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Volume 1: Water Control and River Biographies

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6 Water Control and Agricultural Development: Crafting Deltaic Environments in South-east Asia

F. Molle and D.T. Tuân

Deltas are aquatic environments found at the interface between the final reaches of powerful rivers and the sea. They are formed by river sediment that is deposited at their mouths, which are partly eroded and washed away by tidal and wave actions (Catling, 1992). These areas, despite the possibility of soil problems (salinity, acidity), are lowland environments suitable for rice cultivation. Depending on the natural water regime, which is often modified or controlled by huge land development schemes, different techniques and rice types have been adopted.

What most Asian deltas have in common is a contrasting water regime, with two distinct seasons. Simply, it can be said that for half of the year water tends to flow into the delta in excess, causing drainage or flooding problems on lower lands; during the second half flows are much reduced and often cannot meet growing requirements. Being terminal parts of river systems, deltas are also very sensitive to changes taking place upstream in the basin, in particular to the development of dams or large-scale schemes that may divert part of the river during the dry season. Lastly, they all include a transition zone along the sea, where saline intrusion will often give way to mangrove or other brackish water environments.

Because of the natural unhealthiness of these areas, which are marshy, disease-prone and infested with mosquitoes, and because of the potential destructive power of floods, south-east Asian deltas have, with the exception of the Red River Delta, been colonized on a large scale only recently (despite the evidence of earlier but somewhat limited settlements). While the Chao Phraya Delta was home to 1.2 million hectares (ha) of rice in 1990, the rice area was only 650,000 ha in 1900 and 300,000 ha in 1860.[1] Similarly, whereas paddy land in the Mekong Delta amounted to 2.5 million ha in the 1990s, Cochinchina as a whole had only 200,000 ha of rice land (4 per cent of its total area) in 1868 (Henry, 1932). In the Red River Delta, too, despite its ancient settlement history, many land development and technical changes have occurred in the last 150 years, and especially in the last four decades: in 1945, the area served by pumping irrigation in the delta amounted to only 377,000 ha, or 34 per cent of the area of rice fields of the delta (Dao Thê Tuân and Molle, 2000).[2]

Therefore the development of the deltas has corresponded to an often recent, continuous and colossal effort by humankind, committed to transforming and shaping the environment. In the Chao Phraya Delta, for example, 27,000 kilometres of canals and waterways of all sizes have been excavated or dredged. In the Pearl River Delta, South China, most of the land had to be reclaimed from the sea through the endless process of poldering and earth filling (Kaida, 2003). In the Red River Delta, millions of peasants have been contributing to the erection of huge embankments for flood protection, amounting by now to 9,700 kilometres of river and sea (primary) dykes (Cuc and Rambo, 1993).

This chapter attempts to identify the commonalities of the Chao Phraya (CP), Mekong (MK) and Red River (RR) Deltas, together with their distinctive features, and to show how the response of man has been shaped by environmental constraints and by the human and historical context in which responses have been analysed and implemented. Giving a full picture of the development over time of all the different ecological sub-regions of each delta is a task much beyond the size and the scope of this chapter. Our comparison will be limited to emphasizing the different technical paths followed by each delta in four main types of environments and will be complemented by a more detailed and localized example from the MK Delta. The last section offers some consideration on how human and historical factors have also partly dictated these development paths.

HYDROLOGY

The three deltas first differ by their rainfall patterns, although they all have contrasting seasons: Figure 6.1 shows that the December–April period is invariably dry. Maximum monthly rainfall amounts are also comparable (250–300 mm), but the main difference appears during the first part of the rainy season. It is possible that rainfall in the CP Delta used to follow a bimodal pattern but the first 'hump' has been eroded and precipitation from

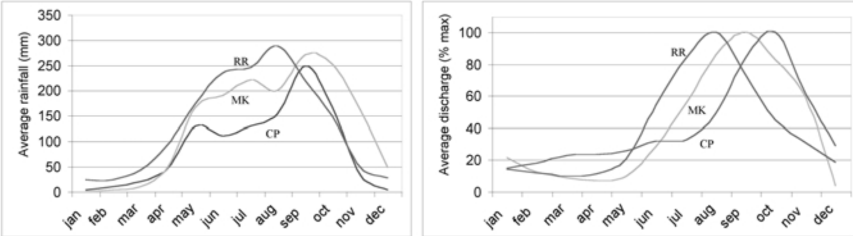


Figure 6.1. Monthly Average Rainfall and Discharges (Three Deltas)

June to August is much lower than in the Vietnamese deltas. This has considerable implications for growing a rainfed crop before the floods occur. In the RR, pre-monsoon crops also benefit from a lower evapotranspiration rate during at least three months, which reduces the amount of water that must be brought in via irrigation.

First, deltas are characterized by the hydrological profile of the river that creates them. Table 6.1 provides a few basic parameters for five Asian river delta systems and emphasizes dramatic contrasts in terms of length, basin area and discharges. The Chao Phraya River and the Red River have comparable length and basin area but the average discharge of the latter is four times higher than that of the former; peak discharges also differ by a factor of 2.5. These discrepancies are attributable to differences in run-off (due to different slopes, land cover and rainfall patterns in the basin).

The MK and Irrawaddy Deltas also tend to have comparable features, while the Ganges–Brahmaputra Delta distinguishes itself by the magnitude of its basin and corresponding discharges, notably peak ones, around September to October.

Table 6.1. Features of Rivers (Main Deltas)

River	Length (km)	Basin area (1,000 km²)	Discharge at mouth		Suspended load (t/km)
			Average (1,000 m³/s)	Maximum (1,000 m³/s)	
Chao Phraya (CP)	990	160	1	4	130
Red River (RR)	1,200	120	4	10	1,310
Mekong (MK)	4,180	795	14	52	530
Irrawaddy (IR)	2,090	430	14	33	1,000
Ganges–Brahmaputra (GB)	2,510	1,730	38	160	1,635

Source: Catling (1992).

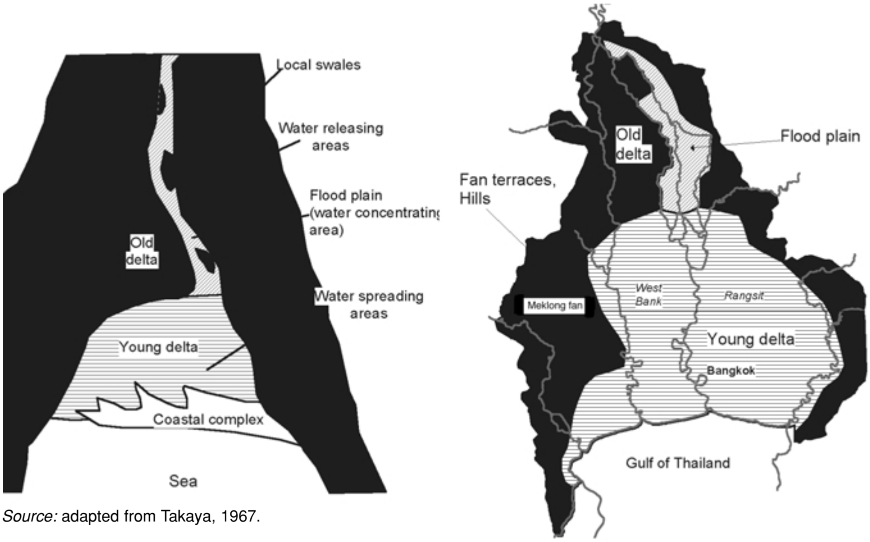
The hydrological regime of the rivers is illustrated in Figure 6.1 which gives their monthly average discharges in the percentage of the maximum value.[3] The pattern observed is by and large the same for all three rivers (except that the peak discharge periods differ by one month), with the important difference that the Chao Phraya River is now regulated by two main storage dams (and therefore benefits from some degree of flood reduction and increased supplies during the dry season), while the Mekong and the Red River are still largely unregulated[4] (natural flow) and their might does not allow the construction of diversion structures.

