Water management in poldered areas, case of the Red River Delta

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Abstract: It's well known that technologies for water resources utilization vary from one region to another due to the variability of natural and socio-economical conditions. In order to contribute to the generalization of water management practices, this paper deals firstly with physical and institutional characterization of polders[1] operation in the Red river delta. Secondly, problems associated with polders management will be summarized to show challenges that this style of rearrangement for water utilization faces.

1. Introduction

The Red river delta (RRD), situated in the North of Viet Nam, is the second agricultural region of the country, after the Mekong Delta in the South. Cultivation together with water resources utilization of the delta has practiced for centuries. However, the extensive introduction of modern technologies for water control began only during the French colonial occupation and developed recently, in the late 50's, in an effort to ameliorate the agricultural production conditions. Physical facilities and institutional arrangements in the delta actually presents one distinguished style for water resources utilization in delta areas, said "water management in poldered areas". Its characteristics allow conveniences and oppositely, cause several problems to management activities. Providing an overall vision about polders operation is what this synthetic paper intends to partake.

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[1] In this paper, a polder refers to a single area completely surrounded by the dikes of the rivers and/or the sea. In the RRD, there are 30 polders with the total area varying from 5 000 to 200 000 ha (cf. Figure 1). Equipments for irrigation and drainage of polders constitute a single hydraulic systems. From hydrological point of view, the 30 hydraulic systems of the delta are independent to some extent as they are directly supplied by adjacent river reaches in irrigation period and directly discharged to them in drainage period.

In this objective, the paper will begin with the brief introduction to the RRD, emphasizing those properties that lead to understand water management principles in the delta. Functioning of polders will be followed in the second and the third paragraph and, main problems related to polders exploitation will be stated in the last.

2. Generalities of the RRD

The RRD is a plain of approximately 12 500 km^2, 7 210 km^2 of which is for agriculture. The delta is originated by alluvial deposed by the Red and the Thai Binh rivers, both flowing in a direction from north-west to south-east. These two parallel rivers and their branches, sometime connecting one river to another, constitute a dense hydrographical network of the delta.

It's firstly important to note that the average annual flow of the rivers is so significant that it presents an **abundant water resource** for the delta. At the entry of the delta, the average annual flow for a period from 1856 to nowadays of the Red river alone[2] is roughly 3600 m^3/s, accounting for an annual arriving volume of 113 billion m^3. However, water regime of the rivers strongly varies according to seasons, from 368 to 34 320 m^3/s in dry and rainy seasons respectively. One of reasons is that river flow is poorly controlled as there are only two significant storage reservoirs in the upstream, the Hoa Binh and the Thac Ba with live storage capacity of 5.6 and 1.2 billion m^3 respectively.

Secondly, it's worth also to mention that the Red river is said to be one of the most dangerous rivers in the world as the **water table is rather steep and may raise very high**. Even for the downstream reaches in the delta, it varies from 0.022 to 0.102 m/km, equivalent to the water table descent of 2.2 to 10.2 m for a distance of 100 km. In rainy season, water level at the central delta may be superior than land level of several meters. Moreover, water level might fluctuate rapidly depending on rainfall in the upstream of the basin.

Belonging to as said south-eastern Asian monsoon massive, the RRD climate is characterized by seasonal variations. In the summer, the monsoon winds associated with tropical storms move

[2] Data for flow of Thai Binh river is not reliable due to the back water effect.

westward from the South China Sea. In the winter, the dry and cold winds come from the center of Asia.

The **annual rainfall** distribution over the delta is fairly uniform and averages 1740 mm. However, it's unevenly distributed over the shorter time period. The dry months from November through April contribute an average of only 200 mm and the wet months from May through October contribute 1500 mm. When viewed on a daily time period, rainfall is much less uniformly distributed. Some drought may occur during the rainy season, even on a year with average total annual rainfall and heavy storms may account for several hundreds of mm in one to five days when tropical storms or tropical barometric depressions occur. That's why rainfall would be sufficient to satisfy crop water requirements in most years, but due to the highly nonlinear temporal distribution of rain, most runs off and cannot be retained in the polders.

