



# MACRO AND MICRO DREDGING AS A TOOL FOR MITIGATING FLOODS AND DROUGHTS IN THE RED RIVER DELTA, VIETNAM

## ABSTRACT

The Government of Vietnam is pursuing a new strategy of Integrated Water Resources Management which includes economic, environmental, technical, social and political considerations. Assisted by the Government of the Netherlands individual studies and reports were conducted. This article covers the initial environmental examination and the development of mitigation measures against adverse impacts of physical works. Detailed investigations of water and groundwater, and sediment and soils support the assessment, backed by field surveys. Though dredging was not a specific subject of the study, the article highlights that integrated development of water resources in deltas should include salinity, sediment and soils and it identifies macro and micro dredging as effective tools for mitigating flood and drought problems.

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## INTRODUCTION

The Government of the Netherlands has assisted the Government of Vietnam by financing the Day River Flood Diversion and Water Resources Development project. DHV Consultants BV, Amersfoort, the Netherlands (leading partner), Hydraulic Research Wallingford Ltd, Wallingford, UK and the Vietnam Institute of Water Resources Research, Hanoi, Vietnam were contracted to do this study. The study covered institutional aspects, hydrology, hydraulic modeling, morphology, agricultural development, engineering, dike management, sociology, environmental impact assessment and economic analysis. For each component, a separate report has been prepared.

The initial environmental examination and mitigation measures developed against adverse impacts of physical works are described. Detailed investigations of water and groundwater, and sediment and soils support the assessment, backed by field surveys and sampling campaigns in the dry

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Above, a drought-prone area, Chuong My, Vietnam. Dredging should be considered as a tool in regulating flood and drought zones in the Red River Delta.

and the wet season. Dredging was not a specific subject of the study, but macro and micro dredging were identified as effective tools for mitigating flood and drought problems.

“Macro dredging” of the Lower Day River to assure rapid release of Red River floodwater via the Day Estuary to the Gulf of Tonkin and “Micro dredging” in the Day River floodplain (“green river”) to assure the perennial flow of Red River water to combat droughts while maintaining soil fertility are suggested. The study highlights that integrated development of water resources in deltas should include salinity, sediment and soils, while macro and micro dredging are tools that can make solutions work.

## INTEGRATED WATER RESOURCES MANAGEMENT

The Government of Vietnam is pursuing a new strategy for water resources management, in which the water sector and the (water) environment is considered in an integrated manner in relation to economic, environmental, technical, social and political considerations:





Figure 1. Protected and flooded zones of the Red River Delta in 1925 (ENPC; Normandin).

in short Integrated Water Resources Management. The passing of the Water Law in 1998 was an important development in this process and the initiation of the Day River project was one of the concrete actions taken in this respect. Integrated Water Resources

Management should take place through interaction with users (population), resources and institutions. Integrated Water Resources Management thus applied takes account of the use of water resources in relation to social and economic activities and functions, and the required water

infrastructure, considering the soil fertility and salinity aspects.

### PROJECT LOCATION

The Day River Project is situated in the Red River Delta of Vietnam, with an area of 16,500 km<sup>2</sup> and a population of 18.5 million. Next to the Mekong Delta, the Red River Delta is the second largest granary, producing 15 to 20 percent of Vietnam's rice. The catchment of the Red River is 169,000 km<sup>2</sup>, half of which lies in China (Figure 1). The Day River project area, situated East of Hanoi, covers parts of the provinces Ha Tay and Ha Nam (Figure 2). Around 600,000 people live in the Day River region, 90 percent of whom work in agriculture. The Red River upstream of Hanoi comprises three major tributary systems: the Da, Thao and Lo Rivers. The flood season in the Red River lasts from June to October, with particularly widespread flooding in August. For the rest of the year, the area is subject to occasional flooding. When large floods occur, as they did in 1971, the flooded area is some 500 km<sup>2</sup> in Ha Tay and 300 km<sup>2</sup> in Ha Nam.

### HYDROLOGY OF THE RED RIVER

The Red River at Hanoi comprises three major tributary river systems, the Da, Thao and Lo Rivers. A number of reservoirs have an impact on the discharge of the rivers: the Thac Ba reservoir on the Chay River completed in 1972 and the Hoa Binh reservoir on the Da River completed in 1989. The potential storage in the Hoa Binh reservoir is approximately 10 times more than the Thac Ba reservoir, and therefore has a significantly higher impact on reducing high flows in the Red River at Son Tay station. Figure 3 shows the seasonal averaged discharge of the Red River.

