RESERVOIR SEDIMENTATION - A CASE STUDY OF WONOGIRI RESERVOIR (INDONESIA)

A DISSERTATION
Submitted in partial fulfillment of the
requirements for the award of the degree
of
MASTER OF TECHNOLOGY
in
WATER RESOURCES DEVELOPMENT

By

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CANDIDATE'S DECLARATION

I hereby certify that the work, which is being presented in the dissertation entitled **"Reservoir Sedimentation – A Case Study of Wonogiri Reservoir (Indonesia)"** in partial fulfillment of the requirement for the award of degree of **Master of Technology in Water Resources Development** in the Department of Water Resources Development and Management of Indian Institute of Technology Roorkee, is an authentic record of my own work carried out during the period from July 2009 to May 2010 under the guidance of **Dr. U.C. Chaube,** Professor of Water Resources Development and Management Department, Indian Institute of Technology Roorkee, India.

I have not submitted the matter embodied in this dissertation for the award of any other degree.

Dated : June 01 , 2010
Place : Roorkee

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CERTIFICATE

This is to certify that the above mentioned statement made by the candidate is correct to the best of my knowledge.

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ABSTRACT

Sedimentation of reservoirs is a matter of vital concern as it adversely affects the useful life of reservoir and benefits from the reservoir. The two aspects of the sedimentation problem, whose knowledge is essential, are the erosion rate from catchment and the pattern of deposition in the reservoir. These two aspects are addressed in this study

Total global sediment discharge is about 14 x 10^9 tones/year (UNEP, 2003). The global suspended sediment discharges to sea range between 15 to 20 x 10^9 tones/year, where the best estimate may be about 20 x 10^9 tones/year (Takeuchi 2004). More than 25% of this sediment discharge may be trapped by large reservoirs. Matatila dam has already lost more than 38% of its live storage capacity.

This dissertation study has focus on GIS based assessment of soil erosion from the catchment (1243.3 km^2) of Wonogiri Reservoir and effect of sediment deposition on elevation-area-capacity relation. The Bengawan Solo basin area is 16,100 km^2 lying on both Central and East Java provinces, which covers approximately 12% of the total area of the Java, Indonesia,

Objectives of this dissertation work are:

i. To critically examine the Area Reduction Method for estimation sediment distribution in reservoir and analyse the effect of progressive sedimentation on elevation-area-capacity relationship of Wonogiri reservoir.

ii. To assess soil erosion and its geographic distribution catchment of Wonogiri reservoir using GIS based estimation of R,K,LS,C,P factors and application of USLE model.

iii. To use GIS based USLE model as a management tool for identification of critical areas and manipulation of C or and P factors to reduce soil erosion.

iv. To predict deposition profile (longitudinal) in Wonogiri Reservoir using an empirical method

Among the empirical methods for estimation of sediment accumulation and distribution in reservoir, the Area Reduction Method proposed by Borland and Miller (1958) is most suitable and widely used on account of its simplicity and minimum data requirement.

The analysis of progressive sedimentation highlights the following:

i) Standard type classification of a reservoir is not constant

ii) Elevation-area-capacity relation varies over life of the project due ti gradual deposition of sediment in live storage zone and this variation should be considered in reservoir planning.

iii) Area reduction method needs improvement in term of standard type classification of reservoir.

Poor land use in the catchment and intensive farming of annual crops using poor practices on the highly erosive and steep-sloped uplands as well as highly populated and intensely farmed areas are the main causes of the sedimentation of the Wonogiri reservoir. GIS based Universal Soil Loss Equation is applied for prediction of soil erosion from different subwatersheds of the Wonogiri Reservoir catchment. Geographic distribution of USLE factors (R,K,LS,C,P) are examined..

Erosion control in Wonogiri Basin region can be improved by: (1) improvement of land, (2) improvement of farming patterns or land use, or (3) a combination of two of these. Procedures for erosion control improvements (improvement factor P) and the pattern of cultivation (factor C) are probably the most easily implemented measures. USLE can be used to identify suitable measures so that soil erosion is within permissible limit. Application of USLE as a management tool to control soil erosion through manipulation of C and P factor in GIS environment is illustrated.

Triangular sediment distribution profile in Wonogiri Reservoir under different conditions of analysis is estimated following method proposed by Mirarki GD (1983). The method is based on analysis of deposition profile in some reservoirs in India.

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CHAPTER 1
INTRODUCTION

1.1 BACKGROUND

All the reservoirs big or small created by constructing a dam across a river are subject to silting which results in reduction of storage capacity. Therefore, sedimentation of reservoirs is a matter of vital concern as it affects the useful life of reservoir and benefit from the reservoir. The two parameters of the sedimentation problem, whose knowledge is essential, are the erosion rate from catchment and the pattern of deposition in the reservoir.

The river catchment above the dam site is the source of sediment to the reservoir. The erosion rate in the catchment and the river transport capacity are the factors which determine the sediment inflow in the reservoir. Sometimes when it is not feasible to measure or to estimate sediment yield from the catchment, the observed data of similar reservoirs is used for planning a reservoir.

The Report of the Goverment of India's National Commission of Integrated Water Resources Development has said (p 85) that a total loss in Live Storage (LS) capacity of 65 BCM (Billion Cubic Meters) by the year 2050 would happen due to reservoir sedimentation. This implies that the country is losing about 1.3 BCM of storage capacity each year.

Sediment deposition in reservoir results in reduction of storage capacity, increase in backwater levels in head reaches rising of floods levels, chocking of irrigation navigation and power outlets and formation of islands. For long term planning of efficient utilization of reservoir capacity, estimation of total sediment deposit alive is not sufficient. More important is the estimation of trapped sediment at different levels in the reservoir. The sediment accumulation in storage zone has direct effect on allocation of storage volumes for irrigation, power, flood moderation and industrial and municipal water supplies. Therefore, realistic estimation of sediment deposition pattern a reservoir is of utmost importance for long term planning of water volume allocations.

1.2 OBJECTIVE AND SCOPE OF STUDY

Objectives of this dissertation work are:

i. To critically examine the area reduction method of sediment distribution in reservoir and analyse the effect of progressive sedimentation on elevation-area-capacity relationship of Wonogiri reservoir.

ii. To assess geographic distribution of soil erosion in catchment of Wonogiri reservoir using GIS based estimation of R,K,LS,C,P factors and application of USLE model.

iii. To use GIS based USLE model as a management tool for identification of critical areas and manipulation of C or and P factors to reduce soil erosion.

iv. To predict deposition profile (longitudinal) using an empirical method.

Chapter 1

Objective and Scope of the present study is provided. This dissertation deals wroth study of soil erosion from catchment of a reservoir, control of erosion and study of progressive sedimentation on elevation-area-capacity relation of a reservoir.

Chapter 2

Global, India, and Indonesian perspectives on erosion, river sediment, and reservoir sedimentation are briefly explained to highlight magnitude of problem

Chapter 3

Catchment characteristics and salient features of the Wonogiri reservoir in Indonesia are discussed, with focus in factors causing soil erosion in the catchment. The Wonogiri reservoir is undergoing heavy sedimentation.

Chapter 4

Area reduction method (Borland and Miller – 1958) for estimation of sediment distribution at different elevation is critically examined. Change in Elevation-Area-Capacity relation due to progressive sedimentation in Wonogiri Reservoir is analysed.

Chapter 5

GIS based Universal Soil Loss Equation is applied for prediction of soil erosion from different subwatersheds of the Wonogiri Reservoir catchment. (geographic distribution of USLE factor (R,K,LS,C,P) are examined. Comparison is made between soil erosion estimates as obtained by use of USLE as a distributed parameter model (GIS).

Chapter 6

Analysis similar to that in chapter 5 is repeated. However, now it is done using USLE model as a management tool to reduce soil loss from the catchment. Geographic distribution of C and P factors are manipulated and effect on tool soil loss is evaluated.

Chapter 7

Garde (1995) has proposed a method for prediction of sediment distribution profile in the reservoir. This is applied for prediction of sediment distribution profile in Wonogiri Reservoir under different conditions of analysis.

CHAPTER 2

PERSPECTIVES ON RESERVOIR SEDIMENTATION

2.1 GENERAL

Surface water resource is generated as a result of rainfall/precipitation in the catchment of a river. Rainfall and surface water flow causes soil erosion in the catchment. Therefore, the surface flow from the catchment is always associated with the sediment flow. Another source of sediment in the river flow is the scouring of the bed and banks of the river channel. Landslides of the hill slopes are sometimes the source of abnormal sediment flow in the river channels.

The process of deposition and erosion depends on hydraulic characteristics of river channel which also controls the sediment transportation rate. The sediment concentration in the flow, the size of sediment, coarse particles moving as bed load and fine particles moving as suspended load are the parameters which create serious sediment problems for all types of water resource development projects which make use of river flows for useful purposes. Figure 2.1 shows schematic representation of the sediment accumulation in a typical reservoir.

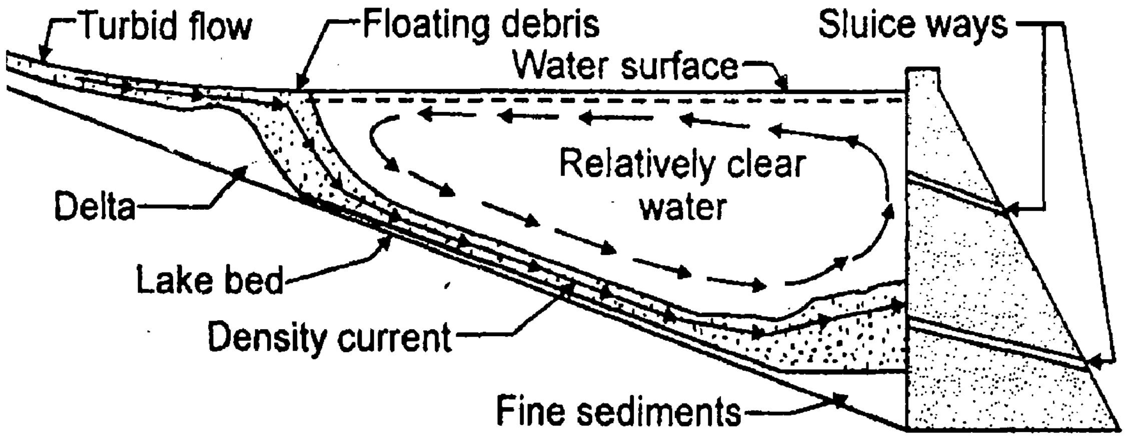


Fig. 2.1 Schematic representation of the sediment accumulation in a typical reservoir

2.2 RESERVOIR SEDIMENTATION

Gregory Morris (Reservoir Sedimentation Handbook, 1997) *"Planned Obsolescence due to sedimentation affects most reservoirs worldwide, not just in India,* *and will render many of them unusable in the foreseeable future… Dams are uniquely different from engineering infrastructure such as roads, harbors, and cities, and which can be reconstructed on the same site occupied by obsolete infrastructure. Dams cannot be reconstructed at the same site once the reservoir has filled with sediment; the sediment must either be removed or the site abandoned. The cost of sediment removal at a large reservoir can easily exceed the original dam construction cost by an order of magnitude."*

After construction of a dam the incoming sediment deposits in the reservoir because of the reduction of velocity. Practically all the bed load and part of suspended load deposits in the reservoir. However, the amount and rate of deposition, its effect and the induced problems of reservoir sedimentation are different in each case depending on catchment characteristics, reservoir geometry, the operational requirement of reservoir which depends on the purpose of reservoir etc. Reservoir sedimentation primarily reduces the storage capacity resulting in the reduction in useful life and the benefits from the reservoir. There are some environmental impacts of the reservoir sedimentation, such as affecting the flora and fauna as well as quality of water, degradation in the downstream etc.

If the water stored in the reservoir is clear and the in-flow is charged with sediment or is mud, the heavier water with sediment will flow along the channel bottom towards the dam under the influence of gravity and the clear light water will flow on the upper surface of the turbid water. This condition is known as stratified flow and the under flow of sediment laden water is known as *density current.* The deposition of sediment in the reservoir is known as *reservoir silting* or *reservoir sedimentation.*

Some reservoirs silt at a very fast rate depending on rate of incoming sediment and reservoir storage capacity. Some reservoirs in China have lost 2 to 3% of storage capacity every year. The storage reservoir in India loses capacity at the rate of 1 to 0.5% every year. Some reservoirs in Japan & U.S.A. have lost their entire storage capacity in a few years of their operations. In India, in Himalayas diversion dams, such as Ichari, Maned, Pandoh have been silted upto the spillway crest in 2 to 7 years of operation.

2.3 MECHANISM OF SEDIMENTATION

The silt deposition in reservoirs resembles in many respects to that of a delta of a river discharging in sea or lake. The four parts of delta deposits are also applicable in the case of reservoir deposits namely.

1. Top set bed.
2. Fore set beds.
3. Bottom set beds.
4. Density current etc.

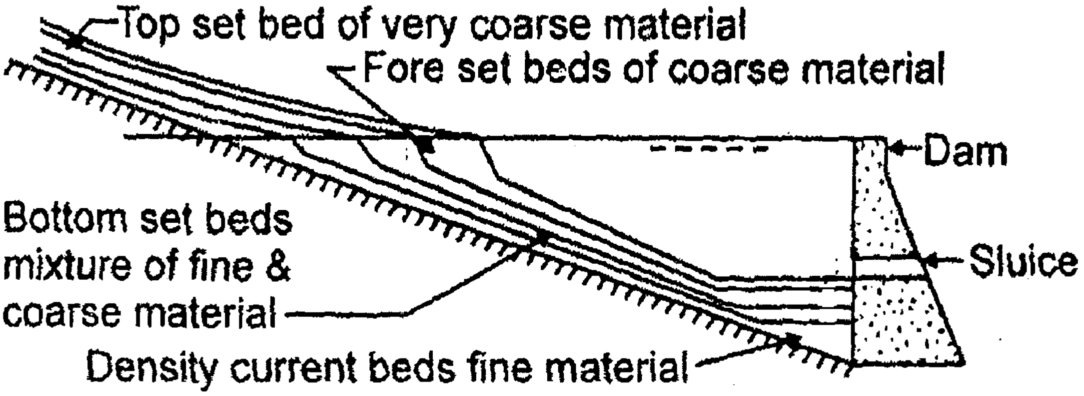


Fig 2.2 Sediment deposition in a reservoir

1. Top set bed

As stated earlier, the velocity of the river is reduced considerably as the river approaches the reservoir even before the river enters the reservoir due to back water effect. Due to the reduction of velocity of flow the the silt carrying capacity of the river also reduces and it deposits the heavy sediment particles in the channel above the highest level of the reservoir or lake and is called the *top set bed.*

2. Fore set bed

As soon as the river water enters the relatively calmer water of the lake or reservoir, the rest of the coarse particles and most of the medium size sediment particles settle down. This deposition is called as *fore set bed.*

3. Bottom set beds

The fine particles or silt and clay do not settle till they have moved through a sufficient distance into the reservoir where they may settle down or get deposited in thin layers. This deposit is known as the *bottom set bed.*

4. Density current

In general a density current may be defined as a gravity flow of a fluid under, over or through a fluid or fluids of approximately equal density. The depth of turbid flow increases at the point where the density current is established, after which it tends to decrease again. The magnitudes of these relative changes and their effects upon sediment deposition depend on many factors such as shape of reservoir, channel slope, ratio of out- flow to inflow and density differences etc. As a rule however density currents move very -slowly.

The two dominant factors influencing the rate of silting in any storage reservoir are (i) sediment in the flow and (ii) the capacity inflow ratio. The other factors which affect the loss in storage capacity in the long run are:

(i) The trap efficiency
(ii) Sediment characteristics, and
(iii) The reservoir operation

These factors are inter-related. If the capacity is small the reservoir can be filled up by sediment much earlier than big reservoir having large capacity-inflow ratio. On the other hand reservoirs having large capacity-inflow ratio will trap large amount of sediment entering the reservoir i.e. these will have high trap efficiency.

The factors favoring sediment deposition in upper portion of a reservoir are:

- Reservoir operation usually at high elevation
- Sediment load consisting mainly of coarse material
- Outlets at low elevation
- Heavy vegetation at head of reservoir.
- Constriction in reservoir between head reach and the dam.

In some small reservoirs having steep river slopes especially run-of-river hydropower schemes, sediment deposition rate is very fast and in some cases deposition up to the spillway crest occurs within a few years of operation

An accurate prediction, of rate of sedimentation and pattern of deposition in a reservoir is necessary for proper planning of a reservoir and its benefits.

2.4 GLOBAL PERSPECTIVE

Reservoir sedimentation is a global challenge. The current estimate of total reservoir storage worldwide is about 7.000 km^3 (Palmieri et al., 2003). Using an average rate, Palmieri et al., (2003) estimated the storage loss to be approximately 45 km^3 per year all over the world. The cost of replacing the lost storage is about USD 13 billion per year, even without counting the environmental and social costs associated with new dams.

The growth of the dam development was intense during 1960 to 1980 (ICOLD 2004) as shown in Figure 2.3. The new dam development since 2000 is significantly less; however the loss of storage capacity is very high. It shows that about 1.000 km^3 of volume will be lost by 2020, which is about 15% of the current gross available storage. Total global sediment discharge is about 14 x 10^9 tones/year (UNEP, 2003). Takeuchi (2004) reported that the global suspended sediment discharges to sea range between 15 to 20 x 10^9 tones/year, where the best estimate may be about 20 x 10^9 tones/year. He further states that more than 25% of this sediment discharge may be trapped by large reservoirs. Figure 2.4 shows the suspended sediment discharge per region, which demonstrates that Asia with Pacific Oceanic Islands contributes nearly 70% of the sediment delivery to the world's oceans and seas. The relative suspended sediment discharge per region is presented in Table 2.1.

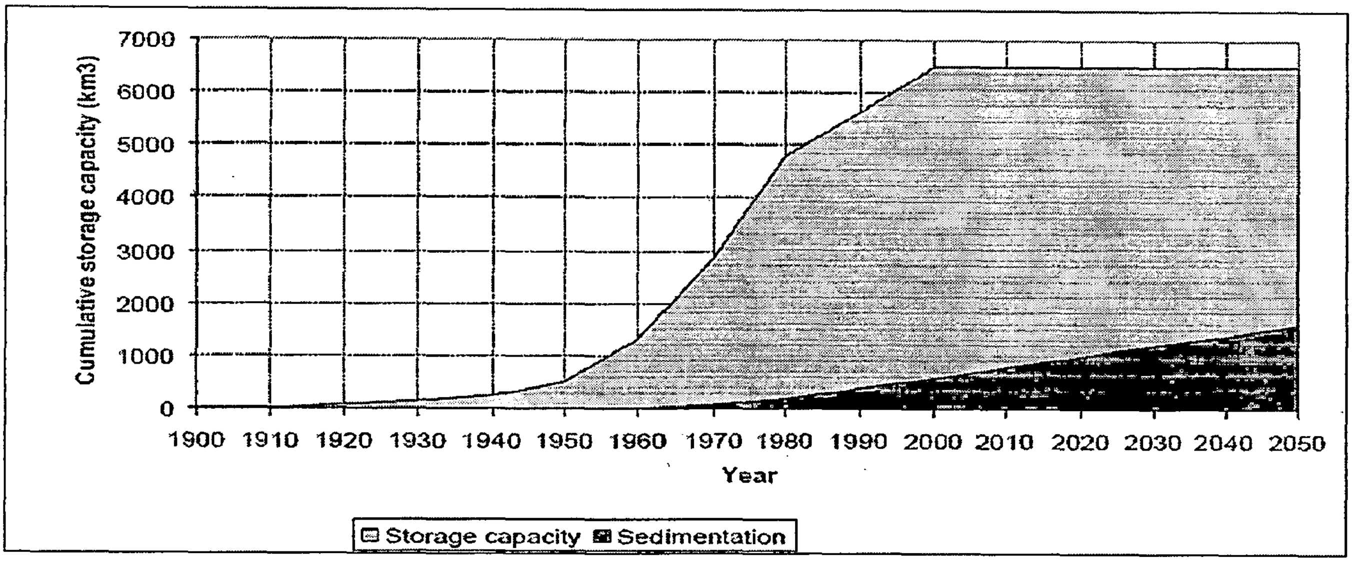


Figure 2.3.: Historical growth in reservoir storage capacity worldwide (adopted from ICOLD, 2004).

