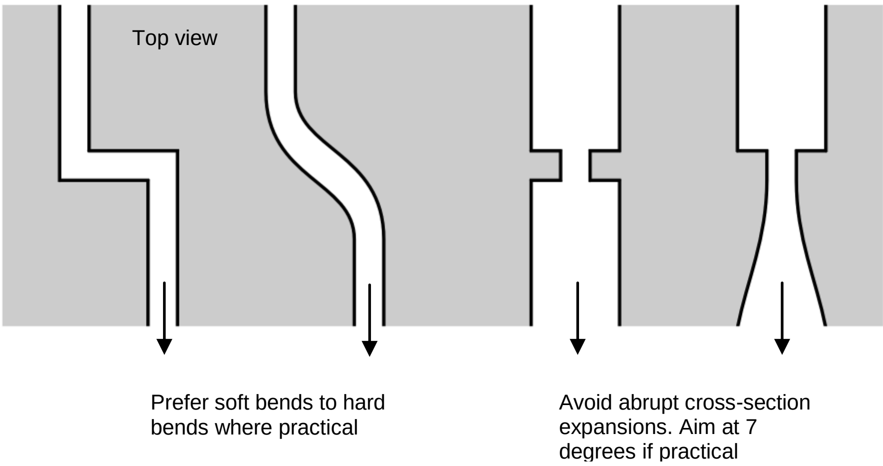
Figure 7: Scour (or leeside erosion) downstream of a structure

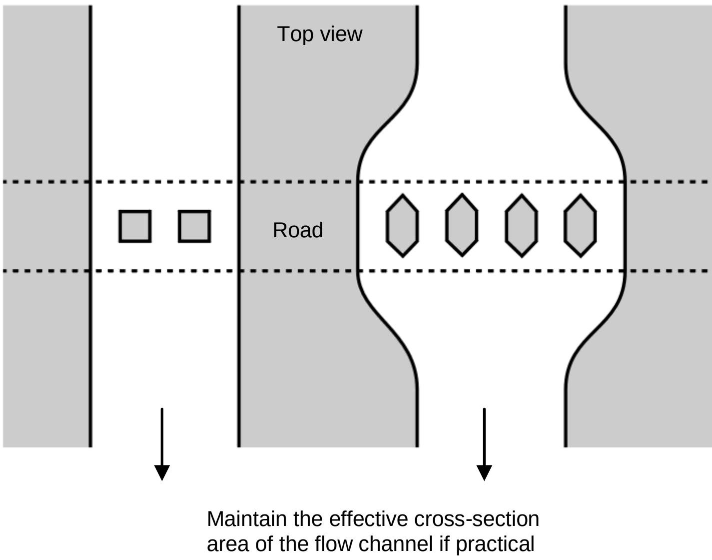
Photo from Pursat May 2006 by PRD Consultants

Scour can be controlled by protection (in the case of irrigation canals mostly concrete lining) and by appropriate flow capacity and design, as illustrated below. Scour downstream of spillways can be controlled by energy dissipating devices.

Reducing the turbulence will not only reduce the scour, but will also increase the flow capacity (and the upstream flood risk).

Figure 8: Reducing the turbulence and risk of scour





5 Operation of irrigation infrastructure

5.1 Significance

The purpose of the operation is to serve the crop water demand. If the requirements for operation are not fulfilled, it will reduce the performance of the scheme, and hereby its value and even its feasibility.

5.2 Guiding principles

- ***Data and information*** must be made available to scheme operators.

- Water allocation (in time and within command area) should be based on ***dialogue and communication,*** with ***predictability and reliability*** as major aims.

- Support ***knowledge-sharing*** among irrigation operators and water user communities. Even if conditions are different, there is a clear scope for learning from each other.

5.3 Suggestions and recommendations

- Provision of ***decision-support services*** (to scheme operators and farmers) should involve the provincial departments and should be coordinated between DOWRAM and DOA.

- Provide ***access to meteorological data*** - real-time as well as historical records.

- Implement ***local rainfall monitoring*** (daily reading of a rain gauge). Short records can be compared with nearby long-term records and provide a highly useful information for a moderate cost. Also, site-specific evaporation may be monitored.

