ISSN 0126-2807

Journal of Applied Sciences in Environmental Sanitation

Volume 3, Number 1: 17-24, January-April, 2008

Sepuluh Nopember Institute of Technology, Surabaya
& Indonesian Society of Sanitary and Environmental Engineers, Jakarta
Open Access http://www.trisanita.org

Practical Case Study

SEDIMENTATION CONTROL: PART II. INTENSIVE MEASURES THE INSIDE OF THE MRICA RESERVOIR, CENTRAL JAVA

SOEWARNO[1]* and PETRUS SYARIMAN[2]

[1]The Experimental Station for Sabo, Research Centre for Water Resources Development, Sopalan Maguwoharjo, Yogyakarta 55282, Indonesia
[2]The Experimental Station for Hydrology, Research Centre for Water Resources, Bandung 40135, Indonesia
*Corresponding Author: Phone: +62 274 886350, Fax: +62 274 885341, E-mail: soewarnohd@yahoo.com, petrussy@bdg.centrin.net.id

Received: 15th March 2008; Revised: 29th March 2008; Accepted: 1st April 2008

Abstract: Decreasing storage capacity of Mrica reservoir due to sedimentation was investigated during the year of 2005-2006 and the measures against sedimentation were assessed. Data collection included river geometry, river discharge and sediment transport and sampling of bed material. Secondary data were provided by local government institutions. Sedimentation in the reservoir resulted in decreasing storage capacity of 19 years faster than designed. In addition to natural process, sedimentation in the reservoir was due to increasing population number, human settlement, deforestation and improper agricultural and sanitation practices within the Mrica watershed. Flushing, sand mining and dredging that carried out inside the reservoir were effective in controlling sediment and directly improve the storage capacity. However, the present measures such as check dams, small reservoir, short-cut and land conservation offer more detailed research on technical, social and environmental approach.

Keywords: Dredging, flushing, remaining capacity, sedimentation rate

INTRODUCTION

Mrica reservoir in Central Java is an important water source for the improvement of community welfare by among others generating electricity of 580,000 MWH year^{-1} and to meet water demand of 7 – 11 m sec^{-1} for the irrigation system at Banjar Cahyana in addition to water requirement for fishery and recreation [1]. The multipurpose Mrica reservoir was built in Serayu river catchment covering an area of 1,022 km^2 or 32% of the entire watershed. Topographic feature of the area can be classified as hilly with ravines of 50% – 90% depth. The landscape is identified as fluvial volcanic comprising material composition formed by volcanic activity and deposit. The river valley is in general steep and V – shaped. Vegetation consists mainly of dry field and perennial plants. The designed useful life time of the Mrica reservoir was 50 years (2040). Sedimentation in the Mrica reservoir was accounted since it is natural process [2-3] however an observed sedimentation rate showed that the remaining storage capacity would not reach the designed life time. In addition to sedimentation, the present condition of the water resources is bad such as floods and pollution. Improper sanitation and agricultural practices within the watershed resulted in decreasing of river water quality. Meanwhile, the decrease of storage capacity was directly due to the rapid sedimentation flow entering the Mrica reservoir. Collected data from PT Indonesia Power showed that sedimentation had seriously influenced the reservoir operation during sixteen years of operation that decreased 18% production of electricity [4]. Therefore, the objective of research was to determine 1) the sedimentation rate that associated to the remaining storage capacity and sedimentation sources; and 2) assessment of the present measures against sedimentation.

MATERIALS AND METHODS

The research was carried out at Mrica reservoir catchment in Central Java (Fig. 1), situated at 109^{o}, 6', 00" – 110^{o}, 07', 49" E and 7^{o}, 17', 04" – 7.47', 07" S, during the year of 2005 - 2006. The construction of the reservoir started in 1983, while impounding commenced in April 1988 and was completed in October 1988 covering a surface area of 12.0 km^2. Storage capacity at full operation is about 140 million m^3.