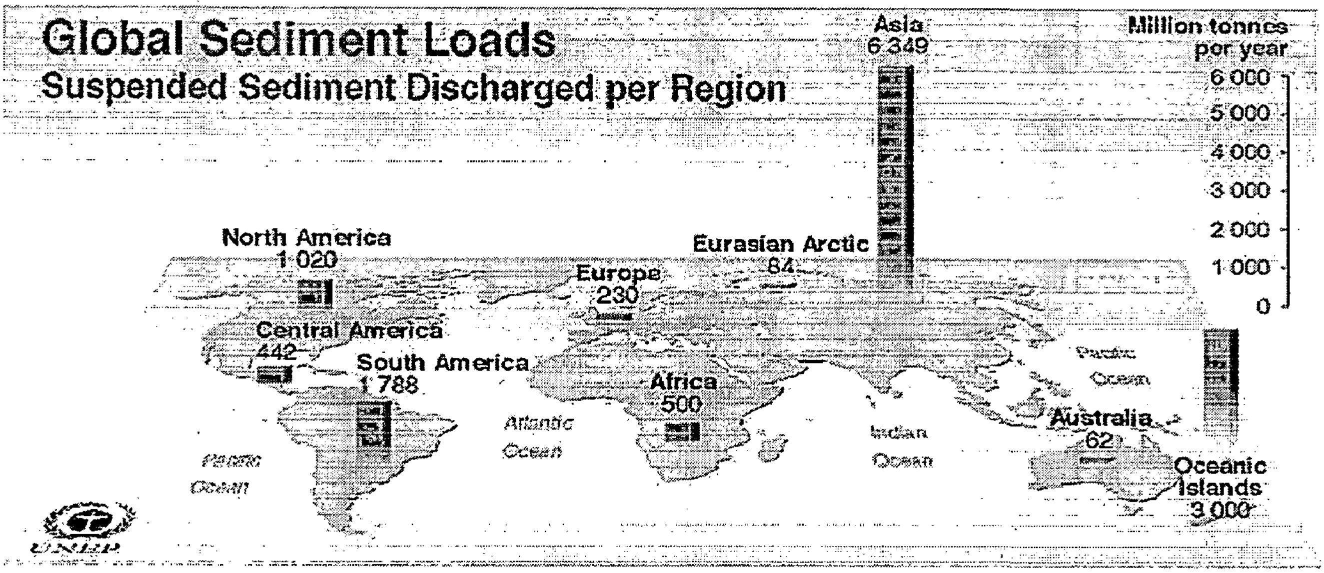


Figure.2.4: Suspended sediment discharge per region (UNEP, 2003)

Table.2.1. Suspended Sedimen discharge, and distribution per region (UNEP, 2003)

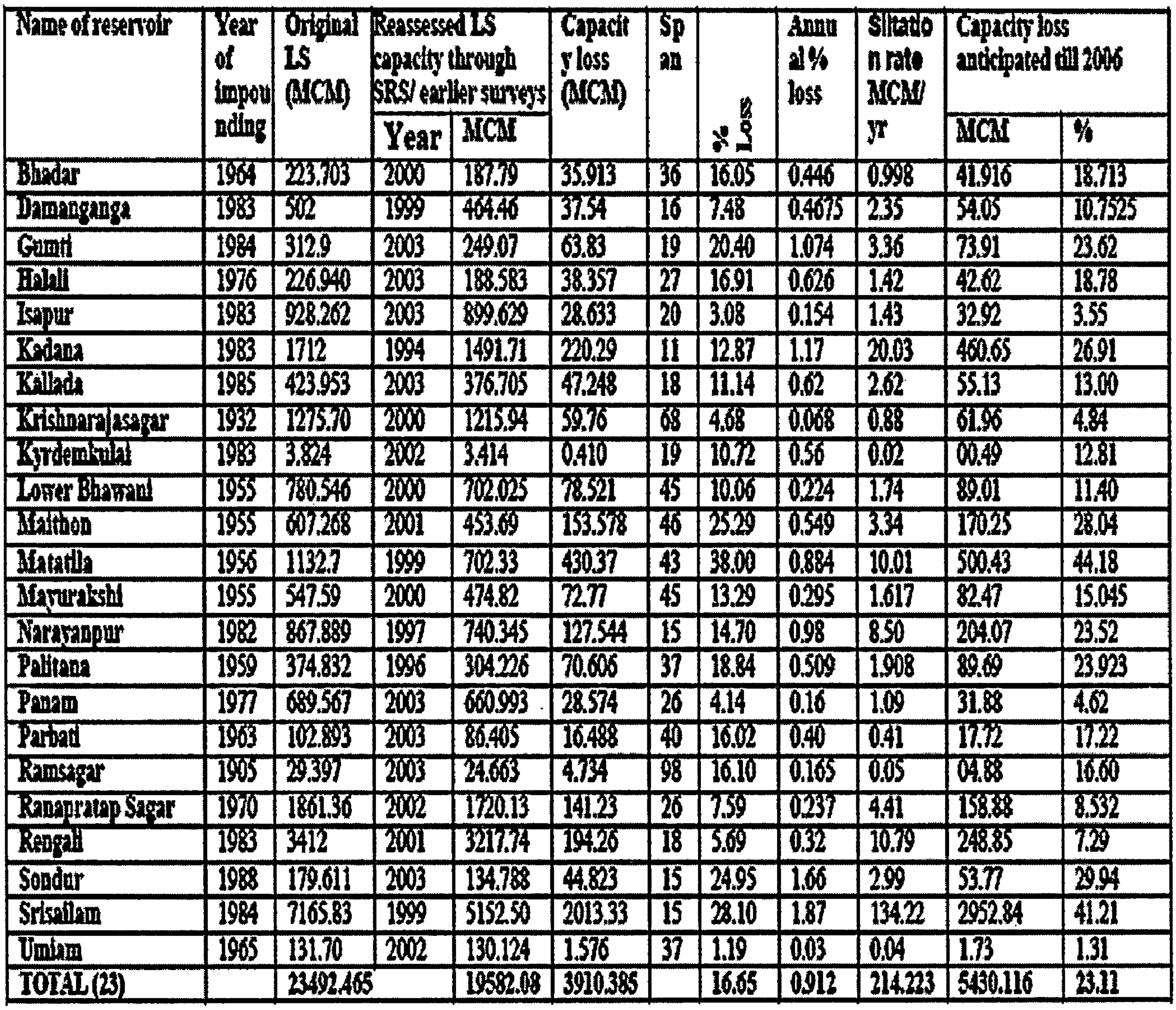
S. No	Region	Suspended sediment discharge (million tonnes/year)	Distribution of suspended sediment discharge (%)	Remarks
1	Asia	6 349	47.1	Global suspended sediment discharge is about 15 to 20 x10^9 tonnes/year.
2	Oceanic Islands	3 000	22.2	
3	Central and South America	2 230	16.5	
4	North America	1 020	7.6	
5	Africa	500	3.7	
6	Europe	314	2.4	
7	Australia	62	0.5	

2.5 INDIAN PERSPECTIVE

Himanshu Trakkar et al (2006) have compiled information on reservoir capacity loss for 23 reservoir in India (table 2.2). Matatila dam has already load more than 38% of its live storage capacity. Even recently completed demo are undergoing high siltation rate.

Khosla(1953) has provided the data on siltation of small and medium reservoir in India. These have been quoted and used for design purposes. Murthy BN (19977 a, 1977b) and CBIP (1981) have provided data on sediment inflow rates, depositin profile for some large reservoirs (Gobindsafar, Panchet Hill, Matatils, Nigamsagar, Mayurakshi, Hirakund, Maithon, Tungabhadra and Gandhi Sagar Reservoir) .

Table 2.2 Reservoir Capacity Loss (Live Storage) in India



Name of reservoir	Year of impounding	Original LS (MCM)	Reassessed LS capacity through SRS/ earlier surveys		Capacity loss (MCM)	Span	% Loss	Annual % loss	Siltation rate MCM/yr	Capacity loss anticipated till 2006	
			Year	MCM						MCM	%
Bhadar	1964	223.703	2000	187.79	35.913	36	16.05	0.446	0.998	41.916	18.713
Damanganga	1983	502	1999	464.46	37.54	16	7.48	0.4675	2.35	54.05	10.7525
Gumti	1984	312.9	2003	249.07	63.83	19	20.40	1.074	3.36	73.91	23.62
Halali	1976	226.940	2003	188.583	38.357	27	16.91	0.626	1.42	42.62	18.78
Isapur	1983	928.262	2003	899.629	28.633	20	3.08	0.154	1.43	32.92	3.55
Kadana	1983	1712	1994	1491.71	220.29	11	12.87	1.17	20.03	460.65	26.91
Kallada	1985	423.953	2003	376.705	47.248	18	11.14	0.62	2.62	55.13	13.00
Krishnarajasagar	1932	1275.70	2000	1215.94	59.76	68	4.68	0.068	0.88	61.96	4.84
Kyrdemkulai	1983	3.824	2002	3.414	0.410	19	10.72	0.56	0.02	00.49	12.81
Lower Bhawani	1955	780.546	2000	702.025	78.521	45	10.06	0.224	1.74	89.01	11.40
Maithon	1955	607.268	2001	453.69	153.578	46	25.29	0.549	3.34	170.25	28.04
Matatila	1956	1132.7	1999	702.33	430.37	43	38.00	0.884	10.01	500.43	44.18
Mayurakshi	1955	547.59	2000	474.82	72.77	45	13.29	0.295	1.617	82.47	15.045
Narayanpur	1982	867.889	1997	740.345	127.544	15	14.70	0.98	8.50	204.07	23.52
Palitana	1959	374.832	1996	304.226	70.606	37	18.84	0.509	1.908	89.69	23.923
Panam	1977	689.567	2003	660.993	28.574	26	4.14	0.16	1.09	31.88	4.62
Parbati	1963	102.893	2003	86.405	16.488	40	16.02	0.40	0.41	17.72	17.22
Ramsagar	1905	29.397	2003	24.663	4.734	98	16.10	0.165	0.05	04.88	16.60
Ranapratap Sagar	1970	1861.36	2002	1720.13	141.23	26	7.59	0.237	4.41	158.88	8.532
Rengali	1983	3412	2001	3217.74	194.26	18	5.69	0.32	10.79	248.85	7.29
Sondur	1988	179.611	2003	134.788	44.823	15	24.95	1.66	2.99	53.77	29.94
Srisailam	1984	7165.83	1999	5152.50	2013.33	15	28.10	1.87	134.22	2952.84	41.21
Umiam	1965	131.70	2002	130.124	1.576	37	1.19	0.03	0.04	1.73	1.31
TOTAL (23)		23492.465		19582.08	3910.385		16.65	0.912	214.223	5430.116	23.11

Source: Himanshu Thakkar And Swarup Bhattacharyya, 2006,

No data are available in India concerning degradation of downstream of large capacity reservoirs. Khosla (1953) related sediment yield V_s (MCM/yr) to catchment area A (km^2) as

$$V=3.23 \times 10^{-3} \times A^{0.72}$$

Dhruva Narayan and Ram Babu (1983) have used data from seventeen major reservoirs in India and obtained relation for annual sedimentation rate Ti (Milliontonnes/yr) as

$$T=0.342 \times 10^{-6} \times A^{0.84} X (EI_{30})^{1.65}$$

Where :

A= catchment area in Million Ha

EI_{30}= product of average annual value of the sum of maximum 30 minutes intensity of rainfall in cm/hr and kinetic energy of rainfall computed as

$E = 210 + 89 \log I_{30}$

Here E is in tones per Ha m. Using this and other associated information they have estimated that annual erosion from Indian cacthments is 2052 M tones out of which 480 Million tones are annually deposited in the rivers.

Garde et al (1983) have analysed data from thirty one small and large reservoir using the trap efficiency curve of Brune, deposited material was expressed as V_{SAB} absolute volume of sediment eroded in Mm^3/yr and obtained the relation.

$V_{SAB} = 1.067 \text{ X } 10^{-6} A^{1.292} P^{1.384} S^{0.129} D_d^{0.397} F_c^{2.51}$

Where S is the average land slope, D_d is the drainage density in km^{-1}. P is annual precipitation in cm and F_c is vegetal core factor defined as

$$F_c = \frac{0.2A_1 + 0.4A_2 + 0.6A_3 + 0.8A_4 + A_5}{A_1 + A_2 + A_3 + A_4 + A_5}$$

Where:

A1 = area of classed and protected forest

A2 = area covered by unclassed forest

A3 = arable area

A4 = scrub and grass area

A5 = waste area

The coefficients of A, i = 1 to 5 were chosen arbitararily. Equation V_{SAB} does not directly into account the effect of lithology of the area on sediment yield; however, it is assumed that F_c and D_d will indirectly account for effect lithology on erosion. This equation gave errors less than thirty percent for 90 percent of data

2.6 INDONESIAN PERSPECTIVE

The Indonesian reservoir developments are mainly directed towards the fulfillment of the irrigation demand and secondly for the electrical demand. The reservoir sizes vary considerably depending upon the optimum design that has been studied. During the fifties thru the nineties of the Indonesian reservoir development, related regulations, laws, as well as design criteria, have been established. The establishment of such instruments was very much influenced by overseas consultants being involved in the reservoir development that was going on at that time. It is known that the distinction between the large dam and the small dam solely based on the dam height, over and equal to 100 m heights are categorized as large dam, and vice versa. Furthermore, a very small dam of less than 15 height is categorized as what it is called 'embung.

Due to the multidimensional crisis in Indonesia in 1997, the reservoir developments have been facing with many problems, which are mainly due to the lack of trust supported by society as the developments may only contribute negative impacts. Some of these many impacts are the loss of the fertile land, many people loss their job as being farmer, unsatisfying the compensation cost for people who are losing their land, etc. Unfortunately, the lifetime of some reservoirs may reach a critical condition that the sedimentation in the reservoir is very close to the dead storage capacity. Previous study mentioned that the sediment production at the catchment area being utilized to estimate the reservoir lifetime ranged from 1.00 – 2.00 mm/year. This is considered too small since the sedimentation at the reservoir after the following years indicated much higher magnitudes.

The rate at which the capacity of a reservoir is reduced by sedimentation depends on: (a) the quantity of sediment inflow, (b) the percentage of this inflow trapped in the reservoir, and (c) the density of the deposited sediment. The quantity of sediment inflow may be estimated by reference to mean annual yield data per unit area from similar basins in the region. Table 2.3 presents some selected values of sediment yield derived from reservoir surveys.

Table 2.3. Sediment Production Rates

No	Name of Reservoir	Drainage Area(km^2)	Annual Sediment Production	
			mm/year	Volume(m^3)
1	Saguling-East Java	2283	2.1	4.791×10^6
2	Kedung Ombo-Central Java	614	2.3	1.412×10^6
3	Karangkates – East Java	2050	1.10	2.272×10^6

CHAPTER 3

STUDY AREA

3.1 BASIN TOPOGRAPHY

The Bengawan Solo River is the largest river on the island of Java, Indonesia. The basin geographically extends between 110°18' and 112°45' of east longitude and between 6°49' and 8°08' of south latitude. Its catchment area is 16,100 km^2 lying on both Central and East Java provinces, which covers approximately 12% of the total area of the Java. The river originates from the Sewu mountain range and flows into the Java Sea to the north of Surabaya after travelling about 600 km.(figure 3.1)

The Bengawan Solo (BS) river basin can be divided into two main reaches, the Upper Solo and Lower Solo River basins, at the confluence with the Madiun River. The former is further subdivided into the Upper Solo and Madiun basins with and area of some 6,072 km^2 and 3,755 km^2 respectively, by Mt. Lawu located at its center. Both Upper Solo and Madiun Rivers have their source in the Sewu Range in the south of the basin.

The Upper Solo and Madiun Rivers flow gathering tributary flows from steep slopes of volcanic cone of Mt. Merapi, Mt. Merbabu and Mt. Lawu in the upper reaches of the river. The tributaries, which flow down carrying continuously a large quantity of eroded volcanic materials, contribute to high sediment load of the Bengawan Solo River.

The BS River originates on southwest slope of G. Rahtawu in Tertiary Volcanic mountainous area and flows westward along the series of mountains. The Solo River generally takes a northward direction, receiving the Alang River, Temon River, Tirtomoyo River and Keduang River (figure 3.1) immediately upstream of the Wonogiri Dam. Downstream of the Wonogiri Dam, the Solo River flows clockwise around Mt. Lawu and flows eastward to Ngawi City after running through the alluvial plains of Surakarta City and Sragen City. After the confluence with the Madiun River, the Solo River flows northward to Cepu City before changing direction to the east-northeast and pouring into the Jawa Sea, about 30 km to the northwest of Surabaya City

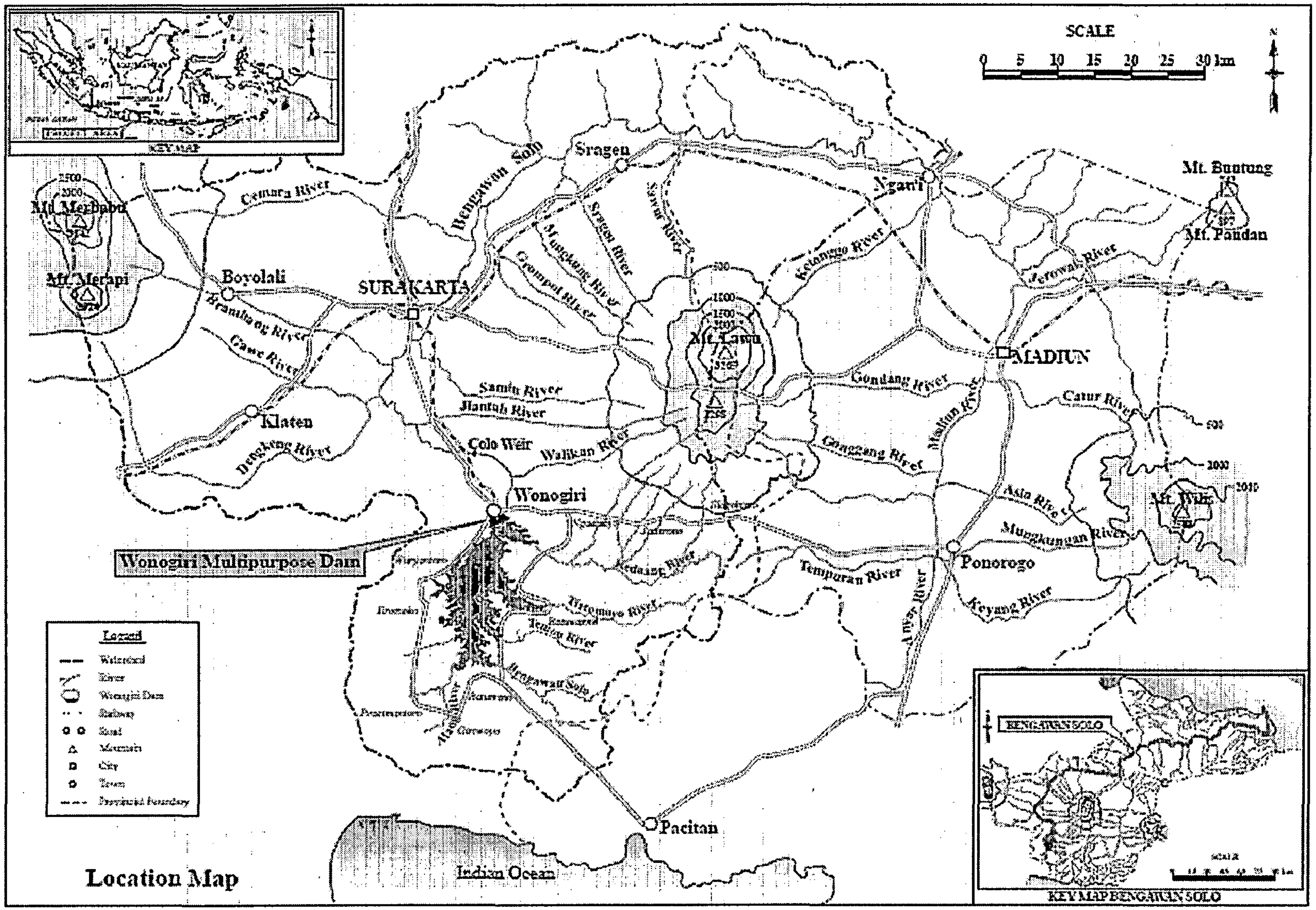


Fig. 3.1 Location Map

3.2 REGIONAL GEOLOGY

The Study Area is located in the southwestern foothill of Mt. Lawu and situated around the boundary between the Solo Zone and Southern Mountains Zone. These geomorphic zones of Java form belts extending in an east to west direction that extends further eastwards to Bali Island. The Wonogiri dam and reservoir area is underlain by volcanic breccia, tuff breccia, tuffaceous sandstone, calcareous sand and limestone of Miocene age belonging to the Southern Mountains Zone. Quaternary volcanic products of Solo Zone are distributed on the right bank of the Wonogiri Dam and the Keduang River.

