JOURNAL OF
ENVIRONMENTAL HYDROLOGY
The Electronic Journal of the International Association for Environmental Hydrology
On the World Wide Web at http://www.hydroweb.com
VOLUME 15 2007

IMPLEMENTATION OF AGRICULTURAL AND ENGINEERING TECHNIQUES FOR SEDIMENT CONTROL IN THE CIMENENG RIVER BASIN, INDONESIA

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The Segara Anakan Lagoon has been predicted to go dry by 2010 due to the silting up of the Cimeneng and Citanduy Rivers feeding the lagoon. To address this problem, the Government of Indonesia, through the Activity Organizer Center for River Catchment Management of Citanduy-Ciwulan has conducted a study involving structural and non structural measures in the Cimeneng River. The study shows that a sediment reduction of 97 % by annual tonnage or 97 % by annual sediment depth is possible in the lagoon by implementing the proposed sediment control measures on the river. This reduction is further confirmed by the low CP factors obtained.

STUDY BACKGROUND

Segara Anakan is a big lagoon located near Cilacap town in central Java, Indonesia. Rich in nutrients, its water and the occurrence of mangrove support living creatures such as various fish and shrimps. The surrounding inhabitants make use the wealth of the lagoon to fulfill their daily needs and for many their livelihood depends on the existence of the lagoon. This dependence on lagoon resources has existed for many generations. At present, the number of inhabitants that depend on the lagoon has increased to tens of thousands of people. Unfortunately, at some time in the near future, the lagoon will go dry as predicted by a study by Binnie Black & Veatch LTD (2005). Its useful life is predicted to end before 2010 due to silting up caused by sedimentation mainly from the Cimeneng River and also from the Citanduy River both of which empty into the lagoon (Figures 1 and 2).

At the beginning, in order to handle the sediment, the Government of Indonesia, through the Activity Organizer Center for River Catchment Management of Citanduy-Ciwulan conducted the development and conservation of the lagoon. The implementation consists of developing short cut structures at the Cimeneng and Citanduy Rivers, dredging the lagoon, and improving the drainage system and flood control along the rivers. However, these efforts are not enough to overcome the problem. There is a need to control the sediment for the entire length of the river from upstream to the estuary. Hence a study involving structural and non-structural measures in the Cimeneng River was conducted to find mechanisms to reduce the sediment quantities carried by the river (Figure 1).

CIMENENG CATCHMENT CONDITIONS

Based on the geographic map, the Cimeneng catchment is located in the Districts of Cilacap and Banyumas, Central Java, Indonesia (108^o 53’ 30” - 108^o 59’ 30” East Longitude and 07^o 22’ 30” - 07^o 37’ 00” South Latitude). Basin elevations range from about 90 to 225 m above mean sea level. The Cimeneng catchment covers areas of four sub districts (Karangpucung, Lumbir, Kawunganten and Gandrungmangu) and is a part of the Segara Anakan catchment. It has average rainfall of 119 mm/month. The Cimeneng River is the main river of the Cimeneng catchment. It discharges to the Segara Anakan Lagoon and carries a sediment load of 12,409,000 ton/year equivalent to a sedimentation rate of 69 mm/year. Concentrations of sediment range from 9.5 g/l to 18 g/l for discharges of 40 and 60 m^3/s, respectively. The sources of sediment are from erosion of the Cihaur catchment (57.53 km^2), the Darmaji catchment (56.26 km^2), the Cikonde catchment (108.29 km^2) and the lower Cimeneng catchment (112.32 km^2). It comprises two types of erosion; the first is sheet erosion from areas generally used for the pine and teak industry by government and private joint venture firms, and traditional agriculture of the local people. This erosion occurs because of poor infiltration and increased runoff caused by land use changing from covered, vegetated land to open land. Most users of those lands are ignorant of and do not practice proper management of the ecology of the catchment area. The second type of erosion is in the river bed and banks where it occurs due to the steepness of the river bed slope. Water flow has the potential to erode the river bed, and where sedimentation on one side of the river directs the flow focus at the opposite side, erosion occurs at the river bank. Examples of these erosion processes are shown in Figure 2.

