Technical Paper

STUDI KELAYAKAN TERHADAP PROYEK LEMBAH SUNGAI MUSI BANYUASIN BAGIAN 1: STUDI UMUM SEDIMENTASI

Feasibility Studies on Projects in Musi-Banyuasin River Basins Part 1: General Studies on Sediment

Sohei Matsuno[1] dan Oktarina[2]

ABSTRACT

This is an extract of a feasibility-study report on the two projects, 'Consolidation of Infrastructure of Biofuel Industry,' in Musi-Banyuasin regency and ditto in Banyuasin regency. PART 1 is of general studies on sediment in the Musi-Banyuasin River system where the project sites are located. The primary objective of this report is to forward solution to the sediment-origin problems, which is a compulsory subject for any projects in the Musi-Banyuasin River system. To attain this objective, it clears the following secondary objectives, viz. (a) identifying every problem hindering human lives and activities, (b) drawing a hypothesis about causality, (c) determining basic data by field surveys, lab tests and data analyses and (d) authenticating the hypothesis to be a theory. To achieve these objectives, the studies have gone forward with four representative objects, viz. (i) the Muba River system as a whole, (ii) the lower reaches of the main stream, (iii) the biggest tributary and (iv) the biggest dis-tributary. It concludes that sediment is the sole cause of major problems, forwards measures to solve the problems, and suggests do's and don'ts. PART 2, 'Particular Studies on a Certain Project,' explains how the results of PART 1 are applied to the project. PART 1 leaves the verification of the suggested technical systems to full-scale / in-situ model tests that are elaborated in PART 2 and to be executed in the first step of each project.

Keywords: *sediment-effects, in-swamp irrigation / transportation*

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INTRODUCTION

Economic development in these three and a half decades has brought on conflicting interests. The case discussed here is a typical example. It is a conflicting interest between logging and other activities. That is, the forest fell (often followed by a burn-away technique) to exploit forest resources or to develop mining, plantations, arable fields, etc in the upper basin of the River system brings about debris flow, flashflood and landslide there, resulting in extraordinary downstream sediment transport. It causes a sediment syndrome (a series of phenomenal, socio-economic effects, viz. a rise of WL / river-estuary beds, formation

[1] *Tridinanti University Palembang*

[2] *CV. Maxikom Palembang*

of bars, floods / droughts, upstream expansion of saline zones, difficulties in land / water transportation, agriculture, fresh-water aquaculture, fishery, water supply and the human lives in general) in the lower reaches. This general setting in the River system is often locally aggravated by second causes, i.e., the irrigation-related diversions. In one case, a diversion has eliminated a 200-km long river. In other case, another diversion has silted up a 750-km^2 irrigation area. To mitigate the sediment syndrome is compulsory before entering any development course. Any project that accedes to past poor philosophy and mediocre engineering cannot conduct it.

These Studies' main objective is to forward solution to the sediment-origin problems in the Muba River system so as to help the lowland development. On the way to achieve the main objective, these Studies clear sub-objectives whose major items are: to identify problems, to determine basic data, and to establish a causality theory.

OUTLINE OF THESE STUDIES

Philosophy

These Studies set up philosophy shored up by six policies that are:

(1) One river system should be planned / managed / executed with one policy.
(2) After usage, water shall return to its original river upstream of (or at) the intake point.
(3) Agricultural engineers should learn from past studies and projects.
(4) Current problems caused by past studies and projects must be addressed first.
(5) The agricultural engineers should make the effort to economize every project.
(6) Regional institutions should identify and prioritize the facing problems primarily.

Scope

The rampant logging and sequent burn-away technique in various projects in these decades in the upper basin of the River system have caused acute phenomena, e.g., a debris flow, there, which accelerate downstream sediment transport. The measure to cope with it is simply reforestation. However, it is a national theme. Further, it takes time by nature until it obtains results. On the other hand, the sediment has brought about a chronic syndrome in the lower reaches, from which local people have been suffering. It should be locally addressed. The scope of these Studies is of the lower reaches except the Komering River case that pertains to the middle reaches.

Sub-objects

To analyze such a vast object as the Muba River system, these Studies select representative sub-objects and proceed with them. The sub-objects are:

(1) The Muba River system as a whole
These Studies probe the whole object for specific purposes, e.g., to determine basic data sorted by the main stream, eight tributaries, three distributaries and a canal.

(2) The Komering River
From among major tributaries, the Komering River is chosen, since it is the biggest, and suffering from a serious sediment syndrome aggravated by an irrigation project. From this sub-object, the feature of sedimentation and its effects in the middle reaches are learnt.

(3) The lower reaches of the main stream of the River
This sub-object no longer joins any tributary after runs into tidal swamps at PLG but meets three diversions before finally pours into the Bangka Straits. From this object, the rule of sedimentation in the lower reaches of the River is learnt.

(4)The PU Canal-Banyuasin River

From among distributaries, the PU Canal (the Canal) and the Banyuasin River, to which the Canal joins, was chosen since it is the biggest distributary of the River and the biggest tributary of the Banyuasin River. The River system is affecting the Banyuasin River system by transporting sediment through the Canal. Analyses of this sub-object induce the mechanism of sedimentation in an originally sediment-free river.

Sequence of these Studies

These Studies have been done in the sequence of: (i) Identification of problems in the whole object, and setting up of a causality hypothesis that sees the problems as a continual series of causes and effects. Comment: As these Studies focus on the syndrome in lower reaches, sediment is regarded as the cause. (ii) Surveys on rivers' flow velocity / cross-section and sampling water for SS tests, at 19 key points in the whole object to gather data, from which basic data, water and sediment discharges were determined. The writers also referred to national and international reports for cross checks. (iii) Analyses of a sediment syndrome with other sub-objects. (iv) Authentication of the causality hypothesis to a theory. (v) Seeking solution to the problems. (vi) Publication of the results of these Studies. Comment: This Report has been composed and herein published. PART 2 '*Particular studies on a certain project*' will be published soon after this Report.

ANALYSES

Determination of basic data

(1) General

The Muba River system consists of the Musi and the Banyuasin River systems.