3.3 WATERSHED Of WONOGIRI DAM

The watershed is drained by the following eight rivers. And the watershed area of these river shown in table 3.1

Table. 3.1 Watershed Area of Wonogiri Reservoir

Wonogiri Reservoir Watershed	SubWatershed Area km^2
Keduang	420.98
Tirtomoyo	230.65
Temon	62.6
Upper Solo	205.53
Alang	169.4
Ngunggahan	82.4
Wuryantoro	44.1
Remnat	27.68
Total Area	**1243.3**

3.4 SOILS AND LAND USE

(1) Soils

The soils distributed in the Wonogiri watershed are classified into four soil types i.e Mediteran (42% of the whole area), Litosol (25%), Latosol (12%) and Grumusol (21%). All of these soils are fine textured (clay to silty clay) and their soil fertility is generally poor, being susceptible to water erosion. Among them, Mediteran and Latosol are categorized as highly fragile to surface soil erosion.

(2) Land Use

Low-lying flat lands in the Wonogiri dam watershed have been widely developed for paddy cultivation. Upland fields with an elevation of 200-1,000 m have been also developed for agricultural uses. Since the completion of Wonogiri dam, forest areas have drastically decreased and upland fields have been increased. It is considered that such changes of land uses in the dam watershed might be one of main causes for the drastic increase of soil erosions within the dam watershed.

3.5 RAINFALL

Based on availability andreliability of the rainfall data in and around the Wonogiri Dam catchment, 5 rainfall stations are selected to analyze the rainfall condition of the Study Area. Mean annual rainfall over the Wonogiri catchment is worked out based on the rainfall data at the selected 5 stations.

3.6 AGRICULTURE

The agriculture sector is the largest economic sector in Wonogiri and contributed 52% in 2002. The crop sub-sector is characterized by paddy field (wet land farming) food crops and upland (dry land farming) food, horticulture and estate crops. Wet land farming is practiced in paddy fields covering low-lying areas and in rice terraces constructed on sloping land. The dry land farming is extensively practiced in terraced fields constructed on moderate to steep sloping land. The primary crop in the wet land is paddy (wet land rice), while in upland, diversified seasonal crops and perennial crops are produced.

3.7 WONOGIRI MULTIPURPOSE DAM AND RESERVOIR

The Wonogiri multipurpose dam is the only large dam on the mainstream of the Bengawan Solo River. The Wonogiri Multipurpose Dam on the upper Bengawan Solo was constructed in the late 1970s to early 1980s to provide flood control, irrigation water and hydroelectric power. Impoundment of the reservoir was initiated on 29 December 1980 and the reservoir was filled about one year later Since impoundment of the Wonogiri reservoir on December 29, 1980, the

Wonogiri dam has much contributed to social welfare in the basin and has greatly benefited the country in both regional and national economic development.

Table 3.2 Capacity of Wonogiri Dam

Storage Zone	**Elevation Range (m)**	**Storage Capacity (10^6 m^3)**
Flood control	135.3 – 138.3	220
Effective (for irrigation & power)	127.0 – 136.0	440
Sediment	below 127.0	120

(1) Principal Feature of Wonogiri Multipurpose Dam

The principal features of the Wonogiri dam and reservoir are summarized on below, and the allocated storage capacities and water levels thereof are shown in Figure 3.2

Principle Features of Wonogiri Multipurpose Dam and Reservoir

Dam Type	: Rockfill
Dam Height	: 40 m
Crest Length	: 830 m
Embankment Volume	: 1,223,300 m^3
Catchment Area	: 1,350 km^2
Reservoir Area	: 90 km^2
Sediment Storage Capacity	: 120 x 10^6 m^3
Sediment Deposit Level	: EL. 127.0 m
Normal Water Level	: EL 136.0 m
Design Flood Water Level	: EL 138.3 m
Extra Flood Water Level	: EL 139.1 m
Type Of Spillway	: Radial Gate
Flood Inflow Discharge (60 Yr Flood)	: 4,000 m^3.s
Flood Outflow Discharge	: 400 m^3/s

Design Flood Discharge (100 yr) : 5,100 m^3/s
PMF : 9,600 m^3/s
Installed Capacity : 12.4 MW
Max Discharge : 75 m^3/s
Annual Energy Output : 50,000 MWh

(2) Operation of Wonogiri Reservoir

1) Reservoir Operation

Mean annual inflow volume into the Wonogiri reservoir was approximately 1.23 billion m^3 in 1983-2005, and mean annual water release from the spillway (spill-out) was around 18% of the total outflow volume or 210 million m^3.

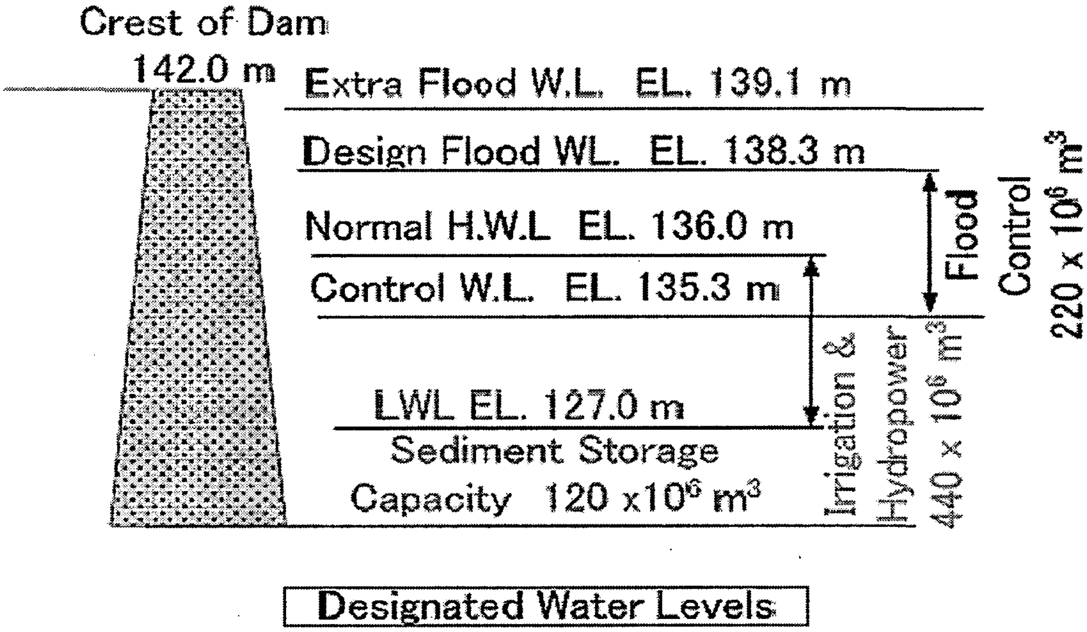


Fig. 3.2 Designated Water Levels

2) Flood Control

For flood control, the reservoir water level is controlled not to exceed the Control Water Level (El.135.3 m) during the flood season to eliminate the possibility of the PMF overtopping the dam crest. The flood control capacity to regulate the standard highest flood discharge with peak discharge of 4,000 m^3/s to the regular outflow of 400 m^3/s.

3) Wonogiri Irrigation System

Water supply to the Wonogiri irrigation system was commenced immediately after completion of the Wonogiri Irrigation Project in 1986. Irrigation water is taken from the Colo intake weir located about 13 km downstream of the Wonogiri dam. At present, the irrigation area has been extended from 24,000 ha in the original plan to 29,330 ha where triple or double crop farming is being practiced..

4) Power Generation at Wonogiri Hydropower Station

The powerhouse is located just downstream of the Wonogiri dam. It accommodates the generating equipment with an installed capacity of 12.4 MW to generate annual en ergy of 55,000 MWh. The maximum discharge for power generation is 75 m^3/s.

CHAPTER 4

PROGRESSIVE SILT DEPOSITION IN RESERVOIR SPACE

4.1 INTRODUCTION

The sediment deposition in a reservoir is governed by factors such as longitudinal and lateral valley slopes, length and shape of the reservoir, grain size distribution of sediment, flow pattern in the reservoir, capacity/inflow ratio and mode of reservoir operation. Predict sedimentation patterns is still restricted due to complexity of sedimentation process, exhaustive data requirement, uncertainties and difficulties in realistic assessment of parameters such as bed friction diffusion coefficient, bed and suspended sediment transport rates (Kulkarni and Deshmukh, 1997). However, use of one and two dimensional models is being made with due consideration to the limitation of such models to simulate the complex process.

Among the empirical methods for estimation of sediment accumulation and distribution, the Area Reduction Method proposed by Borland and Miller (1958) is most suitable and widely used on account of its simplicity and minimum data requirement.

4.2. CLASSIFICATION OF RESERVOIR

Borland and Miller classified the reservoirs in the four standard types. They found from the sediment resurvey data of several reservoirs in USA that there exists a definite relationship between the reservoir shapes and the percentage of sediment deposit at various depths throughout the reservoir. The shape of the reservoir is defined by the depth to capacity relationships and the classification criterion is given in Table. 4.1

Table 4.1 Evaluation of Reservoir Type

M Value	Reservoir Type	Standard Type
3.5 and above	Lake	I
2.5 to 3.5	Flood plain, foot hill	II
1.5 to 2.5	Hill	III
1.0 to 1.5	Gorge	IV

4.3 EMPIRICAL AREA REDUCTION METHOD

This method proposed by Borland and Miller (1958) of USBR is based on the the hypothesis that there exists a definite relationship between the shape of the reservoir and the percentage of the sediment volume deposited up to various depth of the reservoir. The reciprocals (M) of the slope (S) of the line obtained by plotting the reservoir depth as the ordinate and reservoir capacity as the abscissa on log-log paper. For each of the above type, sediment storage and area design curve (Fig 4.1 and Fig 4.2) were developed using observed data of the reservoirs. From these curves or the equation representing the curves, the sediment deposition at various levels could be computed. The method for determining the sediment distribution is given below in brief;

1. Total sediment yield is computed using data on the siltation index (sediment volume/unit area/years), catchment area and period for sediment deposition..
2. The reservoir type and corresponding deposition pattern can be determined by plotting depth-capacity relation
3. Take suitable interval (2 m to 5m) and find the levels over the total depth at dam (up to FRL). Compute relative depth at different levels starting from FRL to riverbed.

   $$\text{Relative depth} = \frac{Depth\,above\,river\,at\,any\,elevation}{Total\,depth\,at\,dam(FRL - bed\,level)}$$

4. For these relative depths, compute relative sediment area factor 'a' using appropriate type of curve.
5. Assume a new bed level (ho) near the dam after siltation. Compute reservoir area, capacity, relative depth and factor 'a' at level 'ho', compute 'K' as :

   $$\mathrm{K} = \frac{Area\,at\,level\,(ho)}{'a'\,at\,level\,(ho)}$$

6. Multiply 'a' at each level computed in step 4 by 'K' to obtain sediment area at each level
7. Compute the sediment volume deposited between two successive levels and cumulative sediment volume deposited below each level

8. If computed sediment volume below FRL or highest water level is equal to the total sediment volume likely to be deposited (computed in step 2 in assumed duration), stop the computation. Else, assume a new volume of 'ho' and repeat step 5 to 8 till the above satisfied
9. Compute revised elevation-area-capacity relation by deducting sediment area and volume from initial area and volume at respective levels.

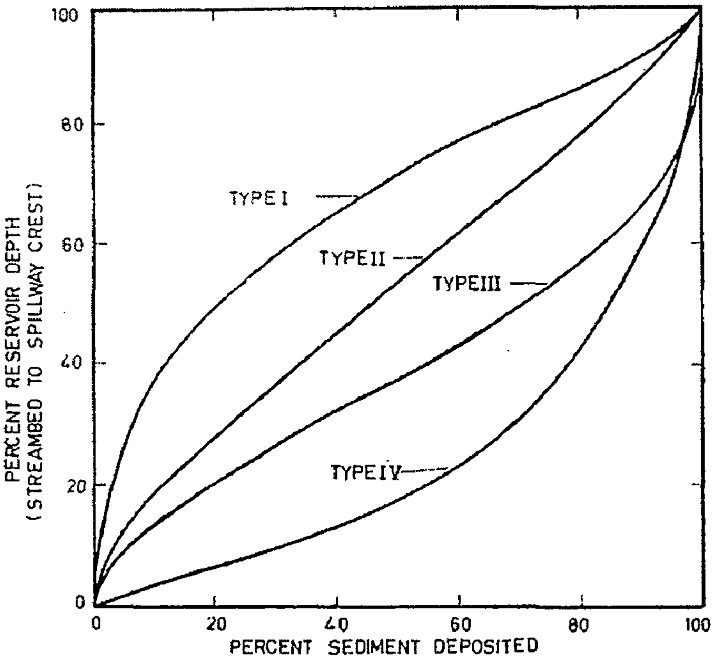


Fig 4.1 Type Curves as per Borland and Miller

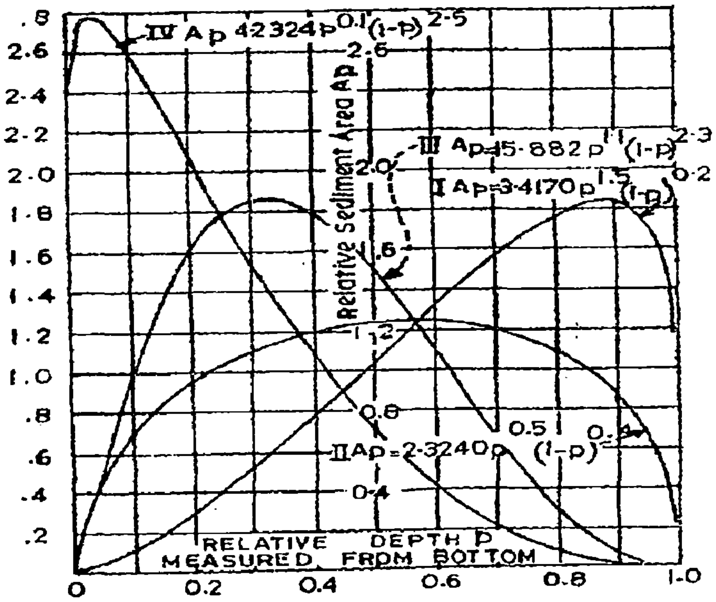


Fig 4.2 Area Design Curves

The computation by Area Reduction Method needs following basic input data:

- Elevation-Area-Capacity Curves
- Estimated of sediment volume (catchment area and siltation index)
- Period for prediction for example or the end of (25,50, 75, and 100 years)
- Deepest riverbed level near the dam

4.4 DISCREPANCIES IN PREDICTED AND OBSERVED DEPOSITION PATTERN FOR SOME RESERVOIRS

Kulkarni and Deshmukh (1997) studied the observed sediment deposition pattern of Bhakra, Ghadisagar, Pagara, Paschet, Maithon and Tungabhadra reservoir in India to check how far these reservoirs behaved differently from the standart deposition pattern indicated by Area Reduction Method.

As per criteria of Borland and miller, the Gandhirgar reservoir falls under Type I (Lake) and major part of sediment nearly 50% of sediment trapped in the reservoir should settle in upper 30% depth i.e in live storage. However, the hydrographic survey of the reservoir in 1975 (15 years after filling of reservoir) indicated that only 30% of incoming sediment was deposited in upper 30% portion. This pattern matches with type II. Considering the reservoir as type II futher studies were carried out by Kulkarni and Deshmukh found. The observed deposition pattern of Bhakra, Maithon, Panchet, Gandhisagar, and Tingabhadra reservoir are superimposed on the four standart deposition patterns (as Borland and Miller). Table 4.2 summarizes observation of reservoirs.

It is obvious that each reservoir will have its own deposition pattern. In reality, the reservoir may have level mixed characteristic of 2 or more standard type. Othe factor such as grain size distribution of sediment, reservoir operation pattern, nature of inflow flood hydrograph, trap efficiency of the reservoir, initial water level at the time of arrival of the flood etc, affect directly or indirectly the deposition pattern in the reservoir. For example, if the reservoir is at MDDL at the time of arrival of first flood then not only incoming sediment but also part of the sediment deposited in live storage will also be carried and deposited into dead storage zone. But with same flood and reservoir at FR, most of the incoming sediment will be deposited in live storage. Thus, the entire process becomes complex due to large number of governing factor.

Table 4.2 Comparison of Observed and Standard Type of Reservoir

Reservoir	Type as per Borland and Miller	Type as per field data	Effect of adopting type as per Borland and Miller
Bhakra	III	I to III	Underestimation of deposition in live storage zone
Gandhisagar	I	I to III	Overestimation of siltation in live storage zone
Panchet	II	I	Underestimation of siltation in live storage zone
Maithon	II	I	Underestimation of siltation in live storage zone
Tungabhadra	I	II to III	Overestimation of siltation in live storage zone

Source : Kulkarni and Deskmukh(1997)

4.5 SEDIMENT DISTRIBUTION IN BATUTEGI RESERVOIR (INDONESIA)

Agung Budi Waskito(Waskito 2002) has carried one study of Batutegi Reservoir in Indonesia. The depth-capacity relation Batutegi reservoir indicated M=2.87, based on original elevation-area-capacity. From M value, the type of Batutegi reservoir is Type II (Flood Plain, Foot Hill). And for next 25 years M value is 2.52 and the type is Type II (Flood Plain, Foot Hill). For next 25 years (from 51st -75th years), M value is 2.36 and the type of reservoir change to Type III (Hill). For next 25 years (from 75th -100th years), M value is 2.55 and type of reservoir is Type II. Table 4.3 summarizes change in M value of Batutegi Reservoir with years.

4.6 STUDY OF SEDIMENT DISTRIBUTION IN WONOGIRI RESERVOIR

In conventional simulation study, the elevation-area-capacity curve as anticipated after half of project life is first derived using Area Reduction Method (or any other appropriate method). With the availability of computer technology, it is now possible to revise elevation-area-capacity at regular interval and incorporate revised relationship in the long-term reservoir simulation study.

In this context, case study of Wonogiri Reservoir has been carried out to:

i. Evaluate change in standart reservoir type (if any) at 25 years interval and
ii. Compute and compare elevation-area-capacity curves for variation condition (original, 25 years, revised 50 years, revised 75 years and revised 100 years)

Table 4.3: M Value, Reservoir Type and New Zero Elevation during 100 years at Batutegi Reservoir

Elevation Area Capacity Curve	M Value	Reservoir Type	Zero Elevation
Original Curve	2.87	II	173.50
Revised after 25 years	2.52	II	184.50
Revised after 50 years	2.36	III	189.50
Revised after 75 years	2.55	II	193.75
Revised after 100 years	2.56	II	198.25

Analysis of Change in Standard Type Classification

Annual Sediment deposited calculated from topographic reservoir map (1993 and 2005). The value of sediment deposited compared capacity of the different years. The value of annual sediment deposited from 1993-2005 is 2.984 MCM

The depth capacity plot based on original elevation-area-capacity curve (1980) indicated M = 2.53 i.e. Type II reservoir as shown in Fig. 4.3.

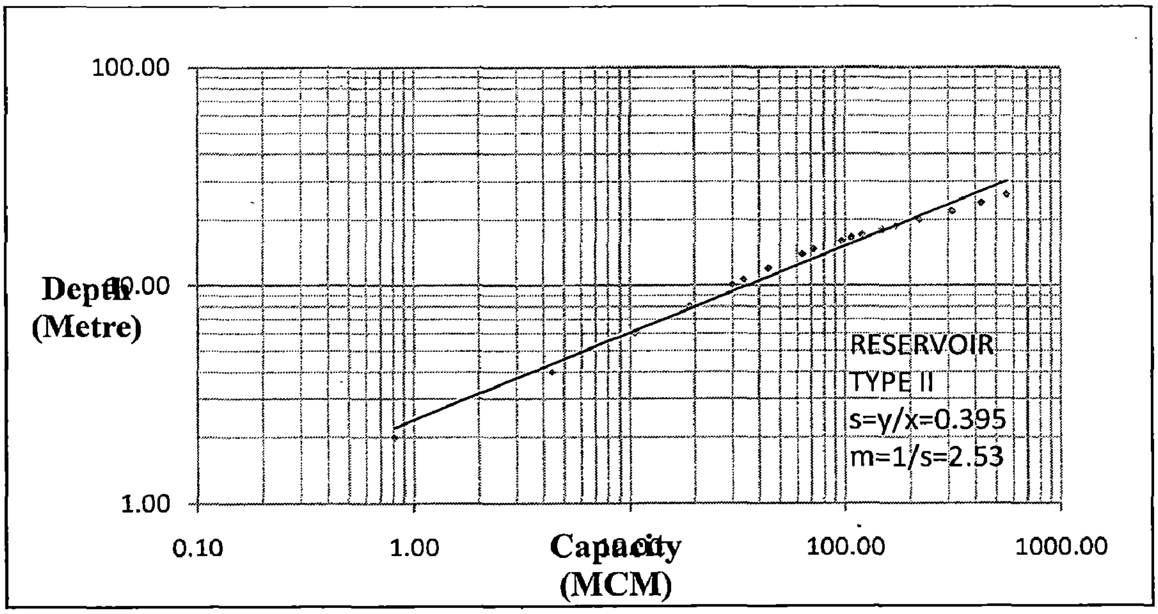


Fig. 4.3 Original Depth-Capacity Relation for Wonogiri Reservoir

For next 25 years (from 25 yr data topography data of wonogiri reservoir), M is computed (M=3.04). Depth capacity relation is shown in Fig 4.4 the reservoir is Type II reservoir. A rea Reduction Method is used to obtain revised elevation-area-capacity relation after 25 years.