LANDFORM[5]

A generic physiographic model of a delta is illustrated in Figure 6.2. For the sake of simplification, three types of area can be distinguished:

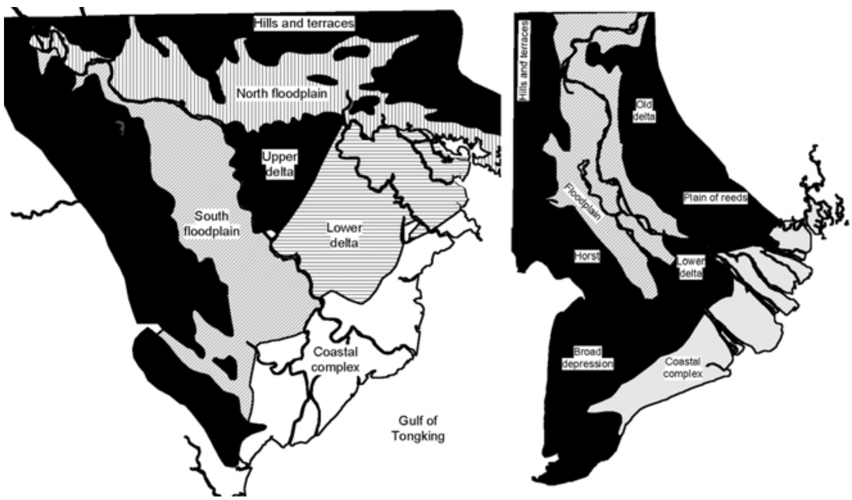
- The higher parts can be considered as *flood releasing areas*, as they are drained quickly and release water to the centre of the deltas: they comprise adjacent terraces and hills, but also may include most of the *old delta* which, with its higher elevation, will also release water, although lower lands along the drainage systems may remain flooded.
- The floodplain itself is a *flood-concentrating area*, with water levels rising quickly in case of floods and water depths reaching several metres. This floodplain, however, presents an alternation of depressions (backswamps) and levees along main water streams. The latter are high lands, where human settlements concentrate because of better protection from floods.
- Further downstream, the young delta also receives water but the flow is spread over a larger flat area; the risk of a prolonged flood is low. It could be termed a *water-spreading area*. At its extremity, a coastal area can be found, with ridges and swales, and salinity problems.

This generic model will, of course, take different shapes according to the delta under consideration. In the CP and MK Deltas, the floodplain borders the old delta on one side, while in the RR Delta it developed on both sides (contrariwise, in the Ganges–Bhramaputra Delta the river severed the old delta in two parts).



Source: adapted from Takaya, 1967.

Figure 6.2. Generic Physiographic Model of a Delta and Landform in the CP Delta



Source: adapted from Takaya, 1967.

Figure 6.3. Landform in the RR and MK Deltas.

'ARTIFICIALIZATION' OF THE ENVIRONMENT

Deltaic environments are not immediately favourable for human settlement and the cultivation of rice or other crops. Coastal areas are affected by both saline soils and salinity intrusion at high tide, especially in the dry season. Floodplains naturally receive too much water in the rainy season, with high and fluctuating flood depths, while in the dry season they are both water deficient and strewn with water that is pounded in depressions. Adjacent terraces and hills, together with older formations of sediments (*old delta*), often near the apex of the delta, are water deficient outside the rainy season. The flat coastal areas (*young deltas* or *delta flats*) are less subject to flooding but water is generally available from a dense network of natural and excavated channels, from which it can be pumped if the higher water levels obtained at high tide do not allow inflow by gravity. We will review here how agriculture has adapted initially to these constrained environments, and how gradually they have been tamed and transformed into rice cropping systems that exhibit great adaptability.

Floodplains

Different adaptive and land development strategies have been implemented in the deltas to deal with flooding regimes (Figure 6.4). The floodplain was the first area of the CP Delta to be cropped with rice on a large scale. During the Ayutthaya period (fifteenth to eighteenth centuries), settlements were scarce and only located on the levees of the rivers. Floating rice was (and still partly is) cultivated in the depressions. Sown with the first rains, the rice would germinate and grow high enough to both withstand the first floods and be able to elongate further in accordance with the water level. The system was very labour extensive (sowing, ploughing) and its fertility was renewed by silt deposits each year. Uncertainty, however, was attached to the date of the first submersion (hence the constraints on the date of sowing), to the maximum height attained by the water, and to the duration of the submersion (water often receding too early). A similar situation was found in the depressions of the *old delta*. A field crop grown with the residual field wetness was sometimes associated with floating rice.

These areas were gradually brought under control. As flooding mostly occurred because of water overflowing the river banks and penetrating inland back through the drainage system, dykes were constructed along the main arms of the Chao Phraya River system. This prevented high waters in the rivers from backing up inland, but the areas protected by the dykes remained partly flooded because the accumulated volume of rainwater could not be drained. Therefore it was decided to stabilize the rise of the water level in these drainage units, in order to reduce the uncertainty of the hydrologic regime needed by the deep-water and floating rice varieties (Molle et al., 1999). This was made possible during the late 1970s and 1980s, only after a network of irrigation canals allowed an adequate amount of water to be supplied to these areas.

In the MK Delta, the floodplain is very long (starting north of Phnom Penh in Cambodia). The water can be extremely deep (five metres) in the Cambodian location but is shallower in the Vietnamese section, where the rise of water is also much more regular and without excess rapidity. This floodplain was also cultivated with floating rice from the beginning of the twentieth century (Brocheux, 1995), with techniques similar to those used in Thailand. A field crop was in general associated with floating rice and grown after its harvest (typically, watermelon or groundnut). However, this system was not established at the very beginning. Earlier settlers, during the nineteenth century, first planted a pre-monsoon rainfed rice crop in the upper parts of the toposequence and only later reclaimed lower lands, shifting to floating rice (Huyn and Vandome, 1993).