The Musi River system comprises a main stream, eight major tributaries and three distributaries. The main stream and seven tributaries originate in mountain zones. A tributary, the Hari Leko River, has its origin in central plains. The River pours finally into the Bangka Straits after a 650-km run. The C.A. of the River system is 60,000 km^2.

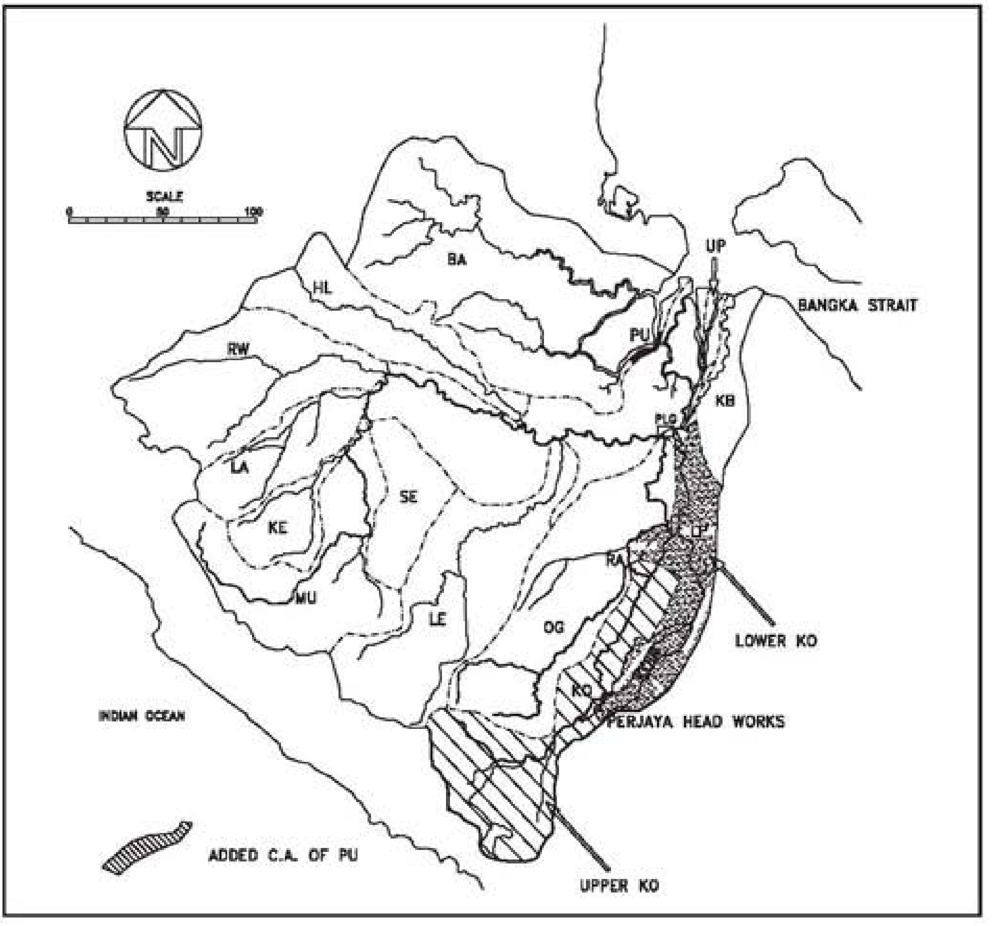
The Banyuasin River system comprises a main stream (100 km long) and three tributaries. It has its origin in central plains but mostly lies on coastal plains. The lower Banyuasin River (so called) is technically a tidal basin of the sea. The C.A. of the Banyuasin River system is 15,000 km^2.

The C.A. of the Muba River system is: 60,000 + 15,000 = 75,000 km^2.

(2) Basic data

The basic data, viz. water and sediment discharges of the Muba River system have yet to be enough determined in the past studies. The JICA report (2003), hereinafter called 'JICA report' shows the water discharge. It says, '*The runoff analysis was carried out at each sub-basin. The runoff model was established by using the software MIKE 11 that was applied for the runoff analysis in the Musi River Basin Study in 1989. The parameters already settled during the Musi River Basin Study were applied for the model in this study.*' However, the models and parameters of the River as of 2003 are substantially different from the ones in 1989. The upper Komering River has become a tributary of the Ogan River, having left the Lower Komering River as a dead river. After the confluences of the Lower Komering Irrigation Canals, the Lempuing River runs into the remnant Komering River with insignificant runoff. Further, it does not take the PU Canal (1976~1978) and the Komering Irrigation Canal (1992~2002), into account. There's no reason to excuse JICA report for forgetting the Komering Irrigation Canal, since JICA is the very body that certified and promoted the Komering Irrigation project. However, there is a reason why it does not take the PU Canal into account. It avoided the painful reminder of the Komering Irrigation Canal. The neglect of the biggest distributary, the PU Canal, is the cause why JICA report cannot define the quantitative sediment discharge of the River. In this context, JICA report cannot talk the sediment-origin problems; much less solution to them. It is discussed again in Sub-sect. 3.3. Given the situation, these Studies carried out their own surveys and tests and to determine the basic data. See **Fig. 1**.

(3) Surveys, water sampling and lab tests
The sub-data needed to determine the basic data are the following three: a cross-section, average flow velocity and SS of each river. Surveys have



Abbreviations of the River and sub-rivers:

MU	: Musi	RW	: Rawas	KE	: Keringi	KB	: Kumbang
KO	: Komering	LA	: Lakitan	UP	: Upang	BA	: Banyuasin
OG	: Ogan	SE	: Semangus	RA	: Randu	PU	: PU Canal
LE	: Lematang	HL	: Harileko	LP	: Lempuing	KOIR:	Komering Irrigation Canal