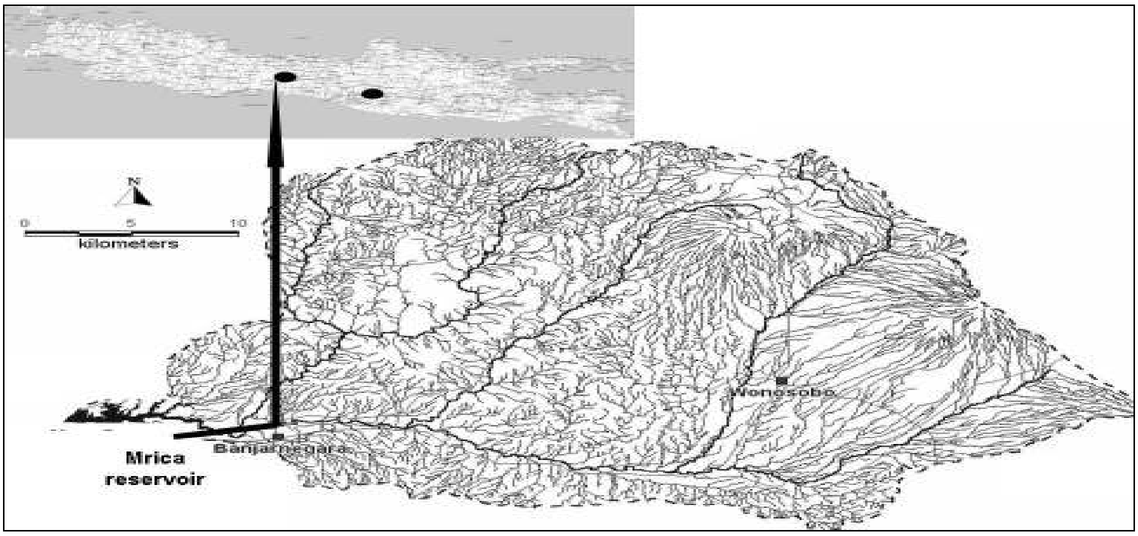

Fig. 1: Mrica reservoir catchments Central Java

Data collection consisted of reservoir sounding time series, inflow, sediment transport concentration, land-use and the Bakosurtanal 1:25000 scaled topographical maps that comprised 13 sheets on the Mrica reservoir catchment area, sand mining volume and flushing, conservation and Sabo plan construction [5]. The qualitative descriptive analytic method was used on secondary data. Interviews were held with institutions, i.e. the Mrica reservoir operation management, regional office of Public Works, and Regional Planning Board (Bappeda).

Field observation of Mrica reservoir inflow was conducted for three rivers, i.e. Lumajang river at Lingga Sari, Merawu river at Clangap, and Serayu river at Banjarnegara. Discharge measurement was carried out by current meter. Sediment sampling was taken using a sediment sampler in compliance with the discharge at time of measurement. Data on flow measurement were used for the analysis of flow and sediment curve. After laboratory particle testing, river bed and reservoir deposit material were used for particle measurement analysis.

The extent of threat of reservoir shallowing was determined by comparison of reservoir useful life time before and after impounding. Reservoir useful life time before impounding was defined by the inflow-outflow method based on the analysis of inflow and outflow and sediment transport data. Reservoir useful life time after impounding was estimated based on the storage capacity data analysis at the time when sounding time series were taken [6-10].

Sediment source was determined by comparison of maximum value analysis results of sediment transport time series in river catchment at Lumajang- Linggasari, Merawu – Clangap, and Serayu – Banjarnegara. With the identification of sediment source, efforts of maintaining remaining reservoir capacity were suggested.