In the early 1970s, while floating rice was covering more than 500,000 ha, this rice system rapidly gave way to double cropping of High Yield Varieties (HYVs), the first being grown before the flood and the second after. In the lower parts, to the west, this change was contingent upon further land development work and was slower (floating rice disappeared totally only in 1999). This flood-avoidance strategy was allowed by the advent of short duration non-photosensitive varieties and required the development of a pumping capacity. Pumping can be collective (public/cooperative, or through entrepreneurs), or, more rarely, individual. Public-initiated collective projects are generally found near the main rivers, where settlements are older and the presence of the government is stronger. Entrepreneurs with mobile pumping units (on boats) widely prevail.

In the RR Delta, lowlands cropped with deep-water rice during the rainy season have always been marginal, although poorly drained areas initially amounted to a significant size. In the western floodplain, the flood was too strong and unpredictable for such cultivation (even for floating rice), especially because of typhoons; also post-monsoon 'fifth-month rice' (winter–spring rice) was grown preferably,[6] with one-fourth of the area also growing a wet season rice crop (Gourou, 1936; Doan, 1993). With the investments in pumps made during the 1960s, some lowlands could be drained and wet season rice increased. Further investments at the local levels during the 1968–85 period first boosted spring rice, then wet season rice. Similar to the gravity canal constructed on the levees of the Chao Phraya floodplain, the Nhe River receives water near Hanoi and allows some irrigation by gravity (Doan, 1993). Nowadays, plot production varies between two and three crops (rice and field crops). Even in the Nam Ha 1 polder, which is located at the lowest extremity of the delta and is affected by floods, investments in irrigation and drainage have allowed a shift from one post-monsoon rice crop to double or triple cropping in most areas (Yanagisawa et al., 1997).

Figure 6.4 summarizes these different options, ranging from adaptive strategies partly allowed by dyking (MK), to the regulation of the flood (CP) through dyking and irrigation canals, and to full flood protection (RR), with huge pumps designed to limit any accumulation of water in the lower parts. The first strategies were adaptive and were later substituted by options allowed by technological development. Figure 6.5 provides a synthesis of the resulting cropping patterns. The adaptive strategies include: (1) using the flood (floating rice in MK and CP, sometimes associated with a field crop); (2) avoiding the flood by growing a crop before (MK, because of favourable rainfall pattern not found in CP); (3) avoiding the flood by growing a crop afterwards (this was done in RR and in the Irrawaddy and the Ganges–Bhramaputra Delta (Boro rice), in slowly receding waters, with additional irrigation).

Dyking, dam control, the development of a pumping capacity and the advent of HYVs have allowed the intensification of agriculture in floodplains. An initial and common flood-avoiding strategy is to grow both pre-monsoon and post-monsoon HYVs, which requires more irrigation supply in the CP Delta than in the MK (rainfall) and RR deltas (rainfall + low evapotranspiration). When poldering is sufficient, or in years of mild flood, three crops can be grown (either three rice crops or rice + rice + field crop). This qualitative typology of strategies also applies by and large to the lower parts of the delta flat, although the flood is of lesser depth and duration, and dyking is easier.[7]

Delta Flats

The *young delta* (CP Delta) remained inhospitable for a long time. Except for some levees along the rivers, its reclamation started only at the end of the nineteenth century. With the progressive digging of canals, allowing transportation, homesteads to be built and better water conditions for rice cultivation, it was planted (either by dry broadcasting or transplanting) with one crop of rice during the rainy season. Because of the reduced amplitude of the tide in the Gulf of

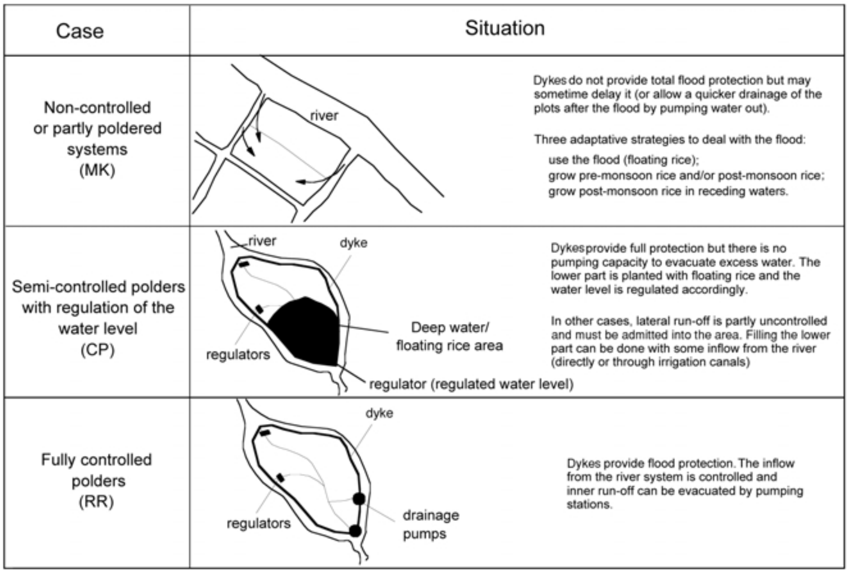


Figure 6.4. Schematic Situations of Water Control in Deltaic Floodplains

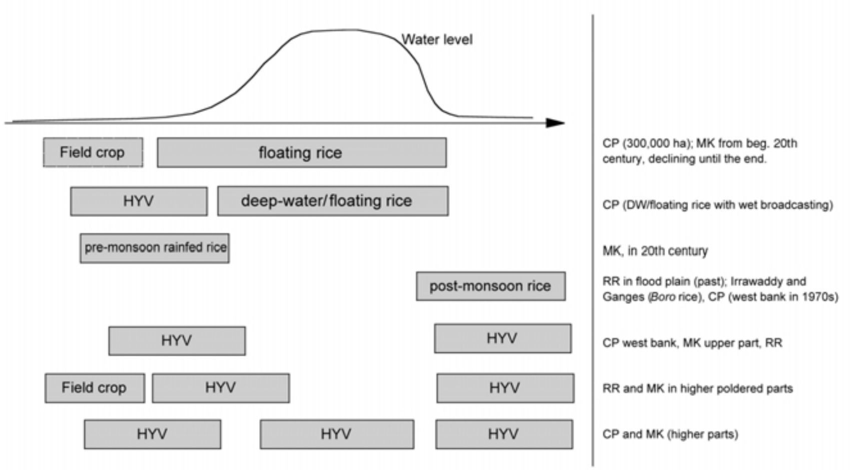


Figure 6.5. Types of Adaptive Strategies and Cropping Patterns in Deltaic Floodplains (and other lowlands)

Thailand, transplanting generally needed some form of water-lifting device (scoops, Chinese bucket-chains (*dragon bone pumps*) powered by windmills, motor pumps after the Second World War, etc.). Without pumps and proper structures to regulate water, this area was considered less favourable than the floodplain.