### Low Flows

The minimum flows at Son Tay after the construction of Hoa Binh reservoir are higher than before, but still below 1000 m<sup>3</sup>/s in the period March to April. The rainy season in the Red River basin ends in October. November-December is the transitional





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period between the rainy season and the season of light rain. The dry season begins in December and lasts until May. In the dry season, rainfall is around 20-30% of the annual rainfall; 60% of this is concentrated in April-May; there is a little rain in January, February and March. The dry continental monsoon blows particularly strongly in December and January. Large precipitation is only 60-80 mm/month; normal precipitation is 20-40 mm/month and small precipitation is less than 20 mm/month. This is not enough to maintain the humidity of the soil cover. The total rainfall added to flows in the river system is negligible because of small precipitation. Dry season flow originates mainly from groundwater. Agricultural production in January requires the maximum water volume for hoeing soil for the spring rice crop. Acid cleansing and salt removal in coastal areas needs plenty of fresh water. In addition, tillage in the Day River needs water, which supply the pumping station at Ham Mon and transfer from the Red River through the Nhue and Nam Dinh rivers.

#### Average Discharge

The average discharge as recorded at Son Tay over the period 1957-1988 is 3,545 m<sup>3</sup>/s, just 2.6% higher than the combined average of the three tributaries, which was 3,455 m<sup>3</sup>/s. Thus relatively little flow is added downstream of the three gauging stations in the tributaries. The impact of the Hoa Binh reservoir on the discharges is

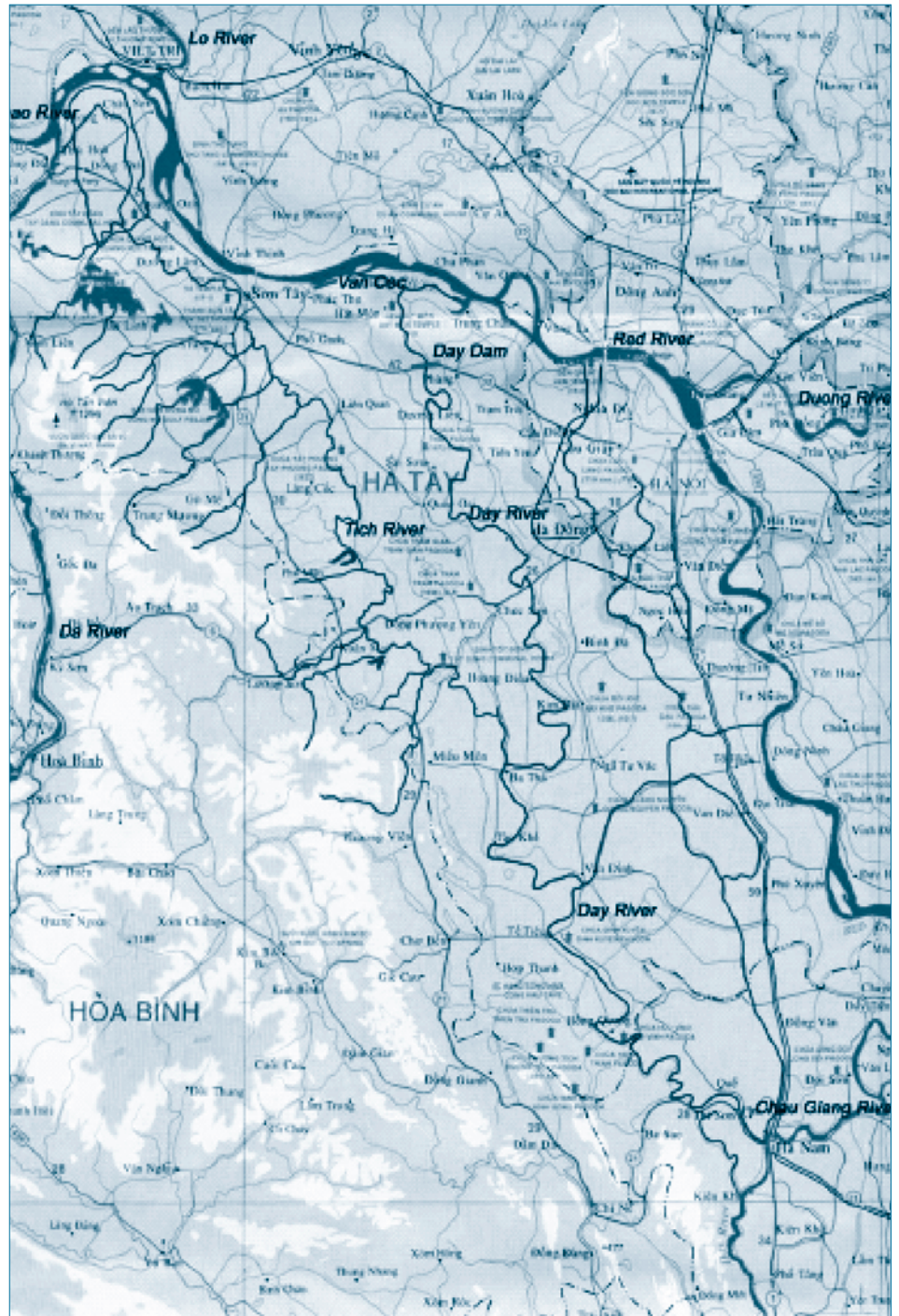


Figure 2. The Day River project area.

significant. The percentage of time that a discharge is less than 1000 m<sup>3</sup>/s has increased after 1989. The percentage of time that discharge is between 1000 m<sup>3</sup>/s and 4000 m<sup>3</sup>/s has decreased. The percentage of time that discharges exceed 4000 m<sup>3</sup>/s has increased. This phenomenon may reflect a strategy of water release for flood

control, in which release of a certain high discharge creates storage to prevent even higher discharges when a real flood comes down the Da River.

