Watershed Management Technology Options and their Impacts on Hydrological Characteristics

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INTRODUCTION

Watershed degradation is a serious environmental problem in Indonesia and the main causes can be differentiated between Java and the other outer islands. In the outer islands, degradation is caused mainly by rapid and heavy deforestation due to logging, fire, and forestland conversion for transmigration and smallholder plantations (World Bank, 1990). In Java, it is generated by population pressure, deforestation, and industrial development. The more populated islands of Java, Madura, Bali, and Lombok cover only about 8% of the country's total area but comprise about 70% of the total population. The forest area is only 22% compared to 65 to 90% in the other islands. From 1883 to 1983, the rainfed uplands and irrigated areas increased from 0.640 to 3.407 million ha, and from 1.845 to 3.501 million ha, respectively.

Watershed degradation is indicated by the condition of natural resources as a basis for production and water regimes as features of hydrological function. These are illustrated by low crop production, eroded soil, drought, sedimentation, and flood damage. Soil erosion is the main agent for exacerbating sedimentation in irrigation facilities, reservoirs, and estuaries. The World Bank (1990) reported that sediment load transported through the Solo River increased drastically from 4,530 mg l^{-1} in 1970 to 23, 700 mg l^{-1} in 1976. It was estimated that the on-site cost caused by erosion in Java was Rp. 515.8 billion. Sedimentation cost includes Rp. 13.0–43.4 billion for siltation of irrigation systems, Rp. 2.3–5.7 billion for harbour dredging, and Rp. 28.8–1,223.6 billion for reservoir sedimentation. This amounts to around Rp. 557.9–688.4 billion or US$ 352–430 million. This estimated value did not include social and psychological losses since they were difficult to quantify.

Watershed degradation also causes changes in the hydrological behaviour of a river system; this affects the quality, quantity, and timing of streamflow. Watershed degradation influences discharge fluctuation. It increases the maximum and minimum discharge ratio, e.g. in Cimanuk, Cisanggarung, and Solo which increased from 58.6 to 66.5, 347 to 1,347, and 865 to 2,620, respectively. Thus flood and drought risk in these watersheds increases.

The serious economic and social consequences of watershed degradation makes it necessary to employ proper management, and to rehabilitate and conserve these watersheds to benefit most from them. This paper discusses the concept of watershed management, some technology options for better management, and case studies on the impact of these technologies on the hydrological characteristics of selected watersheds in Indonesia. It is expected that this information could be used as input for research planning and policy formulation in watershed management.

THE WATERSHED MANAGEMENT CONCEPT

A watershed is a topographically delineated area that is drained by a stream system (Dixon and Easter, 1986; Brooks *et al.*, 1991). It is also defined as a terrestrial region or area that receives, stores, and discharges water through a main stream or river to a lake or sea (DGRLR, 1998). It is similar to a river basin on a smaller scale. The watershed boundary may be hills, ridges or mountains. As a

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watershed is defined according to topography and hydrometeorological attributes, this boundary is usually different from the administrative boundary (Dixon and Easter, 1986). This becomes important when examining how the watersheds should be best managed.

Watershed management is defined by Dixon and Easter (1986) as the process of formulating and implementing a course of action, taking into account the social, political, economic, and institutional factors operating within and surrounding the watershed to achieve some specific objectives. Sheng (1990) considered it as the process of formulating and carrying out a course of action involving the manipulation of resources in a watershed to provide goods and services without adversely affecting the soil and water base. Similarly, Brooks *et al.* (1991) stated that watershed management is a process of organizing land and other resources used in the watershed to provide the desired goal without adversely affecting soil and water resources.

Hufschmidt (1986a, 1986b) proposed a conceptual framework for watershed management. It considers the following components: 1) the process of planning, implementing, and monitoring; 2) management measures and implementation tools; and 3) a set of linked activities for specific management tasks. Planning includes plan formulation and design steps, while implementation includes installation, operation, and maintenance. Implementation may also look at the method (tool), the steps, and the implementation material (technology). Implementation tools consist of institutional arrangements such as regulations, licenses, prices, taxes, subsidies, loans, grants, technical assistance, education, and extension.