Improvements in water supply, dyking, drainage and pumping have allowed this area to shift to double cropping and triple cropping of HYVs. Water availability is the main constraint and water is now supplied all year long by the irrigation facilities located upstream of the area. However, as the western part (West Bank) has been turned into a buffer area to protect Bangkok in case of severe flooding, it still uses a different calendar: one crop being grown before the flood (harvested before October) and the second one afterwards (at a date depending on when the water recedes). With some poldering, higher plots can ignore the risk of flood and grow three crops. Water control and individual pumping capacity have given farmers a high flexibility in calendar and cropping intensity. The tidal effect is low or negligible, in part because of the closure of the delta.

In contrast, the tidal effect in the MK Delta is strong and can be felt up to the Cambodian border. This allows the *recent delta* to benefit from both high and low water levels, which enables both gravity and drainage by gravity in most instances. Pumping will help to drain lower lands (if they are dyked) and irrigate upper areas. In the rainy season, however, the tidal amplitude is reduced and drainage can be problematic. Nevertheless, this area was formerly double-transplanted[8] with a single crop. With the advent of HYVs, its area quickly shifted to double rice cropping. The notable development of *raised bed orchards* must also be emphasized. As in the CP Delta, delta flats are suitable environments to develop orchards, as plots may be protected from flood risk with some poldering and because water is generally available all year long. (This situation is described in more detail in the section 'Adaptiveness and changes at the micro-level' below.)

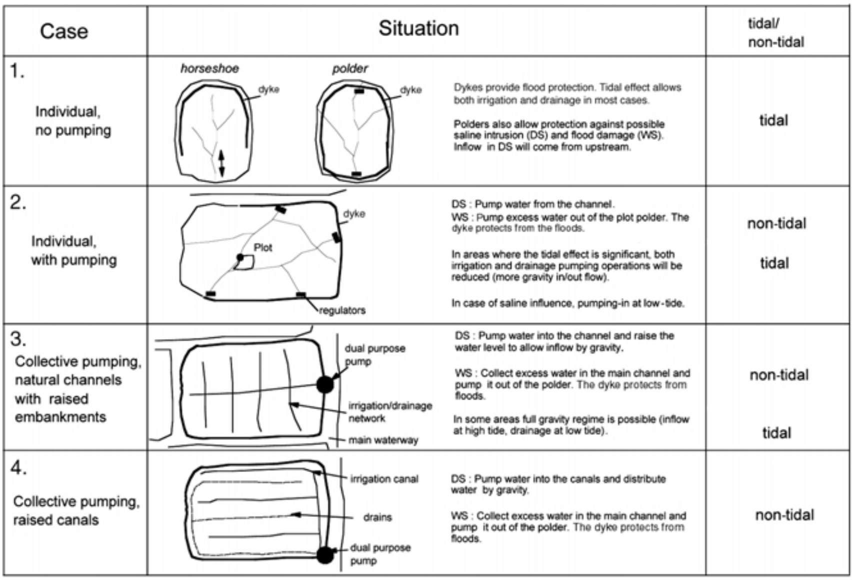
In the RR Delta, the lower delta, once cropped with one transplanted tenth-month rice crop, was already double cropped in the 1930s, thanks to irrigation infrastructures developed by farmers and to poldering (Takaya, 1975). It presents, nowadays, intensive double or triple crop systems, as most of the lowlands are equipped with pumping stations in order to drain excess water. Raised irrigation canals are supplied by pumping outside the rainy season, allowing year-round cultivation in most parts.

One can wonder why individual pumping did not develop in the RR Delta, especially in the coastal polders where the pumping head is low. This is probably due to a series of factors, including the very small size of plots and their scattered nature (making pumping difficult and not profitable); the insufficient density of waterways to access water individually (digging more ditches would also reduce arable land); the collectivist ideology (favouring collective solutions); the possibility to use scooping (very small plots and abundant labour); and the lack of capital for buying pump sets (or the lack of motors used to power boats, as in the MK, and of two-wheel tractors, as in CP).

All these situations are tentatively summarized in Figure 6.6. Case 1 includes protective dyking and basic regulation by check gates. Horseshoe islands can be found in the middle of the Irrawaddy Delta (the upper part is protected from the floods, and the tidal effect allows irrigation and drainage by gravity), while closed dykes (polders) are common in islands under tidal effects (MK and RR). The dyke provides protection against flooding and regulators allow the inflow of freshwater at the upstream extremity, while controlling saline intrusion in the dry season at the downstream extremity. The tidal effect allows management by gravity for most of the year (or all year round; parts of RR coastal polders).

Case 2 is the most common in delta flats. The area is partly or totally protected from tidal effects and from saline influence; freshwater comes from upstream areas, or laterally from the rivers, and fills up a dense network of channels (some natural, some excavated). However, farmers must pump to fill up their plots in the dry season, and sometimes to drain them in the rainy season. This is done individually, most commonly using low-lift axial flow pumps (CP) or shrimp-tail pumps (MK). In some instances, near the river, the tidal effect may still be significant and the frequency of pump use will decrease accordingly.

Case 3 and Case 4 are alternatives, sometimes implemented in areas without tidal effects: instead of relying on individual pumping, these areas use collective pumping stations and medium-scale polders. In Case 3, (excavated or natural) waterways within a given area provided with a dyke (polder) have their embankments raised in order to allow a higher water head and gravity inflow into the plots. Channels are filled by a collective pumping station. Conversely, in case of heavy rainfall, excess water is collected by the waterways, the levels of which are kept low by pumping water out of the polder (the pump is dual purpose). In Case 4, the principle is similar to that of Case 3 but irrigation is done through a special and independent distribution network of classical raised irrigation canals. The natural waterways are used as a drainage system. A dual purpose pumping station can both supply the irrigation canals with



Note: DS = dry season; WS = wet season.

Figure 6.6. Typology of Main Situations Found in Delta Flats

water from the waterway outside the polder and pump water of the inner drainage system out of the polder. This option uses more land but topography and the characteristics of natural waterways may make it more practical.

The rationale for these two technical options is obviously to allow economies of scale. One pumping station for, say, 100 farmers is much cheaper than 100 individual pumps, and so are the consumption costs. On the other hand, it requires farmers to plant at the same time and this rigidity in cropping calendars is an important constraint. Such an option can be driven by political/ideological reasons but is not observed as an endogenous choice. The fact that service group pumping (by private operators) is common in the north of the MK Delta (Lienhard et al., 2001) but very rare in the south is tentatively attributed to two factors. In the south many more farmers have boats and can therefore use shrimp-tail pumps, and the flat network of canals is more ramified down to the plot level, allowing individual access to water. In contrast, higher polder dykes and limited tertiary canals do not easily allow individual pumping in the floodplain. Collective pumping is the rule in the RR Delta, even though large state-run schemes have given way to an upsurge of local pumping stations (Case 4 in the middle delta, Case 3 in parts of the coastal polders). In the southern deltas examples are limited and include some co-operatives in Bac Lieu Province on the MK delta (Case 3), the Bang Bal Project and the Land Reform area of the West Bank in the CP Delta (Case 4).