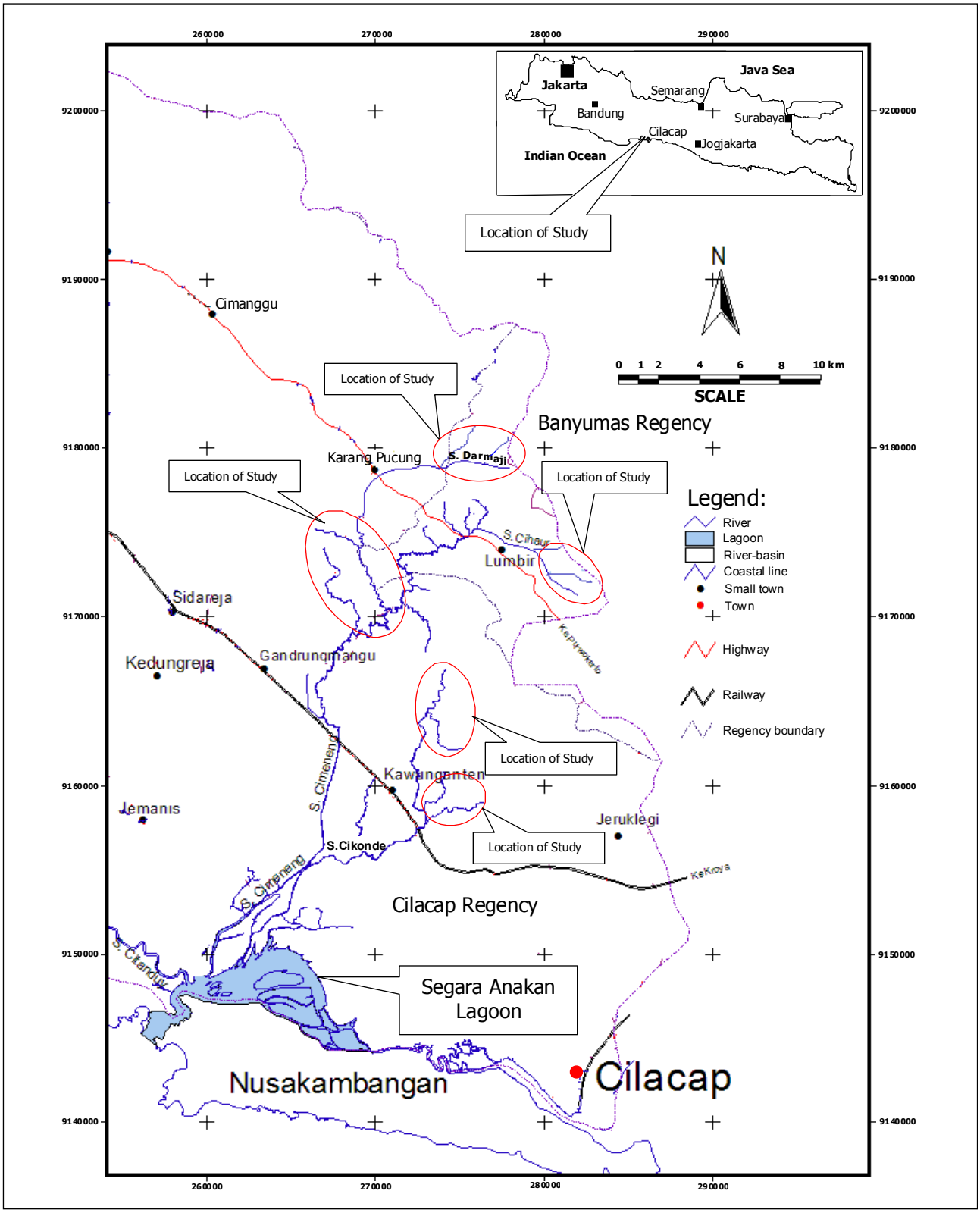

Figure 1. Location of sediment control studies in the Cimeneng river basin.

GEOLOGY OF THE CIMENENG CATCHMENT

Surface geology of the river bed and bank of the upper Cimeneng River shows a significant layer with a slope around 60º to 80º. In the middle of the river is sedimentation of boulders and gravel with diameters around 3 to 20 cm as well as fine sand to rough sand. Gravel and boulders form

Figure 2. Erosion and sedimentation in the Cimeneng River.

semicircular to circular patterns and are derived from colluvial sediments and soft clay stone. The ratio between sand and gravel is about 35% to 65%, respectively. The left and right side of the river exposes a steeply sloping hill mainly consisting of strongly weathered marlstone covered by colluvium as residual material that is typically less than 1 m thick. Vegetation is scarce in the pine forest and bush. The left side of river is a landslide risk area as the slope is steep and the land surface is open. Meandering processes still occur at some points of river, where the water flow focuses only on one side of river to strike and erode the bank.