Fig. 1 Latest state of main- and sub-basins of the Muba River system

Table 1 Basic data of the Musi River system

No.	Name of (Sub-)Basin	C.A. (km^2)	Average Water discharge (M^3/sec)	SS (Wash load) (ppm)	Average sediment discharge (ton/sec)	Average sediment discharge (ton/yr)
-	**Tributaries**	---	**Flow-in**	---	**Flow-in**	**Flow-in**
1	Kelingi	1,900	60	30	0.00180	56,765
2	Semangus	2,150	55	44	0.00242	76,317
3	Lakitan	2,760	80	30	0.00240	75,686
4	Rawas	6,000	200	30	0.00600	189,216
5	Harileko	3,760	160	40	0.00640	201,830
6	Lematang	7,340	290	70	0.02030	640,181
7	Ogan	15,440	600	38	0.02280	719,021
8	Komering	2,690	110	40	0.00440	138,758
Σ	---	**42,050**	---	---	**0.06652**	**2,097,775**
9	Musi before Komering	12,880*	410	42	0.01722	543,050
Total	---	**54,930**	**1600**	---	**0.08374**	**2,640,825**
	Distributaries	---	**Flow-out**	---	**Flow-out**	**Flow-out**
10	Kumbang	1,250	10	50	0.00050	15,768
11	Upang	420	40	55	0.00220	69,379
12	PU Canal	800	190	56	0.01064	335,543
Σ	---	**2,470**	**240**	---	**0.01334**	**420,690**
13	Musi after Komering	2,600*	1400	50	0.07000	2,207,520
Total	---	**5,070**	**1640**	---	**0.08334**	**2,628,210**
Discrepancy between flow-in and –out			**- 40**	---	**+ 0.00040**	**+ 12,615**

* Residual C.A.

been done at 19 key points of the Muba River system, every wet (dry) season, between 2002 and 2005. The River's cross-section is measured in dry seasons by poles (for depth) and a distant-meter (for distance). A propeller type current-meter is used to measure the flow velocity, at two points across the river that divide the river width in a 1 : 3 : 1 proportion and at 1 / 8 depth. The data represent the average flow velocity.

Two bottles of water (500 cc / bottle) were sampled at each flow velocity measuring point. The depth was not considered in sampling since the depth gives no difference in SS ppm. The samples were tested at the Sriwijaya and Tridinanti University labs with calibrated apparatuses of needed accuracy and specified methods.

(4) Water discharge

Fig. 1 delineates the C.A. of the River system of the real state of the River system as of 2005. The average annual water discharge at the end of each channel is shown in **Table 1**. It shows the River system's total runoff as 1620 M^3/sec. It is equivalent to 850 mm/yr rainfall and is about 50 % of average annual rainfall of the River basin. It means annual evapo-transpiration is about 50 %. The run-off / rain-fall of 50 % are much greater than Euro-American data, e.g., 17 % for the Seine River, France (Jemes Gilluly, Aaron *et al.* 1950). One of the causes is the deforestation in rapid zones. *En passant*, annual average rainfall used in these Studies is not 2000 mm/yr as generally acknowledged but 1700 mm/yr. It is based on the fact that the raining area in the River basin, particularly in plains that occupies 2/3 of the River basin, is small.

(5) Sediment discharge

Investigations in the U.S. with thousands of test lands as objects

Table 2 Land Use in the Musi River basin (in 2000) and soil loss by erosion

Item of land use suspected Of producing sediment	Area (km^2)	Ratio of area to Musi River basin (%)	Soil loss by erosion (ton/acre/yr)*	Ditto (ton / Km^2/yr)
Deforested area	3600	6	0.04	10
Deforested & burned area	1800	3	0.72	180
Big scale plantation area	1800	3	0.70	175
Farmers' arable area	24000	40	0.75	185

throughout the country defined the soil loss by erosion sorted by land use (Jemes Gilluly, 1950). It says there's no erosion if the land is covered by a thick forest. (H. H. Bennet, 1939) is quoted by it as stating that 1/3 of eroded soil reaches the sea. Referring to these literatures, the writers assume that 90 % of sediment is from erosion of forest-fell areas with burn-away practices, plantations and farmers' arable lands. The land use of each item is learnt in a satellite image. The annual sediment discharge can be computed based on the data from the survey and the two literatures. It is shown in **Table 1**. Refer to **Table 2** as well. The result is cross-checked with the one derived as per the literatures' method. It yields: (3600 × 10 + 1800 × (180 + 175) + 24000 × 185) / 3 / 0.9 = 1.89 million ton/yr.

This is smaller than writers' estimate, 2.63 million ton/yr. The cause is deforestation. It hints at a need of careful interpretation when a foreign method is applied to in RI.

JICA report allocates eleven lines in the item '*Sedimentation in lower Musi River*' for sediment that is a keyword in the hydrological analyses of the Muba River system. It quotes four studies as reporting, '*The results of sedimentation studies on the Musi River give the sediment level as follows; Frankel USA 1968: 40 cm / month, JICA Japan 1976: 43 cm / month, Observation of Pinbagro Faskespel Sum-Sel 1999: 2-4 cm / day and Observation of Third Pelindo Company 1999: 2-4 cm / day.*' As stated in Sub-sec. 3.3, sedimentation does not occur uniformly along the River; hence, the sediment level does not make sense in sediment transport unless the areas of the level rise are given. Further, Frankel report (1977) committed erroneous thinking when it confused advance of the coast line toward the sea due to a recent unnatural cause and the one due to a natural cause. This theory was fantastically expanded by Haskoning Report (1983) that says, '*PLG was facing the sea 700 yrs ago.*' See **Fig. 8.**

Every plan is kindly advised to refer to **Table 1** with attention to occasional extraordinary sediment transport due to forest-fell in the upper reaches of the River.

Flood and drought in the Komering River

(1) From a global point of view

'*Seven major rivers in the world no longer reach the sea because of the demands of irrigation.*' Margaret Catley-Carlson, Chairperson of the Global Water Partnership, was quoted by the Jakarta Post (August 29 2002) as saying. The writers' interpretation of her remark is, '*.... ditto .... because of the inadequacy of irrigation.*' In ancient times, floods brought fertile soil from upper to lower reaches of major rivers on which civilization flourished. In agriculture-based feudal times, bases of the irrigation system had been settled. Now in modern times when the society largely depends on industry, the irrigation system is basically still the same as old times'. The flood and drought of the Komering River are to be learnt keeping the above in mind.

(2) Second cause

Floods and droughts in the lower reaches are the two effects of the one cause, 'sediment' generated by deforestation. However, this common setting does not excuse worsening the situation by adding second cause. The river-basin dwellers along the Komering River gave the writers a piece of instructive information: '*The situation has become bad to worse since the Perjaya Head-Works started its operation in 1992.*' What they couldn't was to offer a convincing causality. It is agricultural engineers' business. The writers do it.