Coastal areas

Coastal areas under marine influence are home to mangroves. They have often been turned into salt pans or zones for aquaculture production. Further inland, strongly saline soils were generally used to grow one crop of rice and transplanted after the superficial layer was washed away by the first heavy rainfall of the season. This was the case in the CP Delta (Takaya, 1978) and also in the MK Delta.[9] Depending on the intensity of the salinity constraint and the rainfall pattern, two crops could be grown in some places (Xuan, 1974). In the MK Delta, more recently, shrimp farming also developed in these areas. In the RR Delta, sedimentation and the hydrological regime of the river have limited the coastal brackish environment to a thin strip of land.

Dramatic improvements in agriculture can be introduced if these areas are protected from seawater intrusion. This closure of the different channels linking the land and the sea (and also those which communicate, laterally, with the lower reaches of the main rivers) allows freshwater coming from upstream to be trapped in the network of canals. After closure, the coastal areas are supplied with freshwater (thus extending the so-called *conservation area* of the *young delta*) and, except for possible soil problems, their regime tends to be similar to those described above for the delta flats.[10]

In the CP Delta, the eastern coastal part was closed in the 1930s, while the western part was closed only in the 1970s. The closure allowed the spread of rice double-cropping and the development of orchards on raised beds. In the MK Delta, the closure is being completed and will dramatically alter agricultural and water-use patterns, notably in the Ca Mau Peninsula (Joffre et al., 2001). With the closure, however, the benefit of the tidal effect may be largely lost (depending on the degree of closure).[11] Farmers who have developed brackish water shrimp farming may also be prejudiced and examples from the CP and MK Deltas show that the economic trade-off is often in favour of shrimp farming. In the RR Delta, coastal areas have also been poldered: Nguyen Cong Tru encouraged the colonization of the coastal area in the nineteenth century by constructing watergates to control seawater intrusion and to allow drainage, and by channelling some freshwater to these areas. This part of the delta was the easiest one to develop, as the tidal effect allowed the 'capture' of water at high tide in the network of canals and to irrigate directly by gravity (sometimes with some scooping). During the French period, the system was completed in order to allow more freshwater to reach the area (Chassigneux, 1912), and later equipped with pumping stations to allow year-round irrigation of the upper lands.

There are various degrees of closure. Full closure may not be the best option. If some waterways, especially those which allow lateral flows from and to the rivers, remain open, there will be an overall loss of water to the sea (in the dry season) and an average decline in water levels in the network. On the other hand, a few benefits will accrue:

(1) Areas near the river may benefit from the tidal effect and pumping costs will be decreased significantly.
(2) Transportation by boat will be eased.
(3) Polluted water will be diluted (in the CP Delta, this constraint means that some regulators are left partly open in order to mitigate pollution and to allow some constant flushing out).
(4) Even for waterways that bring salinity inland, this effect may be desirable if shrimp farms are using brackish water.

Lastly, the problem of salinity intrusion into the main river estuaries must be mentioned. This problem is now well under control in the CP and RR Deltas, thanks to the control allowed by the dams in the upper part of the basin; but it still looms as the most serious threat in the MK Delta, where both the inflow into the delta and water abstraction within it are on the rise during the dry season (see Can Tho University and IRD, 2001).

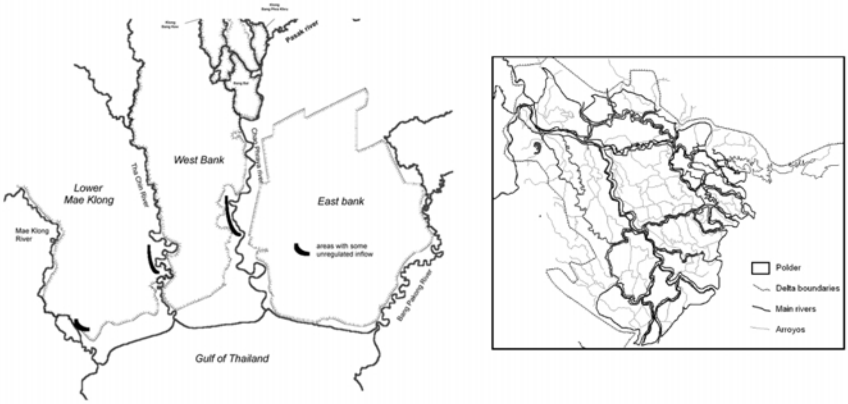


Figure 6.7. Closure of Coastal Areas in the CP and RR Deltas (all polders shown)

Old deltas/terraces

Old deltas, as in the upper CP Delta, or the upper part of the Bac Hung Hai polder in the RR Delta, present undulating relief with an alternation of highlands and lowlands along the drainage system. Proper irrigation (especially in the dry season) can only be achieved by networks of raised canals constructed in the upper parts. In the CP Delta, it is possible to supply such canals by gravity-diverted water from the Chao Phraya River at the apex of the delta. In Bac Hung Hai and other (non-coastal) polders of the RR Delta, gravity supply is usually impossible, and canals must be supplied by pumping stations. Interestingly, the possibility to divert water from the Red River to a network of gravity canals, similar to what was achieved in the late 1950s in the CP Delta, had been envisaged and proposed in 1898 by Godard, a French engineer. However, it was later realized that this was based on a misunderstanding of the local conditions, in particular of the flood regime of the Red River, which is incompatible with diversion works, and the irregular topography of the land (Chassigneux, 1912).

In the rainy season (CP Delta), drainage water flows either to low-lying areas planted with floating rice (similar to the drainage units of the floodplain mentioned earlier) or to a conventional drainage system by gravity. In the RR Delta, land poldering has isolated the land and worsened the evacuation of water. As water accumulation must nevertheless be avoided (no floating rice), the timely drainage of the lowlands involves much local pumping from the plots up to higher channels (resulting in an overload of the canals, commanding higher outflow towards downstream areas in the polder), and the final evacuation out of the polder by gravity or pumping.

In the CP Delta, the same diversion dam also supplies canals that allow the irrigation of lateral terraces, on the margin of the delta. In the Red River, such diversions exist on the lateral tributaries of the Red River and Thai Binh River (defining autonomous irrigated schemes at the margin of the delta). The first such large-scale project was successfully implemented by the French in the Plain of Kep at the beginning of the twentieth century and was followed by other projects.

ADAPTIVENESS AND CHANGES AT THE MICRO-LEVEL

The above discussion only refers to some of the main changes that occurred at the macro-level of the ecological zoning. If we look at a smaller scale, we often encounter a much more complex reality, in which micro-topography and differentiated constraints on farming systems define a much more variegated landscape. This takes us far beyond the scope of this chapter but an example is given for the sake of illustration.