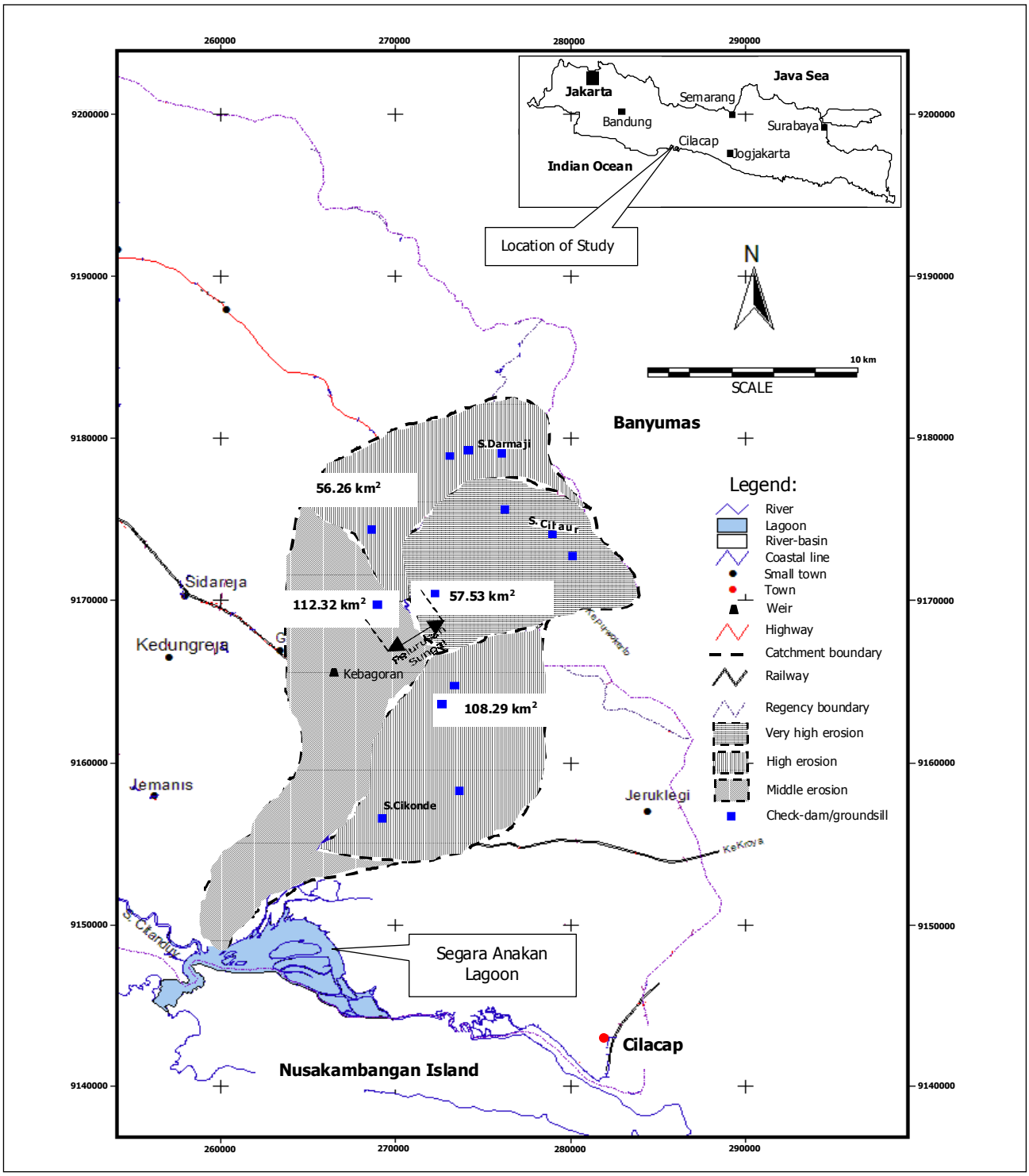

Figure 3. Drainage net map and proposed civil engineering structures for the Cimeneng catchment.