(3) Causality theory

JICA report defines the calamities as '*Distinguished phenomena that are commonly seen in the Musi River system.*' It adds: '*Sedimentation downstream from the diversion point of the Randu channel that bifurcates toward the Ogan River has brought on droughts to the Lower Komering. The Komering River consequently flows into the Ogan River resulting in floods in the Lower Ogan.*' This theory that names the Randu River as the cause is understandable as a subjective insertion by the institution that justified the Komering irrigation project in a pre-project assessment. Objectively speaking, however, the behavior of the Randu River (existing there for a geologically long time) is not the cause but one of the effects of a real cause. What is the real cause then? This Report answers. The Lower Komering River has died out and the Upper Komering River has become one of the tributaries of the Ogan River. Such a drastic morphological fluctuation does not exist anywhere in the River system. Hence, besides the common setting, there must be balance destruction happened concurrently with the fluctuation of the Komering River. The construction of a diversion canal for the Komering irrigation at the Upper Komering (Stage 1 and 2) in 1992~2002 is red-handed in the act. See **Fig. 2**.

As stated already, the rule of sediment transport is: 'the less the quantity (velocity) of water flow is, the less the sediment transport capacity is.' Hence, remarkable sediment-deposit in the River can be seen at every diversion of three distributaries. JICA

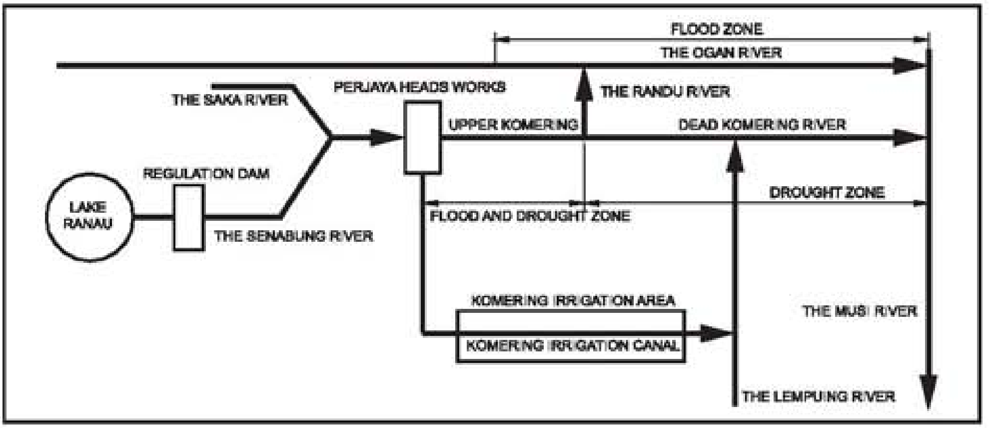


Fig. 2 Komering irrigation in Ogan-Komering River system

report itself acknowledges this fact at the Randu River diversion. The diversion canal from the Komering River for irrigation has the same effect as the Randu's, but it was overlooked in the feasibility study. Worse still, there are operational / structural inadequacies at / of the irrigation's Head-Works. That is, sediment months-long accumulated behind the Head-Works' barrage and the irrigation canals' sedimentation basins is washed away to the Komering River in one-day operation. The structures are so designed to enable it. Refer to **Fig. 3**.

The operation is carried out three times a year. Quantities of sediment discharge are estimated at 430 thousands m^3/yr from the barrage and 70 thousands m^3/yr from the sedimentation basins. That is, the irrigation takes in 50 % (250 M^3/sec) of water from and returns 100 % (500 thousands m^3/yr) of sediment to the Komering River. Miraculous indeed, would such operations bring no matter in the original river. These acts are the cause of exceptional high-level sedimentation along the relatively steep middle reaches.

Fig. 4 shows the longitudinal profiles of the River and the Komering / Ogan Rivers. As seen, the WL of the Komering River down from the Perjaya Head-Works is on average 10 m higher than the Ogan River's. It inundates the Upper Komering in wet seasons and dries up the Lower Komering in dry seasons. After the Randu River diversion, the phenomenon is more intense as it is subjected to double effect of the Komering Irrigation and the Randu River. The WL difference between the two rivers is 15 m at the Randu diversion where remarkable slope change is seen. Normally, a river in a plain shows insignificant profile changes. The Randu River was a tiny river of 10 m wide, 0.5 m deep with slow flow in 1970s. High flow velocity and the due erosion by an increased WL difference between the two rivers have made it be of 120 m wide, 6 m deep at the diversion with 5 m/sec average flow velocity now, bringing frequent waterway accidents that have claimed a dozen people including school children who were going to school by boats.

The fate was sealed when JICA judged the minimum water release to the original Komering River at 35 m^3/sec without considering sediment's reaction. It should have been 500 M^3/sec unless otherwise river-trained. The basic data, when the Komering

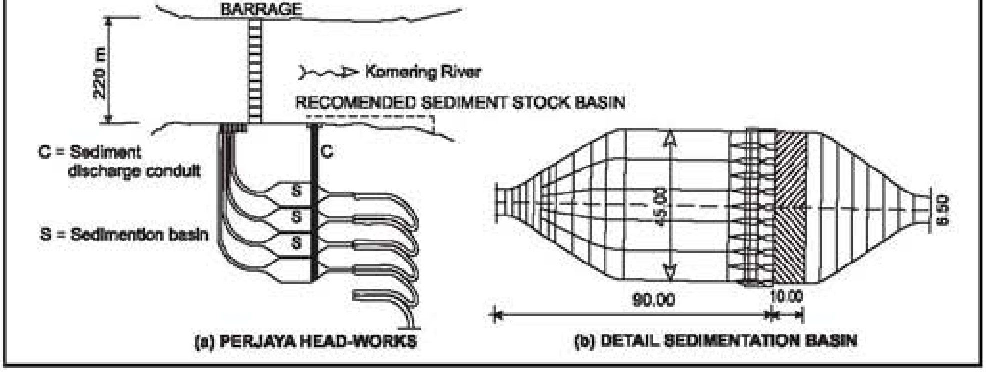


Fig. 3 Perjaya Head-Works (based on PU data)

Irrigation project was planned, had been ill-defined.