Similarly, other climatic factors vary according to seasons: humidity, evaporation from open water surface, temperature are high in summer and low in winter.

The **topography** of the DFR is dominated by the general slopping direction from north-west to south-east. The relief is low, varying between the sea level and the isometric curve of 10 m, 72 % of its total surface being inferior of 2,5 m. However, natural land elevation is rugged because of the presence of dikes "that prevent rivers ... to fill up the topographical depressions". In a certain cultivation blocs of 1000 ha, differences between the lowest plot and the highest plot may reach 5 m.

The RRD has a **population** of 17 million. It is one of the most densely populated regions in the world with many rural areas supporting 1000 persons/km^2. Since most of the rural population is occupied with rice-based cultivation[3], the high demographic density has called for an urgent need for irrigation and drainage introduction to allow intensive cultivation. However, agricultural production has dramatically developed only from 1988 to present, under the policy of the

[3] The cropping pattern of about 70% of cultivated area composes of spring rice from February to June and summer rice from July to October. The rest 30% are occupied by spring rice, summer rice and winter upland crops (vegetable, potato, maize, etc.) from November to January.

decentralization and privatization movement known as *Doi Moi*. The operation and management of the irrigation systems is also evolving rapidly at all levels; from the development of central control and authority to the local and **self-sustaining management enterprises**. Agricultural diversification is also one important feature of these period. Others cropping patterns such as rice-fish, valuable cash crops year-round replace rice-based cultivation.

3. Description of polders

The hydraulic systems of polders is based on the same technical model that composes of three components: (i) the primary gravity network, (ii) the irrigation units and, (iii) the drainage units. The description of polders that follows will start with brief characterization of the three components and finish with explanation of how they operate together.

3.1. Primary gravity network

Reaching all over the polder, the primary gravity network serves the dual purpose: it provides water sources for numerous irrigation units and receives waters excesses extracting from drainage units. In addition, it plays a role as a receiving body for wastewaters of urban and industrial areas in the polder. Thus, this network can be considered as a intermediary of rivers and irrigation and drainage units.

The primary gravity network consists of a main channel and a big number of branch channels (cf. Figure 2). For a large polder, the length and the width of the main channel may be as big as 100 km and 100 m respectively, and total length of branch channels bigger than 10 m of width may reach several hundreds of kilometers.

This primary gravity system involves one or more intake gates and one or more outlet sluices to let water transfer into or out of the polders. However, there are only one intake gate and one outlet sluice for a polder in most cases. The big gates in the delta can be as large as several tens of meters. To gain from big water table gradient and to facilitate irrigation and drainage at the same time, the intake gates are situated in the upstream of the polder where water level of river is highest and drainage sluices in the downstream where water level is lowest.

There are also water control sluices on the primary gravity system to divide the network into several independent reaches.

3.2. Irrigation unit

In irrigation period, the polder is divided into a large number of irrigation units, each of which is served by one pumping station or one turnout depending on whether it's irrigated by pumping or by gravity. Command area of irrigation units varies from several tens of hectares to more than ten thousands of hectares and averages 150 hectares.

Due to low water level in the primary gravity system, irrigation by pumping is dominated (70 to 80% of total arable land). According to the technical norm, pumping stations are designed for a delivery capacity of about 1 litter/second/hectare. After a period of multiplication of pumping stations from 1988 to present however, delivery capacity is actually much more important. It may reach 7 l/s/ha in many cases.

In common situation (more than 75% of total arable land), irrigations units are served by the primary gravity system, meaning that their pumping stations or their turnouts are scattered along the main channels and its branches. Others are independent units not covered by the primary gravity system. They are supplied directly by rivers, through pumping stations or turnouts situated along the main dikes.

In each irrigation unit, there exists one distribution network consisting of elevated irrigation canals and control devices, which plays a role to deliver water to all plots in the unit.