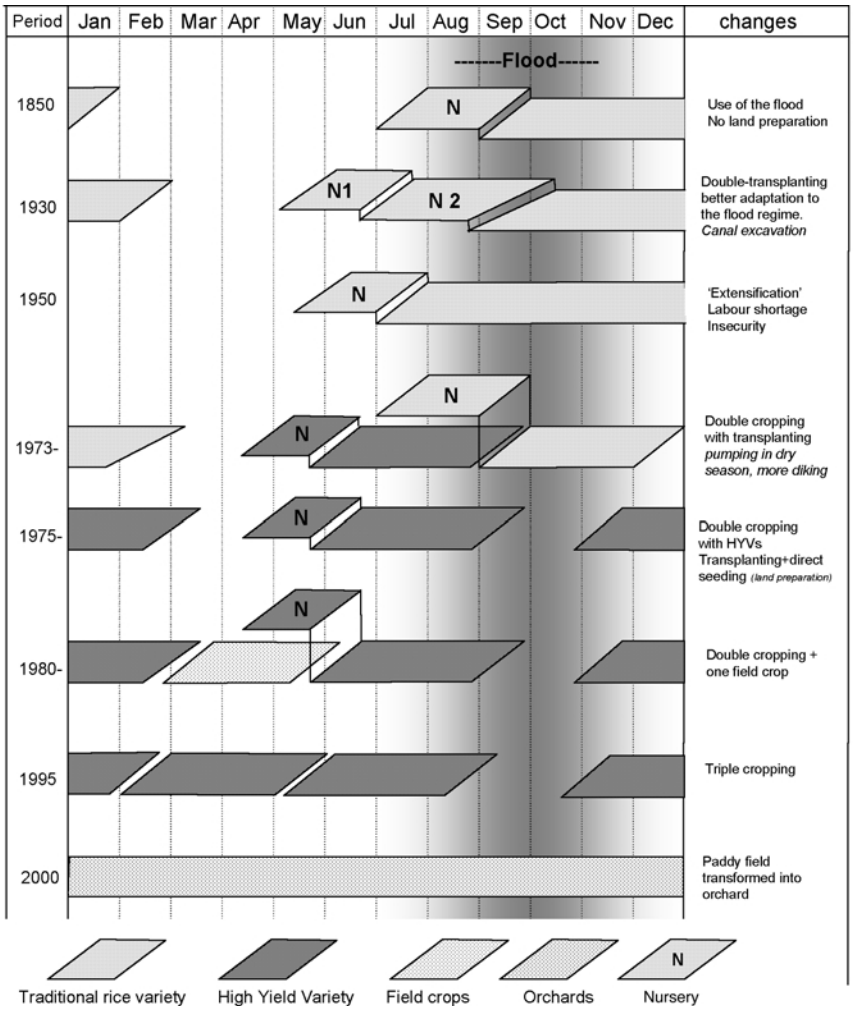
The Province of Can Tho is located in the centre of the MK Delta and enjoys an intermediate location between northern areas, affected by severe floods, and the coastal area, subjected to saline influence. In addition, the tidal effect provokes a daily fluctuation of the water level in the canals and allows a large part of the plots to benefit from both irrigation and drainage by gravity. Three ecological strata commonly are considered: the river levees, where most older settlements are confined, the backswamps, subject to limited flooding (0.4–1 m, for approximately two months), and the more remote, inland broad depressions where the flood is more prolonged and soils are often acid. If we consider the moderately flooded backswamps and how they have been transformed and exploited in the last 150 years we get a fascinating picture of both the adaptiveness and the innovation of humankind in the delta;[12] for example, some of the plots are likely to have undergone, successively all of the changes described below.

Around 1850, the land was reclaimed by slash and burn, and rice was sown by dibbling. After a few years, fields were transplanted (with a stick) and crudely bunded, but land preparation was limited to grass-cutting and burning. Around 1930, the excavation of main canals allowed the lower parts of the backswamps (as well as the depressions) to be brought under cultivation with a new technique: double transplanting, where plants from a first nursery are retransplanted in a second nursery, where they can grow up to 70 cm before being transplanted in the fields with some flexibility, when the water conditions are suitable. No land preparation was done in general. Yields averaged 2 t/ha. Farmers also created temporary dams in the natural waterways in order to retain the floodwater in the fields.

In 1950, because of the dislocations due to the war and the insecurity in the countryside, the availability of draught animals and human labour decreased and so did the yields. Double transplanting often gave way to a more extensive type of cultivation where floating rice varieties were transplanted and sometimes, if the means for land preparation were available, sown directly. Consequently, productivity decreased.

In the early 1970s, the HYVs of the green revolution and the development of mechanization triggered the intensification of rice cultivation. Double cropping in the backswamps was achieved by accommodating an HYV in the early part of the rainy season and later transplanting a traditional deep-water variety (in September).

This required some degree of irrigation (as part of the cycle was in the dry season), which was ensured by expanding the network of secondary canals and ditches and using either the tidal effect or individual pumps (depending on the plot elevation). With this process in operation during the 1970s, the traditional winter rice



Source: Adapted from Le Coq, 2001.

Figure 6.8. A Sequence of Land Use Transformations in the MK Delta (CAn Tho Province)

crop was soon replaced by a second HYV, which was sown after the receding of water (sometimes accelerated by pumping water out of a bunded plot). In 1975, some farmers began to intercalate a field crop between the two rice crops. Good access to canal water was needed and irrigation was often manual.

In the 1990s, triple cropping of HYVs became common in the delta. It was allowed by using short duration varieties, mechanization, pumping and direct seeding (usually one of the crops was also established with zero-tillage).

This sequence of transformation took us from the middle of the nineteenth century, with a precarious rice crop yielding 1.7 t/ha, to a current system of triple cropping yielding 14 t/ha/yr! Several agents of change appear in this short description. The 'artificialization' of the landscape included the State-initiated excavation of primary and secondary canals, in particular by the French colonial state during the first two decades of the twentieth century (Brocheux, 1995), and during the 1970s, and by the provision of watergates (to retain freshwater). It also included the constant improvement of the tertiary network (in order to extend the benefit of water further inland) and of the plots (levelling, dyking), mostly done by local farmers. Mechanization has also been of paramount importance, not only to improve and accelerate land preparation, but also with regard to pumping devices. Individual pumps, in general shrimp-tail pumps, constructed by using the propeller and the motor of a boat, have allowed earlier drainage of the plots after the flood, irrigation in the dry season, drainage of orchards in case of heavy rainfall, etc. Pumps have been the necessary complement of the investments in canals and dyking. Lastly, innovations in biological material and cropping techniques, notably short-duration non-photosensitive HYVs and direct seeding, have allowed farmers to adapt to the water regime with increasing flexibility.

RICE, WATER AND HUMANKIND IN DIFFERENT ECOLOGICAL AND HUMAN SETTINGS

Ishii (1978) attempted to describe agricultural development in the CP Delta by distinguishing between 'technological' and 'agronomic' adaptations. This useful dichotomy, however, brought some confusion as the term technological was not clearly defined. This prompted Tanaka (1991) to coin the notions of environment-adaptive and environment-formative adaptations. Humankind is perceived both to adapt to the environment (using floating rice varieties in the floodplain, farming shrimps in brackish environments, etc.) and to 'artificialize' or reshape it (by dyking, damming, levelling, etc.). It appears that both aspects are often interrelated (HYVs were introduced in suitable locations and induced further transformation in land and water control to allow its spread).