SEDIMENT HANDLING CONCEPT

An ecosystem is a system that consists of biotic components which are integrated with one another to form a well regulated unit. Activity of any component always has an effect on another component. Catchment area can be considered as an ecosystem, and human activity one of the important components of the system. An ecosystem must be considered holistically by identifying its key components and studying their interaction. The holistic approach is carried out in order that the exploitation and conservation of natural resources can be done efficiently and effectively to

fully realize the exploitation of natural resources for sustainable development. Management of the catchment area as an ecosystem is required and finding benefits from production and service must consider the natural balance to avoid damage to land and water resources. Some activities of managing the catchment area in the upper stream reaches, such as land management activities which do not consider the conservation system, can generate high erosion and impacts downstream in the form of silting up of the river and channel (Asdak, 2000).

To optimize the management efforts for erosion and sediment in the Cimeneng catchment requires that both erosion processes (sheet erosion and river bed and bank erosion) be considered simultaneously. The river bed and bank erosion can be controlled by building civil engineering structures at the observed erosion risk points (Figure 3 and Table 1), while the sheet erosion can be controlled by using land conservation methods (Table 2). These efforts are part of a national program aimed at saving forest, land, and water resources. There are four targets: 1) to improve the function of the hydrology of the catchment area, 2) to enhance the productivity of natural resources, 3) to enhance the awareness of people who use land about the principles of land and water conservation, and 4) to enhance the quality of the living environment. While the main target of land conservation is to get land production to a sustainable level by keeping the rate of erosion under an acceptable limit, theoretically the rate of erosion loss must be lower or the same as the rate of land formation. As erosion is a natural process which cannot be avoided, the only effort is to reduce the rate of erosion up to the maximum acceptable limit. The first step is to make an inventory and classification of the land for optimum land use.

RESULTS AND DISCUSSION

Managing erosion in an engineering manner must include support and rehabilitation for erosion control using reforestation and greening methods (efforts in agricultural techniques). A check dam functions as effective control of erosion and sediment, and in this study several check dams are proposed to be built mainly in the Darmaji and Cihaur catchments (Figure 3). The first step in the determination of check dam location is to prepare a map of actual erosion risk level which has high and very high erosion risks, and overlay it on a map of the drainage net. The location of check dams which are able to detain the rate of erosion can then be determined. Based on this method, nine check dam locations are proposed including four cribs, four retaining walls, one river straightening, one river structure improvement, and four groundsills as listed in Table 1.

By using the prediction method (Uniform Soil Loss Equation method) of Wischmeier and Smith (1958) which is based on the present land use, a map of actual erosion can be made (Figure 3). From this map, the locations which have high and very high erosion risk can be found. According to the classification of erosion level (Table 3), the main priority is to handle erosion in the locations with high and very high risk using agricultural methods. The second step is to design the proposed land use which is listed in Table 3 so that the rate of erosion can be reduced to an average erosion level, or even if possible to a minimal erosion level. The erosion rate is assessed using the following equations:

1. Rainfall erosivity index,

$$R = E \times I_{30} \times 10^{-2} \quad (1)$$

$$E = 14.374 \times r^{1.075} \quad (2)$$

where:

Table 1. Proposed civil engineering structures for the Cimeneng catchment.