(4) Matters with the case

The first matter is that JICA consultants learnt nothing from past lessons. First, the cause of the problems of Komering is the same as the cause of popular no-more-dam movements in Japan. Well, there may be an excuse for ignorance of it since the sites are far distant each other. Then, how about the PU Canal diversion? The 750 km^2 irrigation areas and 40 km long upper reaches of the Banyuasin River have been totally silted up due to the similar cause to the Komering's. These two canals are in the same River system in the same province, and when the Komering Irrigation project commenced in early 1990s, the problems of the PU Canal diversion had been already painfully obvious. Again, it may be no wonder since they are not aware of the consequence of their own project.

The second matter is if the parties concerned acknowledge the fact. JICA carelessly confesses to the fact when it says in the JICA report, '*There are serious sedimentation problems in the middle and lower reaches of the Komering River. River flow in the downstream of Perjaya Head-Works is not stable because of sedimentation caused by the divergence,*' but won't confirm it in due diligence statements. NGO is unreliable. The writers were disappointed when they learnt Japanese NGO's *review-the-case* action plan paying no attention to the project's side-effects but only to its effects.

This Report recommends a set of do's and don'ts in this regard later.

RESULT AND DISCUSSION

Complex problems in the lower reaches of the River

Rivers are generally in dynamic balance under the three given elements, sediment load, quantity and velocity of

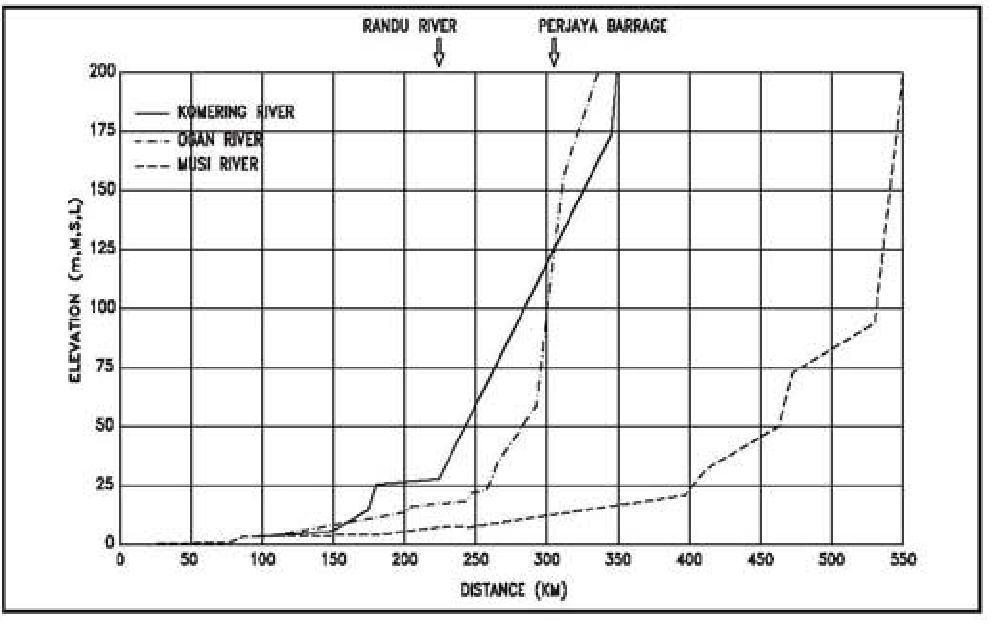


Fig. 4 WL gap between Komering and Ogan Rivers (based on the JICA report)

water flow. However, the balance is broken when even one of them changes. Rivers adapt themselves to the change dynamically. The natural fluctuations are invisible in a human historical time range. In these modern times, however, rivers are often exposed to man-made balance changes. Yearly dredging of the lower reaches of the Musi River (a sediment load decrease vs. a constant water flow) is an example. The River quickly recovers the original regime against the minor balance change. A major balance change by deforestation (a sediment load increase vs. a constant water flow) is a different example. It forces rivers to change their regime, i.e., raising river bed / WL so that they adapt themselves to the new setting. A drastic balance change by Komering River diversion (a water flow decrease vs. constant sediment load) is an extreme case in which a river responses with a morphological regime change, i.e., disappearance of the river itself. A similar example is the silting-up of irrigation areas in the Banyuasin River tidal swamps.

Fig. 5 shows the longitudinal profile of the Lower Musi River in Jan. 2002. The survey was done 1.5 yrs after the last dredging. It was in dynamic equilibrium. The rule 'the sedimentation is governed by quantity and velocity of water flow vs. quantity of sediment transport' is proven by the **Fig. 5** and **6** that show: (i) the places where the depth is shallow are diversions, (ii) the places where dredging is yearly done (the places where sediment is conspicuous) are diversions, and (iii) the section where greatest dredging is executed every year is the estuary where water no longer flows.

Floods and droughts in the Banyuasin River basin

(1) The site particulars

Fig. 9 shows an irrigation network in the lower reaches of the Muba River system.

It measures at about 2000 (net 1500) km^2 and occupies 1/3 of Muba tidal swamps that are mostly in Banyuasin regency (about 1100 km^2) and partially in Muba regency (400 km^2). There is a socially influential construction plan of an outer port at the estuary of the Banyuasin River mouth, Api-api Cape. However, the Lower Banyuasin River (technically the Banyuasin Bay) is quickly losing its depth and width by sediment from the Canal, resulting in lowering its