#### Floods

The floods in the Red River are the combination of floodwaters from the Da,

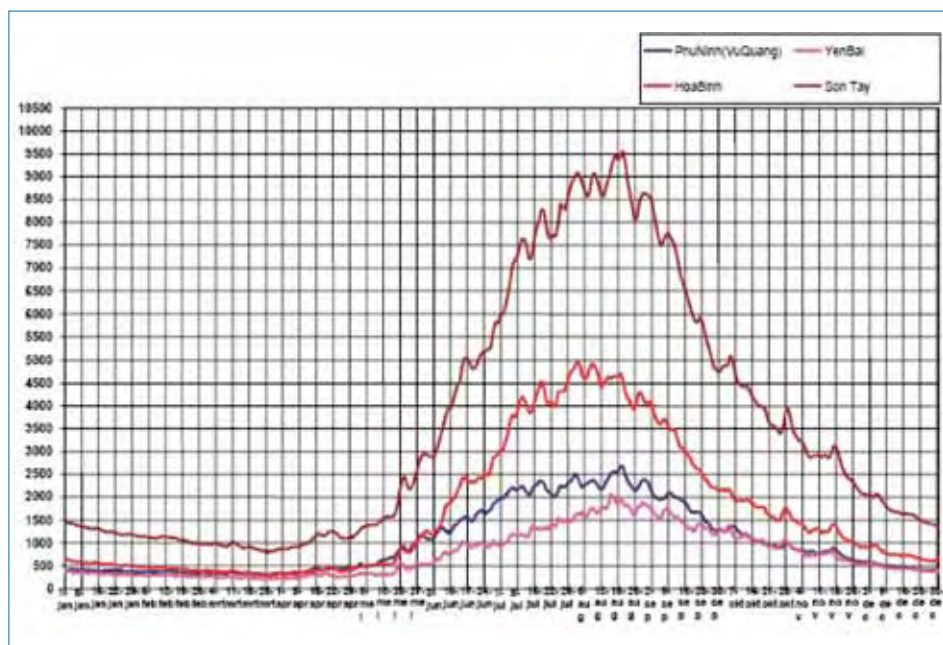


Figure 3. Chart of the seasonal averaged discharge of the Red River.

Thao and Lo rivers. The waters of these three tributaries come together at Viet Tri, and thereafter form one flow channel to Hanoi. The floods may rise quickly, taking just 2 or 3 days to attain the peak level, and subside more slowly, taking a 3- to 4-fold longer period. However, the opposite has also happened. Furthermore, one flood may not have fully subsided when another flood already begins. The flood season in the Red River lasts from June to the end of October, with particularly big flood events in August. Statistically distributed, the peak flows have occurred as follows: July (32%), August (55%), September (7.3%), and October (4.4%). In some years, the peak flood level occurred in June (1.6%).

There are three alarm levels for flood warning in Hanoi. The records of the measurements show that during the last 90 years in only two years (1917 and 1931) was the water level of the Red River in Hanoi above the alarm level.

### Dangerous Floods

Dangerous floods in the Red River can occur when large floods occur in one, two or all three of these rivers. Such special cases of coincidence did take place:

1. in 1945 resulting from the historically large floods in Da River and the relatively large floods in the other two rivers;

2. in 1971 resulting from historically large floods in Lo River combined with very large floods in both Thao and Da rivers;
3. in 1968 resulting from historically large floods in Thao River combined with small floods in Da and Lo rivers;
4. in 1969 resulting from large floods in Da River combined with large floods in Lo River and medium floods in Thao River.

In 1989, the Hoa Binh reservoir on the Da River was completed. This reservoir has had a significant impact on reducing large flood flows in the Red River at Son Tay upstream of the Day River Flood Diversion.

### THE DAY RIVER PROJECT

The Hanoi area has grown to be of primary importance to Vietnam as a development centre for trade and industry and as the national administrative centre. Reducing the risk of flooding in the area because of high discharges in the Red River is a major concern of national importance. The recent floods in China have further emphasised this concern. In line with the Water Law, the Government of Vietnam has formulated two main objectives for the Day River Flood Diversion and Water

Resources Development Project:

1. To reduce the risks of inundation caused by flood flows in the Red River and resulting damage to the city of Hanoi and other important areas downstream; and
2. Rural development through integrated water resources management in the Day River leading to increased agricultural production.