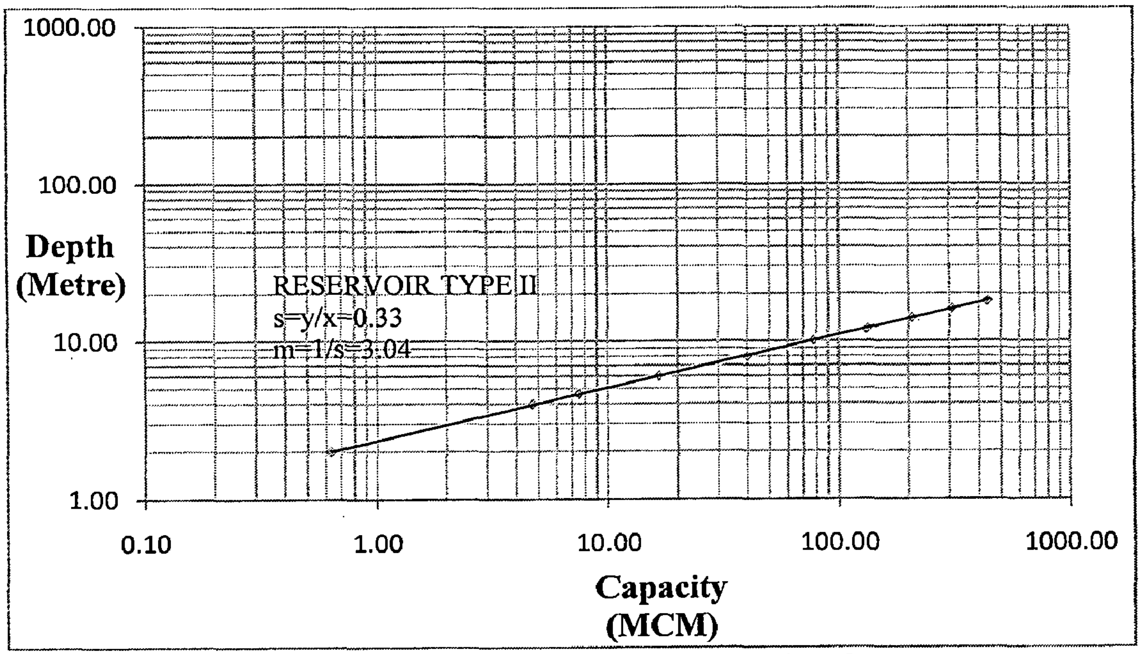


Fig. 4.4 Depth- Capacity Relation for Wonogiri Reservoir After 25 Yr

For next 25 years i.e. from 51st to 75th years, this revised elevation-area-capacity relationship is used as 25yr elevation-area-capacity curve Computed M is 4.76 as shown by depth-capacity relation (Fig 4.5). And the type of reservoir is same type I.

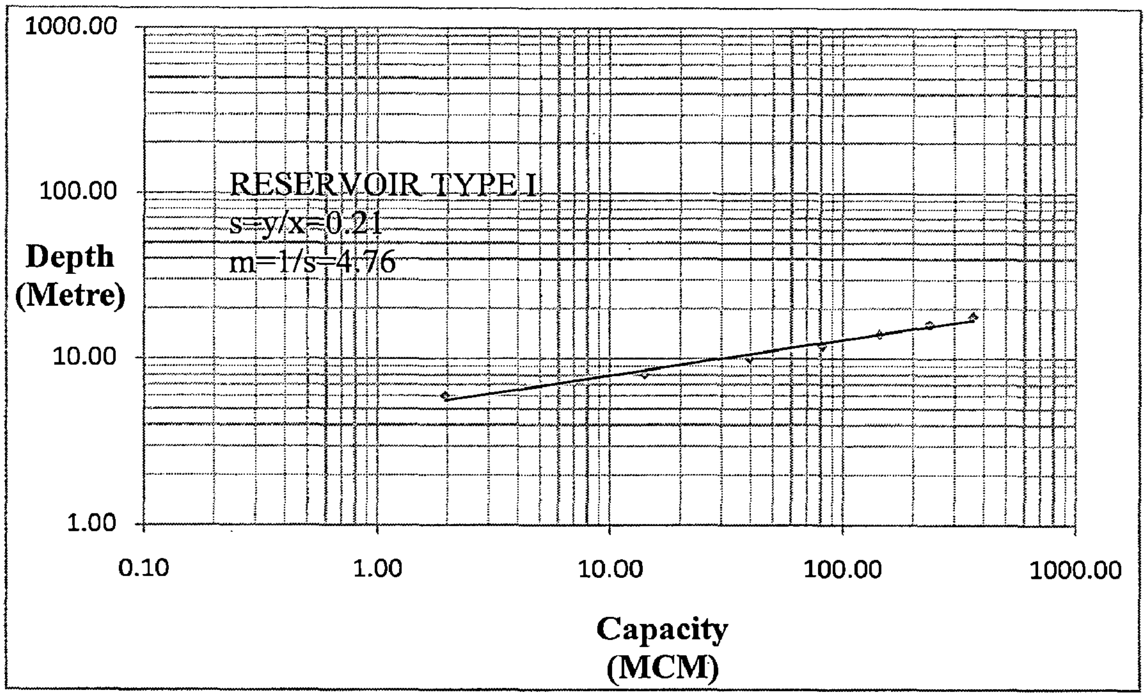


Fig. 4.5 Depth- Capacity Relation for Wonogiri Reservoir After 50 Yr

For next 25 years i.e. 76^{th} to 100^{th} years, computed M is 2.11 i,e, type of reservoir is Type III again. Fig 4.6 shown depth-capacity relation

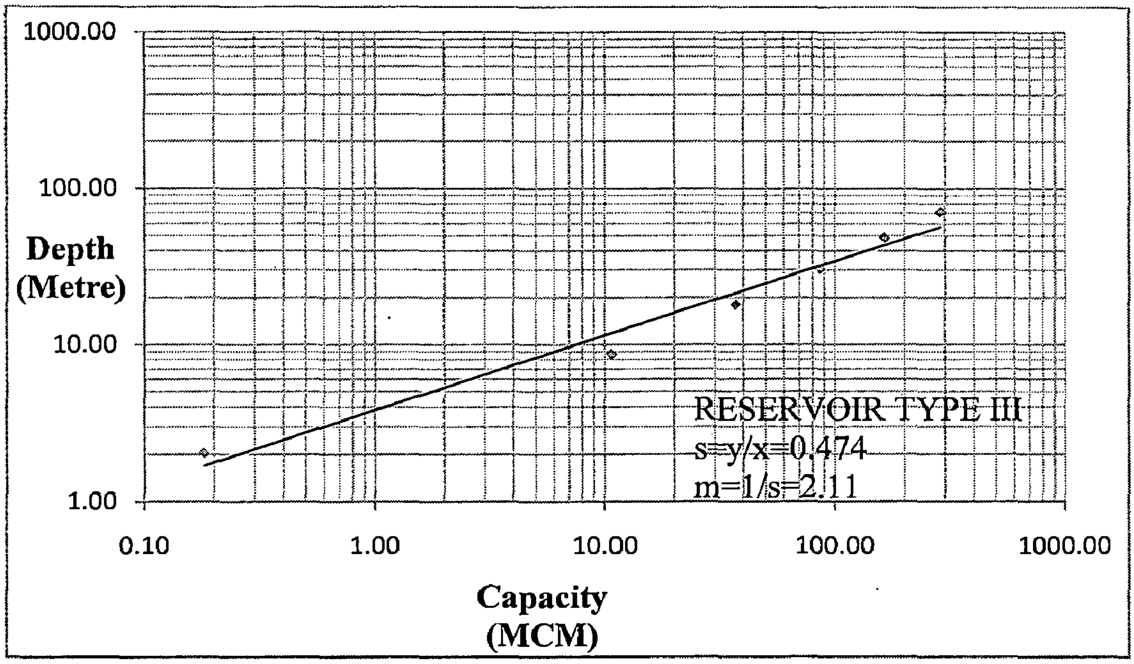


Fig. 4.6 Depth- Capacity Relation for Wonogiri Reservoir after 75 Yr

After 100 years, M value is 6.17 indicating Type I, reservoir as shown by depth-capacity relation in Fig 4.7.

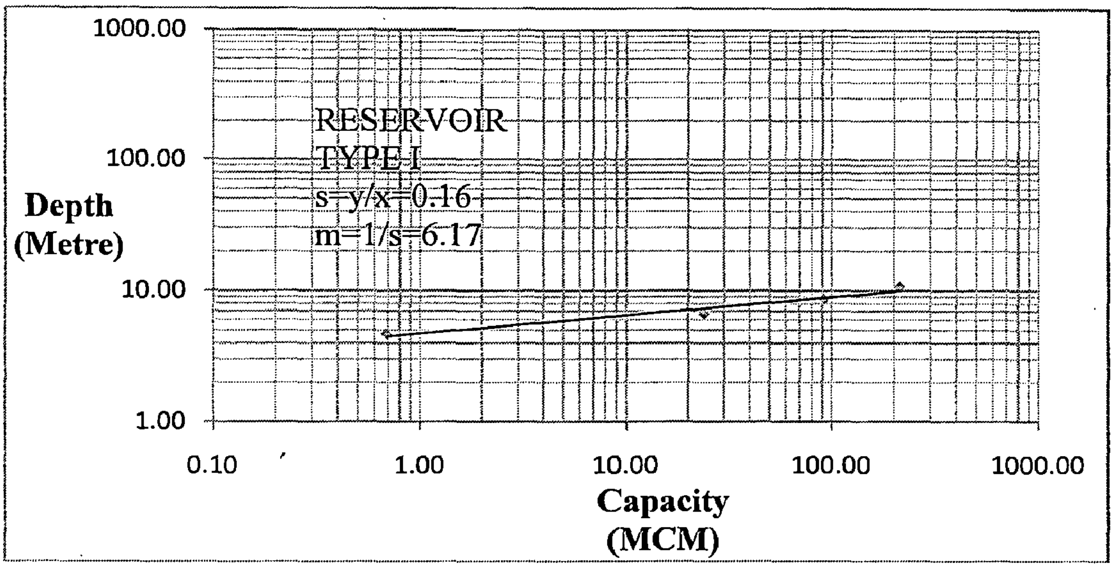


Fig. 4.7 Depth- Capacity Relation for Wonogiri Reservoir after 100 Yr

Table 4.4 shown M value, reservoir type and new zero elevation during 100 years project life. Fig 4.8 shown variation in M value and Fig. 4.8 shows variation in new zero elevation. Comput ation of revision in elevation-area-capacity relation after 50 years, 75 years, and 100 years are calculated by similar procedure as shown in Appendix.

Table 4.4: M Value, Reservoir Type and New Zero Elevation during 100 years at Wonogiri Reservoir

Elevation Area Capacity Curve	M Value	Reservoir Type	Zero Elevation
Original Curve	2.53	II	110.00
25 years	3.04	II	118
Revised after 50 years	4.76	I	122.7
Revised after 75 years	2.11	III	125.3
Revised after 100 years	6.17	I	129.7

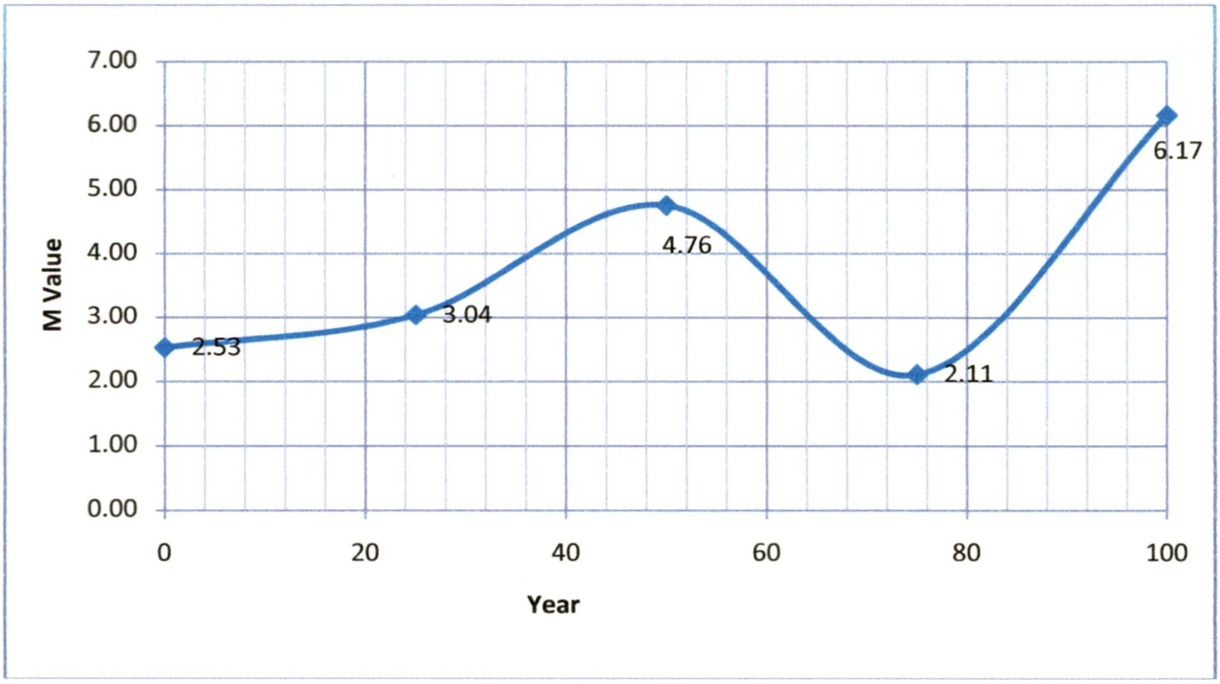


Fig. 4.8. M Value Variation during 100 years – Wonogiri Reservoir

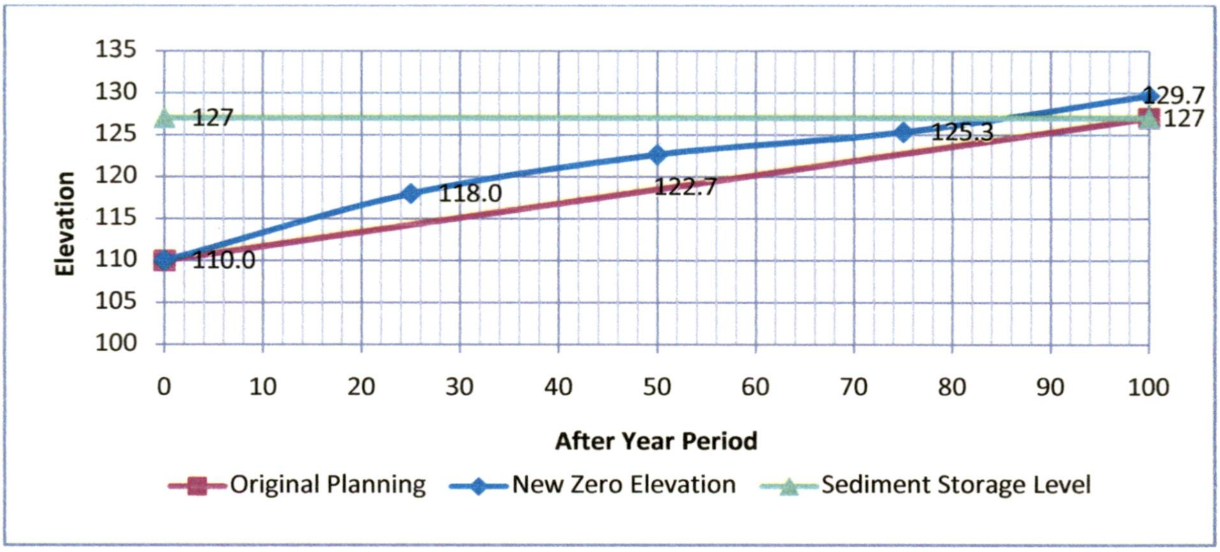


Fig. 4.9 New Zero Elevation Variation during 100 years – Wonogiri Reservoir

Elevation-area-capacity curves are compared in Fig 4.10. Elevation-Area-Capacity curves in the beginning and after 100 years are compared in fig 4.11.

Table 4.4 and Fig 4.8 have shown the change in standard classification of reservoir and new zero elevation during 100 years period. Analysis shows that the standard classification of reservoir is not constant. Based on elevation area capacity curve in 25 years, the standard classification of reservoir is Type II. Up to 25 years from 25 years, it is Type I, and then it is Type I from 50 years to 75 years and Type III from 75 years to 100 years.

Figure 4.9 shows the change in new zero elevation during 100 years. This figure shows that new zero elevation will get elevation 127 in 84.5 years (below sediment storage level). Where the elevation of sediment storage is EL. 127 and the sediment storage capacity is 120 MCM.

4.7 CONCLUSION

Analysis of sediment distribution in the Wonogiri reservoir by Area Reduction Method highlights the following important aspects:

a. Standard type of classification of a reservoir is not constant over entire project life. Due to change in standard type of classification, sediment distribution pattern will also change as per method of Borland and Miller in case of Wonogiri Reservoir. From beginning (project design) the reservoir behaves as Type II, up to 25 years, reservoir behaves as Type II and then it is Type I from 50 years to 75 years and Type III from 75 years to 100 years, and back to Type I after 100 years. Even if standard type classification does not change during a period, elevation-area-capacity curve will still undergo revision due to variation in new zero elevation, it is therefore, necessary to consider progressive change in elevation-area-capacity relationship in long term simulation study a reservoir.

b. In the conventional procedure as recommended by Central Water Commision in India, the wonogiri reservoir would have been designed considering revised elevation-area-capacity curve obtained after sediment deposition during 50 years and assumed to apply uniformly over the entire project life (100 years). With the likely change in new zero elevation and elevation-area-capacity curve at regular interval say 25 years as shown in Fig 4.8 and Fig. 4.9, the use of conventional procedure would result in underestimation or overestimation of silt deposition in different time intervals.

c. Existing Reservoir

For the existing reservoir the hydrographic surveys at about 10 to 15 years interval provide most useful clues for improvement of prediction capabilities. Critical comparison of observed and initially assumed reservoir pattern could be made to find out extent of deviation from predicted deposition pattern. Depending upon various situations following measures are suggested for improving further prediction for sediment deposition.

i. After each survey, the type of the reservoir must be rechecked by Borland and Miller procedure, using new depth-capacity relationship. If the type remains unchanged then compare observed deposition pattern with that assumed for the design. If these are in close agreement, further predictions should be made by following same reservoir type.
ii. If the observed deposition pattern follows the pattern other than that assumed during design then further computations may be made by adopting new pattern.
iii. If the curve for observed deposition pattern lies between the curves for any two standard types, the further computation may be done with appropriate interpolation between two standard types at different relative depths.
iv. If the curves for observed deposition pattern crosses some of the standard types, then further computations bay be done by following values interpolated between different standard type at different relative depths.

d. Proposed Reservoir

In case of proposed reservoirs it is difficult to check whether the reservoir will behave as per type assumed for the design. The situation is more difficult when the value of parameter M indicating the type is close to the limit particular type. For example, if the value of M is 2.5, then it could be treated as type II or type III. This difficulty arises mainly because there is no transition between any two types. In reality the transition exists and if the value of M is 2.5, them after siltation, the reservoir with type III is likely to change to type II and a reservoir of type II with value of M at upper limit of 3.5 is likely to change to type I. So one needs to take care of such possibilities in advance when the values of type deciding parameter (M) are close to the limiting values.