3.3. Drainage unit

Similarly to the irrigation period, the polder is divided into a large number of drainage units which are drained to the primary gravity system or directly to rives through pumping stations or outlets along the gravity system or river dikes. Inside each drainage unit, there's one network of drains which plays a role to collect water excesses from cultivation plots as well as villages and convey them to the unit's pumping station and/or outlet. Even in the case of drainage by pumping, the drains systems are usually arranged so that the water can also drain by gravity through the primary system when the river levels are low enough to permit this. As the volume of water to be drained in whatever time period is bigger than that to be delivered in irrigation mode, infrastructures for drainage purpose are designed with high capacity, from several l/s/ha to more than ten l/s/ha.

To terminate the description, it's important to pay an attention to following remarks.

- Limits of irrigation units rarely coincide with that of drainage units. One irrigation unit might composes of several drainage units and vice versa. In general however, the number of drainage units is smaller than that of irrigation.
- Some of the pumping stations are configured so that they can serve both irrigation and drainage functions. In these cases the number of pumps served for irrigation is usually significantly smaller than that for drainage.

3.4. Operation of polders

The polders can be said to be primarily operated in either a *irrigation mode* or a *drainage mode* at any given time. However, both functions may be served simultaneously during much of a typical period. To easily describe the operation principles of polders, irrigation and drainage modes are distinguished.

- **In the irrigation mode**

In the irrigation period, the main intake gate is opened to feed the primary gravity system with waters available in the river and the outlet sluices are closed to store water in the polder.

Sluices along the main channel are justified to maintain differently water levels in different reaches to meet the irrigation demands of different zones, which are normally different due to the elevation variability of landforms. Moreover, they help share water deficits between different zones when water level in the river is too low.

Available water in the primary gravity network is elevated by pumping stations and then distributed all over the irrigation units by the delivery networks. When irrigation by gravity is possible, turnouts are open to allow gravity flow from the primary gravity system to plots.

- **In the drainage mode**

During drainage period, water flows in inverse direction. Water excesses in drainage units are accumulated in drains and then extracted to the primary gravity system by pumping stations or outlets. The main intake gates are closed to prevent river waters penetrating in the gravity network and main outlet sluices are opened to drain water out to rivers whenever it's possible. The main control sluices are opened too to maximize the flow in the primary gravity system.

It's important to note that water level in the primary gravity system may rise higher than land elevation due to the high water level in rivers. That's why the primary gravity network is associated with secondary dikes both sides.

4. Institution for water management

There are two parallel organisms involving in water management: '*administrative*' and '*technical*'. While administrative organisms deal with policymaking, technical organisms are responsible for system operation, maintenance. They are both hierarchically organized from central to local levels and have different tasks.

4.1. Administrative organisms

Function of administrative organisms is based on administrative boundaries such as state, province, district, commune.

They are headed at the central level by the Department of Water Resource belonging to the Ministry of Agriculture and Rural Development. The department is responsible for issuing relevant documents related to water management (rules for the calculation of the water fee, water laws, etc. for example) and approving the implementation of major projects (planning, design, construction and funding).

At provincial level, the Water Resource Service belonging to Provincial Office of Agriculture and Rural Development provide policy advice (setting the provincial water fee based on national guidelines), decides on investments for small intervention projects and provides subsidies for technical organisms when needed.

At local level, from district to commune, specified organisms are assigned to oversee whether issued guidelines and decisions are respected and whether irrigation and drainage services are performed as intended.

4.2. Technical organisms

After the construction of system is accomplished, infrastructures are handed over to technical organisms to exploit them. Unlike administrative organisms, they are functioning on either natural or administrative boundaries.

On large polders which embrace more than one district, one Irrigation and Drainage Management Company (IDMC), a state company, is established to manage (operate, maintain and financial manage) the primary gravity system, including the main intake gates, drainage sluices and control sluices. The management of infrastructures at lower level such as branches of the primary gravity system, centralized pumping stations, principal irrigation canals and drains is designated for District Irrigation and Drainage Management Companies (DIDMC), a state company too [4]. There may be more than ten DIDMC under the IDMC in one polder in same cases. While IDMC functions in a basic of areas or zones having natural boundaries (polders), DIDMC is based on district boundaries.