Watershed management is also related to such activities as land use allocation, on-site activities like agriculture, forestry, grazing, mining, etc, and off-site activities like stream bank protection, debris removal, channel dredging, check dam construction, etc. In Indonesia, land use allocation at the central level is coordinated by the National Agrarian Agency of the Ministry of Home Affairs, on-site activities are under the Ministries of Agriculture, Forestry, Energy and Mineral Resources, and off-site activities are mainly under the Ministry of Settlement and Regional Infrastructure.

Watershed management principally involves identifying and defining the natural resources within the watershed, defining the desired objectives based on the local problems, and formulating the strategies to achieve the objectives using community participation (Pasaribu, 2000). The objectives may be for: 1) rehabilitation, 2) protection, 3) natural disaster prevention, 4) regional economic development, and 5) a combination of two or more objectives. Multiple-use watershed management may be aimed at management of water, timber, crops, forage, wildlife or minerals on the land for irrigation, pulpwood, food, etc. (Brooks *et al.*, 1991).

INDICATORS OF WATERSHED DEGRADATION

One important step in determining the condition of a watershed is the assessment of its health. Basically, watershed degradation is an indication of low or bad watershed health. A watershed in a poor condition can be categorized as a degraded watershed. Sheng (1990) considered a degraded watershed as one that has lost its value over time, including the productive potential of land and water resources, accompanied by marked changes in hydrological behaviour of a river system resulting in inferior quality, quantity, and timing of streamflow. This can result from the interaction of physiographic features, climate, and poor land use, deforestation, inappropriate land cultivation, disturbance of soil and slope by mining, construction and improper diversion, storage, transportation, and use of water. A healthy watershed (catchment) is one that can recover from perturbation, being economically viable and environmentally self-sustaining (Walker and Reuter, 1996a).

Watershed degradation may be indicated by some natural phenomena such as extreme flow fluctuation, low water quality of streamflow and groundwater, and a high rate of sedimentation. Thus, watershed health may be determined by comparing or monitoring some indicators of its biophysical and socioeconomic conditions and trends (Walker and Reuter, 1996b). On-site condition indicators may include soil consistency, texture, colour, water intake rate, strength, etc., while off-site indicators could be groundwater electrical conductivity and tree cover. Trend indicators may consider effective root depth, soil electrical conductivity, stream pH, turbidity, etc. Indicators for farm productivity are financial performance, and product quality, percent yield, timber productivity, farm cash income, etc. Basically, the indicators could be used to categorize the watershed condition as excellent, good, fair or poor as discussed by Walker and Reuter (1996a).

Establishment of watershed health indicators is important to manage watersheds based on determined objectives of watershed management. In Australia, indicators of catchment health are established for watershed management at farm/site scales. This management level is a prerequisite for successful watershed management at higher levels such as regional/catchment scale and national scale.

WATERSHED MANAGEMENT IN INDONESIA

Watershed management in Indonesia is aimed mainly to achieve optimal conditions for vegetation, soil, and water to provide maximum benefits and sustainable social welfare (FORDA, 1998). Priority for watershed management is based on criteria like land condition as a medium for production and hydrological control, socioeconomic and regional development policies. These criteria consider percentage of land cover, slope, degree of erosion, flood and drought risk, investment cost, and population density.

Watershed management in Indonesia started in 1961 with the creation of the Committee for Saving Forest, Soil and Water by the Ministry of Forestry and Agriculture. In 1965, the committee was changed into a programme, and since 1976, the programme has been intensified through national re-greening and reforestation activities (Mulyana, 2000). The objectives of the programme are: 1) promote optimum watershed hydrology by reducing flooding, erosion, and sedimentation; 2) increase farmer income; and 3) enhance farmers' roles as conservators of natural resources.