In Ha Nam Province the industrial activities include cement production and quarrying of rocks and aggregates for concrete and road construction. Ships transport them to Hanoi to support the booming building sector. The navigation route leads first south before taking the Red River channel northwards and has a length of about 200 kilometres. This long route in effect hampers the planned development of Ha Nam's industrial development. For this reason "Improving navigation facilities between Ha Nam province and the main economic development areas near Hanoi" is formulated as a third objective, though of secondary importance.

### DAY RIVER PROJECT HISTORY

The Day River is a tributary of the Red River, which branches off from the Red River some 30-km upstream east of Hanoi, flowing to Ninh Bihn, where the Day River meets the Nam Dinh Branch of the Red River, jointly flowing to the sea through the Day Estuary. Before 1937, the Day River acted as a natural flood diversion route, an event that happened yearly (see Figure 1, Normandin, M.A).

Each year, large parts of the Day River Region were flooded. This happened in those parts not protected by dikes, south of the present Highway No 6, between Ha Dong and Hao Binh and in the low area downstream of Phu Ly. The inundation lasted for months, creating the largest waterlogged area in the Red River Delta, apparent after every flood. These two areas were almost the only areas being flooded yearly, since from 1925 dikes protected the whole delta, except some patches of land in the northeast of the Red River Delta.





Figure 4. The Day Barrier built in 1937, with six moveable weirs with a maximum capacity of 5,000 m<sup>3</sup>/s.

This situation prompted the French Government to construct the Day Dam with movable gates in the upstream part of the Day River, some 8 km downstream of Hat Mon (Jean Rigal, 1939) (Figure 4). This was a logical location for the Dam, since the dikes of the Day River and the Red River used to converge here, creating a natural funnel. The Day Dam was commissioned in 1937 and flood diversion followed by several times since then. Unfortunately, the intervention in the Day River resulted in the closing-off of the Day River for dry season flows, because of the silting up of the entrance. The floodplain of the Red River at Hat Mon became higher and higher, preventing the Red River water at low flows from entering the Day River. This prompted construction of the Van Coc sluices commissioned in the year 1966 to facilitate passage of large floods (Figure 5). The regular water supply from the Red River to the Day River ceased completely after the construction of a low dike of 8-km length in 1974.

#### PHYSICAL WORKS PROPOSED BY THE DAY RIVER STUDY

The present Day River study recommended physical works for flood diversion and flood control works, dike improvement,

intake of irrigation water and shortening of the navigation lane to Hanoi. These were based on study of hydrology, hydraulic modelling, morphology, agricultural development, engineering and dike management, taking into account sociological, economic and environmental conditions.

#### Flood Diversion and Flood Control

The study classified flood mitigation and flood control measures into four broad categories:

- flood storage,
- river diversion,
- increased river capacity; and
- flood defense.



Figure 5. Van Coc's Flood Diversion Structure with 25 gates; and a spillway of 8.6 km length carrying together a maximum diversion of 5,000 m<sup>3</sup>/s from the Red River into the Day River.



Figure 6. Da River downstream from the Hoa Binh Dam at 500 m<sup>3</sup>/s, with one gate of eight opened.

Though these were described as separate options, it was recognised that the optimum strategy might involve a combination of measures, for example, flood defense measures implemented in conjunction with improved upstream flood storage. The hydraulic model confirmed that the current level of flood protection to Hanoi is approximately once in 450 years.

It demonstrated that flood diversion through the Van Coc-Day Dam system is most effective when carried out based on the time of the flood peak in the Red River, rather than based on a fixed water level at Hanoi, as is the current practice.

Though costly, it also showed that a new structure replacing the Day Dam and the Van Coc sluices would reduce the frequency of flood diversion to once every 250 years and increase the level of flood protection to Hanoi to once every 550 years. This structure would have a discharge

capacity of 8,000 m<sup>3</sup>/s, and it confirmed that use of upstream flood retention areas could have a significant impact on reducing water levels in Hanoi. For the Day River, the solution would imply that the likelihood of a flood would be much less, but the impact would be much greater than under current circumstances. Routing a larger flood through the same profile would imply larger flow velocities and correspondingly higher flood induced damages.

For Hanoi and the Red River Delta, the impact is limited since the recurrence period would change from once in 450 to once in 550 years. Current operating procedures for Hoa Binh Reservoir could increase flood attenuation downstream and so reduce the flood risk to Hanoi (Figure 6). Further upstream storage, such as the proposed Son La reservoir, would also reduce the flood risk to Hanoi. In light of the high sediment loads in the Red River, the option of trying to increase the flow capacity of

the Red River by carrying out dredging would not be economical and was eliminated early on in the study.