No.	Name of Catchment	Proposed Structures	Location	Notes
1	Darmaji Sub river of Cimeneng River (57.53 km^2)	Check dam	*Jemblongan orchard, Tayem Timur village, Sub district of Karangpucung *Bongas orchard, Tayem Timur village, Sub district of Karangpucung *Cihampel orchard, Tayem Timur village, Sub district of Karangpucung *Sindeh Timur orchard, Wringinharjo village, Sub district of Gandrungmangu	*It will be priority constructed ahead at Darmaji river *It is a series check dam placed at Pangkalan river (sub river of Darmaji river) *It is placed at Darmaji river *It is placed at Cibenda river (sub river of Darmaji river)
		Crib and Retaining wall	*Cihampel orchard, Tayem Timur village, Sub district of Karangpucung *Ceger orchard, Tayem Timur village, Sub district of Karangpucung	*It is placed at Darmaji river *They are placed around the piers of bridge at Darmaji river
2	Cihaur Sub river of Cimeneng River (56.26 km^2)	Check dam	*Kali Salak orchard, Lumbir village, Sub district of Lumbir *Kali Salak orchard, Lumbir village, Sub district of Lumbir *Cijanggot orchard, Sidangbarang village, Sub district of Lumbir *Wanasari orchard, Cingebul village, Sub district of Kawunganten	*It will be priority constructed ahead *It is placed at the downstream of check dam I *It is placed at Cijanggot river (sub river of Cihaur river) *It is placed at Wanasari river (sub river of Cihaur river)
		Crib and Retaining wall	*Kali Salak orchard, Lumbir village, Sub district of Lumbir *Butulan orchard, Lumbir village, Sub district of Lumbir	*It is placed at Cihaur river *It is placed at Cihaur river
3	Cikonde Sub river of Cimeneng River (108.29 km^2)	Groundsill	*Bulaksari village, Sub district of Kawunganten *Kawunganten Lor village, Sub district of Kawunganten *Kawunganten village, Sub district of Kawunganten *Bojang village, Sub district of Kawunganten	*It is placed at Cigandis river (sub river of Cikonde river) *It is placed at Jakadenda river (sub river of Cikonde river) *It is placed at Kawunganten river (sub river of Cikonde river) *It is placed at Bugel river, (sub river of Cikonde river)
4	Lower Cimeneng Sub river of Cimeneng River (112.32 km^2)	Check dam	*Karangbintung village, sub district of Gandrungmangu	*It is placed at Cikranji river (sub river of Cimeneng river)
		River structure improvement	*Sub district of Gandrungmangu	*At the meeting point between Darmaji and Cihaur rivers
		River Straightening	*Sub district of Gandrungmangu	*At the downstream of meeting point between Darmaji and Cihaur rivers
		Weir structure mprovement	*Sub district of Gandrungmangu	*At the Kebagoran weir, reducing the water level by changing the weir structure into barrage structure

R = index of rainfall erosivity (ton.cm/ha.hour)

E = energy of rainfall kinetic (ton.m/ha.cm)

r = monthly rainfall (mm)

I_{30} = maximum rainfall intensity during 30 minutes

2. Potential and actual erosion,

$$E_{pot} = R \times K \times LS \times A \quad (3)$$

$$E_{act} = E_{pot} \times CP \quad (4)$$

where:

Table 2. Proposed land use for the Cimeneng catchment.

(1)	(2)			(3)	(4)	(5)	(6)	(7)	
Catchment	**Present Land Use**			**CP Factor Value**	**Proposed Land Use**	**Proposed CP Factor**	**Erosion Potential**	**Actual Erosion**	
							(ton/year)	(ton/year)	(ton/yr/ha)
		(S)	(ha)						
1. Darmaji	Agriculture	15.0	1,369.48		Agriculture Conservation	23.8% x 0.004 = 0.0010	5,752,284.54	1,150,456.91	
	Underbrush	3.0	905.63		Underbrush Conservation	15.7% x 0.001 = 0.0001	413,473.46	124,042.04	
	Field rice	25.0	1,145.00	0.331	Field rice Conservation	19.9% x 0.004 = 0.0010	4,809,391.74	48,093.92	
	Un-irrigated agriculture	41.0	1,287.13		Agriculture Conservation	22.4% x 0.012 = 0.0030	13,986,086.48	4,629,394.62	
	Settlement	41.5	907.45		-	= 0.0000	9,860,444.69	3,263,807.19	
	Un-irrigated field rice	35.0	138.13		Field rice Conservation	2.4% x 0.159 = 0.0040	580,193.26	192,043.97	
						Total = 0.0100	35,401,874.18	9,407,838.65	1,635.34
2. Cihaur		(S)	(ha)						
	Agriculture	15.0	2,501.10		Agriculture Conservation	44.5% x 0.004 = 0.0018	14,690,253.61	4,960,424.24	
	Underbrush	3.0	1,450.70		Underbrush Conservation	25.8% x0.0003 = 0.0001	926,164.27	312,735.76	
	Field rice	25.0	110.68	0.338	Field rice Conservation	2.0% x 0.002 = 0.0000	1,681,730.95	567,093.92	
	Un-irrigated agriculture	41.0	562.13		Agriculture Conservation	10.0% x 0.003 = 0.0003	3,301,680.16	1,114,870.77	
	Settlement	41.5	556.88		-	= 0.0000	8,461,531.74	2,857,186.01	
	Un-irrigated field rice	35.0	444.43		Field Rice Conservation	7.9% x 0.060 = 0.0047	2,610,367.93	881,436.71	
						Total = 0.0100	35,401,874.18	10,694,519.73	1,900.94
3. Cikonde		(S)	(ha)						
	Agriculture	3.0	3,348.18		Agriculture Conservation	30.9% x 0.020 = 0.0060	2,008,113.36	496,004.00	
	Underbrush	41.0	46.88		Underbrush Conservation	0.4% x 0.100 = 0.0000	669,181.60	165,287.85	
	Field rice	5.0	3,557.43	0.247	Field rice Conservation	32.9% x 0.004 = 0.0010	2,133,613.70	527,002.58	
	Un-irrigated agriculture	41.0	608.75		Agriculture Conservation	5.6% x 0.080 = 0.0040	8,689,511.44	2,146,309.33	
	Settlement	4.0	1,778.88		-	= 0.0000	1,066,905.81	263,525.74	
	Un-irrigated field rice	6.0	1,488.70		Field Rice Conservation	13.7% x 0.080 = 0.0110	892,866.68	220,538.07	
						Total = 0.0200	15,460,192.59	3,816,667.57	352.64
4. Lower Cimemeng		(S)	(ha)						
	Un-irrigated agriculture	20.0	4,950.00	0.289	Agriculture Conservation	44.1% x 0.003 = 0.0010	26,375,538.42	7,622,530.60	
	Field rice	5.0	6,282.003		Field Rice Conservation	55.9% x 0.002 = 0.0010	3,638,364.79	1,051,487.42	
						Total = 0.0200	30,013,903.21	8,674,018.03	776.26
T o t a l: for Cimeneng Catchment							112,547,697.90	32,595,043.98	