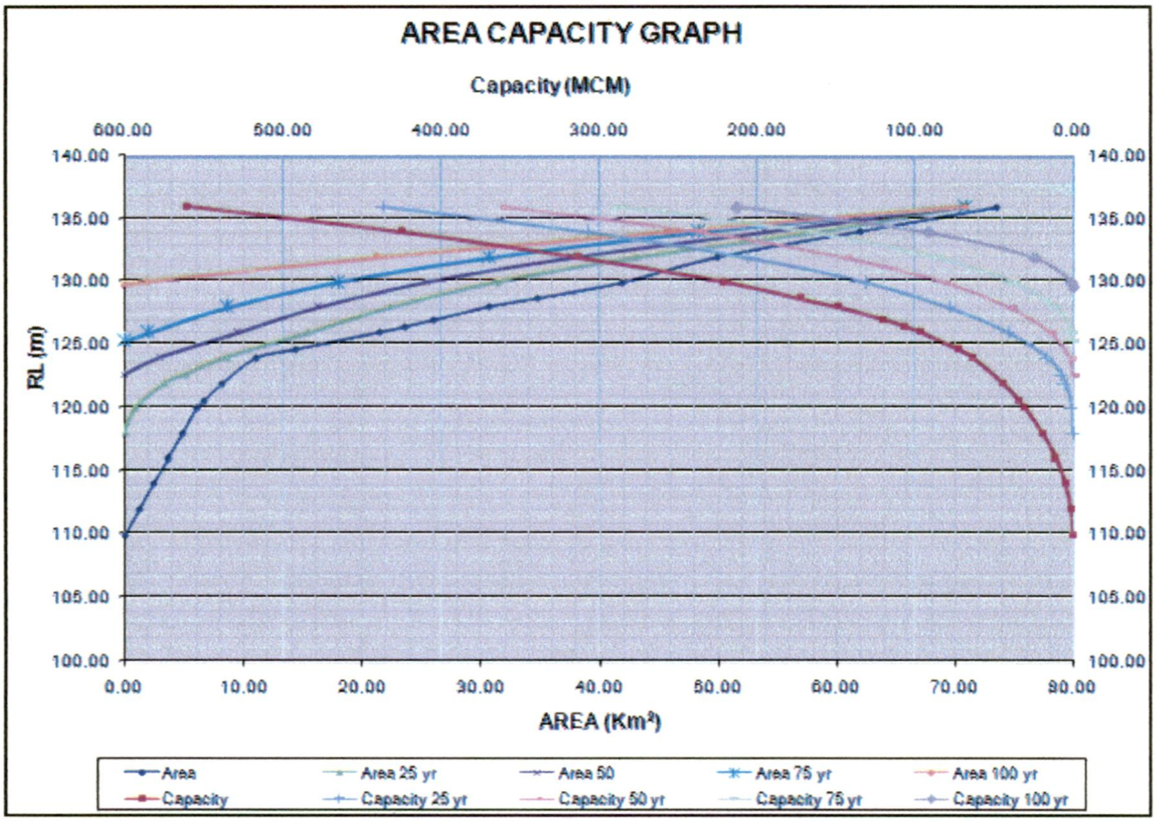


Fig. 4.10 Change Elevation-Area-Capacity Curves at 25 year interval during 100 years

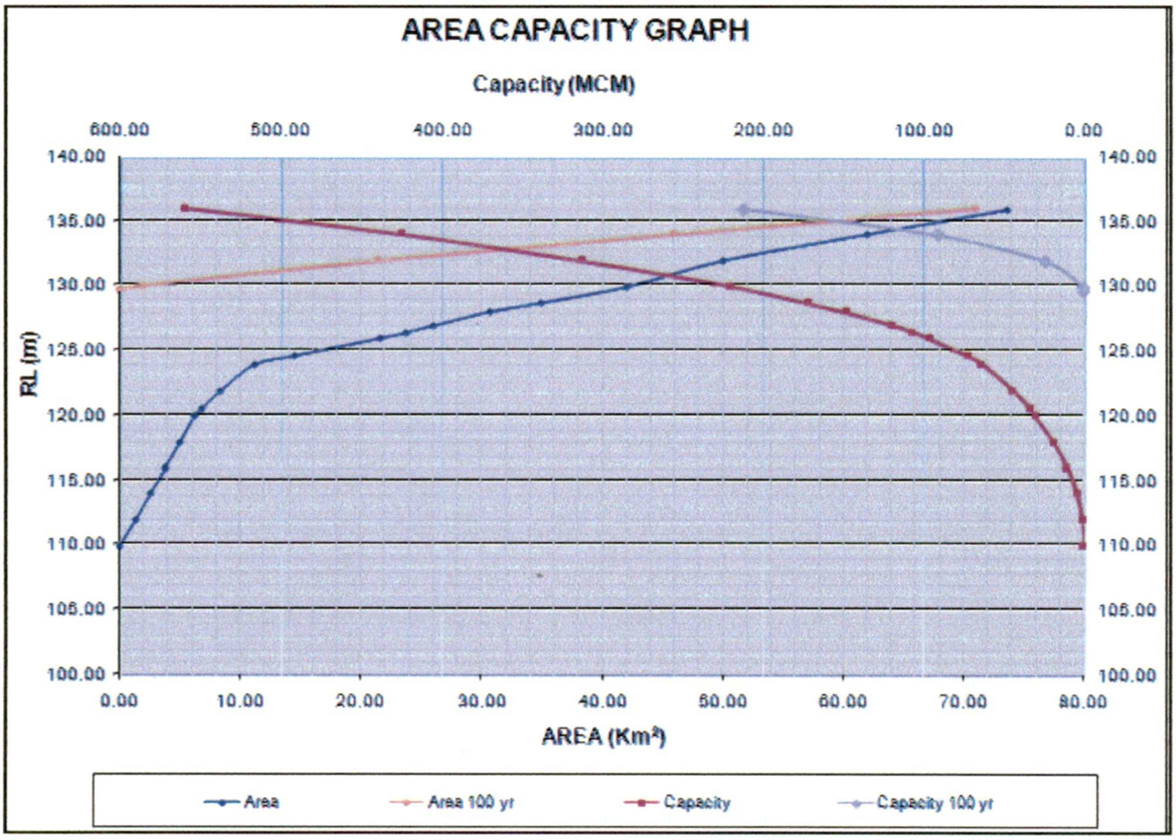


Fig. 4.11 Elevation–Area-Capacity Curves in the beginning and after 100 years.

Table 4.5

Sediment Distribution Pattern After 50 years based on M value at end of 25 years

Max Water Level (FRL)	136 m
Original Stream Bel Level	118 m
Est of sediment vol during 25 yr	74.59 (Mm^3)

New zero elevation	122.7 m
Area	5.1 km^2
Relative depth	0.259
Ap	1.049
K=Area/AP	4.8745

No	Elevation m	Original Area (25 yr) (km^2)	Original capacity (25 yr) (Mm^3)	Depth (2)-118 m	Relative depth P (5)/18	Ap Type II	Sediment area Kap 4.8745 x (7) (km^2)	Sediment volume (Mm^3)	Accumulated sediment volume (Mm^3)	Modified accumulated volume (Mm^3)	Revised	
											Area (3)-(8) (km^2)	Capacity (4)-(11) (Mm^3)
1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**
1	136.0	71.0	436.4	18.0	1.000	0.000	0.00	2.96	74.59	74.59	71.04	361.80
2	134.0	58.5	307.1	16.0	0.889	0.910	4.43	9.89	71.64	71.64	54.02	235.46
3	132.0	43.1	205.9	14.0	0.778	1.123	5.47	11.43	61.75	61.75	37.64	144.17
4	130.0	31.5	131.6	12.0	0.667	1.223	5.96	12.06	50.32	50.32	25.54	81.29
5	128.0	22.5	77.9	10.0	0.556	1.252	6.10	12.07	38.25	38.25	16.37	39.63
6	126.0	15.5	40.1	8.0	0.444	1.225	5.97	11.53	26.18	26.18	9.55	13.92
7	124.0	8.6	16.6	6.0	0.333	1.141	5.56	7.14	14.65	14.65	3.04	1.93
8	122.7	5.1	7.5	4.7	0.259	1.049	5.11	2.80	7.51	7.51	0.00	0.00
9	122.0	3.4	4.7	4.0	0.222	0.991	3.39	4.08	4.72	4.72	0.00	0.00
10	120.0	0.9	0.6	2.0	0.111	0.739	0.95	0.63	0.63	0.63	0.00	0.00
11	118.0	0.0	0.0	0.0	0.000	0.000	0.00	0.00	0.00	0.00	0.00	0.00

CHAPTER 5

ANALYSIS OF USLE FACTORS AND EROSION ESTIMATE

5.1 THE WONOGIRI WATERSHED

The Wonogiri multipurpose dam is the only large dam on the mainstream of the Bengawan Solo River, which is the largest river in the Java with a catchment area of around 16,100 km^2 and a length of about 600 km. Various irrigation development projects and river improvement works have been implemented in the Bengawan Solo River basin under the technical and financial assistance of Japan. In the Wonogiri Dam catchment, about 90% of the total land has been cultivated with dry-land farming that is categorized as highly fragile to surface soil erosion. Figure 5.1 shows location of Wonogiri Dam and Kabupaten. Figure 5.2 shows the subwatershed in the catchment of Wonogiri dam.

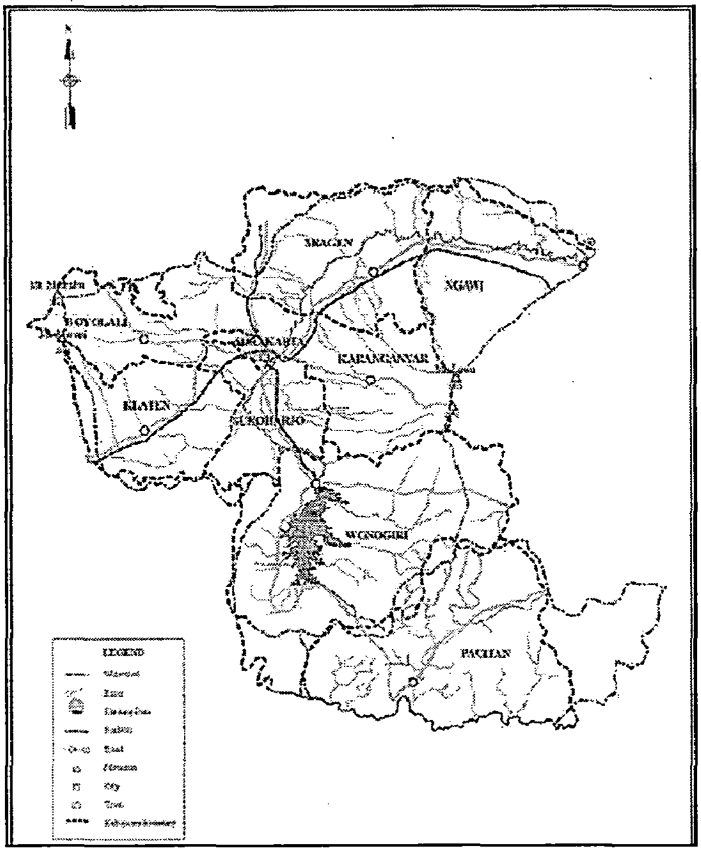


Figure 5.1. Location Map of Kabupatens

There is high population density in the catchment. The Wonogiri reservoir has been rapidly filled with sediments transported from the catchment. Poor land use of its catchment and intensive farming of annual crops using poor practices on the highly erosive and steep-sloped uplands as well as highly populated and intensely farmed areas are the main causes of the sedimentation of the Wonogiri reservoir.

Figure 5.2. Wonogiri Watershed, Central Java, Indonesia

5.2 PREDICTION of SOIL EROSION by USLE

5.2.1 The Universal Soil Loss Equation (USLE)

The USLE (Universal Soil Loss Equation) mathematical model is used to predict soil losses due to erosion. Basic equation is written as:

$$A = R.K.L.S.C.P$$

Where,

A = the computed soil loss per unit area (ton ha-1 yr-1)
R = Rainfall erosive factor (MJ mm ha-1 hr-1 yr-1)
K = Soil erodibility factor (ton ha hr MJ-1 mm-1 ha-1)
LS= Slope length and steepness factor (dimensionless)
C = Cover management factor (dimensionless)
P = Conservation practice factor (dimensionless)

5.2.2 Estimation of R Factor

The number of erosion index units in the period of consideration, the EI units is a measure of erosive force of specific rain.

The rainfall erositivity (R) is verified as application for soil erosion in Java (Indonesia). Bols (1978) developed the following equations to estimate monthly EI 30.

$$EI_{30} = 6.119\ (RAIN)^{1.21}\ (DAYS)^{-0.47}\ (MAXP)^{0.53}$$

Where,

RAIN is average monthly rainfall in cm.
DAYS is average number of rain days per month in day
MAXP is average maximum 24-hr ranfall for the month in cm

$$R = \sum_{i=1}^{N=12} (EI_{30})_i$$

In which R is the resulting calculation were summed as annual values of erosivity. Computed monthly EI30 and Annual Erosivity Factor (R) are as shown in Table 5.1

This data calculate from 5 station and using Thieesen Polygon to calculate Annual Erosivity Factor (R)

Table 5.1 R Factor Nawangan Rainfall Station

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Average Monthly Rainfall (mm)	308	295	254	148	69	58	23	13	24	63	142	212
Average no of days rainfall	19.4	17.5	16.3	11.2	5.8	4.2	2.6	1.0	1.7	5.1	9.7	14.4
Average max rainfall (mm)	62.3	63.2	57.6	43.4	29.3	31.7	10.3	10.2	11.7	18.3	43.8	49.5
EI	252.91	254.59	208.53	111.84	48.93	48.09	10.72	8.72	15.05	36.14	113.80	163.76

Annual R = 1273.06989

Example Calculation of R factor for the month of January

Average Monthly Rainfall (mm) = 308 mm = 30.8 cm

Average Max 24 hr Rainfall (mm) = 62.3 mm = 6.23 cm

Average no of days Rainfall (day) = 19.4 day

$EI_{30} = 6.119\,(30.8)^{1.21}\,(19.4)^{-0.47}\,(6.23)^{0.53}$

$= 252.91$

$$R_{\text{Nawangan}} = \sum_{i=1}^{N=12} (EI_{30})_i = 1273.06989$$

$R_{\text{Ngancar}} = 1681.87749$

$R_{\text{Wonogiri}} = 1497.1131$

$R_{\text{Purwantoro}} = 1474.0986$

$R_{\text{Tawangmangu}} = 2738.5593$

And We get value of average R_{Wonogiri} by calculate using Thiessen Polygon:

Average R_{Wonogiri} (wonogiri watershed) = 1579.920297 = we say 1579.92

5.2.3 Estimation of Soil erodibility factor(K)

"K" values of the representative soils in the Wonogiri dam watershed, based on diagnoses of soil profile, soil particle distribution analysis and basic infiltration rate measurement are taken from JICA report. The following K values may be adopted are listed in Table 5.2 below:

Table 5.2 Applied Soil Erodibility Factor "K"

Kind of soils	**Soil erodibility factor (K)**
Mediteran soils	0.31
Grumsols	0.48
Latosols	0.32
Lithosols	0.015

Source : "Rehabilitasi Lahan Dan Konservasi Tanah Daerah Tangkapan Waduk Serbaguna Wonogiri (Land Rehabilitation and Soil Conservation Watershed Multipurpose Wonogiri) Book", Annex teknik

Weighted area average K value for the subwatersheds have been computed as shown below table 5.3

Table 5.3 Factor "K"

SubWatershed	Area	Area Mediteran Soil	Area Grumsols Soil	Area Latosols Soil	Area Lithosols Soil	Weight Average "K" Factor
	ha	ha	ha	ha	ha	
Soil Factor		***0.310***	***0.480***	***0.320***	***0.015***	
Keduang	42,098	17,779	0	14,842	9,477	0.25
Tirtomoyo	23,065	6,941	7,082	0	9,042	0.25
Temon	6,259	3,628	2,631	0	0	0.38
Upper Solo	20,553	14,276	3,606	0	2,671	0.30
Alang	16,938	6,140	5,142	0	5,656	0.26
Ngunggahan	8,240	2,653	3,338	0	2,249	0.30
Wuryantoro	4,412	693	2,919	0	799	0.37
Remnant	2,768	287	1,343	0	1,139	0.27

Example Weighted average K for Temon Subwatershed

$$\text{Temon Area} = \frac{(3628x0.310) + (2631x0.480) + (0x0.320) + (0x0.015)}{6259}$$

$$= 0.38$$

5.2.4 Estimation of factor for slope length and steepness (LS)

L = Slope length factor

S = Slope gradient (in %) or

Topographic factor (LS) is calculated based on the following equation.

$$LS = \sqrt{(\lambda/22.1)}\ x\ (65.41\ sin2\theta + 4.56 sin\theta + 0.065)$$

where,

LS: Topographic factor

λ: Slope length

θ: Steepness

The equation above is very difficult to be applied to pixel-based GIS for the long slope variability is very complex. Moore and Burch (1986) in Kinnell (2008) and Abdul Rahman As-syakur (2008) have developed an equation to find the value of LS DEM data using the GIS. The equation is:

$LS = (X*CZ/22.13)^{0.4} *(\sin \theta / 0.0896)^{1.3}$

Where :

X = Flow Accumulation

CZ = Cell Size

θ = Slope (Slope DEM)

LS factor has been computed in each subwatershed as shown in table 5.4.

Table 5.4 Factor "LS" (using GIS)

SubDAS	LS
Keduang	2.65
Tirtomoyo	3.65
Temon	1.39
Upper Solo	2.35
Alang	0.96
Ngunggahan	1.72
Wuryantoro	0.73
Remnant	2.40

5.2.5 Estimation of Cropping management factor (C)

Cover and management factors "C" were generally determined by reference to Badan Penelitian dan Pengembangan Pertanian Departmen Pertanian (Department of Farm) 1990, the diagram the reports of Rencana Teknik Lapangan Departemen Pertanian (Department of Farm) 1985, Bogor Agricultural University, Indonesia - Sitanala Arshad (1989) as presented in Table 5.5. C factor for various subwatershed have been computed as shown in Table 5.6.

Table 5.5 Support Crop Cover and Management Factor "C"

Land use	**Cover and Management Factor (C)**
Paddy field	0.05
Home settlement areas/Building/Rocky Hill	0.1
Crop factor for mixed cultivation of maize and cassava	0.6
Crop factor for mixed cultivation of beans and cassava	0.45
Crop factor for cassava	1
Grassland /Bush land	0.3
Forest	0.01

Orchard/Plantation :	
High Density	0.1
Medium Density	0.2
Low Density	0.5
Water body	0
Rain-fed paddy	0.561
Mixed cultivation of Cassava and Soybean	0.3
Maize	0.7
Soybean	0.4

* Calculation Cover Management Factor Upland (p.59) used

$$C = (C_i \cdot R_i + C_{ii} \cdot R_{ii} + C_{iii} \cdot R_{iii} + \cdot \cdot \cdot \cdot + C_{xii} \cdot R_{xii}) / R_{i\sim xii}$$

where,

C : Annual overall cover and management factor C

Ci : Crop factor for mixed cultivation of cassava and maize, mixed cultivation of cassava and beans, and crop factor for cassava

$R_i = (EI_{30})_i$: Monthly rainfall erosivity factor for i-th month

$R_{i\sim xii} = (EI_{30})_{i\sim xii}$: Annual rainfall erosivity factor (accumulated Jan. to Dec.)