### Dike Improvement

Consultants assessed the safety of the dikes by considering the hydraulic and geotechnical failure mechanisms. These mechanisms are: overflow, wave overtopping, erosion of the outer and inner slope, macro stability of the outer and inner slope, piping or sand carrying wells and micro-stability of surface layers on the dike slopes. The safety assessment revealed that a number of dike subsections are not safe, meaning that additional areas may flood. The breaching of a dike by failure mechanisms other than overtopping causes this flooding. Consultants developed scenarios for dike improvement along the area affected by the flood diversion.

### Intake of Irrigation Water

Consultants proposed a structure for the intake of irrigation water into the Day River

west of the Van Coc sluice. The design capacity of the structure is 50 m<sup>3</sup>/s. This includes the irrigation demand and an environmental duty flow of 10 m<sup>3</sup>/s.

There are two alternatives for the structure. Alternative 1 is an intake structure with gates that connect to a canal planned immediately east of the Ngoc Thao dike west of the retention area. The other alternative (2) is a pumping station. This will also feed a canal with the same alignment. Alternative 1 will have a very flat slope, requiring all year-round maintenance dredging. The canal of Alternative 2 can have a steeper slope that does not require dredging.

### Shortening Navigation Distance to Hanoi

This component envisages reopening the Chau Giang shipping route between Ha Nam and Hanoi by constructing new sluices (Phu Ly Navigation Sluice and Phuc Navigation Sluice) and navigation locks (Tac Giang Ship-Lock). Maintenance dredging of the Chau Giang fairway will be required every 5 years.

### INITIAL ENVIRONMENTAL EXAMINATION

Extended consultations were held with the competent authority at the different levels of Government: National (MARD), Provincial (DARD) and Regional Water Management Authorities (Day Dam Operational Unit) and the Flood Preparedness Committee at Commune level. Interviews with selected beneficiaries and affected people helped identify stakeholders' positions and opinions. The consultant screened the Day River Project following the recommendations of the Environmental Legislation of Vietnam (Part IV, Guideline Documents, 1998). The consultant scoped the project following a Driver, Pressure, State, Impact, and Response (DPSIR) approach, to recognise the environmental issues and to identify to which extent the nature and extent of the project affects them.

The consultant collected baseline data in Government and Research Institutes, and

organised a physical-chemical field survey, covering the dry and the wet season in the year 2001 to typify the initial conditions before the project intervention.

The survey included:

1. The water quality and sediment boundary conditions set by the Red River;
2. The primary flood zones in the Day River bed (quality of surface water, sediments, groundwater and soils);
3. The secondary flood zones outside the Day Riverbed (quality of surface water, sediments, groundwater and soils); and
4. The other areas possibly impacted by collateral water logging, downstream of Ha Nam (quality of surface water, sediments, groundwater and soils).

The aim was to identify the fingerprint of Red River deposits and effects of pollution caused by human interventions. The in-situ observed parameters were pH, DO, turbidity, EC. The Laboratory of the Center of Water Resources Development and Environment (CWE) of the Vietnam Institute of Water Resources Research analysed physical, chemical and biological parameters for water, groundwater, soil and sediment, including heavy metals. The Department of Vegetation Protection of the Northern Pesticide Control Center tested soil and sediment on pesticides' residues.

### BASELINE DATA

#### Surface and Groundwater

Surface water quality in Day River and Red River generally is good and suitable as sources for domestic water supply with proper treatment. Nitrite and ammonia are the most common pollutants in the stagnant parts of the Day River, causing abundant growth of water plants. They reflect the disposal of untreated wastewater and the absence of flow.

Wastewater discharge from resident areas, industrial areas and agriculture production areas locally pollute Day and adjacent rivers. Nevertheless, mixing with Red River water can generally improve water quality of Day River and Nhue River. Groundwater

generally can serve as sources for drinking water supply. However, in some areas, microorganisms and NH<sub>4</sub><sup>+</sup> pollute some wells. Heavy metals incidentally occur at levels not tolerated in OECD countries. Partly they reflect the chemical footprint of the Red River, originating from copper mines in China. Otherwise, heavy metals originate from industrial parks along the Red River and village industry in the Day River, notably lead. High copper concentrations possibly affect biodiversity in the project area, acting as inhibitor for aquatic life.

#### Soils in Day River

Soils in the Day River strongly reflect present or antecedent deposition of Red River sediment, or the absence of such depositions. Red River sediment is rich in lime that maintains the buffer capacity of soils under hot climate. Soils receiving Red River sediments usually are more fertile, less acid and better drained. They have the highest crop yields and allow crop diversification. Soils receiving less Red River sediment are less fertile. This notably applies to gleyic soils in the lower areas, remote from the Red River, showing yellow and gray mottling produced by partial oxidation and reduction of iron, caused by intermittent water logging. The specific problem here is acidification caused by high urea gifts, in a waterlogged environment.

It results in loss of fertility and land degradation. In addition, the Vietnamese soil scientists reported other soil deficiencies, connected with the drainage regime, the application of fertiliser and the tropical climate. Their observations confirmed that regular flooding and deposition of Red River sediment is paramount for maintaining soil fertility and guaranteeing sustainable use of the land.