RESULTS AND DISCUSSION

Sedimentation in Reservoir

Before the Mrica reservoir was constructed, a hydrometric station for discharge and sediment transport measurement in Serayu river-Mrica was set-up at the present site of Mrica reservoir. During the year of 1959 up to 1981, an average suspended sediment transport was 7.04±2.64 million tonne year^{-1} [1]. The laboratory analysis showed a sediment specific gravity of 1.097 tonne m^{-3}, indicating the sediment transport equivalent to sediment volume of 6.42±2.41 million m^3 year^{-1}. Assuming bed sediment transport reached 10% of the suspended sediment, thus the total sediment transport at Serayu-Mrica hydrometric station before reservoir construction would be 7.06±2.65 million m^3 year^{-1}. In addition to recorded sediment transport, the average river flow rate was 2,610±500 million m^3 year^{-1}. Using the lowest limit of sediment volumetric rate of 4.41 million m^3 year^{-1} and the reservoir capacity of 140 million m^3 at full operation, the useful life time of reservoir before impounding could be estimated as shown on Table 1. Limiting the sediment deposit volume of 80% of total reservoir capacity, Table 1 showed that sediment deposit would be settled in reservoir in thirty eight years. The yearly rate of capacity decrease in Mrica reservoir was 2.60%. The estimation was primarily based on sediment originated from upstream soil erosion.

Table 1: Estimation of the Mrica reservoir useful life time based on 1956-1981 hydrometric data

Capacity million m^3	Inflow million m^3	Capacity Inflow Ratio	Trap efficiency		Annual sediment trapped	Increment volume Million m^3	Years to fill
			At indicated volume percent	Average percent			
140	2610	0.054	0.79				
112	2610	0.043	0.75	0.770	3.40	28.00	8.25
84	2610	0.032	0.70	0.725	3.20	28.00	8.76
56	2610	0.021	0.62	0.660	2.91	28.00	9.62
28	2610	0.011	0.45	0.534	2.35	28.00	11.89
						Total	38.51

Yearly sounding time series for sedimentation using echosounder commenced in 1989. Results of the monitoring showed that mean annual sedimentation rate was about 4.19 million m^3 year^{-1} (Fig. 2). In 1997, El Nino influenced the sedimentation rate, showing a minimum value of 2.17 million m^3 and maximum value of 7.02 million m^3. The cumulative sedimentation volume from 1989 – 2004 was 67.10 million m^3.

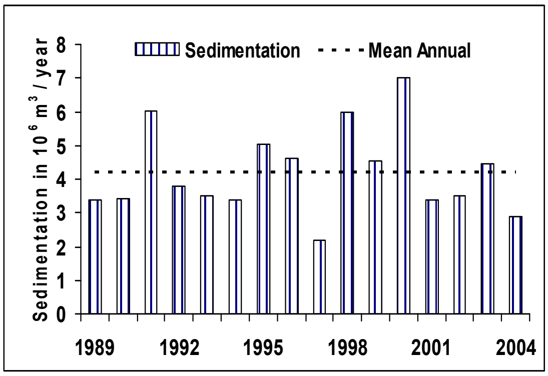

Fig. 2: Sedimentation rate in Mrica reservoir (sounding results 1989-2004)

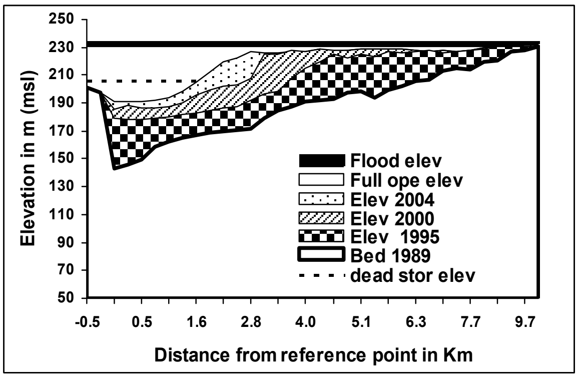

Fig. 3: Long Sectional Sedimentation Distribution in Mrica Reservoir

The long sectional sedimentation distribution in Mrica reservoir (Fig. 3) clearly revealed the decrease of storage capacity. The effective capacity at full operation elevation was about 140 million m³ in 1989. Cumulative sediment volume of 67.10 million m³ replaced water storage, indicating the remaining reservoir effective capacity of 72.9 m³ in 2004 (62.1% of the original capacity). Based on the sounding data (Fig. 4), it can be projected that 100% cumulative sediment deposit will be in 2021 and the remaining storage capacity of 20% will be in 2014, revealing the actual sedimentation rate was faster than previous prediction. The actual field data indicated a serious threat of shallowing.