On small polders which embrace only one district, IDMC doesn't exist and DIDMC is responsible for all tasks from water source creation in the primary gravity system to pumping station and then principal secondary canals.

At local level, cooperatives are the last formal technical organisms who are involving in water management. Their main task is to receive water delivered by DIDMC then distribute it to all parcels and to maintain field canals. When there are local pumping stations, cooperatives have to operate and maintain their system from the pumping station down to the fields.

Since late 1980s, all above mentioned technical organizations are expected to act as self-sustaining management enterprises, meaning to cover their water source creation, irrigation and

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[4] Centralized pumping station is defined as those which are constructed by Government and managed by state company. In contrary, local pumping is those which are constructed and managed by local communities.

drainage services, and maintenance costs through the collection of a water fee paid by farmers. Water fee is divided into three parts: (i) water sources creation in the primary gravity system (said also water fee for water source creation), (ii) irrigation and drainage costs, including pumping expenditure and maintenance of related channels (said also water fee for irrigation and drainage) and, (iii) water distribution and canals maintenance at field level (said also field water fee). The payment is carried out bottom up from farmers to IDMC and each organisms keep the relevant parts to spend for their activities. In common situation, the cooperatives keep the field water fee, the DIDMC the water fee for irrigation and drainage and IDMC the water fee for water source creation. When there are local pumping stations, cooperatives only pay for water source creation and drainage costs and keep irrigation fee for themselves.

5. Problems related to polders management

Although contributing to agricultural production development, experiences from the last 50 years of exploitation show that this style of water management encounters some obstacles that restrict its potential service capacity. There are still unsolved technical, economical and institutional problems that challenge the sustainability of the systems. The analyses of key issues related to system operation that follow will demonstrate this statement.

5.1. Integration of scales

We have seen that the polders components are physically hierarchical and operate in interaction. To ensure the efficiency of system operation, all the components should be technically compatible. However, it's not the case in the reality.

In all polders, the primary gravity system and its branches rest almost unchanged since the creation of the system from late 1950s. Additionally, sedimentation deposing in their beds significantly decreases its conveyance capacity. Whereas, many pumping satiations have been additionally constructed. This situation leads to technically dysfunction of the system.

In irrigation period, newly constructed pumping stations at the tail-end of braches of the primary gravity network can’t operate normally because available water is utilized by others situated in the upstream. In drainage period, multiplication of pumping station makes the primary gravity network overloaded. Water excesses extracted from drainage units is hardly withdrawn to the rivers. Water level in the network may raise so high that managers have to stop pumping stations to avoid overflowing and to close outlets of drainage units which are drained by gravity to avoid water penetrating in the units. *It's then more convenient to examine the needs for upgrading the primary gravity system and the need to construct more pumping stations.*

5.2. Optimization of system operation

It's obvious that an application of appropriate operation rules potentially increases the exploitation efficiency of any kinds of systems. For the complicated system like the polders, the large size or the important system inertia, the mixed utilization for both irrigation and drainage purposes, the heterogeneity of the system, the rapid evolution of irrigation and drainage units, and the unpredicted variability of climatic and hydrological conditions etc. prevent managers to understand how the system would respond to different operation options. In other words, the elaboration of optimum solutions for polders operation is a sophisticated problem so that the heuristic methods that are actually applied can't handle. Statistics show different situations where water deficits or waterlogging are caused not only by severity of climatic conditions nor limitation of system's physical capacity but also by inappropriateness of systems manipulation. Failure to share water sources for irrigation during water shortage period and to use effectively storage capacity of units in drainage period is an example demonstrating the statement. Other example concerns the operation solutions to meet contradictory service purposes. The strategy to maintain low water level in the primary gravity system during rainy season in order to facilitate the drainage, without considering that the storage capacity of the system is negligible in comparison with the rain, has historically caused water stress in rainy season when water is abundant.

Thus, identification of adaptive solutions for systems operation is one of technical difficulties associated with the complexity of the polders.