Table 5.6 Calculation Weighted Factor “C” in Subwatershed

SubDAS	Land use (m2)											C factor
	Water	Buildings	Rocky Hill	Upland	Grass Land	Home settlement	Plantation	Irrigation paddy_field	Rain_fed_Paddy	Bush_land	Forest	
	0	0.1	0.1	0.711	0.3	0.1	0.5	0.05	0.561	0.3	0.01	
Keduang	1692512.6	18476.7	40515.5	118330110.2	533606.5	110749238.9	55068042.6	127179922.2	1577046.5	2286227.5	3505509.7	0.31
Tirtomoyo	1263224.3	533.2	0.0	106558920.2	537788.2	38284218.5	29386257.3	48753750.5	2724884.2	2078326.3	1058849.7	0.43
Temon	685649.1	0.0	0.0	21137010.7	34244.8	14602474.7	10518253.7	13544229.3	682445.0	1389546.7	0.0	0.37
Upper Solo	1229569.6	1852.5	90902.0	82666156.5	412919.1	41268248.6	39635438.4	35910532.5	2147337.8	2159902.4	6208.5	0.42
Alang	582036.3	5548.5	28643.8	76116065.0	154455.4	35871723.6	20563320.9	31467415.9	2339316.8	2252717.6	0.0	0.42
Ngunggahan	336484.3	1352.2	56724.3	25942392.3	73741.3	14226480.7	15894208.2	24893435.8	702407.3	272317.4	0.0	0.36
Wuryantoro	88842.2	1854.2	0.0	15562077.9	8340.1	9911163.6	6168290.9	11171851.2	809283.9	11132.6	386815.3	0.37
Remnant	4891.4	796.8	102636.0	12603793.2	56860.3	3534196.5	7658686.1	1514065.5	433988.2	81551.4	1687773.8	0.49

Example : weighted C Factor for Temon subwatershed

$$= \frac{\begin{gathered}((0\,x685649.1) + (0.1x0) + (0.1\,x\,0) + (0.711x21137010.7) + (0.30x34244.8) + (0.1x14602474.6) + (0.5x10518253.7) + \\ (0.05x13544229.3) + (0.561x682445)@ + (0.3x1389546.7) + (0.01 * 0))\end{gathered}}{(685649 + 0 + 0 + 21137010.7 + 34244.8 + 14602474.6 + 10518253.7 + 13544229.3 + 682445.0 + 1389546.7 + 0)}$$

$= 0.37$

5.2.6 Estimation of Erosion control practice factor (P)

The support practice factor "P" for land use categories of the land use map in the Wonogiri dam watershed is mainly determined in reference to the data and information in the reports of Rencana Teknik Lapangan (Field Technical Plan) (1985) and Risalah Lokakarya Pemantapan Perencanaan Konservasi Tanah dan Evaluasi Tingkat Erosi, Proyek Penelitian Penyelamatan Hutan, Tanah dan Air (Workshop on Strengthening of Planning and Evaluation of Soil Conservation Erosion Rate, Forest Rescue Research Project, Land and Water) (1990) as follows computation of P factor for various subwatershed is explained in table 5.8.

Table 5.7 Support Practice Factor "P"

Erosion-control practice	**P-factor value**
No treatment of soil conservation	0.8
Ridge terrace	0.8
Composite (land of composite of condition of ridge terrace and non-treatment)	0.8
Traditional bench terrace	0.5
Bench terrace for uplands	
(1) Good quality	0.04
(2) Medium quality	0.2
(3) Fair to bad quality	0.4
Terrace of irrigated paddy field	0.02
Rain-Fed Paddy	0.5
Orchard/Plantation	0.4
State forest	1
Home settlement area/Buildng/Rocky Hill	1
Grass/ Bush land	1
Water Body	0

Table 5.8 Calculation Weighted Factor “P” in Subwatershed

SubDAS	Terrace (m^2)														P factor
	Water_body	Building	Rocky Hill	Uplands	Uplands	Uplands	Uplands	Grass_Land	Home settlement	Plantation	Irrigation paddy_field	Rain_fed Paddy	Bush land	Forest	
				composite	Fair	Medium	Good								
Factor	**0.00**	**1.000**	**1.000**	**0.800**	**0.400**	**0.20**	**0.040**	**1.000**	**1.000**	**0.400**	**0.020**	**0.500**	**1.000**	**1.000**	
Keduang	1692512.6	18476.7	40515.5	19616701.6	96781666.8	1931741.8	0.0	533606.5	110749238.9	55068042.6	127179922.2	1577046.5	2286227.5	3505509.7	0.47
Tirtomoyo	1263224.3	533.2	0.0	52534852.6	51739787.0	2112315.0	171965.6	537788.2	38284218.5	29386257.3	48753750.5	2724884.2	2078326.3	1058849.7	0.52
Temon	685649.1	0.0	0.0	10064188.2	11072822.4	0.0	0.0	34244.8	14602474.7	10518253.7	13544229.3	682445.0	1389546.7	0.0	0.53
Upper Solo	1229569.6	1852.5	90902.0	42005980.0	36769514.3	2578581.1	1312081.0	412919.1	41268248.6	39635438.4	35910532.5	2147337.8	2159902.4	6208.5	0.54
Alang	582036.3	5548.5	28643.8	31055439.0	35336664.9	3316150.6	6407810.5	154455.4	35871723.6	20563320.9	31467415.9	2339316.8	2252717.6	0.0	0.52
Ngunggahan	336484.3	1352.2	56724.3	16562115.6	7218910.9	768775.3	1392590.5	73741.3	14226480.7	15894208.2	24893435.8	702407.3	272317.4	0.0	0.46
Wuryantoro	88842.2	1854.2	0.0	2732233.6	7837992.0	4586777.9	405074.3	8340.1	9911163.6	6168290.9	11171851.2	809283.9	11132.6	386815.3	0.45
Remnant	4891.4	796.8	102636.0	3918513.1	6588445.8	2096834.4	0.0	56860.3	3534196.5	7658686.1	1514065.5	433988.2	81551.4	1687773.8	0.54

Example : weighted P Factor for Temon subwatershed

$$= \frac{\begin{array}{c}((0\,x685649.1) + (1x0) + (1x\ 0) + (0.8x10064188.2) + (0.4x11072822.4) + (0.2x0) + (0.04x0)@(1x34244.8) + \\ (1x14602474.7) + (0.4x10518253.7) + (0.02x13544229.3) + (0.5x682445)@ + (1x1389546.7) + (0.01 + 0))\end{array}}{(685649 + 0 + 0 + 10064188.2 + 11072822.4 + 0 + 0 + 34244.8 + 14602474.7 + 10518253.7 + 13544229.3 + 682445.0 + 1389546.7 + 0)}$$

= 0.53

5.3 ARC GIS

A geographic information system (GIS) is a computer-based tool for mapping and analyzing spatial data. GIS technology integrates common database operations such as query and statistical analysis with the unique visualization and geographic analysis benefits offered by maps. These abilities distinguish GIS from other information systems and make it valuable to a wide range of public and private enterprises for explaining events, predicting outcomes, and planning strategies. GIS is considered to be one of the most important new technologies, with the potential to revolutionize many aspect s of society through increased ability to make decisions and solve problems.

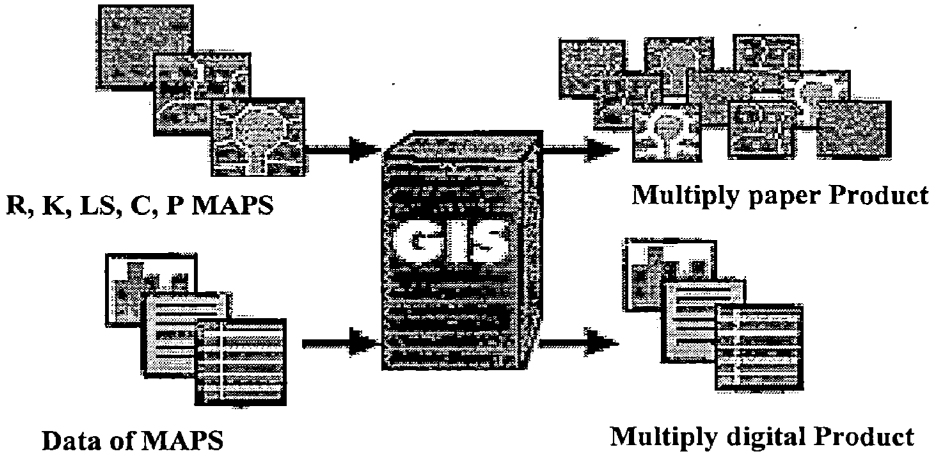
The major challenges that we face in the world today pollution, deforestation, erosion – all have a critical geographic dimension. Local problems also have a geographic component that can be visualized using GIS technology, whether finding the best soil for growing crops, determining the critical erosion area, or discovering the best way to control erosion. Careful analysis of spatial data using GIS can give insight into these problems and suggest ways in which they can be addressed. Map making and geographic analysis are not new, but a GIS performs these tasks better and faster than do the old manual methods.

Input of Data

Before geographic data can be used in a GIS, the data must be converted into a suitable digital format. The process of converting data from paper maps or aerial photographs into computer files is called digitizing. Modern GIS technology can automate this process fully for large projects using scanning technology; smaller jobs may require some manual digitizing which requires the use of a digitizing table. Today many types of geographic data already exist in GIS-compatible formats. These data can be loaded directly into a GIS.

Map Making

Maps have a special place in GIS. The process of making maps with GIS is much more flexible than are traditional manual or automated cartography approaches. It begins with database creation. Existing paper maps can be digitized and computer-compatible information can be translated into the GIS. The GIS-based cartographic database can be both continuous and scale free. Map products can then be created centered on any location, at any scale, and showing selected information symbolized effectively to highlight specific characteristics. The characteristics of atlases and map series can be encoded in computer programs and compared with the database at final production time. Digital products for use in other GIS's can also be derived by simply copying data from the database. In a large organization, topographic databases can be used as reference frameworks by other departments. Maps of R, K, LS, C, P is preparing to calculate erosion using GIS.



Overlay Analysis integrates different data layers to look for patterns and relationships. At its simplest, this could be a visual operation, but analytical operations require one or more data layers to be joined physically. For example, to analyze the impact of urbanization on ecological characteristics of an area, an overlay could integrate data on soils, slope, vegetation, and land use. Queries could be used to identify sources of pollution, to delineate potentially sensitive areas, or to plan for increased population growth in the area.

5.4 USLE ANALYSIS USING ARC GIS

5.4.1 Maps of R, K, LS, C, P Factor

R factor map, K factor map, the S factor map, C factor map and P factor map have been prepared using GIS.. These maps contain the geographic information on the R, K, LS, C, and P factor.

LS factor map has been prepared with data from LS factor calculation (Table 5.4)

Figure 5.3 : Geographic distribution of R factor

Figure 5.4 : Geographic distribution of K factor

Figure 5.5 : Geographic distribution of LS factor

Figure 5.6 : Geographic distribution of C factor

Figure 5.7 : Geographic distribution of P factor

5.4.2 Overlay Technique

Overlay technique has been used to combine R, K, LS, C , P factor maps to create a map of soil erosion A = R . K . LS . C . P as erosion is Figure 5.8. Table 5.9 shows erosion classification of area s. This classification has been used to identify area according to level erosion .

Table 5.9 Classification Level Of Erosion

Class	Total Erosion (ton/ha/yr)	Information
I	<15	Very Low
II	>15 - <60	Low
III	>60 - <180	Medium
IV	>180 - <480	High
V	>480	Very High

Source: Forestry Department of Indonesia Government

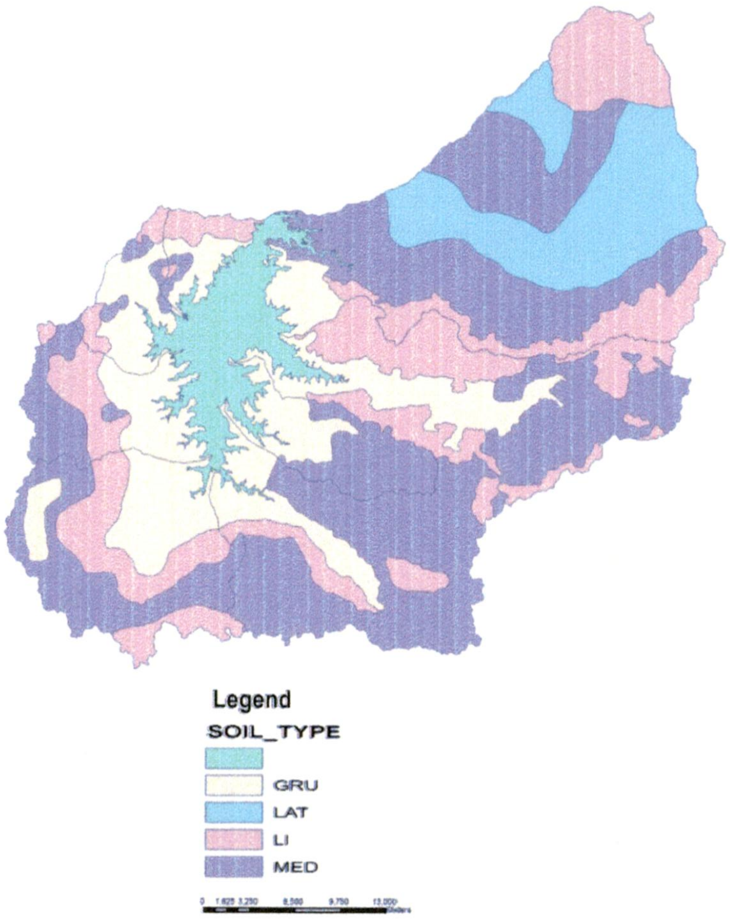


Figure 5.4. K Factor Map

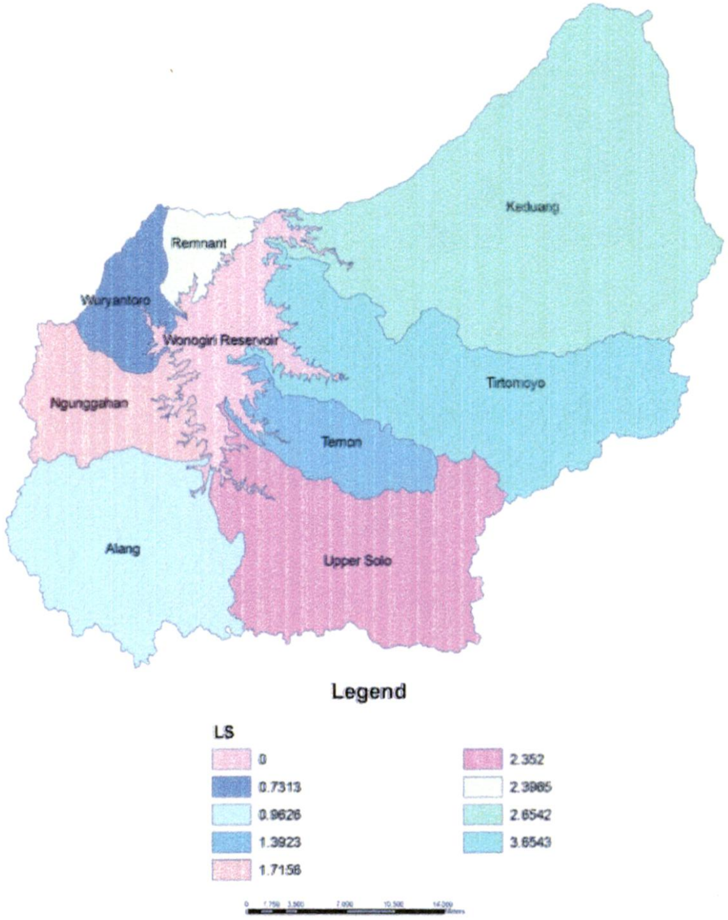


Figure 5.5. LS Factor Map

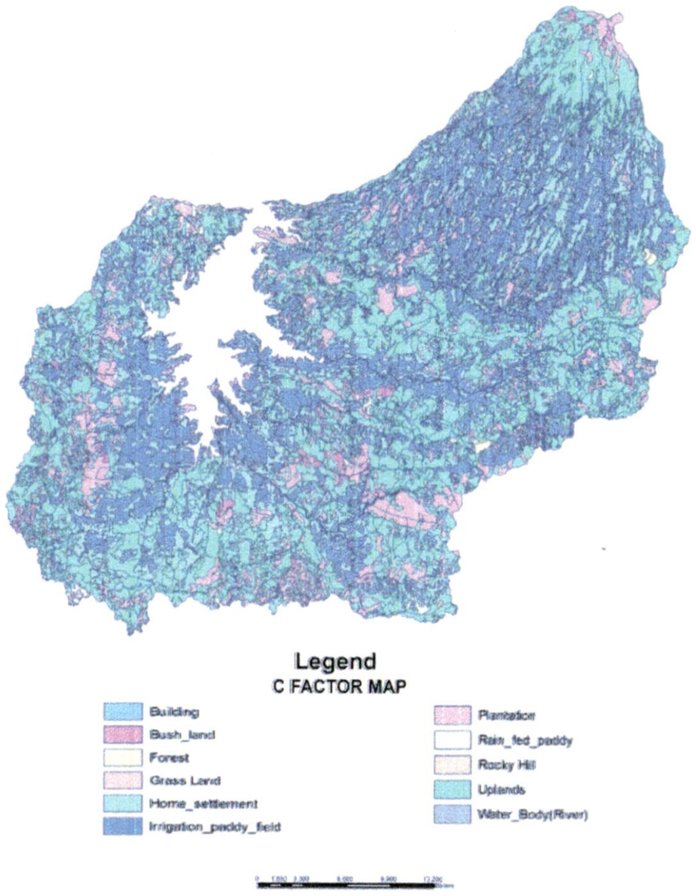


Figure 5.6. C Factor Map

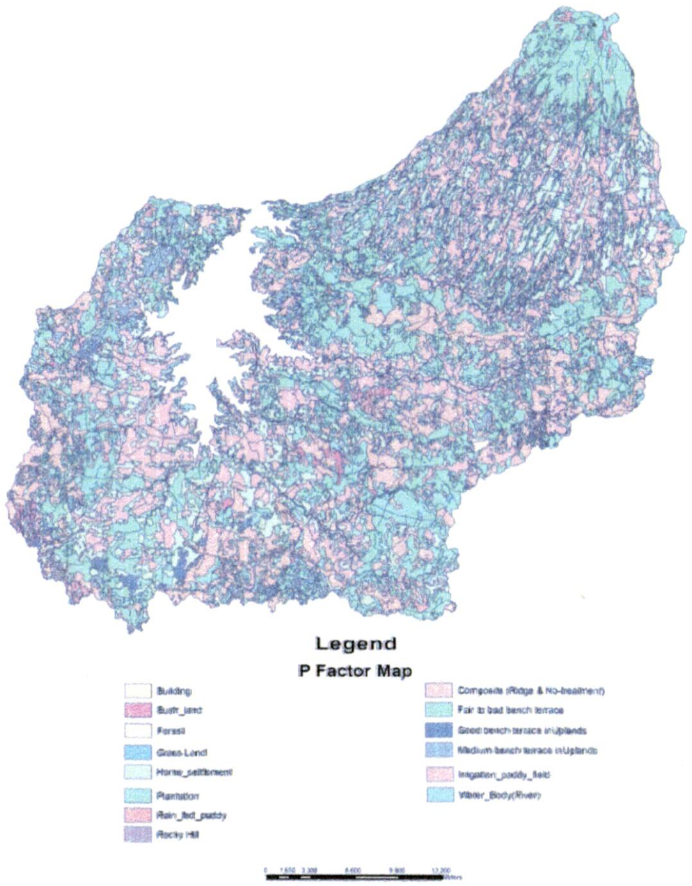


Figure 5.7. P Factor Map

5.4.3 Erosion Estimate Under Existing Condition

Value of R, K , LS, C, P factor for the subwatershed have been computed and a given tables:

R factor : Table 5.1
K factor : Table 5.3
LS Factor : Table 5.4
C Factor : Table 5.6
P Factor : Table 5.8

The erosion estimates in the subwatershed using analytical calculation (excel software) and GIS Technique are compared in Table 5.10. Computation of erosion using GIS shows less amount of erosion computed using analytical calculation based tabular calculation. Estimate using GIS are more accurate because more detailed geographic variation in K factor, C factor, and P factor are considered in GIS. In tabular calculation weighted K, C, P factor are used which are assumed to be uniform over the subwatershed.