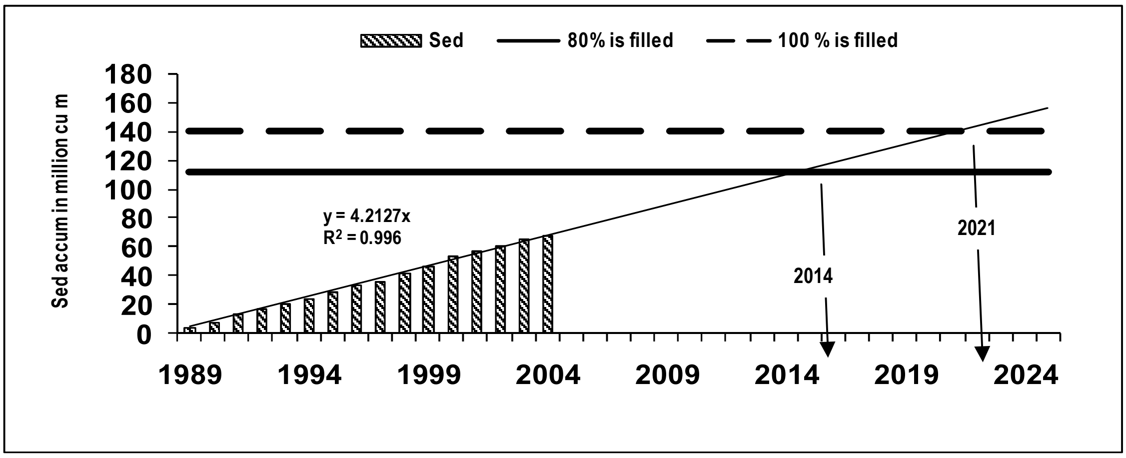

Fig. 4: Prediction of remaining useful life time at Mrica reservoir

Sediment Sources

Since 1989, water resources in the Mrica reservoir catchment were enriched with garbage from households and paddy fields etc and the presence of aquatic plant, waterhyacinth in particular. Degradation of garbage and dead aquatic plant could increase sedimentation. Sediment and nutrient delivery are inseparable because much of the nutrient delivered to streams is attached to sediment particles, particularly clay particles. The main nutrients of concern in stream water are phosphorus and nitrogen. All organisms require these nutrients for growth. However, in excess quantities they can lead to the occurrence of some organisms such as algae and macrophytes reaching nuisance levels. Excess delivery of sediment to streams also has a direct impact on aquatic ecosystems in river that it increases turbidity and smothers benthic habitat. The combination of these factors means that more sediment and nutrient passes from hillslopes to riparian land and streams than is the case under natural conditions. Observation showed that within the Mrica watershed, riparian land is now a source of sediment and nutrient that happened in many places around the world [11].

The topographic feature of the Mrica reservoir catchment is hilly with steep sloping of more than 50%. Slope gradient of more than 15% was classified as high erosion hazard [12] and thus the Mrica reservoir catchment was potentially high soil erodibility. In fact, natural disasters such as slope failure and rockfall are common in the Mrica reservoir catchment that accounted for sediment sources. Examples were 1) at Desa Kabunan, Kecamatan Banjarmangu, Kabupaten Banjarnegara, Central Java, slope failure had dammed the Merawu river for approximately half an hour in the end of 1999. The river slope sliding had been more than 100 meters. Due to the condition that fall of sediment had been able to dam the Merawu river, volume of sediment was measured as relatively extensive. Sediment deposit obstructing the river had finally collapsed and was carried by river flow to downstream direction into the Mrica reservoir; and 2) at the beginning of 2007, slope failure occurred at Desa Sijeruk with volume of approximately 550.000 m^3 and caused more than 50 dead victims. In addition to the steep sloping and hilly land, rainfall rate of the area exceeds 2500 mm $year^{-1}$ that contributed high soil erosion in the catchment.