- Keep track of ***actual irrigation supplies,*** as a basis for knowledge-building and continued streamlining.

- Keep track of ***events*** - storms, floods, drought, pest attacks, saline intrusion, and damage to structures - that affect the performance of the system, as a basis for decisions on improvements. Maintain a record with dates and a few lines about what happened.

- Assure that the paddy fields are ***level.***

- Maintain the ***dikes*** around the fields (to prevent seepage).

- Keep ***drainage canals and structures*** operational and tidy at all times.

- ***Protect reservoirs*** against siltation.

- ***Avoid hard pollutants*** (such as bio-accumulating and slowly decaying pesticide residuals, like heavy metals and polychlorinated hydrocarbons). The consequences can be severe for the environment in general and for public health and fisheries in particular.

5.4 Options for consideration

- ***Soil quality*** improvement can increase the soil's moist retention and thereby reduce its vulnerability to (short) drought incidents.
- ***Direct seeding*** will reduce the cultivation cycle by a week or so (and save some water, as well as a lot of labour), but at the cost of a somewhat reduced yield. It could be an option when introducing a second crop.
- ***Correct use of fertilizer*** can increase the yield as much as many m3 of water. Depending on the starting point, 1 kg of nitrogen fertilizer can produce up to 10–15 kg more rice. If so, with an irrigation demand of 3 m3/kg paddy, 1 kg of fertilizer can replace 30-45 m3 of water.
- Consider ***fish breeding*** in the paddy fields as a supplementary production.

5.5 Technicalities

Data and information

Activation of the intended, potential benefits of an irrigation scheme requires that certain data and information are readily available to scheme operators and farmers: [11]

Typically, the persons who are responsible for scheme operation have no information even of the normal rainfall.

(The same is probably the case for those who conceived and designed some of the schemes that were constructed in 1975-79).

Examples of required (or useful) data and information

- Knowledge about optimal and critical crop requirements.
- Conceptual information about scheme capacities (for storage and flow) and related capacity margins.
- Historical information about normal and 'reliable' rainfall and runoff. For example, the 'small dry season' is critical to the traditional cultivation cycle and hereby to the livelihoods and household economy of the farmers. Any knowledge about its characteristics can support an appropriate scheme operation (as well as decisions on when and how to cultivate).
- Real-time information about rainfall and water level.
- Short-term forecasts of rainfall and water level (all year) as well as flood forecasts (in the wet season).

11 This and the following paragraphs have been edited from Yem and Nielsen (September 2006)

Access to information about actual storage capacities and (unserved) demands would indicate what is technically possible under the circumstances, and hereby facilitate appropriate decisions on cultivation in general and irrigation scheme operation in particular.

The same is the case with information about rainfall, drought and floods. Whether one or more crops are grown per year, their optimal timing relative to the hydrological cycle is crucial to maximizing the yield and minimizing the risk of failure.

Decision-support during drought periods is of a particular value.

Cultivation technology services

Agricultural research and extension stations (where they exist) would be in a particular position to contribute, providing site-specific expertise within crop characteristics, cultivation and irrigation technology, and related water demands. These entities can activate the potential benefits of a more reliable water supply (and the associated reduced water availability risks), which would emerge only in combination with the right crop varieties and cultivation techniques.

Learning from each other

Networking among the water user groups would highly assist in consolidation. This could take place in different ways, including seminars where the farmers and scheme operators could share their positive and (hard-earned) negative experiences within cultivation, scheme operation, and marketing. Ability to cooperate is one of the determinants for good scheme operation, and farmers (in Cambodia and elsewhere) tend to prefer to learn from their peers rather than from unfamiliar experts - possibly with good reason. [12]

12 Support to such networking is provided under a separate CARP component

6 Bottom line

Below are listed some key considerations for successful climate adaptation of irrigation systems:

General

- High over-all efficiencies of water-dependent production systems: High output and high value per m3 of water
- Adequate hydraulic feasibility; good design; and good operation

Hydraulic feasibility

- Balance between water demand and raw water availability
- Limited reliance on pumping
- Adequate drainage