This conceptualization sees agricultural development both constrained by physical factors and facilitated by their alteration by man. From the typologies described earlier it is already apparent that each delta has a few peculiarities that have made some alternatives both feasible and desirable, while others have had to be discarded. However, this does not allow a more holistic understanding of how culture, social structures, organizations, institutions (with its wider meaning) and ideologies come into play in this process, neither how they are shaped by it in return. Although a wider approach based on cultural ecology (see Wood, 1977; Netting, 1977; Cleveland, 1998) lies far beyond the scope of this chapter, a few elements deserve to be brought into the debate for a better understanding of our discussion.

The RR and MK Deltas are well known for their differences in social structure. Although reclaimed by migrants from the north or from China, the MK Delta borrows several traits from frontier societies and shares them with the CP Delta. The corporate clustered villages of the north are characterized by their well-defined boundaries, Confucian culture bestows a history of common struggle against calamities, banditry and foreign invasions and a certain degree of autonomy in village affairs under the control of a council of *notables*. Cottage industries were controlled by trade guilds. The system of communal land was conserved and even protected by the state. The land was distributed regularly to eligible villagers, and religious activity in general served to limit the accumulation of capital. There were limitations for outsiders to become members of the community.

In contrast, the two southern deltas were reclaimed by individuals of different geographical origins, who most often established linear settlements along the canals and river levees. Dispersion was accentuated by the high degree of defections of *ta dien*[13] in the MK Delta and tenants from the East Bank in the CP Delta, who fled from debts and exploitation by moving further inland. In the case of the MK Delta, this was accentuated by the dislocation of war (forced population regrouping, exodus from insecurity). In addition, much of the land reclamation was done individually, by clearing land and testing its hydrological regime through a process of trial and error, and further developing local dykes and canals. The state only provided the main and secondary canals, at least until the Second World War. Reflecting on the controversial loose-structure characteristic of the Thai society, Kemp (1992) interprets processes in central Thailand as being ‘not the result of personal idiosyncrasies but the consequence of a far wider set of social responses to a range of economic, demographic and political factors’. Rather than a deviance from a hypothetical and normative traditional, primordial, communal and rather timeless peasant society, the CP Delta was a frontier society where ‘local troubles, problematic social relations, disputes over property rights, and the like could be solved by migration . . . thus reducing the necessity of commitments to others’. Likewise, as the region shifted from a status of land abundance to one of land scarcity, the patterns of social relationships were altered.

Population density, itself a reflection of the duration of colonization, has also dictated the nature and pace of transformations regarding both land development and farming. For example, the use of the dry-broadcasting technique in the reclamation of the CP Delta until the late 1920s can be clearly linked to the conditions of land abundance and labour shortage typical of a frontier society. Double cropping was reported as early as the beginning of the twentieth century (Prince Dilok Nabarath, 1907; Thompson, 1910) but did not develop until the agrarian crisis *c.*1970 (which also corresponded with the advent of HYVs) (see Molle and Srijantr, 1999), more or less at the same time that it occurred in the MK Delta (see Xuan and Matsui, 1998). In contrast, Chinese historical records mention the occurrence of two crops of rice in the RR Delta as early as the beginning of the Christian era (Trân Quôc Vuong, 1963) and 45 per cent of the rice land was double cropped (rice + rice, or rice + field crop) in 1930 (Gourou, 1936).

The rising population of the MK Delta has led the government to support the reclamation of the last remaining (and harsher) uncultivated environments. The Plain of Reeds and the Camau Peninsula have been reclaimed gradually over the past years, through a mixture of canal development, salinity control and innovation in dealing with acid soils (Husson, 1998). These environment-formative initiatives were clearly aimed at expanding agricultural land in order to accommodate a growing population. The development of the floodplains, examined earlier, also mirrors such differences. In the CP Delta’s floodplain, the full-drainage option adopted in the RR Delta is also feasible, but the population pressure and need to intensify have not been high enough to justify the corresponding investments in pumps and dykes. Full poldering is also possible in parts of the MK Delta, but it is not considered a good solution in terms of fertility replacement and flood management (higher risk), and would, in addition, be extremely costly.

Thus, more generally, state intervention – irrespective of its motivations and of the means employed to translate it into action –

has been critical in setting the stage for the successive development steps. This includes not only large-scale land development, roads and dams, which require the intervention of a centralized power, but also diverse actions such as public security (post-war CP), land titling or land reform, the provision of HYVs and other improved biological material, and overall policies (for example, The Bowring Treaty in CP, the *Doi Moi* Reform in Vietnam). In parallel, however, history makes a fascinating case for the possible negative impact of the state, as illustrated by the episodes of collectivization, when production and yields dramatically plunged. This returns the stage to a political context. The RR Delta's history is marked by a strong bias in favour of centralized and collective options of development. The Chinese and Confucian background was reinforced (or induced) by the necessity to tame the floods and to carry out huge collective works of dyking, poldering and drainage, and, later, by the communist ideology. As such, the centralized state can be seen as a form of the Asiatic mode of production (Dao Thê Tuân, 1985).[14] In the MK Delta, the influence of the central power was less, although the colonial period and the reunification were times in which the state attempted – with limited success – to increase its control. In the CP Delta, the independence of the peasants at the frontier was even higher.

These differences are reflected, in part, in the development of pumping infrastructures in the deltas. In the dry season, most locations need pumps to access water. Variations in scale and technology appear to be governed by: (1) the density of the water-courses from which water can be drawn; (2) the pumping head; (3) the average level of capital endowment of farms; and (4) the political/ideological context and the role of the state. These factors gave way to varied solutions, including: state-initiated/collective pumping units (with a network of raised irrigation canals or existing channels with embankments raised); farmer-initiated collective pumping (contract pumping as is commonplace in the MK Delta) and individual pumping (CP and MK Deltas). The ideological impact of collectivization on the choice of large state-run pumping units in the RR Delta appeared more clearly in the last two decades, as the gradual decay of the distribution networks was paralleled by a surge of local pumping stations. This demonstrated the lack of flexibility of large-scale units in dealing with high cropping intensities, tight cropping calendars and spatial heterogeneities, despite theoretical benefits from economies of scale (Kono et al., 1998; Fontenelle, 1999).

Population pressure on agricultural land – and the land development operations that the state is pushed to undertake in order to relieve it and avoid political and social turmoil – is conditioned not only by population growth but by the capacity of the wider economy to generate a 'pull' transfer of labour from the agricultural sector to the non-agricultural sectors, either locally or through migration to urban centres. In this respect, our three deltas stand in complete contrast, from the RR Delta where industrialization is still limited and, despite emigration, human density is close to 1,000/km^2, to the MK Delta where economic diversification is more significant, and the CP Delta where it was strong enough to slash the agricultural labour force from 3.5 million in 1987 to 2.5 million in 1997 (Molle and Srijantr, 1999).