The population density showed an increase from 798 person km^{-2} (1999) to 829 person km^{-2} (2003). Land clearing associated to the need of human settlement increased that resulted in increasing run off, leading to soil erosion. During the year of 1999-2003, it was recorded that improper implementation of crop cultivation did not consider land conservation. As a result, soil erosion in the area enhanced sufficiently. Moreover, sanitation infrastructures were not properly designed, constructed and managed for instance open dumping of solid waste and discharging wastewater directly to water bodies. These conditions enhanced sediment accumulation in the river. During rainy season, the transported soil from bare land produced sedimentation in the river and in addition to resuspension of accumulated sediment they entered the Mrica reservoir.

The Mrica catchment consists of Merawu catchment (27.9%), Serayu catchment (71.2%) and Lumajang catchment (0.8%) that contributed sedimentation rate of 3.10, 1.20 and 0.30 mm $year^{-1}$ respectively. Referring to the size of area and its sedimentation rate, the erosion flow in Merawu and Serayu catchments exceeded the permissible limit of erosion flow (1 mm $year^{-1}$).

Sedimentation Control

Based on data analysis of bed material [13] it was defined that various sizes of particle in the Mrica reservoir were distributed into upstream direction as follows: clay or dust with a gradation up to 0.005 mm from intake up to a distance of 1.10 km (A), mud or silt with gradation of 0.005 mm – 0.05 mm from (A) up to a distance of 1.3 – 2.5 km (B), fine sand to coarse sand with gradation of 0.05 mm – 2.0 mm from (B) up to a distance of 2.5 -9.0 km (C), fine to coarse gravel from (C) up to a distance of 9.0 – 9.2 km (D), and pebbles or coral stone from (D) up to a distance of more than 10 km. Methods of reducing sediment in reservoir was in conformity with these bed particles distribution, i.e. sediment control inside and outside the reservoir. Sediment control inside the reservoir consisted of flushing, sand mining and dredging whereas check dam, short cut, constructing small reservoir and land conservation were conducted outside the reservoir.

Flushing

One of the efforts carried out by the operation management of Mrica reservoir in maintaining remaining storage capacity was by flushing. Sediment flushing is concerned with the removal of sediments which have settled in the reservoir at a previous time. Sediment flushing was used to remove sediments up to and including sands and gravels. Water level in reservoir decreased when the drawdown culvert was opened, driving the water to flush sediment deposit up to 2.5 km. As observed from the sediment distribution (Fig. 3), sediment deposit in front of the Mrica reservoir flushing intake gate reached at elevation of + 190.0m. Flushing was mainly carried out to flush the sediment deposit at power intake. In order to prevent sediment block in the power intake, the water gate at flushing channel was opened frequently without disturbing the electricity production. Periodic flushing had been carried out since February 15, 1996 up to February 15, 2004 with the total amount of water of 0.73 million m^3 that is very small compared to the removed sedimentation volume of 34.7 million m^3 that was accumulated during the year of 1996 – 2004. Flushing method effectively removed sediment deposit that increases the useful life time of reservoir. Experience has shown that low reservoir water levels provide the most effective conditions for sediment flushing. To allow water levels to be lowered requires confidence that rainfall can be relied upon to refill the reservoir. It follows that well defined wet and dry seasons will be favourable for a sediment flushing regime. Care should be taken to limit flushing water, because increasing water volume of more than 1 million m^3 could cause flood in the downstream of Serayu river such as Banyumas and Cilacap areas.

Sand Mining

The sediment flow into the Mrica reservoir carried a large volume of sand deposit causing shallowing of the reservoir. This extensive sand volume attracted local community to mining the deposited sand. Being a community selfhelp business, actual mining volume was not recorded. In addition to high quality material, sand of less quality needed for fill was also exploited. Field observation during the year of 2006 recorded that an average 100 trucks per day uploaded the sand from Mrica reservoir. The amount of uploaded sand was approximately 0.30 million m^3 which was only 7.7% of sediment inflow. Sand mining in reservoir was considered effective in extending the reservoir useful life time. Unfortunately, there was no significant involvement of the reservoir operation management and/or the government in providing access road, market or guideline on good mining practice.