5.3. Organization of irrigation and drainage units

The operational schema of polders hasn’t changed for the last 50 years, since the creation of hydraulic systems. However, it’s not the case for the organization of irrigation and drainage units. Regarding to irrigation and drainage, the polders evolution can be divided into two principal periods:

- From system creation to 1980: this period, well known as a period of modernization and collectivization of production, is marked by construction of large irrigation and drainage units associated with capacitive pumping stations. The command area of some units may reach several tens thousands hectares.
- From 1980 to present: during this period of the promotion of decentralization, many small pumping stations are additionally constructed inside the existing command area of big pumping stations. Other large number of capacitive pumping stations are installed along the main dike, that convert units initially drained to the primary gravity system into independent units drained directly to rivers. As a result, irrigation and drainage channels and some pumps of big units are no longer used.

The mentioned situation of fragmentation of large irrigation and drainage units show the uncertainty of definition of irrigation and drainage units. *Thus, a question of how to determine their size and their organization to adapt to managerial and physical conditions is still unsolved.*

5.4. Water quality management

Hydraulic systems of polders don't include a separate sewerage network to drain out wastewaters coming from cities, industrial centers, handicraft villages. All kind of wastewaters are discharged in the primary gravity networks of polders, dispersed all around the networks, and then reused for irrigation in combination of available fresh water. Untreated wastewaters contain high levels of inorganic and toxic substances, and dangerous pathogens. Severe direct and indirect impacts of water pollution to communities health and agricultural production have been reported, notably in polders that embrace densely agglomerations and important industrial centers.

Theoretically, application of infrastructure or operation measures to increase the assimilation capacity of water receiving bodies can help minimize pollution impacts. Unfortunately, no measures have been sufficiently considered in reality. *Thus, due to the polders configuration, water quality management is one of major challenges to improving irrigation water.*

5.5. Institutional issues

Institutional problems relating to water management in polders include difficulties to (i) ensure economical sustainability of technical organisms involved in water management and (ii) to share responsibilities between them.

We have seen that technical organisms involved in water management have to cover their operation and maintenance cost by collected water fee. However, it's reported that almost all of them lack of financial sources to maintain the systems as well as needed. They fall in a vicious cycle: lack of financial source to maintain the systems leads to systems deterioration, leading to high water loss, leading to high operation cost (electricity expenditures), leading to lack of financial sources. From technical point of view, the main issue is that different irrigation and drainage units are commonly served by the primary gravity system. Even in rainy season when the water level in rivers is much more higher than field levels, water level in the primary gravity network has to be maintained not too high to avoid unexpected "artificial inundation" for low laying units and to minimize the storage in order to facilitate the drainage that may be eventually necessary. In drainage period, pumped waters from drainage units make water levels in the primary gravity system so high that drainage by gravity is rarely possible. That's why irrigation drainage is normally carried out by pumping even though gravity irrigation and drainage is theoretically possible. *It's then interesting to consider possibility to expand irrigation by gravity to minimize electricity expenditures*.

We have seen that water management tasks is assigned to different operational organisms at different scale, due to the large size of polders. While the whole hydraulic system of polders technically function in communication, the operational organisms are completely independent in decision making. In this case, a smooth circulation of information between users in the downstream and decision makers in the upstream is necessary. Unfortunately, it's not easy to realize due to the lack of technical means. The IDMC controls the primary gravity system by their experiences, without consulting DIDMC about their demands. Another problem coming from the splitting of managerial tasks is that there may exist complicating factors due to the divergence of operational objectives of different organisms. The first example is that while the district who operates the pumping station tends to minimize electricity expenditures, another district who is responsible for delivering wants to receive as much water as possible. The second example is that there may exist no man areas. Many parts of the primary gravity system is badly maintain because the task is assigned to districts companies, who is not profitable from maintenance works, rather than to cooperatives, whose pumping cost and production conditions depend on the conveyance capacity of the channels. *Thus, we can conclude that physical complexity of the polders may produces difficulties in solving institutional problems.*

Conclusion

The example of water resources utilization in the Red River Delta suggests three topics for further discussions.