#### Socio-Economy

The population in the Day River Flood Diversion area is developing fast, from 150,000 in the year 1937 to 600,000 in the year 2001. Still 90% of Day population is working in agriculture. They are subject to constraints in development, imposed by its "green river function". They face costs of emergency preparedness, guaranteeing the safety of the other 17.9 million people



living in the Red River Delta. They also face delay in agricultural development, caused by water shortages, water logging and lack of fertilisation by Red River sediments after the siltation of the Day River entrance. In parallel, flood diversion functions retarded other village infrastructure developments, like tapped water supply, sanitation, and electrification, while primitive village industries substantially contribute to the pollution of water and soils with heavy metals and other pollutants.

The flood diversion function of the Day River otherwise prompted a restricted spatial planning. It imposed constraints to urbanisation and industrialisation in the flood zone, demanding careful control of building licences in the area. It also prompted the establishment of emergency preparedness. The National Flood Control Office takes the decision to open the Van Coc sluices; the Day Dam Office implements it by delegation to Village Flood Committees, who are directly in charge of emergency preparedness, evacuation or sheltering. Hence, all people in the Day River observe a yearly period of emergency preparedness, extending from July 1 to September 30.

### IMPACT OF THE PROJECT AND ITS MITIGATION

#### Day River Flood Diversion

By interviewing authorities and stakeholders, consultants extensively studied the impact of the 1971 event (Figure 7). The impact of flood diversion in the Day River strongly depends on the following factors:

- Area flooded
- Depth of inundation
- Destructive power of the currents
- Scour and deposition of sediment
- Displacement and accumulation of debris
- Duration of water logging
- Accumulation of pollutants, their decay and release of nutrients
- Aggravate effect of coincident or possibly prolonged rainfall
- Rate of denudation as related to micro and macro drainage system
- Evaporation and infiltration of water from the fields