Table 2. (continued) Proposed land use for the Cimeneng catchment.

(8)		(9)	(10)				(11)			
Actual Erosion After Management		**SDR**	**Sedimentation Potential**				**Sedimentation Potential After Management**			
(ton/year)	(ton/yr/ha)		(ton/year)	(ton/yr/ha)	(m3/year)	(mm/yr)	(ton/year)	(ton/yr/ha)	(m3/year)	(mm/yr)
48,020.74		0.37	428,201.71	312.67			17,873.79	13.05		
3,451.72		0.26	31,760.61	35.07			883.80	0.98		
40,149.36		0.39	18,606.76	16.25			15,533.14	13.57		
116,757.48		0.40	1,849,995.42	1,437.30			46,658.54	36.25		
82,316.14		0.39	1,286,564.70	1,417.78			32,448.31	35.76		
4,843.52		0.35	67,825.79	491.03			1,710.63	12.38		
295,538.96	51.37		3,682,954.99	3,710.11	1,426,948.85	24.80	115,107.82	111.99	44,598.15	0.78
101,612.34		0.38	1,885,434.87	753.84			38,622.39	15.44		
6,406.27		0.26	81,321.85	56.06			1,665.85	1.15		
11,632.52		0.35	198,869.90	1,796.80			4,073.77	36.81		
22,837.69		0.38	418,231.05	744.01			8,567.30	15.24		
58,528.33		0.39	1,101,773.69	1,978.48			22,569.40	40.53		
18,055.88		0.38	333,487.00	750.37			6,831.35	15.37		
219,073.02	38.94		4,019,110.35	6,079.56	1,557,194.25	27.68	82,330.06	124.54	31,898.51	0.57
47,042.32		0.27	132,056.45	39.44			12,524.58	3.74		
15,676.33		0.33	53,925.66	1,150.29			5,114.45	109.10		
49,982.31		0.31	165,618.89	46.56			15,707.73	4.42		
203,561.60		0.39	830,705.85	1,364.61			78,786.32	129.42		
24,993.47		0.29	76,049.84	42.75			7,212.77	4.05		
20,916.41		0.32	70,645.49	47.45			6,700.20	4.50		
362,172.45	33.45		1,378,551.12	2,691.10	514,917.54	4.76	126,046.05	255.23	48,836.13	0.45
64,374.91		0.40	3,043,216.76	614.79			25,701.02	5.19		
8,880.18		0.32	335,334.36	53.38			2,832.01	0.45		
73,255.09	6.52		3,378,551.12	668.17	1,309,008.57	11.65	28,533.03	5.64	11,055.03	0.10
950,039.52			12,409,626.64			68.89	352,016.96			1.89

Table 3. Classification of erosion after Suripin (2002).