Another fundamental difference between the three deltas is the degree of integration to external markets. While the peasants of the RR Delta have been struggling to ensure self-sufficiency, their counterparts in the southern deltas have long been integrated to an export-oriented rice economy, either through a mercantile 'internal colonization' (CP) or through the presence of colonial powers. They match the distinction made by Kaida (forthcoming) between agrarian and mercantile deltas. Only in the last two or three decades did the predominance of rice cultivation give way to a growing process of diversification (Kasetsart University and IRD, 1996; Le Coq, 2000; Xuan and Matsui, 1998. This trend is also observed in the north, to a lesser extent; see Yanagisawa et al., 1997, and Fontenelle et al., 2000). This trend is also an indication of a new degree of commercialization of agriculture, due to a satisfaction of consumption needs (and the production of surplus), to the decline in the profitability of rice paralleled by a reduction of the average farmland, to the development of agro-industries, transportation facilities and urban/foreign markets, and to the *doi moi* liberalization policy for Vietnam.

In summary, the reclamation processes of the three deltas, conditioned and sometimes dictated by ecology, have shaped different societies; this cannot be seen simply as different historical stages of development. In particular, Rambo (1973) has made the point that the MK Delta should not be seen as a pioneer or immature version of northern society but, rather, that the specificity of this new habitat and of its historical transformations has generated a different social fabric. Necessity has undoubtedly pushed humankind to both adapt to and transform the environment but the options taken also reflect the process of society formation, demographic patterns, the degree of integration to higher levels of the wider economic system, and political development. From widely virgin and inhospitable environments, deltas have been crafted to form the rice bowls of the regions and to house the highest population densities. In south-east Asia, this has been a process of paramount

Table 6.2. Natural Environment and Socio-economic Aspects of the Red River, Mekong and Chao Phraya Deltas

Red River Delta	Mekong Delta	Chao Phraya Delta
Natural environment		
Small catchment basin, steep gradient, high sediment load	Large watershed, low elevation, flat relief	Medium watershed, low elevation, flat relief. Partial control of the basin by two storage dams
Erratic and heavy rainfall, frequent typhoons	More regular rainfall pattern; infrequent typhoons	Rainfall pattern with irregularities, especially during the early rainy season, no typhoons
Strong tidal effect and limited saline intrusion	Strong tidal effect and saline intrusion	Relatively weak tidal effect and limited saline intrusion
Limited soil constraints (low natural fertility)	Widespread problems of soil salinity and acidity	Limited soil salinity and acidity constraints
Irregular and abrupt flooding with rapid rise of water	Regular flooding with regular annual gradual rise and fall of water	Relatively regular flooding with regular annual gradual rise and fall of water
Diversion of flows possible only on tributaries (terraces)	No diversion of flows possible	Diversion dam feasible: large area irrigated by gravity canals
Historical and socio-economic aspects		
Early reclamation* (10th century)	Late reclamation* (18th century)	Late reclamation* (18th century)
High population density	Medium population density	Low population density
Exploitation by intensive cultivation, adapted to different landforms and high know-how on fertility reposition	Exploitation by extensive methods of cultivation, with recent intensification	Exploitation by extensive methods of cultivation, with recent intensification
Struggle against banditry, foreign invasions and flood damage	Strengthening the southern state and struggle against the northern state	Heritage of *Muang* slavery and *Sakdina* system
Early central state of oriental despotism	Military and civil colonization by soldiers and criminals; medium state influence	Civil colonization by migrants and Chinese labour force
Strong influence of Confucianism	Strong influence of Mahayana Buddhism	Strong influence of Hinayana Buddhism
Stronger village communitarianism; ideology for collective solutions**	Loose village communitarianism, limited ideology for collective solutions	Loose village communitarianism, little ideology for collective solutions
Closed corporate community**	Open peasant system	Open peasant system
Subsistence agriculture (little surplus)	Development of a market economy	Development of a market economy
Higher equity**	Medium equity	Medium–low equity
Large emigration	Large immigration from the North	Immigration, including from China, and emigration from the 1950s onward
Slow industrialization and urbanization, few job opportunities out of agriculture	Emerging industrialization and urbanization	Rapid industrialization and urbanization
Strong Chinese cultural influence	Strong Chinese economic influence	Strong Chinese economic influence

* Approximate of large-scale reclamation (but all deltas have earlier settlements, notably the RR Delta, Oc-Eo in MK and Mon-Dvaravati in the CP Delta)

** This does not ignore the debate on the nature of the village in the RR Delta (and elsewhere) and on the ideological constructs the 'village' has given rise to. However, in relative terms such a characterization of the RR delta as opposed to the southern deltas appears acceptable.

significance, and, including Burma but with the exception of the RR Delta, a rather recent and rapid transformation.

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NOTES

1. The 1860 and 1900 values are orders of magnitude because data were kept for the central region and not the delta itself.
2. However, approximately two-thirds of the Chao Phraya and Mekong Deltas had already been reclaimed in 1930. In the Red River Delta, the total area of rice lands has decreased by 18 per cent from 1930 to the present day.
3. All these deltaic areas are in fact cut across by several rivers and not just one. The Red River Delta is also joined by the Thai Binh River; the Mekong Delta forms a continuum with the Saigon and Dong Nai Rivers, while the Chao Phraya Delta comprises not only the Chao Phraya River (and its distributaries) but also the Mae Klong River (to the west) and the Bang Pakong River (to the east). Values for the Mekong River refer to the south of Phnom Penh (NEDECO, 1993).
4. The ongoing or just completed dam projects in China and Laos are gradually changing this situation. Some regulation of the Red River system is allowed by the Hoa Bin dam (on the Black River).
5. This section draws on the work by Takaya (1975, 1978).
6. These kinds of post-monsoon rice grown in receding water, generally with the contribution of irrigation, are also found in some parts of the Ganges–Bhramaputra Delta (*Boro* rice) (Takaya, 1975) and in the Irrawaddy Delta.
7. For example, the triple cropping option is more common in the delta flats than in the floodplain, where it is restricted to the higher parts of the levees.
8. A peculiar technique adapted to the local water regime, where final seedlings are established with a height of 70 to 80 cm after having being transplanted a first time (Xuan 1974).
9. A similar situation was to be found in most of the Plain of Reeds (but with soil toxicity due to acidity).
10. But regulators are rarely located along the seashore. A greater (MK) or lesser (CP, east bank) but still large part of the coastal area therefore remains as a brackish environment.
11. Interestingly the closure of the CP Delta resulted in a higher inland average water level in the dry-season (conservation), while the opposite occurred in the MK Delta – for example, see, the Quan Lo-Phung Thiep

Project, where it dropped by 70 cm (Joffre et al., 2001) because of the loss of the tidal effect.

12. The description draws on Xuan and Matsui (1998) and on the recent work of Le Coq (2001).
13. A type of tenant engaging in land clearance with capital borrowed from a landlord.
14. We do not wish to expand here on the debate generated by Wittfogel's theory. Its application to Asia has generated an enthusiastic literature by authors who have identified hydraulic states where, at best, modest irrigation facilities existed and where state control was, on average, standard. However, if the North Vietnam case may lend itself to such a characterization, it is not the case in the two southern deltas.

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