Design

- As much storage as possible
- Good control of water allocation over time and within the scheme
- Limited losses

Operation

- Predictable and reliable water allocation
- Good collaboration between the farmers
- Good access to information about the normal and actual weather
- Good knowledge about management options, covering both cultivation and water management

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Appendix A: Terminology

Availability of water(in a river basin): The flow from upstream (if any) plus the (surface and groundwater) resources generated by net rainfall minus priority allocations in the basin or downstream. The availability is largely determined by the rainfall. It changes slowly - from one decade to the next, due to medium-term and long-term climate variations, or due to construction of reservoirs or diversions. The availability can be measured, and/or determined by numerical modelling, with an accuracy that is determined by the coverage and quality of the basic hydrological data

Climate: The general weather conditions in a long-term perspective

Climate adaptation: Measures that address the adverse effects of climate change - as compared with *climate mitigation:* Measures that address the causes of climate change

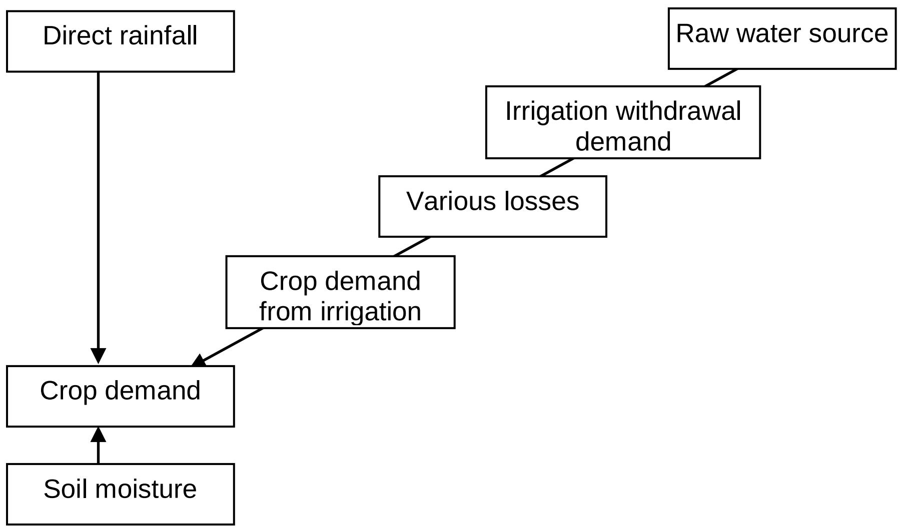
Climate change: Systematic long-term climate trends, whether natural or generated by human activities, for example increased temperature *('global warming'),* increased weather irregularities, changed rainfall, and sea level rise

Climate resilience: (1) The ability to recover from an adverse (climate-related) event; (2) the ability to withstand a (climate-related) pressure. A high resilience is related to a low vulnerability, and the other way around

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

Conveyance: Moving (water) from one place to another

Crop demand (or crop 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. Compare with *crop demand from irrigation*



Crop demand from irrigation: The part of the crop demand that is not supplied by rainfall or by soil moisture variation

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 %.

Demand (of water):The amount of water required for a given purpose, for example litre per person per day, or mm per crop. The demand can be present or future, and it can be actual (i.e. related to an available infrastructure) or potential (assuming full infrastructural development and no raw water shortage). *Off-stream demand* (e.g. for irrigation) relates to water that must be removed from the river, while *in-stream demand* (e.g. for fisheries or for navigation) relates to water that remains in the river. The serviceable (part of the) demand is limited both by infrastructure and raw water availability. The demand depends on consumer lifestyles; land use; crops and cultivation routines; and infrastructural and industrial development and technology. It can be estimated by various techniques, often with a large uncertainty. Availability and demand of water are largely independent

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)

Effective rainfall: The part of the direct rainfall that can actually be used by the crop. For paddy rice, the effective rainfall equals the direct rainfall. For other crops, the effective rainfall is the direct rainfall minus surface runoff minus seepage to the underground (below the root zone)

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 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* 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)