Classification		**Value of Erosion (ton/ha/year)**
Potential Erosion:		
1. Light Erosion	(LE)	0 - 1,000
2. Small Erosion	(SE)	1,000 - 2,000
3. Middle Erosion	(ME)	2,000 - 5,000
4. High Erosion	(HE)	5,000 - 10,000
5. Very High Erosion	(VHE)	More than 10,000
Actual Erosion:		
1. Small Erosion	(SE)	0 - 200
2. Middle Erosion	(ME)	200 - 1,000
3. High Erosion	(HE)	1,000 - 3,000
4. Very High Erosion	(VHE)	More than 3,000

E_{pot} = potential erosion (ton/hour)

E_{act} = actual erosion (ton/hour)

R = index of rainfall erosivity (ton.cm/ha.hour)

K = land erodibility (cm^{-1})

A = area of catchment (ha)

CP= plant and conservation factors

LS = slope and length factors

3. Slope and length factors,

$$LS = L/100\ (0.76 + 0.53 + 0.076\ S^2) \quad (5)$$

where:

LS = slope and length factors

L = length of slope (m)

S = percent of slope

4. Sediment delivery ratio,

$$SDR = S \times \frac{\left\{1 - 0.8683\left(A^{-0.2018}\right)\right\}}{2\left(S + 50\,n\right)} + 0.8683\left(A^{-0.2018}\right) \quad (6)$$

where:

SDR = sediment delivery ratio ($0 < SDR < 1$)

A = area of catchment (ha)

S = average of land surface slope

n = Manning's coefficient

CONCLUSIONS

Managing sediment of the Cimeneng River using engineering methods (building civil engineering structures, i.e.check dams, groundsills, retaining walls, cribs, river structure improvements, and river straightening) and agricultural methods (land conservation using land use management) simultaneously can reduce the sedimentation in the Lagoon of Segara Anakan from 12,409,600 ton/year to 352,000 ton/year or 69 mm/year to 1.9 mm/year.

b) According to the risk danger of erosion as determined in Table 1, it can be concluded that the most effective CP factors which can be implemented in the Cimeneng catchment are as shown in Table 4.

c) The final results of the study on the Cimeneng Catchment are listed in Table 5.

ACKNOWLEDGMENT

The authors wish to express sincere thanks to Suwanto Marsudi, Caturyanto and Harris of Saka Bhuana Yasa Selaras Consulting Engineers LTD, for their contributions to the report.

Table 4. Most effective CP factors for the Cimeneng catchment.

No.	Catchment	Land Use	Agriculture Management	Most Effective CP Factor
1	Darmaji	- Agriculture - Bush - Irrigated field rice - Unrrigated agriculture - Settlement - Unrrigated field rice	- Very dense peak - Wide leaved grass - Wet irrigated field rice - Intercrop plant system - - Plant system in sequence	0.004 0.001 0.004 0.012 - 0.159
2	Cihaur	- Agriculture - Bush - Irrigated field rice - Unrrigated agriculture - Settlement - Unrrigated field rice	- Very dense peak - Wide leaved grass - Wet irrigated field rice - Intercrop plant system - - Plant system in sequence	0.004 0.0003 0.002 0.003 - 0.06
3	Cikonde	- Agriculture - Bush - Irrigated field rice - Unrrigated agriculture - Settlement - Forest	- Very dense peak - Wide leaved grass - Wet irrigated field rice - Intercrop plant system - - Selected felling industrial forest	0.02 0.10 0.004 0.08 - 0.08
4	Lower Cimeneng	- Unrrigated agriculture - Irrigated field rice	- Intercrop plant system - Wet irrigated field rice	0.003 0.002

Table 5. Study results for the Cimeneng catchment.

No.	Cathment Area (CA)	Area Of CA	Length of Main River	Average Slope of Bed of Main River	Existing Potential Sedimentation			Potential Sedimentation After Management		
		(km^2)	(km)		ton/year/ha	m^3/year	mm/yr	ton/yr/ha	m^3/year	mm/yr
1	Darmaji	57.53	18.00	0.0150	3,710.11	1,426,948.85	24.80	111.99	44,598.15	0.78
2	Cihaur	56.26	20.00	0.0130	6,079.56	1,557,194.25	27.68	124.54	31,898.51	0.57
3	Cikonde	108.29	22.00	0.0014	2,691.10	514,917.54	4.76	255.23	48,836.13	0.45
4	Lower Cimeneng	112.32	34.00	0.0012	668.17	1,309,008.57	11.65	5.64	11,055.03	0.10

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