Table 5.10 Estimation of Erosion

Sub Watershed	Area (ha)	Factor USLE					Erosion Calculation (Analytical)		Erosion Calculate using GIS	
		R	K	LS	C	P	t/ha/yr	t/yr	t/ha/yr	t/yr
Keduang	42,098	1579.92	0.25	2.65	0.31	0.47	150.97	6,355,542.3	124.93	5,259,458.24
Tirtomoyo	23,065	1579.92	0.25	3.65	0.43	0.52	315.92	7,286,693.5	260.48	6,007,860.57
Temon	6,259	1579.92	0.38	1.39	0.37	0.53	165.83	1,038,021.5	164.39	1,029,003.65
Upper Solo	20,553	1579.92	0.30	2.35	0.42	0.54	253.42	5,208,574.3	226.55	4,656,321.54
Alang	16,938	1579.92	0.26	0.96	0.42	0.52	88.11	1,492,429.1	67.71	1,146,876.75
Ngunggahan	8,240	1579.92	0.30	1.72	0.36	0.46	134.45	1,107,897.0	107.08	882,304.90
Wuryantoro	4,412	1579.92	0.37	0.73	0.37	0.45	69.64	307,230.6	52.46	231,448.89
Remnant	2,768	1579.92	0.27	2.40	0.49	0.54	271.31	750,957.0	211.53	585,499.59
Total	124,333						189.39	23,547,345.4	159.24	19,798,774.12

Erosion range for different subwatersheds is from 67.71 t/ha.yr in Alang subwatershed to 260.48 t/ha/yr in Tirtomoyo Watershed. Sediment erosion from catchment of Wonogiri reservoir is 19.798 Million Tons per year

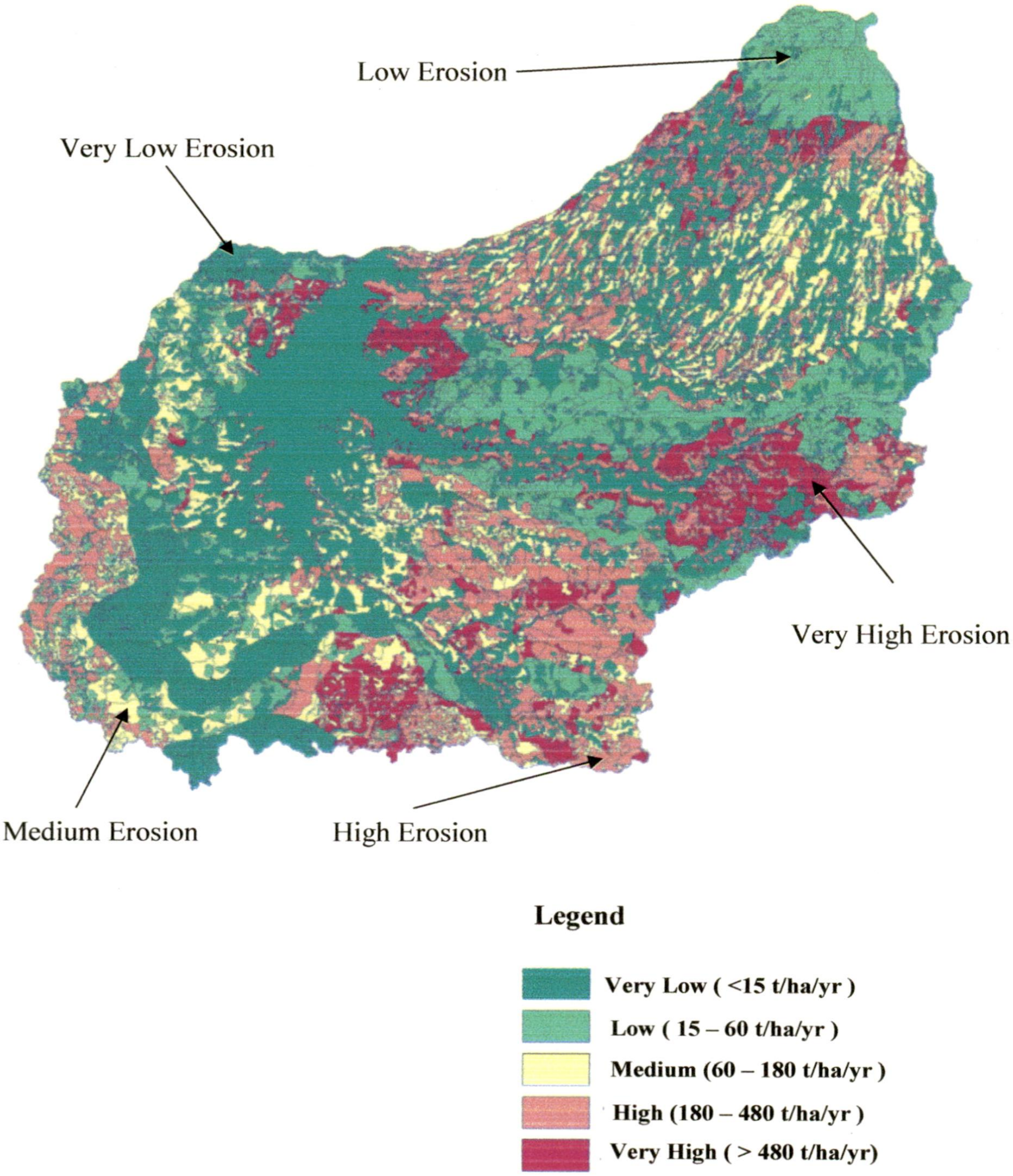


Figure 5.8. Erosion Map

5.5 SEDIMENT DEPOSIT IN RESERVOIR

Much of the eroded sediment from a distant source will typically encounter more opportunities for re-deposition before the watershed outlet. The ratio between the erosion rate and sediment yield is the "sediment delivery ratio (SDR)". Gregory L.Morris and Jiahua Fan (1997) have described the sediment delivery ration as follows:

> *"The sediment delivery ratio cannot be measured directly because gross erosion is never measured in a watershed; erosion rate is extrapolated from smaller plots or computed from modeling. Thus, the delivery ratio is actually the ratio of measured yield to the estimated erosion rate based on USLE or some other erosion prediction methodology. Delivery ratios much greater than unity have been reported by some researchers, and reflect the inability of erosion prediction models to account for all the erosion processes upstream of the point of yield measurement."*

The SDR for soil erosion from land surface was extrapolated by using the measured sedimentation volume in the Wonogiri reservoir. SDRs for each tributary have been taken from JICA report (2007), these are summarized in table 5.11. And density of the sediment material as 1.064 ton/m^3

Table 5.11 SDR in each subwatershed

Sub Watershed	SDR (%)
Keduang	23.6
Tirtomoyo	10.4
Temon	6.7
Upper solo	16.5
Alang	32.9
Ngunggahan	26.6
Wuryantoro	30.7
Remnant	17.1

Table 5.12 Sediment Deposit Using SDR

Sub Watershed	Soil erosion t/yr		SDR (%)	Sediment (m^3/yr)	
	Analytical	GIS		Analytical	GIS
Keduang	6,355,542.33	5,259,458.24	23.6	1,409,687.96	1,166,571.56
Tirtomoyo	7,286,693.53	6,007,860.57	10.4	712,233.20	587,234.49
Temon	1,038,021.52	1,029,003.65	6.7	65,364.14	64,796.28
Upper solo	5,208,574.33	4,656,321.54	16.5	807,720.64	722,079.94
Alang	1,492,429.08	1,146,876.75	32.9	461,474.78	354,626.36
Ngunggahan	1,107,897.02	882,304.90	26.6	276,974.26	220,576.22
Wuryantoro	307,230.55	231,448.89	30.7	88,646.41	66,780.83
Remnant	750,957.02	585,499.59	17.1	120,689.52	94,098.15
Total	23,547,345.39	19,798,774.12			
Sediment Inflow				3,942,790.91	3,276,763.85
Sediment Deposited				2,983,721.63	2,983,721.63
Sediment Outflow				959,069.28	293,042.22

5.6 CONCLUSION

Estimated soil erosion under existing condition from the entire catchment of Wonogiri Reservoir is 23.547 million ton per year (Analytical calculation) and 19.798 million ton per year (Arc GIS calculation). Soil erosion estimate using GIS is more accurate.

Rate of erosion is highest in Tirtomoyo sub watershed and lowest in Wuryantoro sub watershed with an average of 189.39 ton/ha/yr (Analytical calculation) and 159.24 ton/ha/yr (Arc GIS calculation) for entire catchment. Based on these results it can be concluded that the Wonogiri Watershed is undergoing Medium Level of erosion. Soil erosion in Upper Solo, Tirtomoyo and Remnant watershed are is of High Level and Tirtomoyo Watershed produces the largest erosion. But Keduang Watershed give contribute sediment to reservoir largest (1.167 MCM). The erosion from watershed causes sedimentation of reservoir and will reduce level capacity of reservoir and life of reservoir too. Because of it, management tools to reduce the erosion are necessary. These will be explained in next chapter.

Computation of erosion using GIS shows less amount of erosion compared to analytical calculation. Arc GIS give less sediment inflow than the analytical method. The difference between these is 666,027.06 m^3/yr. Estimated erosion using GIS are more accurate because more detailed geographic variation in K factor, C factor, and P factor are considered in GIS.

CHAPTER 6

GIS BASED UNIVERSAL SOIL LOSS EQUATION AS A MANAGEMENT TOOL

Erosion control in Wonogiri Basin region can be improved by: (1) improvement of land, (2) improvement of farming patterns or land use or (3) a combination of two of these. Procedures for erosion control improvements (improvement factor P) and the pattern of cultivation (factor C) are probably the most easily implemented measures. Soil improvement (improvement factor K) is not technically difficult, but it is expensive. Repair farming patterns, let alone improving land use, is one effort that is easily implementable in the reduction of erosion because the material is easily available and at cheap prices

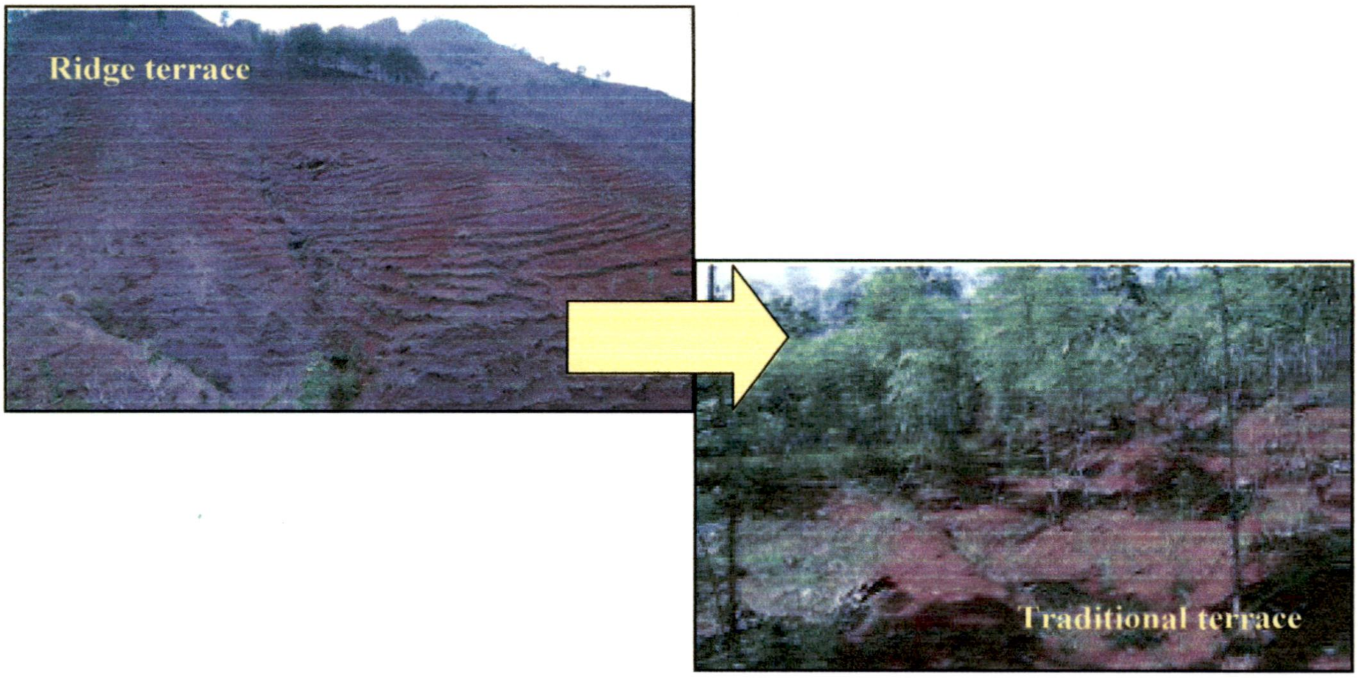
6.1 MANAGEMENT BY IMPROVING P FACTOR

It is considered success of that watershed conservation depends on minimizing the cost of soil conservation measures and the project works could be easily carried out by the beneficiaries of the project. The proposed soil conservation measures are shown in Table 6.1. The improved bench terrace is illustrated in the Figure 6.1 below.

Table 6.1 Proposed Terrace Improvement Works

Measures	Component
Physical Measure	Bench Terrace Improvement Construction Work. Improvement from composite/ridge terrace to traditional terrace.

Soil and water conservation measures envisaged in uplands with benched terraces are defined as "Terrace improvement works" and include improvement of terrace structures of terrace bench, lip, riser, waterway and drop structure at different degrees depending on current terrace type and condition. Further, the works include vegetative measures for vegetating the terrace lip and riser with grass or shrub for their stabilization.



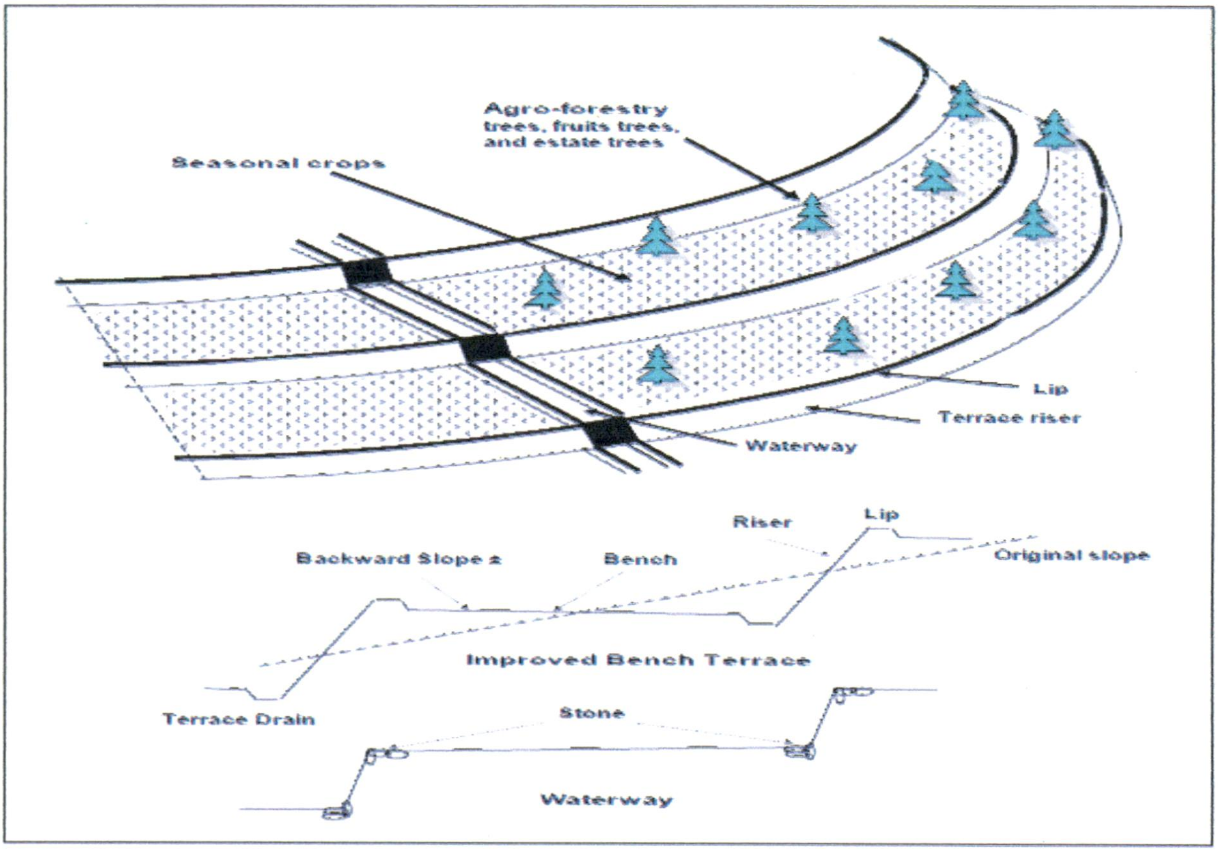


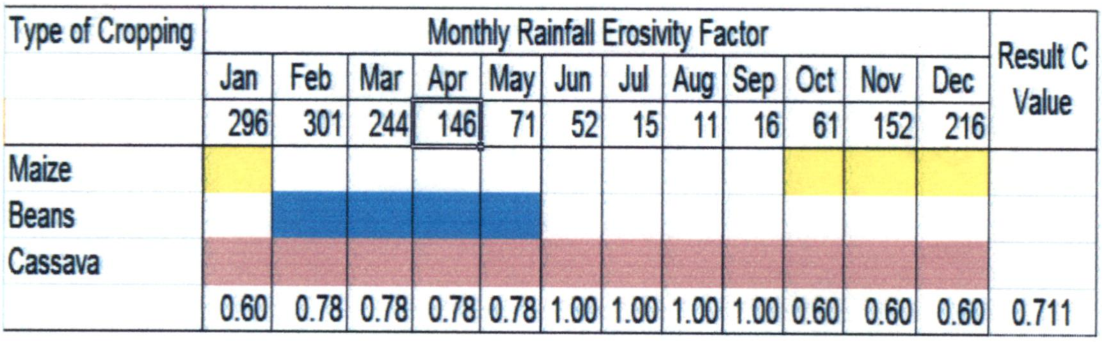
Figure 6.1 Improvement Bench Terrace

6.2 CROP COVER AND MANAGEMENT FACTOR C

The varieties of maize are different depending on the locality. In Wonogiri, dry farm lands are largely governed by those of seasonal crops. The overall cropping intensity on the dry farm lands a 1st cropping season is 100%, second cropping season is 40% and third cropping season is 1%. C value for current cropping pattern is 0.711

Table 6.2 Current Cropping Pattern

Cropping Session	Cropping Pattern
1. Cropping Session (MT)-1	maize and cassava
2. Cropping Session (MT)-2	beans and cassava
3. Cropping Session (MT)-3	cassava



Type of Cropping	Monthly Rainfall Erosivity Factor												Result C Value
	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	
	296	301	244	146	71	52	15	11	16	61	152	216	
Maize	🟨									🟨	🟨	🟨	
Beans		🟦	🟦	🟦	🟦								
Cassava	🟥	🟥	🟥	🟥	🟥	🟥	🟥	🟥	🟥	🟥	🟥	🟥	
	0.60	0.78	0.78	0.78	0.78	1.00	1.00	1.00	1.00	0.60	0.60	0.60	0.711

In order to obtain an accurate value for the crop factor, an overall cover and management factor for upland areas is calculated by the following equation (JICA Report-2007) by using cropping intensity data at the Wonogiri:

$$C = (Ci \cdot Ri + Cii \cdot Rii + Ciii \cdot Riii + \cdot\ \cdot\ \cdot\ \cdot + Cxii \cdot Rxii)/Ri{\sim}xii$$

where,

C : Annual overall cover and management factor C

Ci : Average annual crop factor for mixed cultivation of cassava and maize, mixed cultivation of cassava and beans, and cassava

$Ri=(EI_{30})i$: Monthly rainfall erosivity factor for i-th month

$Ri\sim xii=(EI_{30})\ i\sim xii$: Annual rainfall erosivity factor (accumulated Jan. to Dec.)

Planting of crops depends on the water demand for each type of cropping. Crops which need high water demand cannot be planted in dry season. The comparison of cropping plant combination and cropping time is shown in Table 6.3. From the table, combination of Rain-Fed-Paddy + Soybean + Cassava is given the lowest C. This combination will recommend cropping pattern in Wonogiri catchment area so as to reduce erosion. And cropping intensity will be change 100% in all cropping session.

Orchard or Plantation will be change from low density to medium density. Rainfed paddy will be change too, it will be same value and cropping combination of upland. However other factors such as economic social, cultural, seed availability support for both local government and central and several factors supporting agriculture, such as soil and so forth also need to be considered.