FAO: United Nations Food and Agriculture Organization

Flood preparedness: Due awareness of the flood risk, and knowledge and ability of appropriate response. An appropriate flood preparedness is supported by measures such as awareness campaigns, education, and flood forecasting services, as well as flood proofing measures

Flood proofing (or flood protection): Preventive (structural and non-structural) measures to reduce the vulnerability to floods

Flood risk: The general probability that a location or an area will be flooded, expressed as a frequency of occurrence, or sometimes as the relation between inundation depth, duration, and frequency of occurrence. The flood risk can be influenced in many ways by human activities

Flood vulnerability: The value lost due to a given flood (depending on the population density, land use, and infrastructure in the area)

Flood-prone: With a high flood risk

Groundwater recharge: The replenishment of groundwater with surface water

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)

Infiltration: Loss of surface water by absorption and seepage into the ground. Infiltration capacity is the ability of the soil to absorb surface water. Deep infiltration is seepage from the root zone to the underlying soil layers, whereby the water becomes lost to the vegetation

Integrated Water Resources Management (IWRM) (as defined by Global Water Partnership): A process which promotes the co-ordinated development and management of water, land and related resources, in order to maximize the resultant economic and social welfare in an equitable manner without compromising the sustainability of vital ecosystems

Impact (of floods): Same as effects. These can be positive and negative; and can be actual effects (of an actual flood) or potential effects (of a given, hypothetical flood)

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

Irrigation: Deliberate supply (or retention) of water for cultivation, as a supplement to or replacement of direct rainfall. FAO makes a distinction between 5 possible sources of irrigation water: Surface water, renewable groundwater, fossil water, treated wastewater and desalinated water

Irrigation demand: The amount of water needed to be withdrawn from the raw water source to raise a crop (mm/crop or mm/month). Irrigation withdrawal demand = irrigation water 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

Overland flow: The flow of water on the ground from precipitation to streams located at lower elevations. Occurs when the infiltration capacity of an area has been exceeded

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

No-regrets solution (for climate adaptation): A solution that is robust to quantitative assumptions about the climate change;

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

Perennial: That takes place all year. A perennial river flows all year. Perennial crops grow (and need water) all year

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. Oryza sativa, (Asian rice), domesticated 10-15,000 years ago, is by far the prevalent cultivated species. It has thousands of varieties, covering a broad span of properties

Seepage: Slow movement of water in the ground, or from the ground to the surface

Scour: Erosion caused by turbulence; often seen on the downstream side of bridges, regulators and other structures that locally reduce the cross-section area and hereby increase the local flow velocity

SRI (System for Rice Intensification): This methodology was developed in Madagascar the early 1980s by a Jesuit priest, Father Henri de Laulanié. 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 involves management of rice plants; soil; water; nutrients; and weeds. Seedlings are transplanted very young; one by one (rather than 3-4 together); and widely spaced. A good soil quality is aimed at. Only a minimum of water is applied during the vegetative growth period; the fields are not flooded - so weeding becomes necessary. SRI has been implemented or tried in many countries, from case to case with positive, inconclusive or negative results

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

Water logging: Formation of a stagnant water volume in the root zone, impeding or preventing cultivation, caused by lack of drainage. Can for example occur in connection with impoundment for flood protection, road construction, and/or due to lack of maintenance of drainage systems

Water use: The part of the demand that is actually served at a given time. Many uses generate a return flow, (for example sewage, or irrigation tailwater). The return flow can occur at a different time or place than the withdrawal (for example a storage reservoir retaining water for release in a different part of the year). The use of water can be increased by infrastructural development and reduced by demand management

Transplanting : 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)

Weather: The conditions of the atmosphere at a given location: Temperature, precipitation, cloud cover, fog, sunlight, air pressure and wind. Compare with climate

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. Paddy (raw rice) is processed to brown rice by threshing and winnowing, losing 20-30 percent of the weight. Brown rice is milled to white (or milled) rice by milling, losing some 10 percent of the weight

Withdrawal demand: Same as irrigation demand

Yield (of rice): Production (in t/ha/crop or t/ha/year). 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

Yield gap: 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. Narrowing yield gaps not only increases rice yield and production, but also improves the efficiency of land and labour use, reduces production costs and increases sustainability