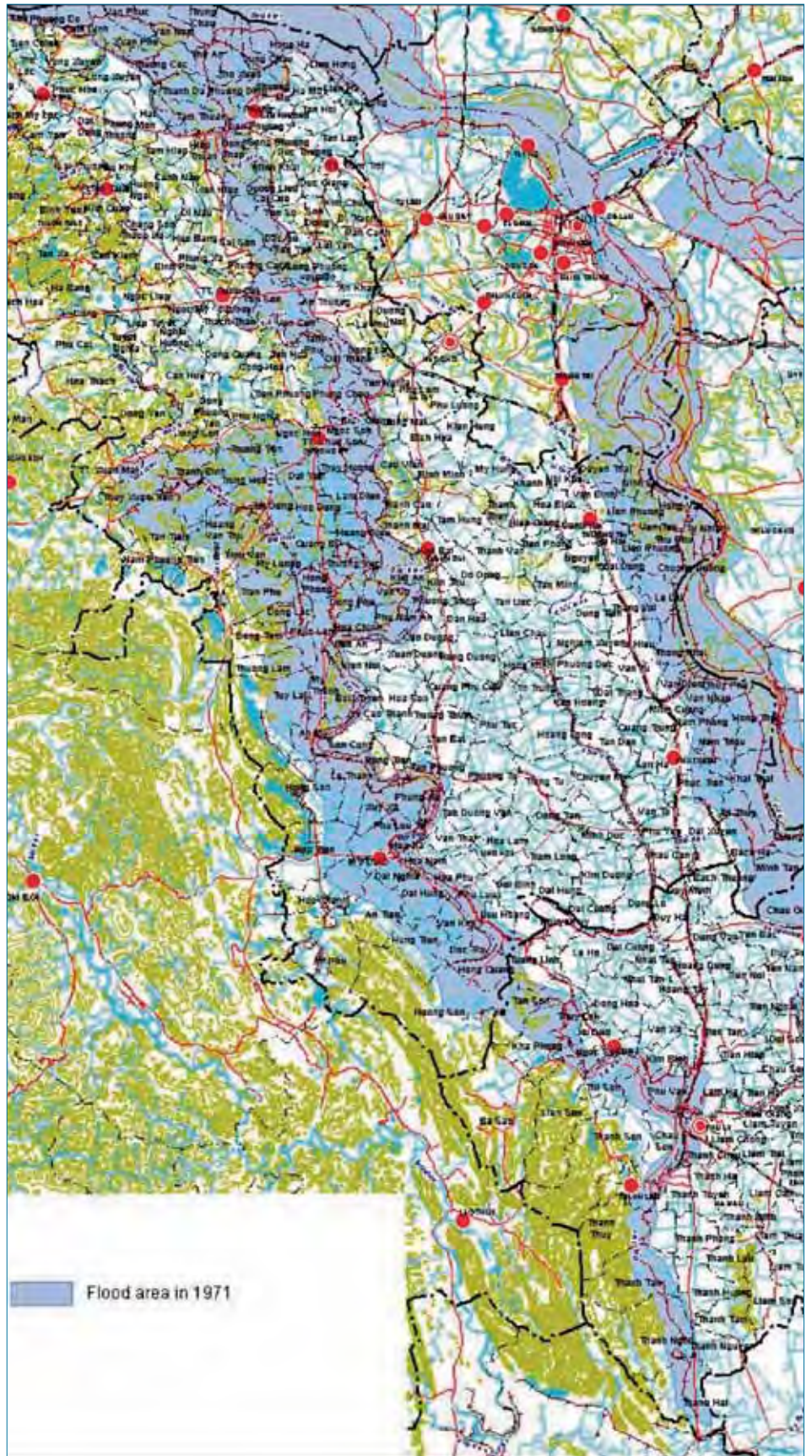


Figure 7. The flooded area in 1971.



Flooding potentially results in loss of life, flood-induced injury, economic damage owing to loss of property, crops and infrastructure, to outbreak of waterborne and water related diseases and social infringements. In the perception of the authorities, there are three zones of impact: front zones, tail zones and danger zones:

1. *Front zones*: People at the front end inundate fast and deep, prompting a high state of emergency preparedness, but the lands denude quickly as well. Upon return, the people will find sediment (“chocolate”) everywhere. Though crops will be lost, the fertilising effect of sediment deposition has profound positive effects on the crop yields, notably in the areas inundated deepest. Rapid clean up, repair and rehabilitation of properties, utilities and infrastructure is possible here. If the dry

season sets on quickly, business can soon be as usual.

2. *Tail zones*: Land at the tail end inundates more slowly and less deeply, prompting a lesser state of emergency preparedness (Figure 8). People have to make the difficult decision, whether to evacuate or to stay in their isolated hamlets, cut off from transport, communication, schools, and so on. Sediment is not covering their property, but debris and scum cover their premises. The water surrounding them will be stagnant for months. It will accumulate decaying organic matter, prompting pathogens and varminths to flourish. People are susceptible to the outbreak of water related diseases and the situation might not improve for months.

3. *Danger zones*: The power of the flood

directly affects some places upstream and downstream of man-made and natural structures. Obstacles will induce streamlines to converge and velocity to accelerate. Downstream of obstacles, velocity streamlines will diverge and velocity dissipates energy. The flood will level such obstacles, unless they are reinforced and resistant to the destructive power of the flood. For example it concerns zones behind spillways where overtopping starts, around bridges, in narrow zones between the dikes and such.

Mitigation measures for Day River Flood Diversion include:

- Structural measures (civil works)
- Emergency preparedness (contingency planning)
- Flood forecasting (rainfall and runoff monitoring)



Figure 8. Flood-prone area in Kim Bang.



Figure 9. Shallow narrowness of lower Day River between Phu Ly and Ninh Binh.

- Flood warning (communicating the likelihood of a flood diversion)
- Attenuation and delay the flood by proper operation of structures
- Sheltering or evacuation (people cattle, properties)
- Denudation (making the land dry after flood)
- Return, clean-up and rehabilitation of properties
- Acting upon lessons learnt (applies to all mitigative measures)
- Improved spatial planning observing the vulnerability zones

### Day River Water Resources Development

The construction of the flood diversion structures in the entrance of the Red River to the Day River blocked the regular flow of water and sediments. Currently some 25,000 ha irrigated land in the project area derives its irrigation water from pumping stations along the Day River. Most of the pumps have an irrigation function, some of them have a dual irrigation / drainage function, others are for drainage purposes only. Most of them need overhaul or replacement. Water shortages are prevalent in the upper and middle reach of the Day River and its tributary, the Tich River.

On the other hand, intensive rainfall at the start and end of the monsoon often creates drainage problems, incidentally in all places or, more commonly and persistently, in the lower reaches of the Day River. The shortage of water for paddy is most serious during spring when land preparation requires large amounts of water. Water logging occurs mostly during late spring (close to the time of harvesting) and late summer, with the onset and end of the monsoon. High use of urea and lacking supply of Red River sediment, in combination with water logging, cause acidification of soils and degradation of low lying lands.

For mitigating droughts and infertility losses, the water taken from the Red River should bring the optimum amounts of water and sediment to Day River's irrigation command area, notably to fields at great distance from the intake, requiring sediment most. During the irrigation season, sediment level in Red River is relatively low (200 mg/l). This is the period that water brought into the Day River will be largest (50 m<sup>3</sup>/s), so that sediment is in suspension. Potentially a maximum amount of 10 kg sediment / second will be taken from Red River. The amount of 40 m<sup>3</sup>/s supports irrigation and 10 m<sup>3</sup>/s is a

minimum base flow needed for flushing the Day River down to the confluence with the Tich River. If there would be no sedimentation losses, 8 kg TSS/s would enter the fields and 2 kg TSS/s would go downstream. Otherwise, the irrigation and drainage infrastructure should be robust at the front, but more flexible at the tail to absorb the impact of flood diversion.