First topic relates to collectivization against individualization of water management. At delta scale, the abundance of water sources allow to create independent polders, unlikely other delta where irrigation of the whole delta depends on a common water source (reservoir in the upstream for example). As a consequence, there’s less technical nor institutional problems coming from resource competition and coordination for water sharing. At polder level in contrary, the collective mode for irrigation and drainage of a large number of units provoke not only technical but also institutional problems. The discussion in the last chapter demonstrate this statement. It’s then convenient to consider whether maximizing of individualization of water management is preferable.

The second topic is the compatibility between technical and institutional dimensions of water management. Ineffective exploitation of polders due to the lack of appropriate operational rules, historical fragmentation of irrigation and drainage units in the polders because the technical plan isn’t suitable to managerial capacity, and deterioration of infrastructures due to the inappropriate institutional framework can be considered as examples demonstrating this statement.

Lastly, it's seemingly interesting to create necessary conditions allowing all decision makers, stakeholders and users to discuss about identification of problems and possible solutions. We have seen that not all of above mentioned problems come from the severity of natural conditions. The failure to asses the needs for upgrading the primary gravity system instead of multiplication of irrigation and drainage units is a typical example of misunderstanding of overall operation of polders.

Figure 1: Layout of 30 polders of the Red River Delta

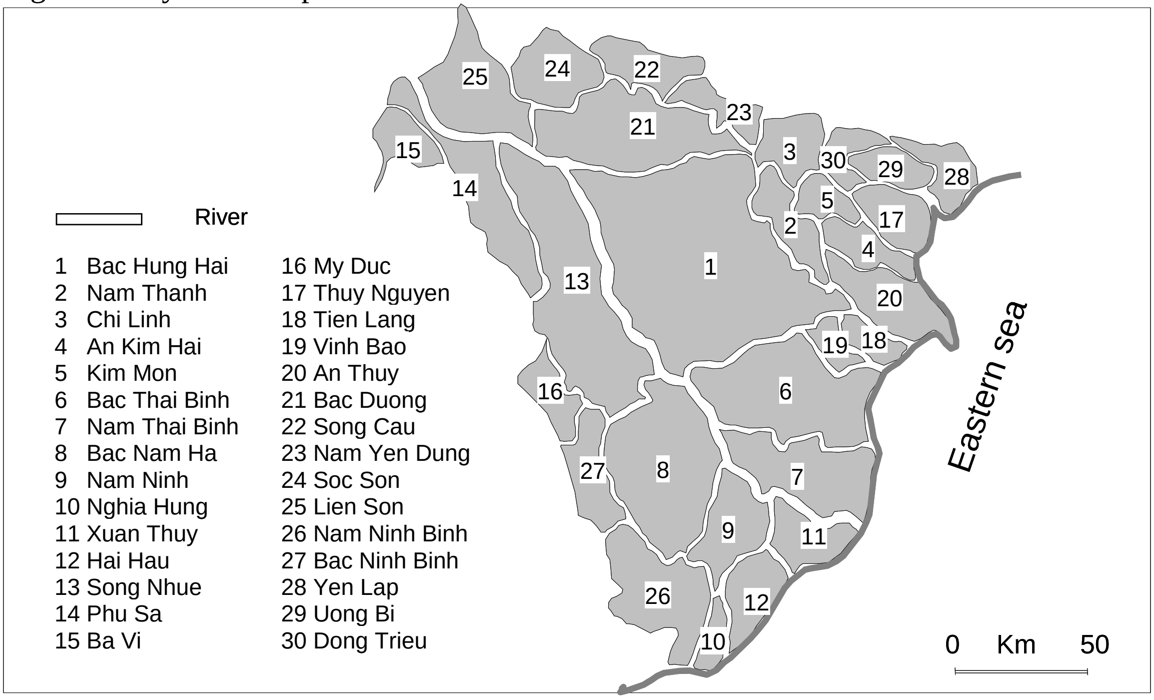

Figure 2: Schematization of hydraulic system of a polder