Appendix B: Cultivation practices in the pilot provinces

Source: CDC website, http://www.cambodiainvestment.gov.kh/preah-sihanouk-province.html

Preah Sihanouk Province

Area of province: 2,537 km2

Crop	Cultivated area	Yield	Production
Rice	14,115 ha	2.650 t/ha	37,211 t/year
Subsidiary and industrial crops	588 ha		3,432 t/year
- Maize	129 ha		200 t/year
- Cassava	105 ha		1,575 t/year
- Sweet Potato	15 ha		112 t/year
- Vegetables	295 ha		885 t/year
- Sugar Cane	44 ha		660 t/year
Fruit and permanent crops 1)	12,078 ha		
Total	26,781 ha		

1) banana; black pepper; cashew; coconut; custard apple; durian; guava; jackfruit; longan; mango; oil palm; pineapple; rambutan; and 8,902 palm trees

Koh Kong Province

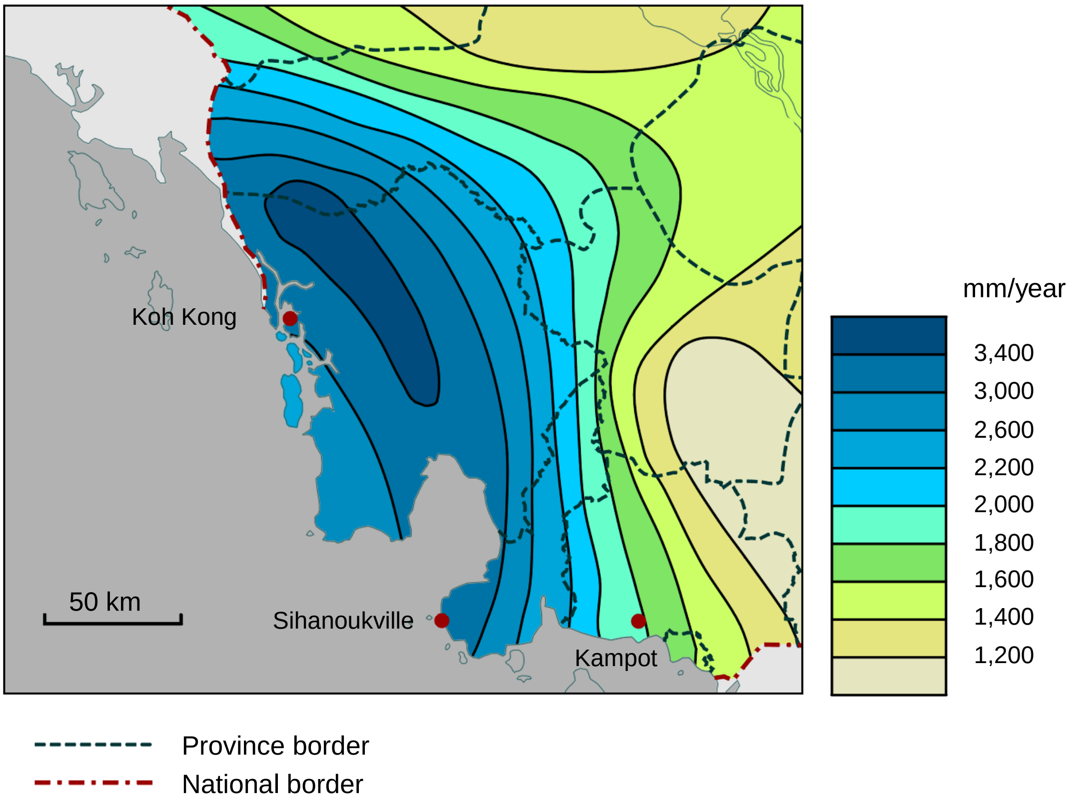
Area of province: 10,046 km2

Crop	Cultivated area	Yield	Production
Rice	9,057 ha	2.614 t/ha	23,679 t/year
Subsidiary and industrial crops	312 ha		2,939 t/year
- Maize	62 ha		311 t/year
- Cassava	50 ha		1,009 t/year
- Sweet Potato	19 ha		136 t/year
- Vegetables	143 ha		571 t/year
Fruit and permanent crops 2)	6,959 ha		
Total	16,328 ha		