### SCOPE FOR DREDGING

Amongst alternative solutions developed during the environmental impact assessment, dredging had a prominent place. Though traditional dredging is practiced in the Red River Delta, for example for the maintenance dredging of the intakes of the irrigation canals, the present technical opportunities are not used to the full extent.

### Macro Dredging

In addition to the scope of the present project, consultants identified the option for "macro-dredging" of the Lower Day River between Phu Ly and Ninh Bin. The Lower Day River here has to pass limestone barriers at the surface and in the underground, preventing natural scour and deepening of the river. As demonstrated by the 1971 floods, the bottom slope and the perimeter of the Lower Day River do not allow rapid runoff of the water accumulated in the area inundated by the Day River Flood Diversion (Figure 9).

Widening of the Lower Day River and / or possible deepening would speed-up the denudation of the waterlogged areas.



It would require robust interventions, based on blasting and cutting the limestone over a length of several kilometres. One option is to widen the perimeter, requiring resettlement of several hundreds of people and industrial facilities from the densely populated embankment. The social economic costs of expropriation and resettlement will be substantial.

Another option is to deepen the perimeter, creating risks for intrusion of salt water from the Day Estuary in episodes with low river discharge. Prevention of seawater intrusion might require a larger intake of irrigation water from the Red River to the Day River than foreseen in the 50 m<sup>3</sup>/s scenario. There even are prospects for a larger dry weather flow through the Day River. One scenario considered reconstruction of the Day River into a perennial river with a nominal capacity of 1,000 m<sup>3</sup>/s, which would have certain physical and economic benefits.

Investigating the feasibility of this intervention was outside the scope of the present study. An additional study is required for investigating macro dredging as a feasible tool for river training, covering the whole Red River Delta and the joint impact on water, salinity and sediment in an integrated manner

### Micro Dredging

Consultants identified the need for smaller dredging operations for several components of the project. These included maintenance dredging of the Hoa Binh Reservoir to remove silt, capital and maintenance dredging of the fairway of the Chau Giang shipping route and ecological dredging in the Day River floodplain to deliver the Red River water to the irrigation command areas.

Though consultants recommend a lined trapezoidal channel (Q=50 m<sup>3</sup>/s) for routing Red River water from the intake from the Van Coc Sluice to the Day Dam, supported by the required structures for passing the structures, they consider a less robust supply solution downstream from the Day Dam. Rather than continuing the lined trapezoidal channel, they suggest recurrent

micro dredging, harvesting the Red River sludge for deposition on the command area for maintaining and improving fertility. Easy transportable small dredgers would build up and maintain natural waterways in the old Day River bed and floodplain. The small dredger would guarantee a sustainable supply of irrigation water, reception of drainage water and help create a natural buffer for water and sediment in abandoned oxbow lakes. They would enable a flexible response after a major flood diversion, affecting the floodplain.

The antecedent Day River bed would guide the dredgers in finding the best canal's alignment, as topography is the footprint of earlier flood and sedimentation patterns.

Abandoned meanders, steep levees and swampy depressions mark the old Day River. Planting wicker, bamboo and cane would create levees in the wider parts of the dredged channel. Wetlands would be stimulated beyond these levees. Infiltration and overflows from the main artery would feed these impoundments and strengthen their traditional use as village ponds, enabling production of fish, waterfowl, vegetables, water supply or treatment and maturation of wastewater. Dredgers should remove and isolate sediment from "hot spots", contaminated by heavy metals from village industry. Dredgers also should carefully remove, dispose and contain sulfurous clay, apparent near the surface in the lower delta. The primary task of the dredgers however would be to keep the irrigation and drainage canals open, while depositing the fertile Red River sludge on the lands in the command area.

### CONCLUSIONS

Proper management of the deposition of sediment is of paramount importance under tropical climate. Sustainable development of land and water in deltas not only depends on large flood diversion structures, dikes and pumping stations.

The present study scope found scope for "micro dredging" in the Day River flood diversion zone by mobilising movable

dredgers for maintaining irrigation and drainage canals, while depositing fertile Red River sediment on agricultural lands.

The example suggests that dredging can help develop flexible responses to flood- and drought-prone deltas under tropical climate, while maintaining soil fertility and their granary function. To avoid thinking in mega structures and giant dikes, integrated development of water resources in deltas should consider macro and micro dredging as flexible options for keeping up soil fertility and managing floods and droughts.

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*Part IV of the Guideline Documents to Implement Environmental Protection in Urban and Rural Management and Development and Construction Investment, issued as a Circular Letter of the Ministry of Science, Technology and Environment No. 490/1998/TTBKHCMNT 29 April 1998, acting as a guide for EIA in Vietnam. For the water sector, reference is made to Sectoral Standard, 14 TCN – 1997, "Guideline for Environmental Impact Assessment of Water Resources Development Project".*