Dredging

Dredging was conducted in reservoir to maintaining the remaining storage capacity. Dredging started at dam and was extended to 9 km upstream. The practice was taking into consideration of dredging experience in the Sengguruh reservoir, East Java. Field observation indicated a limited spoil bank in vicinity of Mrica reservoir because the area outside the Mrica reservoir was mostly fertile paddy fields and densely populated settlement. Facing to the limited space for dumping of sediment volume with an equivalent to 3000 dump trucks, an intensive haulage dredging material was carried out even requires extensive cost. Dredging had an immediate impact on sediment reduction at the Mrica reservoir however continuous implementation should take into account environmental problems as observed at Sengguruh reservoir. A detailed research has to be carried out particularly on the selection of location for spoil bank, use of excavation material, cost of dredging etc. The storage of dredged material poses problems of several kinds. When fine-grained sediments are polluted, as is often the case, uncontrolled dumping in the environment is undesirable.

Sabo Dam and Check Dam

Eroded materials, entering the river channel in Merawu, Serayu and Lumajang catchments, were controlled by Sabo dams (Table 2). Sabo dams were constructed in the river channel where high sediment content was measured. At present, the size of Sabo dams could reduce significantly sediment in rivers entering the Mrica reservoir.

Table 2. Designed Location of Sabo Dam in Mrica Reservoir

No	River	Location	Height (m)		Width (m)	Volume (m^3)	
			Total	Effective		below crest	above crest
1	Lumajang	Linggasari	3.5	2.0	10.0	924	462
2	Merawu	Kesenet	12.0	9.5	50.0	1,152	57,627
3	Songgoluang	Wonokerto	5.0	3.0	30.0	16,448	8,224

On going project the so called Sabo Dam Network Map identified more than 40 sites were appropriate for the provision of Sabo dam. Sabo dams of greater capacity are constructed in certain type of river channel and should consider technical criteria in selecting location. Taking into account the threat of shallowing, a more detailed study is required for increasing the number of location of Sabo dams particularly in the river channel upstream of Mrica reservoir catchment.

The construction of check dams in small river channel is very simple and could involving local community participation. Experiences showed that check dams should be used only in small open channels and should not be placed in streams. The maximum height of the check dam should be 0.6 m. They may kill grass linings in channels if water stays high or sediment load is great. A check dam can be built from logs, stone, or pea gravel-filled sandbags. Log check dams are more economical from the standpoint of material costs, since logs can usually be salvaged from clearing operations. However, log check dams require more time and hand labor to install. Since log check dams are embedded in the soil, their removal will result in more disturbance of the soil than will removal of stone check dams. Consequently, extra care should be taken to stabilize the area when log dams are used in permanent channels.

Short Cut

Short cut was carried out by diverting sediment outflow from Mrica reservoir into Pekacangan river, located on right side of the reservoir. A structure was provided at spillway of Wonodadi where the probable maximum flood would occur. However, more detailed and integrated study should be conducted since the short-cut structure will change the reservoir body and embankment as well as the probable maximum flood at spillway.

Construction of Small Reservoirs

Small reservoirs were provided in the upstream of Mrica reservoir catchment, particularly at Karangkobar and Dieng plateau. Additional provision of small reservoirs in Merawu catchment at Maung was not possible to be carried out due to geological condition of the site is situated on a fault even they could reduce sedimentation flow of 20% [14] .

Land Conservation

The analysis on landuse data identified approximately 60% of cultivated area and 15% forests, which does not comply to the law on Forestry requiring at a minimum 30% of forests. Land clearing and cultivated land were intensively carried out in the mountainous area upstream of the Mrica reservoir. Improper planting pattern contributed the damage of the environment due to erosion. The regional government of Kabupaten Banjarnegara assessed the sedimentation flow that was attributable to the activity of local farmers in cultivating potatoes in the Dieng plateau and Karangkobar. Slopes in the hilly area were also used for the potato plantation and no trees were observed. Another potential of sediment source was the custom of local farmers in treating crop with a mixture of soil and manure in addition to improper agricultural practice.