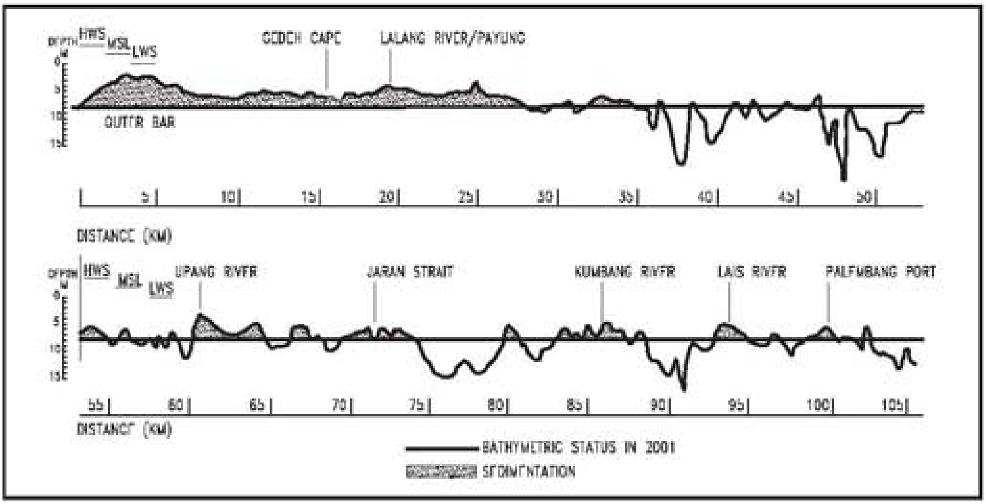


Fig. 5 Profile of the lower-reaches of the Musi River

function as a tidal basin. This tendency is symbolized by the sudden emergence of a new Is., Pulau Baru, in early 1970s along the western edge of the Bay near the Cape. The flow velocity at the Bay mouth (synonymous with *natural dredging capacity*) has reduced from 3 knots (2002) to 2.5 knots (2005). Thus, the criterion on which the site was selected for an outer port is quickly disappearing.

(2) Problem and analysis

In general, rivers in swamps develop no sedimentation by nature. The Banyuasin River system (almost totally in swamps) belongs to this category. However, the irrigation system developed from 1969 to 1986 has been paralyzed by sedimentation since early 1980s. Farmers are suffering twofold calamity of flood and drought every wet and dry season. The harvest is 0~1 crop a year. It was 2~3 crops a year before 1980. In many irrigation units, farmers have given up agriculture and working outside the irrigation areas. In one case, the manpower in a unit of 208 families is all working outside. The cause of the trouble is sediment from the Canal. The Canal (5 km long) was 20 m wide, 1 m LWS deep, 0.01 % surface-water slope and 0.2 m/sec flow velocity when it was completed in 1978. They are now 80 m, 4 m, 0.04 % and 1 m/sec respectively (all on average, surveyed and

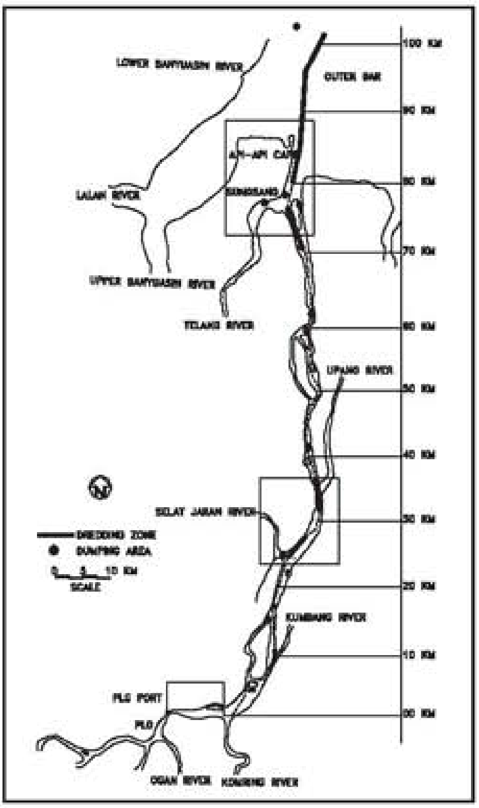


Fig. 6 Places where dredging and dumping are done routinely, (PLG Port)

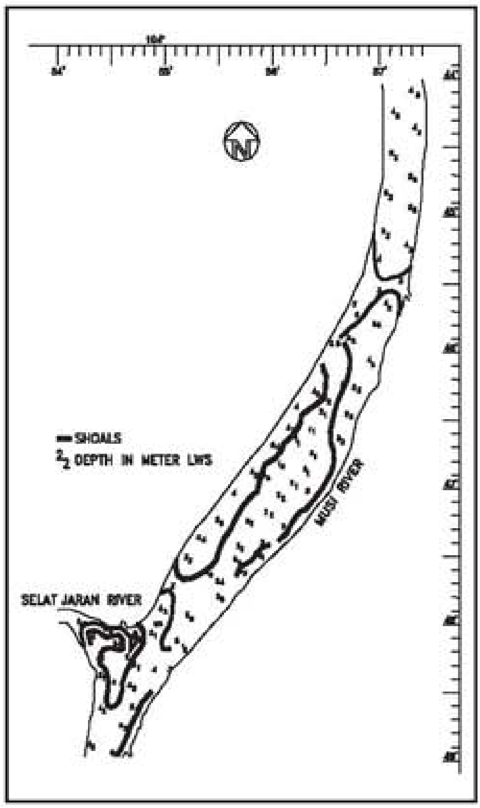


Fig. 7 State of shoals at Selat Jaran River diversion that leads to the Canal, (framed in **Fig. 6**, Hasconing1983)

supplemented by Chezy's formula). The regime fluctuation of the Canal and the Randu River is similar. That is, sedimentation took place in the original Telang River (the name of the lower reaches of the Selat Jaran River after the Canal diversion). It restrains water from flowing into the Telang River and raised WL at the diversion. As the WL at the confluence is unchanged, the surface-water slope (flow velocity) has increased. It causes erosion and scouring of the Canal. The enlarged Canal is transporting 340 thousand ton/yr sediment. The silting-up of the irrigation system occurs in a following mechanism: (i) Sediment discharged at the Canal confluence follows tide. (ii) If it ebbs, the sediment runs down the Banyuasin River toward the estuary. (iii) While the sediment has yet to reach the Bay mouth, it meets high tide, then the sediment runs up. (iv) When it reaches the confluence of a tributary, the Lalan River, the sediment runs up both the main stream and the tributary. (v) After it covers the irrigation area, the tide slacks for about 20 minutes before it ebbs, during which SS deposits. This mechanism can be read in a satellite image in which behavior of SS is clearly seen as yellow colored streams. To fully explain the silting-up, one more fact must be taken into account. It is occasional extraordinary sediment transport. The phenomenon happened in the upper reaches can reach the Canal within months. The irrigation system is such that taking in and draining out water at the same point(s) following tide. This setting accelerates the sedimentation. The plugged irrigation canals and the Banyuasin River bring floods and droughts as the Komering River does. To reach a sustainable solution, the closure of the Canal and the establishment of a lower-to-upper-flow irrigation (see **Sect. 4**) are essential. The situation in other paddies in the River's basin are qualitatively the same but quantitatively less affected by sediment than the Banyuasin River's because of greater natural dredging due to a greater water flow there.