In support of the programme, a number of watershed management projects have been implemented. From 1973 to 1982, FAO/UNDP conducted a watershed management study in the upper Solo Watershed to develop appropriate watershed management approaches and technologies. Similar studies were implemented through several pilot projects with grant or loan funds from international organizations. These include the Yogyakarta Rural Development Project started in 1976, the Citanduy Project started in 1982 and funded by USAID, the Upland Agriculture and Conservation Project (UACP) Project in Jratunseluna (Central Java) and Brantas Watersheds, the Upper Solo (Wonogiri) Watershed Protection Project, and the Kali Konto Project (World Bank, 1990).

From the findings of these projects, some institutional changes have evolved both at central and local levels. Institutions involved in planning, monitoring, and evaluation, and in implementation have been identified. Currently, the Land Rehabilitation and Soil Conservation Centres (LRSC Centre or Balai RLKT) under the Ministry of Forestry is in charge of the planning, monitoring, and evaluation function while the implementation at the sub-sub watershed or district level is the responsibility of the Forestry and Soil Conservation Services (FCS, or Dinas PKT) under the Ministry of Home Affairs. In carrying out the programme, these institutions have been supported by several research and development organizations such as the Watershed Management Technology Center (WMTC) and the Center for Soil and Agroclimate Research (CSAR) (Mulyana, 2000; Pasaribu, 2000).

Watershed management planning consists of the master-plan (15–25 years) called the LRSC Pattern (Pola RLKT), and medium-term plan (five years) called the LRSC Field Engineering Design (FED) (RTL-RLKT). Monitoring and evaluation are carried out both on and off site and examine hydrology, LRSC activities, land use change, and socioceonomic aspects.

The LRSC Pattern contains general recommendations for zonal function and sub-watershed priority and activities. The LRSC FED identifies the location and options of LRSC practices, steps of implementation, monitoring, and evaluation.

Annual Planning/Designing (Rencana Teknik Tahunan, RTT) produces an annual operational plan with information on the boundary location, technology to be applied, and budget allocation. It includes Regreening Engineering Planning (Rencana Teknik Penghijauan, RTP) for private land and Reforestation Engineering Planning (Rencana Teknik Reboisasi, RTR) for government forestland.

Formulation of the annual plan should be referred to LRSC FED. Annual planning is conducted in an integrated, multisectoral, catchment approach. The smallest unit of LRSC activities is called the Reforestation Management Smallest Unit (Unit Terkecil Pengelolaan Penghijauan, UTPP). It is based on the priority set by Pola and RTL RLKT and covers around 500 ha (Java and Bali islands) or around 750 ha (other islands).

While the governor of the province approves the LRSC Pattern as a long-term plan in the upper watershed, implementation of the watershed management plan still encounters some problems. According to Pasaribu (2000), some of the weaknesses of the LRSC Pattern are: 1) it does not provide an alternative solution to regional development problems; 2) it has not been integrated with regional production and market condition; and 3) the methodology of the LRSC Pattern still needs improvement to assure accuracy and efficiency. The plan cannot be fully implemented because of some sectoral interest. Monitoring and implementation should involve community participation and results should be discussed to provide feedback for planning.

Finally, watershed management policy in Indonesia should be able to address such issues as: 1) regional autonomy that tends to promote conflict of interest for natural resource utilization, minimization of negative impacts and losses up- and downstream, rights and obligations for sustainable management between up- and downstream cultivators; 2) empowering local people's participation in management and utilization of resources in watersheds; 3) law enforcement to prevent advanced degradation such as protection of upstream areas (e.g. the case of Puncak, in Ciliwung—upstream) and regulation and monitoring of waste disposal by industrial activity (the case of Surabaya River, downstream of Brantas Watershed); 4) establishment of watershed management institutions for coordinating the planning, monitoring, and evaluation and promotion of legislation to consider sectoral and regional interest; and 5) limited financial and human resources for research.

WATERSHED MANAGEMENT INTERVENTIONS AND HYDROLOGICAL CHARACTERISTICS

Research and development provide a key support to watershed management. The application of improved technologies on LRSC resulting from research could restore the degraded watersheds in Indonesia. LRSC interventions have been introduced since the implementation of the Program for Saving Forest, Soil and Water. The following sections present three case studies of watershed management technologies that have been applied and evaluation of their impact on watershed hydrological characteristics. The three watersheds are Samin Watershed, Wonogiri Reservoir Catchment, and Garang Watershed, all in Central Java.