2) banana; black pepper; cashew; coconut; coffee; custard apple; durian; guava; jackfruit; longan; mango; milk fruit; oil palm; orange; pineapple; rambutan; sapodilla; and 157,000 palm trees

Appendix C: Rainfall in the pilot provinces

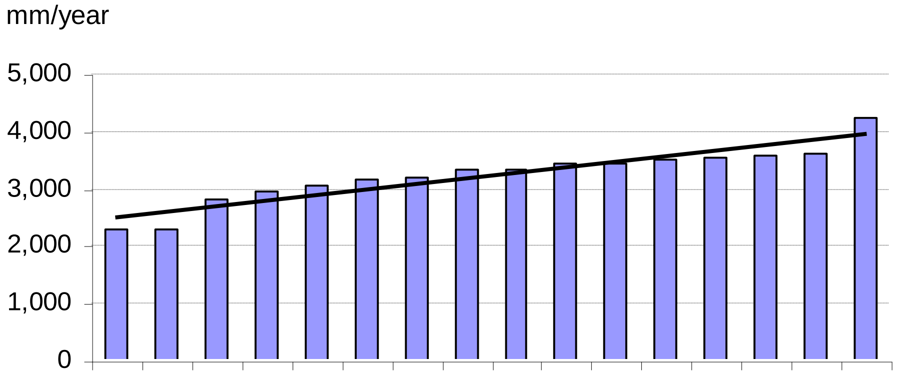
Area distribution



Data: 1981-2004, MOWRAM, Department of Meteorology

Annual rainfall

Figure 9: 16 years of annual rainfall in Sihanoukville, sorted by magnitude



Data: Kg Som 1984-99 (16 years)

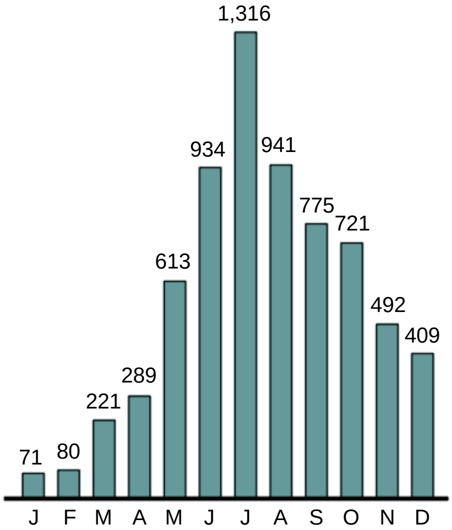
Table 2: Estimated annual rainfall at 3 locations

	Sihanoukville	Koh Kong	Kampot
Highest in 16 years	4,230 mm/year	3,970 mm/year	2,450 mm/year
Average over 16 years	3,240 mm/year	3,030 mm/year	1,870 mm/year
Lowest in 16 years	2,290 mm/year	2,150 mm/year	1,320 mm/year
Available every 2nd year	3,330 mm/year	3,130 mm/year	1,930 mm/year
Available 4 out of 5 years	2,940 mm/year	2,750 mm/year	1,700 mm/year
Available 9 out of 10 years	2,560 mm/year	2,400 mm/year	1,480 mm/year

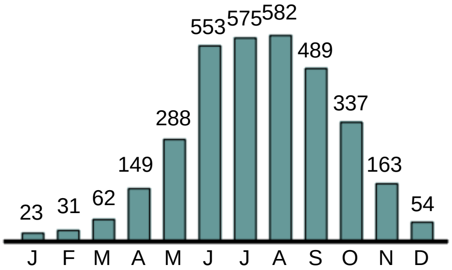
Note: *The rainfall varies significantly within each province, as illustrated on the map on the previous page*