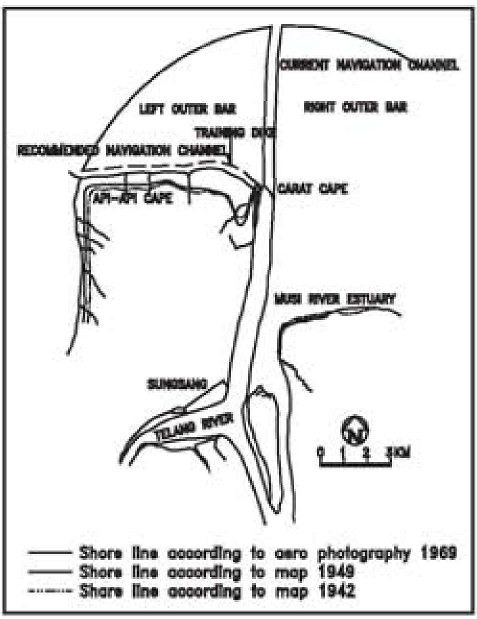


Fig. 8 Erosion and expansion of Coast lines (framed in **Fig. 6**), (Frankel 1977)

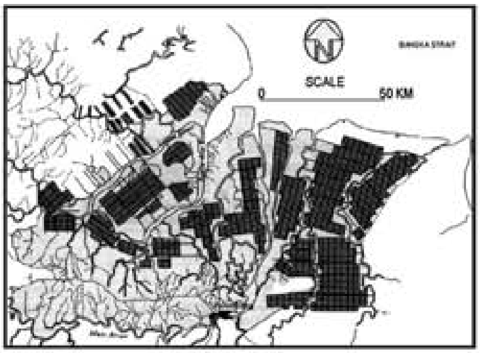


Fig. 9 Paddy irrigation system in the lower Muba lowlands (PU Banyuasin)

Specific Techniques

For better achievement of measures, there are specific techniques, such asn follows:

(A) Lower-to-upper-flow irrigation system

(1) Origin of the idea and practices

These Studies recommend a gradual conversion of the conventional reversal-flow or upper-to-lower-flow irrigation system in plains into the lower-to-upper-flow one. The idea was motivated by the fact that a sediment-origin inundation in plains proceeds in a lower-to-upper direction, because it occurs in a form of backwater due to sediment bars as submerged weirs. If the natural inundation goes in a run-up mode, irrigation, an artificial inundation, will better fit if let it go in the same manner by man-made weirs.

In this irrigation system, used water returns to an original river upstream of (or at) an intake point. In this way, water quantity and velocity of the original river are less reduced than in the conventional way. There is no slack in this irrigation system, hence, is less affected by sediment. This method has been applied to thousands hectares of tidal swamps as of 2005 since it was published in a local newspaper and two academic journals in 2002.

(2) Types and operation

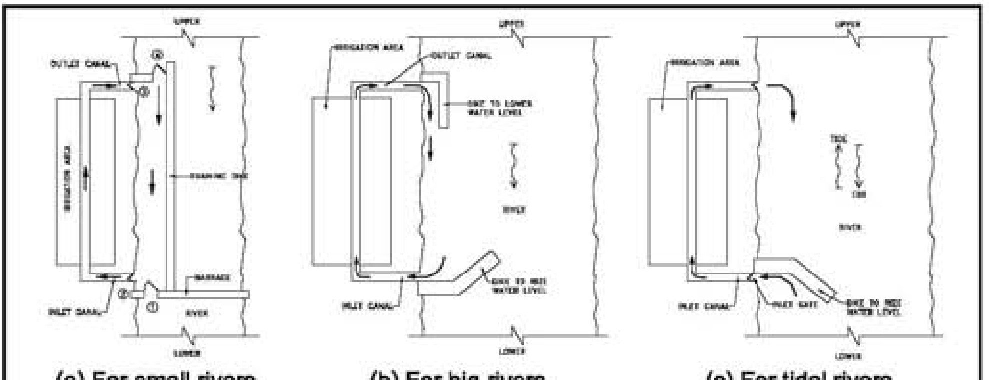
There are three types of the system (see **Fig. 10**).

Type (a) is for non-tidal rivers of less than 30 m wide. In a one shift of operation, gate (1) / (3) closed and gate (2) / (4) opened. When water has saturated the irrigation area, gate (1) / (3) opened and gate (2) / (4) closed. Repeat the same process. The WL adjusting chamber of the barrage is used for a level-lock chamber for vessels that pass the barrage. Type (b) is for non-tidal rivers of more than 30 m wide, to which a barrage across the river is unfavorable. The lower dike is to heighten the WL, and the upper one is to lower it. This type has no gate. Type (c) is for tidal rivers. The lower dike (amplifier of tidal waves) can be omitted if HWS at the intake point is equal to or higher than EL at the outlet points. The method is applicable to any river in plains.

(B) Training-dike installation for natural dredging

(1) General

Though the lower-to-upper-flow irrigation system mitigates the sedimentation in the irrigation system, the other chronic problem,



(a) For small rivers (b) For big rivers (c) For tidal rivers

Fig. 10 Three types of lower-to-upper-flow irrigation system sedimentation at the River estuary remains. It is solved in a different way, i.e., the installation of total 25-km long SSF-made training dikes. The training-dike guided canal is designed learning the width-depth (W-D) and radius-depth (R-D) relationships of the River and calculations by Chezy's formula. The height of the dike above HWS is determined by the wave height that measures maximum 2 m at the edge of outer bars.

(2) Width and depth

As discussed earlier, the capacity of sediment transport is governed by quantity and velocity of water flow. This rule also governs the W-D, R-D relations. Suppose the water flow quantity and sediment transport are constant, what the W-D would be. To have a quantitative solution is a conundrum, though it is qualitatively sure, 'the wider (narrower) the width is, the shallower (deeper) the depth is.' Then, let's find the solution at the site!