Rehabilitation of Samin Watershed

The Samin Watershed is a subwatersheds of the upper Solo Watershed which represents a volcanic area. A watershed management study in Samin was part of the Upper Solo Watershed Management and Upland Development Project, established in 1973 and funded by FAO/UNDP. The study covered representative areas in the upper (Tapan) and lower (Goseng and Dumpul) segments. Land rehabilitation and soil conservation techniques were implemented in Dumpul and Tapan (the treated areas) while Goseng served as the control watershed. At Dumpul, bench terraces on most of the dryland (53 ha), reforestation (4 ha), and paddy fields in the degraded dryland (34) were introduced while bench terraces with waterways on the dryland with slopes below 50%, and forest on the steeper slopes were established in Tapan (Table 1)

Table 1. Land use and soil conservation practices in three subwatersheds of Samin Watershed.

Land use	Pre-development			Post-development		
	Goseng	Dumpul	Tapan	Goseng	Dumpul	Tapan
Paddy field	124	22	10	124	56	10
Traditional dryland	159	91	102	159	-	20
Terraced dryland	-	-	-	-	53	36
Forest	40	-	62	40	4	108
Others	273	73	10	273	73	10
Total	**596**	**186**	**184**	**596**	**186**	**184**

The application of land rehabilitation and soil conservation (LRSC) techniques at Dumpul subwatershed reduced surface runoff but did not produce significant change in Goseng (Table 2). The LRSC practices at Tapan subwatershed did not indicate any influence on the runoff coefficient. The slope could have been too steep and the four-year old pine forest plantation had had no effect in controlling runoff.

Table 2. Water yield as affected by land rehabilitation and soil conservation measures in three subwatersheds of Samin Watershed.

Year	Precipitation (mm)			Runoff depth (mm)			Runoff coefficient (%)		
	G	D	T	G	D	T	G	D	T
1974	3261	1318	1099	1855	666	618	0.569	0.505	0.562
1975	3902	3212	4034	2285	1636	2982	0.586	0.509	0.739
1976	2081	1927	2326	927	648	1758	0.445	0.336	0.756
1977	1756	2006	2069	1045	401	1701	0.595	0.200	0.822

Source: Data from Achlil, (1978).
G: Goseng SW (control), D: Dumpul SW (treated), Tapan SW (treated) In 1974. precipitation on Goseng SW from January to December, Dumpul SW from May to December, and Tapan from October to December.

The ratio of sediment yield to rainfall at Dumpul and Tapan tended to decrease with time (Table 3). This indicates that the LRSC measures were effective in controlling erosion and sedimentation in both subwatersheds. Based on three years of monitoring of the runoff coefficient, bench terracing on steeper slopes (Tapan subwatershed) showed less effect than on moderate slopes (Dumpul subwatershed).

Table 3. Sediment yield as affected by land rehabilitation and soil conservation measures in three subwatersheds of Samin Watershed.

Year	Rainfall (mm)			Sediment load ($g\ cm^{-2}$)			Sediment to rainfall ratio ($g\ cm^{-2}\ m^{-1}$)		
	G	D	T	G	D	T	G	D	T
1974	3261	1318	1099	2.746	1.127	-	0.842	0.855	-
1975	3902	3212	4034	3.243	1.641	5.098	0.831	0.511	1.307
1976	2081	1927	2326	1.482	1.350	2.379	0.712	0.701	1.023
1977	1756	2006	2069	1.530	1.143	2.203	0.871	0.570	1.065

Source: data from Achlil (1978)
G: Goseng SW (control), D: Dumpul SW (treated), Tapan SW (treated) In 1974, precipitation on Goseng SW from January to December, Dumpul SW from May to December, and Tapan from October to December.