Collected data from Bappeda Kabupaten Banjarnegara showed that many of preserved forests were used for land cultivation. Prohibiting such activity would be difficult, because most of these forests are owned by individuals. Boundaries of preserved forests are also not clear causing confusion of ownership. The Office of Forestry and Plantation, Kabupaten Banjarnegara has already planted various trees as well as crops with an attempt to conserve the area. The efforts slightly reduced sedimentation flow into Mrica reservoir. In response to National Movement Program for Land and Forest Rehabilitation (GERHAN) it was planned to provide various sizes of gully plug, absorption well, stream bank protection, terrace rehabilitation, society forest, bamboo plantation, and provision of greenspace in urbanized area.

CONCLUSIONS

The topographic feature of the Mrica reservoir catchment is hilly with steep sloping of more than 50% that has high potential in contributing sediment flow into Mrica reservoir in addition to anthropogenic activities in the watershed. Bed material deposited in the Mrica reservoir was mainly clay to coarse sand that controlling the accumulation was effectively carried out inside the reservoir by means of flushing, sand mining and dredging. Sediment control using Sabo dam and check dam, short cut, constructing small reservoir and land conservation offers comprehensive research, involving technical and social approach as well as environmental impact. Improper sanitation and agricultural practices within the watershed suggested to conduct social awareness campaign as the first stage.

REFERENCES

1. Pusat Litbang Pengairan, 1988. Studi Pengaruh Pembangunan PLTA Mrica terhadap Pengelolaan Air di DAS Serayu, Bandung, Pusat Litbang Pengairan-PLN
2. Hairsine, P., 1997. Controlling Sediment and Nutrient Movement within Catchments, Industry report, Cooperative Research Centre for Hydrology, Melbourne.
3. Strand, R.L, and E.L. Pemberton, 1982. Reservoir Sedimentation, Technical Guideline for Bureau of Reclamation, Denver
4. Indo Power, PT., 2005. Laporan Pelaksanaan Penyelidikan Sedimentasi Waduk PLTA Mrica, Banjarnegara.
5. Departemen Pekerjaan Umum, 2005. Sistem Pengendalian Angkutan Sedimen dengan Teknologi Sabo Di DAS Waduk Serbaguna, Bandung.
6. Departemen Pekerjaan Umum, Metode Perhitungan Awal Laju Sedimentasi Waduk, SK SNI M-37-1993-03, Dep PU Jakarta
7. Dewan Riset Nasional, Metode Pengukuran Debit Sungai dan Saluran Terbuka Dengan Alat Ukur Arus Tipe Baling Baling, SNI, 03-2819-1992
8. WMO, 1990. Manual on Operational Method for Measurement of sediment Transport, Operational Hydrology (WMO-No 686), Geneva , Switzerland .
9. WMO, 2003. Manual on Sediment Management and Measurement, Operational Hydrology No. 47 (WMO - No 948), Geneva, Switzerland
10. Linden, P.V., 1981. An input-output Analysis With Respect to Water and its load for tropical watershed (central Java-Indonesia), The Indonesian Journal of Geography. 11 (42) : 19-38
11. Lovett, S. and P. Price (eds), 1999. Riparian Land Management Technical Guidelines, Volume One: Principles of Sound Management, LWRRDC, Canberra. P198
12. Prince George.s County Soil Conservation District, 1994. Soil Erosion & Sediment Control/Pond Safety Reference Manual.
13. Departemen Pekerjaan Umum, 1989. Laporan Akhir Pengukuran Sedimentasi Waduk PLTA Mrica, Jakarta.
14. PLN, 1982. Water Management, Mrica Hydro Electric Power Project, Detail Project Report Vol III, Book I.