Seasonal variation, Sihanoukville

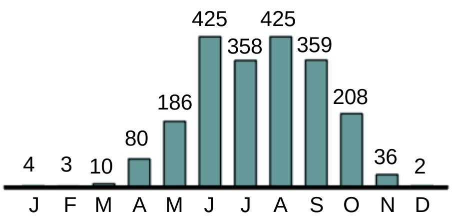
Highest in the period



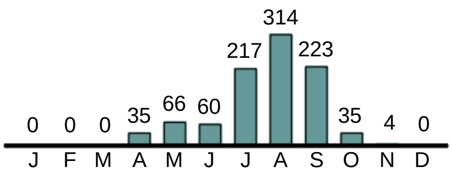
Average



4 out of 5 years



Lowest in the period



Data:

Station: Kampong Som, elevation: 13 m

19 years (1982-2000), coverage 93 percent

Average: 3,203 mm/year

Appendix D: Water management in the pilot provinces

Sources: CDC website, http://www.cambodiainvestment.gov.kh/preah-sihanouk-province.html
FAO website, http://www.fao.org/nr/water/aquastat/irrigationmap/khm/index.stm

Preah Sihanouk Province

Total irrigated area:	(Nil)
Irrigation drainage:	Total length: 132 km
Dam/dike	Total length: 90 km

Koh Kong Province

Total irrigated area:	600 ha
Dam:	98 places
Irrigation:	199 lines = 670,254m
Sub-irrigation:	85 lines = 402,666m

Kampot Province

Total irrigated area:	3,000 ha
Irrigation system:	46 places (2 big-size, 31 medium-size, 13 small-size)
Drainage:	3 lines
Water pump stations:	2 places

Appendix E: Climate screening and assessment

Examples of climate-related opportunities

- General improvement of livelihoods (and poverty reduction), improving the adaptive capacity and reducing the vulnerability to climate change

- Embankments and storage capacity reducing the flood exposure

Examples of climate-related risks

- Increased extreme rainfalls and stormwater runoff, amplified by interventions such as dykes, embankments (for flood protection, roads and other purposes), landfill operations, coastal land reclamation)
- Interventions that change (increase or reduce) the flow resistance of a river/watercourse section: Intersections, regulators, sand mining
- Land subsidence caused by drainage
- Developments in flood-prone areas: Flood risk affected by embankments and reclamation

Screening checklist

□ Are there any direct climate-related benefits?

□ Are there any potential climate-related opportunities (perhaps external to the direct purpose of the project)?

□ Are there any climate-related risks?

□ Are there any climate-related interactions with existing, parallel or planned development initiatives?

Unless *'no'* to all questions: Consider conducting a climate assessment. It can be minimal if the impacts are entirely positive.

Examples of responses

- Institutional capacity-building covering climate-related concerns and management options related to operation
- Additional storage capacity
- Additional stormwater drainage capacity, and improved operation and maintenance of drainage facilities, supported by public awareness
- Flood risk mapping
- Drought preparedness, including contingency planning
- Improved monitoring, providing data and information for operation

Appendix F: A look into the future

Good irrigation practices play an important role in the ongoing transition of Cambodia's economy, from agriculture to industries and services. Agriculture will remain a cornerstone, with more (and more valuable) food being produced by much less people. The urban migration will continue until only a few people live in the rural areas.

The following trends can be expected: [13]

- Efficient production systems will prosper. Less efficient ones will be replaced by imports (or will be left behind as subsistence economies). Cambodia is starting from behind in the respect as compared with Thailand and Viet Nam
- Yields will increase - both in terms of t/ha/crop and t/ha/year
- Meat (and vegetables) will become more prevalent in the diet (as compared with cereals)
- Large-scale systems and contract farming arrangements will provide most of the agricultural outputs - but room could remain for parallel small-scale independent operation, including niche production
- Farm gate prices will be further dependent on world market prices beyond the control of the country. There will be an enhanced need of balancing sustainable income for the farmers and affordable food for the urban population
- Agro-processing industries will grow, and so will branding of products
- Fertilizers and pesticides will be used much more - and hopefully better way - than today, but still causing additional pressure on the aquatic environment
- Cultivation will be expanded to marginal areas that may be less suited for cultivation (and irrigation). (Most suited areas are already cultivated today).
- Impacts of drought will remain potentially serious, due to cultivation over larger areas and over a larger part of the year

13 Please refer to Van Ngo (April 2010) and CARP (July 2012) for an elaboration