Soil erosion control in the catchment area of Wonogiri dam

The project was carried out in the upper Solo Watershed within Wonogiri District from 1989 to 1994 with funding from IBRD. It has a total area of 121,073 ha, covers six subwatersheds, namely, Keduang (42,644 ha), Wiroko (20,580 ha), Temon (6,753 ha), Upper Solo (20,225 ha), Alang Unggahan (23,538 ha), and Wuryantoro (7,333 ha). The objectives were to minimize sedimentation in the Wonogiri Reservoir by introducing soil conservation measures and to improve the income of the farmers in the catchment area.

The catchment is located at 110°04', 111°18' E and 7°32', 8°15'S. Lithologically, the catchment area is dominated by limestone and old volcanic rocks. Soil varies from Grumosol (Vertisol), Mediterranean (Luvisol or Alfisol), Lithosol (Entisol), and Latosol (Cambisol or Inceptisol). Land use in the catchment is dominated by dryland areas and home gardens (Table 4). Precipitation is characterized by four to nine wet months (>200 mm month^{-1}) and three to eight dry months (<100 mm month^{-1}). The reservoir area covers 13,036 ha.

Table 4. Land use distribution within the Wonogiri reservoir catchment area.

Subwatershed	Land use				
	Forest (%)	Dryland (%)	Home garden (%)	Paddy field field (%)	Total area (ha)
Keduang	14.53	30.13	33.50	21.84	42,644
Wiroko	13.32	55.44	17.38	13.86	20,580
Temon	11.41	52.45	22.89	13.25	6,753
Upper Solo	9.75	58.38	18.08	13.29	20,225
Alang U.	12.89	28.09	37.92	21.10	23,538
Wuryantoro	16.01	33.14	38.31	12.54	7,333
Total	13.21	40.18	28.74	17.87	121,073

Mechanical and vegetative soil conservation measures were introduced. These include gully head structures (250 units), small dams (40 units), big gully plugs (160 units), and small gully plugs (1,300 units). In addition, 200,000 m^2 steep banks were sloped and planted to grass, 1,000 m of stream banks were protected, 80 km of roadside were protected, and 22,000 ha of bench terraces were rehabilitated (USWP, 1992). Vegetative measures introduced were improved cropping patterns, private forest (5,000 ha), and green belts (500 ha).

It was observed that the dryland farms were the main source of erosion and surface runoff (USWPP, 1982). The recommended cropping patterns improved the watershed condition by reducing erosion and runoff (Table 5). They showed a better effect when combined with improved terracing. Productivity of upland rice, maize, groundnut, soybean, and cassava also increased by 45, 35, 23, 26, and 62%, respectively (RDWM Project, 1995). In financial terms, the farmers' income was increased from the equivalent of 391 to 1,606 kg of rice.

LRSC interventions in the upper Garang subwatershed

Based on the information on Garang Watershed obtained from LRSC Centre of Pemali-Jratun, the upper Garang subwatershed was identified as the first priority for watershed management. The main problems identified by the LRSC FED were high soil erosion and sedimentation, flooding, and inappropriate land use (LRSSC Jratunseluna, 1991). To address these problems some LRSC measures were implemented by the local LRSC FSCS of Semarang District. These included the establishment of smallholder plantations, private forests, terraces, check dams, gully plugs, recharged wells, and provision of soil conservation credit (Table 6). The establishment of smallholder plantation was most extensive.

Table 5. Effect of different conservation treatments on soil erosion and runoff in 5 subwatersheds in the Wonogiri reservoir catchment area.

Subwatershed	Treatment	Soil loss		Runoff		Runoff coefficient	
		Value (t ha^{-1})	% Reduction from control	Value (%)	% Reduction from control	Value (%)	% Reduction from control
Keduang	1	49.0	-	5592	-	40	-
	2	35.0	28	4810	14	35	13
	3	6.0	88	3456	38	23	43
Wiroko	1	7.3	-	2024	-	30	-
	2	3.9	41	764	62	12	60
	3	2.2	70	414	80	7	77
Temon & U. Solo	1	21.0	-	5482	-	45	-
	2	18.0	14	4210	28	33	27
	3	5.0	76	3470	40	27	40
Alang U.	1	3.9	-	1772	-	15	-
	2	2.9	26	1289	27	11	27
	3	1.3	67	504	72	4	73
Wuryantoro	1	28.0	-	6095	-	40	-
	2	25.0	34	4729	22	31	23
	3	10.0	74	3686	40	23	43

Source: Data from USWPP (1992).