The W-D and R-D relations along the main stream down from PLG are shown in **Fig. 11 (a)** and **(b)**. Both show clear correlation. The width of the curved sections of the River is shown in parenthesis, e.g., (W = 263 M), in **Fig. 11 (b)**. It is the total width of the river. There's no relation in W-D. However, the relation is visible if D represents the deep channel of the curved section. When water flows in a curved section, water flows quicker along the outer side than the inner side. The shorter the radius is, the quicker the water flow is (the greater the dredging effect is). If the width of this deep channel vs. the depth of the deep channel is plotted, it falls on the same curve as in **Fig. 11 (a)**. That is, R-D is another expression of W-D.

A W-D (or an R-D) combination for a particular purpose can be found with these **Figs**. For instance, depth of 7 m LWS is needed, following arrow lines in the **Figs**., the width (or radius) of the navigation channel, 550 m (or 3150 m), can be found. The River's width (or radius) thus chosen gives dynamic equilibrium unless otherwise disturbed. The outlet of the channel is off the Api-api cape so that transported sediment is washed away by tidal currents that is 1~1.5 m/sec (2~3 knot) there. The construction cost of the training dike, made of secondhand 6" and 3" steel oil/gas

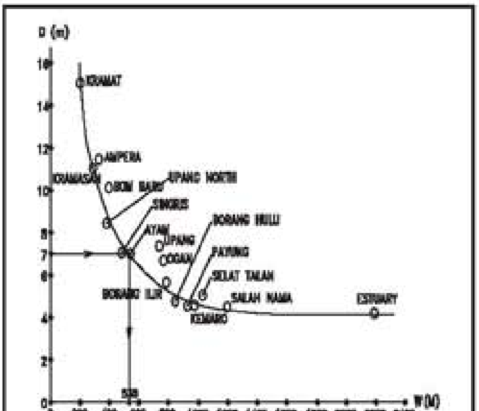


Fig. 11 (a) W-D relation in the Lower Musi River (Dec. 2000)

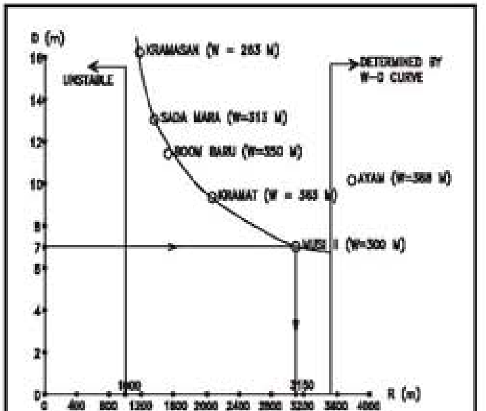


Fig. 11 (b) R-D relation in the Lower Musi River (Dec. 2000) pipes or equivalent and plastic soil sacks, is Rp 4 billion /km. The necessary length of the training dikes is 25 km long at the estuary Cape and 15 km long for three locations of the River section. It is less than the present value of the forever annual dredging cost (Rp 16 billion /yr). It enables 18000 DWT boats to free sail up to PLG. The outer port and its inevitable consequence, eco-environmental destruction, can be scaled down by this measure. The effect of the training-dike can be confirmed by full-scale / in-situ model tests.

The waterway thus designed reduces the floods by eliminating bars' dam-up effect.

It also minimizes upstream saline zone expansion. The mechanism of the phenomenon is: When it tides, brackish water overtops the sediment bars (2.5 m high) when a tidal wave (3 m high) runs up. When it ebbs, the brackish water forms a lower layer. The fresh water at the upper layer overtops the hurdles (sediment bars), leaving the lower layer behind. The uppermost saline zone has already reached the northern PLG, Kenten Laut, and brought big damage to fresh-water aquaculture there.

(3) Conceptual structure

Fig. 12 shows a concept of the training dike. The structure (other structures as well) is made of combined S(C)SF, plastic strings, and secondhand steel gas/oil pipes (normally coated), electric poles or logs. Any other alternatives are uneconomical.

CONCLUSIONS AND RECOMMENDATIONS

(1) The basic data in sediment analyses have been determined for the Muba River system.

(2) Imminent sedimentation in the River is observed at every diversions and estuary. It causes chronic sediment syndrome in the lower reaches.

(4) Man-made diversions aggravate the situation in the Muba River system expanding the suffering areas up to the middle reaches and to an originally sediment-free river.

(5) As the current problems are the consequences of the projects of past philosophy and engineering, the measures to solve the problems need reform and innovation. One of the suggestions is the lower-to-upper-flow irrigation system.

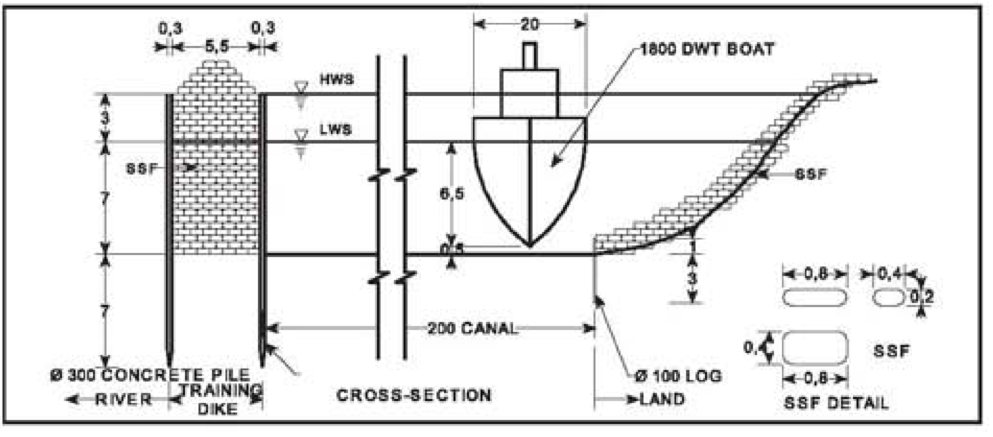


Fig. 12 Training dike for sediment free waterway

(6) These Studies recommend lists of strategic do's and don'ts for the River's future fitness.

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