Treatment: 1. Dryland with traditional terrace and existing cropping pattern (control).
2. Dryland with traditional terrace and improved cropping pattern.
3. Dryland with improved terrace and improved cropping pattern.

Table 6. Implementation of LRSC activities at the upper Garang subwatershed from 1993 to 1998.

LRSC activity	Area (ha unit^{-1})							
	1998	1997/ 1998	1996/ 1997	1995/ 1996	1994/ 1995	1993/ 1994	Before 1993/94	Total (1985)
Smallholder plantation	-	20	50	60	20	-	705	855
Private forest	-	-	-	20	-	-	50	70
Terrace	-	-	-	-	-	10	70	80
Check dam	-	-	2	1	1	2	5	11
Gully plug	-	-	2	-	1	4	2	9
Recharge well	-	16	10	10	20	10	-	66
Conservation credit	-	-	-	-	-	-	50	50

Source: Data from LRSSC Jratunseluna (1999).

LRSCSC of Jratunseluna (now under LRSCC of Pemalijratun) conducted the monitoring and evaluation of the activities and their effect (LRSCSC Jratunseluna, 1998, 1999 a,b). Table 7 shows that there was a tendency for the water retention capacity of the subwatershed to become worse as indicated by the increasing streamflow and runoff coefficients from 21 to 78 and from 0.596 to 0.863, respectively (DLRSC, 1994). However, sediment yield tended to be stable. In fact, the sediment yield was lower than the target yield of 21.36 t ha^{-1} y^{-1}. This shows that the interventions were effective in reducing soil erosion, but not in stabilizing streamflow fluctuation and improving soil infiltration and water holding capacity. Consequently, flood and drought risk was still high. There was a suggestion to intensify the introduction of vegetative control measures and recharge wells. The vegetative measures should be introduced to the farmlands and the recharge wells on homestead areas.

Table 7. Hydrological characteristics of the upper Garang subwatershed as monitored from 1995 to 1997.

Characteristics	**Year**		
	1995	**1996**	**1997**
Annual precipitation (mm)	1,789.000	1,877.000	1,266.000
Precipitation days total	127.000	147.000	71.000
Average water level height (m)	0.300	0.35	0.280
Maximum discharge (m^3 s^{-1})	13.27.000	12.500	18.810
Minimum discharge (m^3 s^{-1})	0.630	0.580	0.240
Streamflow coefficient	21.000	22.000	78.000
Averaged discharge (m^3 s^{-1})	0.712	0.837	0.612
Annual runoff (mm)	1,066.000	1,157.000	1,093.000
Runoff coefficient	0.596	0.616	0.863
Sedimentation yield (t ha^{-1})	14.92.000	13.88.000	14.760
Sediment to precipitation ratio	150.000	129.000	1,768.000

CONCLUSION AND RECOMMENDATIONS

Watershed degradation is a serious problem in Indonesia. It causes negative impacts on natural resource sustainability and productivity, economic loss, social disturbances, etc. To cope with the problem, watershed management institution should be established to implement the concept of proper watershed management. Watershed management in Indonesia faces problems related to multisectoral coordination, regional autonomy, people empowerment and participation, and law enforcement. The main objective of watershed management under the Ministry of Forestry is to restore degraded watershed through land rehabilitation and soil conservation (LRSC) practices. Institutions responsible for planning (long term, medium term, and annual), implementation, and monitoring and evaluation were identified.

Based on a number of case studies, further improvement in the LRSC measures is still needed to attain the desired hydrological conditions of the watersheds. Thus, formulation of a research and development (R&D) agenda for producing appropriate watershed technology is crucial. The R&D activities should be implemented using the integrated catchment approach. To improve the quality of R&D for watershed management, methodology, human resources, instrumentation and problem-oriented research should be prioritized

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