Table 6.3 C Value Based on Crop Calendar and Rainfall Erosivity Factor

No	Type of Cropping	Monthly Rainfall Erosivity Factor												Result C Value
		Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	
		296	301	244	146	71	52	15	11	16	61	152	216	
1	Rain-fed paddy		🟩	🟩	🟩	🟩								
	Soybean	🟧					🟧	🟧	🟧	🟧	🟧	🟧	🟧	
	Cassava	🟪					🟪	🟪	🟪	🟪	🟪	🟪	🟪	
	C value	0.30	0.561	0.561	0.561	0.561	0.30	0.30	0.30	0.30	0.30	0.30	0.30	0.426
2	Rain-fed paddy	🟩	🟩	🟩	🟩	🟩					🟩	🟩	🟩	
	Soybean						🟧	🟧	🟧	🟧				
	Cassava						🟪	🟪	🟪	🟪				
	C value	0.561	0.561	0.561	0.561	0.561	0.30	0.30	0.30	0.30	0.561	0.561	0.561	0.545
3	Rain-fed paddy		🟩	🟩	🟩	🟩								
	Soybean						🟧	🟧	🟧	🟧				
	Maize	🟨									🟨	🟨	🟨	
	C value	0.70	0.56	0.56	0.56	0.56	0.40	0.40	0.40	0.40	0.70	0.70	0.70	0.615
4	Rain-fed paddy		🟩	🟩	🟩	🟩								
	Soybean						🟧	🟧	🟧	🟧				
	Maize	🟨									🟨	🟨	🟨	
	Cassava	🟪					🟪	🟪	🟪	🟪	🟪	🟪	🟪	
	C value	0.60	0.561	0.561	0.561	0.561	0.30	0.30	0.30	0.30	0.60	0.60	0.60	0.563
5	Rain-fed paddy		🟩	🟩	🟩	🟩								
	Maize	🟨									🟨	🟨	🟨	
	Cassava	🟪					🟪	🟪	🟪	🟪	🟪	🟪	🟪	
	C value	0.60	0.561	0.561	0.561	0.561	1.00	1.00	1.00	1.00	0.60	0.60	0.60	0.605
6	Rain-fed paddy	🟩	🟩	🟩	🟩	🟩					🟩	🟩	🟩	
	Maize						🟨	🟨	🟨	🟨				
	Cassava						🟪	🟪	🟪	🟪				
	C value	0.561	0.561	0.561	0.561	0.561	0.60	0.60	0.60	0.60	0.561	0.561	0.561	0.563
7	Rain-fed paddy		🟩	🟩	🟩	🟩								
	Beans	🟦					🟦	🟦	🟦	🟦	🟦	🟦	🟦	
	Cassava	🟪					🟪	🟪	🟪	🟪	🟪	🟪	🟪	
	C value	0.45	0.561	0.561	0.561	0.561	0.45	0.45	0.45	0.45	0.45	0.45	0.45	0.504
8	Rain-fed paddy	🟩	🟩	🟩	🟩	🟩					🟩	🟩	🟩	
	Beans						🟦	🟦	🟦	🟦				
	Cassava						🟪	🟪	🟪	🟪				
	C value	0.561	0.561	0.561	0.561	0.561	0.45	0.45	0.45	0.45	0.561	0.561	0.561	0.554
9	Rain-fed paddy		🟩	🟩	🟩	🟩								
	Maize	🟨									🟨	🟨	🟨	
	Beans						🟦	🟦	🟦	🟦				
	Cassava	🟪					🟪	🟪	🟪	🟪	🟪	🟪	🟪	
	C value	0.60	0.561	0.561	0.561	0.561	0.45	0.45	0.45	0.45	0.60	0.60	0.60	0.572
10	Rain-fed paddy		🟩	🟩	🟩	🟩								
	Soybean	🟧									🟧	🟧	🟧	
	Beans						🟦	🟦	🟦	🟦				
	Cassava	🟪					🟪	🟪	🟪	🟪	🟪	🟪	🟪	
	C value	0.30	0.561	0.561	0.561	0.561	0.45	0.45	0.45	0.45	0.30	0.30	0.30	0.435

6.3 REDUCTION OF SOIL LOSS PRODUCTION

Reduction of soil loss in the Wonogiri dam watershed is expected after implementation of the watershed conservation projects. The conservation projects will be carried out over about change condition Composite/Ridge Terrace to Traditional Terrace for Management P Value and or combination cropping plant (Rain-fed Paddy-Soybean-Cassava)-orchard/plantation (low density-medium density) for C value. The soil loss in the Wonogiri dam watershed after implementation of the improved P and C factors is discussed below .

This calculation is using Arc GIS with the same management tools shown in Fig 6.2, Fig 6.3, Fig. 6.4 and Table 6.7.

Using Arc GIS

The analytical calculation have same factor management with Arc GIS calculation.. The results of the Arc GIS calculation can be seen in the figure below

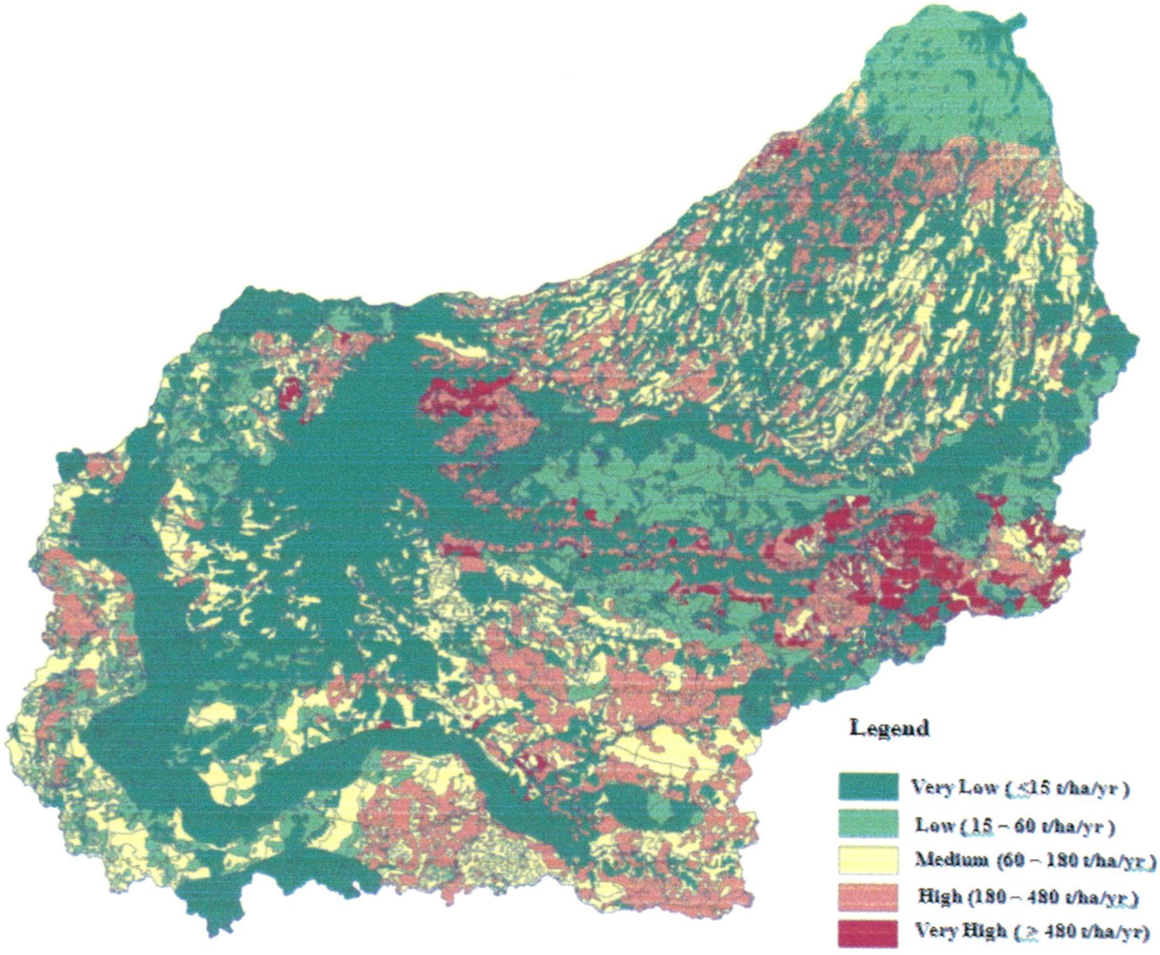


Figure 6.2 Effect of C Factor Management

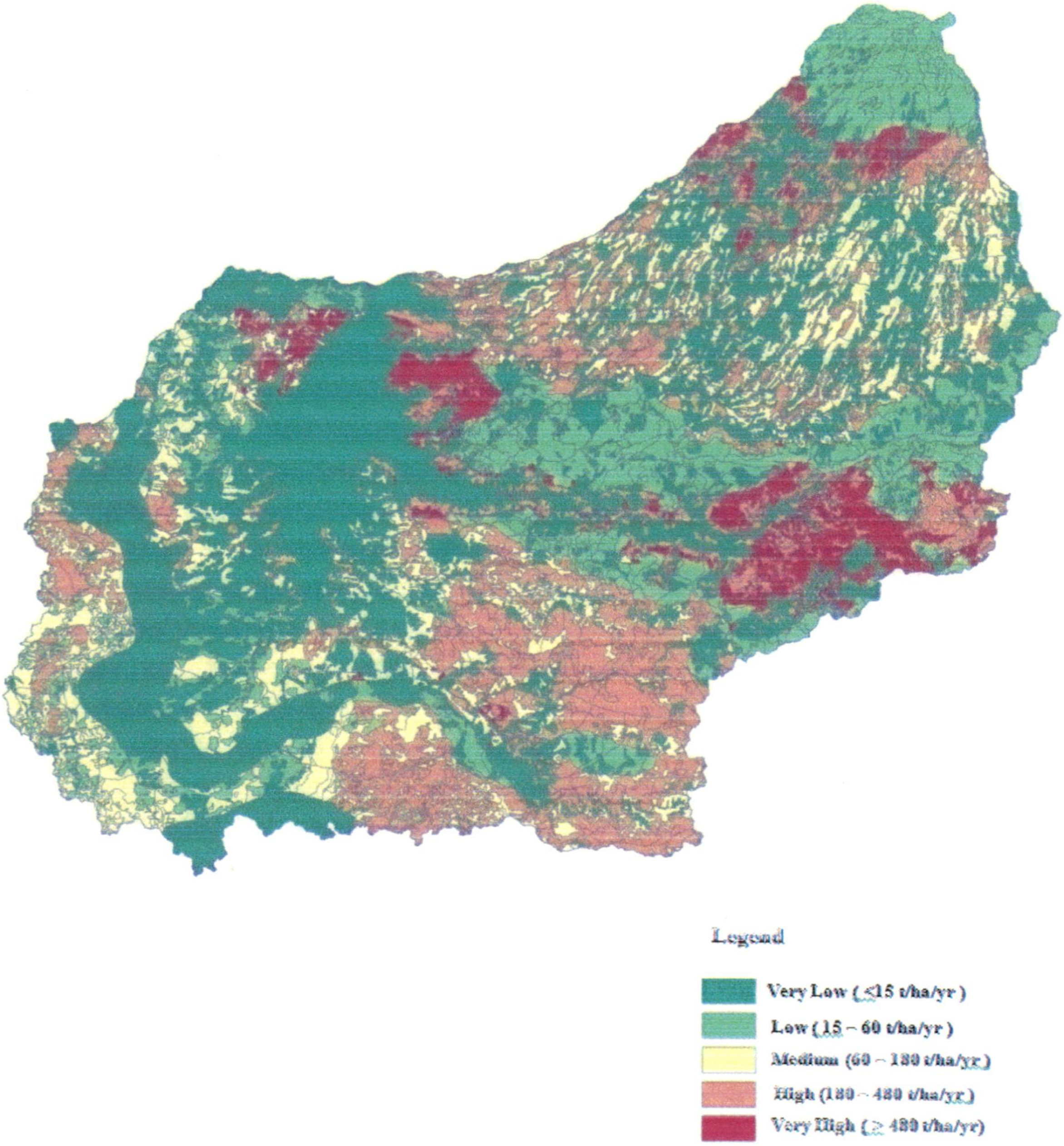


Figure 6.3 Effect of P Factor Management

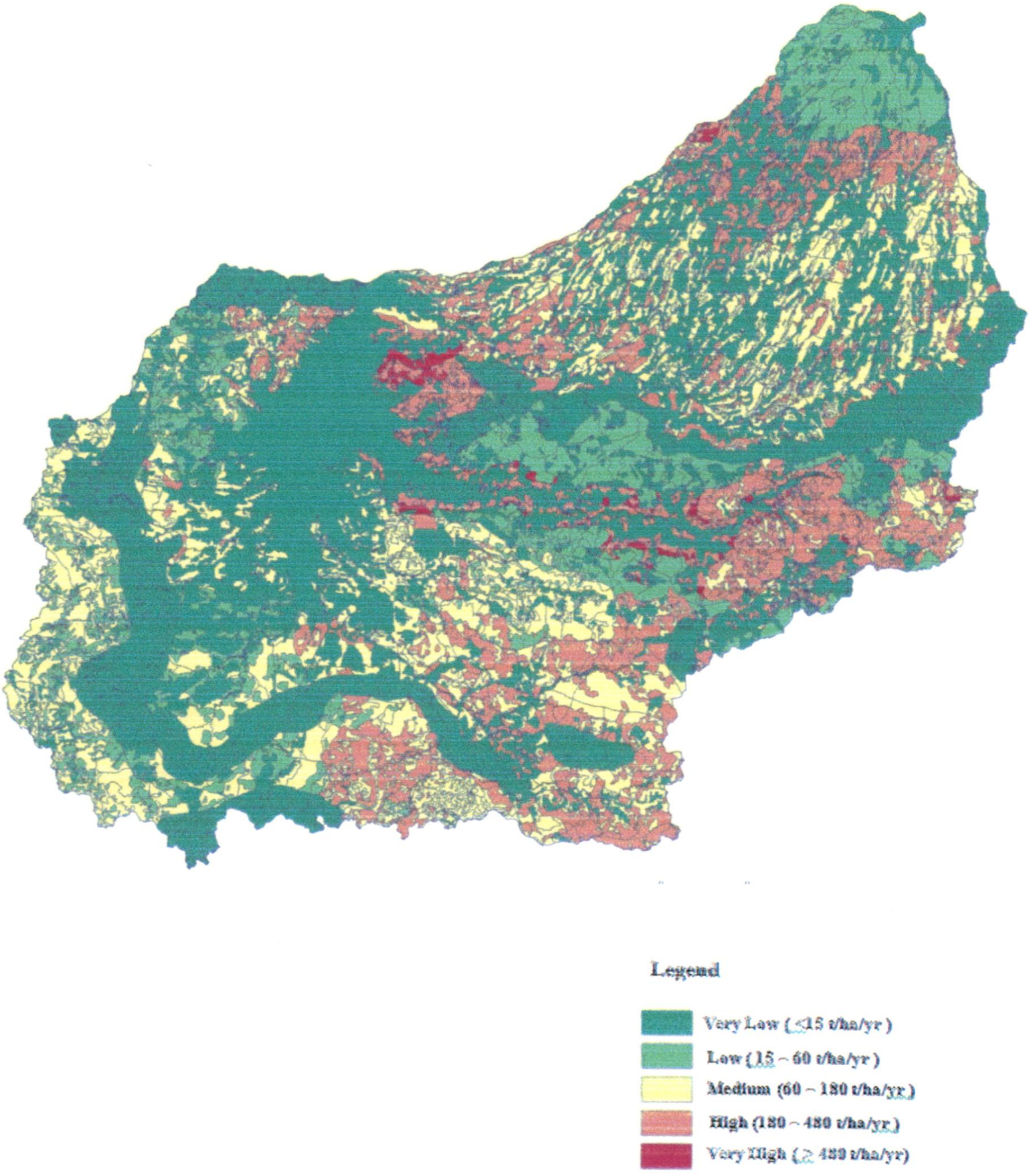


Figure 6.4 Effect of C and P Factor Management

Table 6.4 Calculation of Erosion Using ARC GIS with Management Tools

Sub Watershed	Area (ha)	Erosion Using GIS							
		No Management		Manage C Factor		Manage P Factor		Manage C and P Factor	
		t/ha/yr	t/yr	t/ha/yr	t/yr	t/ha/yr	t/yr	t/ha/yr	t/yr
Keduang	42,098	124.93	5,259,458.24	84.93	3,575,374.25	121.29	5,106,029.68	82.75	3,483,446.59
Tirtomoyo	23,065	260.48	6,007,860.57	163.05	3,760,683.97	212.53	4,901,927.39	134.32	3,098,057.34
Temon	6,259	164.39	1,029,003.65	103.88	650,196.43	139.07	870,513.15	88.70	555,235.87
Upper Solo	20,553	226.55	4,656,321.54	138.34	2,843,307.13	188.35	3,871,185.49	115.45	2,372,858.56
Alang	16,938	67.71	1,146,876.75	43.23	732,295.58	55.64	942,372.93	36.00	609,765.87
Ngunggahan	8,240	107.08	882,304.90	66.94	551,560.31	86.83	715,435.73	54.80	451,579.63
Wuryantoro	4,412	52.46	231,448.89	34.98	154,322.84	49.68	219,204.47	33.17	146,329.14
Remnant	2,768	211.53	585,499.59	125.16	346,419.90	192.62	533,170.67	113.83	315,066.70
Total	124,333	159.24	19,798,774.12	101.45	12,614,160.41	138.01	17,159,839.51	88.73	11,032,339.70

Management of C factor is shown in the figure 6.2. In this figure shown very high erosion areas (red colour) are decrease. But there are still very high erosion areas in Keduang, Tirtomoyo and Remnat

Management of P factor is shown in the figure 6.3. In this figure shown very high erosion areas (red colour) are decrease but not significant than Management of C factor. It can be seen from areas with red color in Figure 6.3 more than Figure 6.2.

In Figure 6.4, Management of C and P factor decrease very high erosion area better than management C (single) and management P (single). The figure shown there is little area with red colour.

Based on the above parameters, the annual average soil loss produced in the Wonogiri dam watershed and sub-basins is estimated and shown in the table 6.4. With management of C factor, the erosion decrease by 57.79 t/ha/yr. With management of P factor, the erosion decrease by 21.22 t/ha/yr. And with management of C and P factor, the erosion decrease by 70.51 t/ha/yr. It can seen in Table 6.5 below:

Table 6.5 Comparison of Erosion

	Using Arc GIS (t/ha/yr)	
Management Factor	Total	Decreasing
No management	159.24	
C	101.45	57.79
P	138.01	21.22
C and P	88.73	70.51

Calculation process is same as in previous chapter that is by using the Sediment Delivery Ratio (Chapter 5) and density of the sediment material as 1.064 ton/m^3 (Chapter 5) The results of the calculations are given in Table 6.6

6.4 CHANGE HAPPENS IN RESERVOIR AS MANAGEMENT TOOLS

Management C factor and P factor will reduce deposited erosion. Thereby reducing sediment deposited reservoir.

Table 6.6 shown the changes to the deposit of sediment each year declined from 2.98 Mm^3/yr with decline is

Management of C factor : 1,813,972.35 m^3/yr = 1,814 Mm^3/yr
Management of P factor : 2,592,961.54 m^3/yr = 2,593 Mm^3/yr
Management of C and P factor : 1,579,651.80 m^3/yr = 1,580 Mm^3/yr

Table 6.6 Sediment Deposited (Management Tools)

Sub Watershed	Soil erosion t/yr			SDR (%)
	New Calculation			
	C	P	C and P	
Keduang	3,575,374.25	5,106,029.68	3,483,446.59	23.6
Tirtomoyo	3,760,683.97	4,901,927.39	3,098,057.34	10.4
Temon	650,196.43	870,513.15	555,235.87	6.7
Upper solo	2,843,307.13	3,871,185.49	2,372,858.56	16.5
Alang	732295.5804	942,372.93	609,765.87	32.9
Ngunggahan	551,560.31	715,435.73	451,579.63	26.6
Wuryantoro	154,322.84	219,204.47	146,329.14	30.7
Remnant	346,419.90	533,170.67	315,066.70	17.1

Sub Watershed	Sediment deposit (m3/yr)		
	C Factor	P Factor	C and P Factor
Keduang	793,034.14	1,132,540.42	772,644.17
Tirtomoyo	367,585.65	479,135.76	302,817.63
Temon	40,942.82	54,816.15	34,963.16
Upper solo	440,926.39	600,324.82	367,971.49
Alang	226,433.50	291,391.63	188,546.03
Ngunggahan	137,890.08	178,858.93	112,894.91
Wuryantoro	44,527.36	63,247.91	42,220.91
Remnant	55,674.63	85,688.14	50,635.72
Sediment Inflow	2,107,014.56	2,886,003.75	1,872,694.01
Sediment Outflow	293,042.22	293,042.22	293,042.22
Sediment Deposited	1,813,972.35	2,592,961.54	1,579,651.80

Sediment reduction will decrease zero elevation and thus increase reservoir capacity which is calculated using Area Reduction method based

Elevation Area Capacity 25 yr. The results of these calculations are given in the table 6.7

Table 6.7 Change in Zero Elevation and Reservoir Capacity Due To Management Tools

Years	No Management		Manage C		Manage P		Manage C P	
	Zero Elevation	Capacity	Zero Elevation	Capacity	Zero Elevation	Capacity	Zero Elevation	Capacity
	m	Mm^3	m	Mm^3	m	Mm^3	m	Mm^3
0	110.0	559.8	110.0	559.8	110.0	559.8	110.0	559.8
50	122.7	361.8	121.4	391.0	122.3	371.6	121.0	396.9
100	129.7	212.6	124.4	300.3	127.2	241.9	123.9	317.9

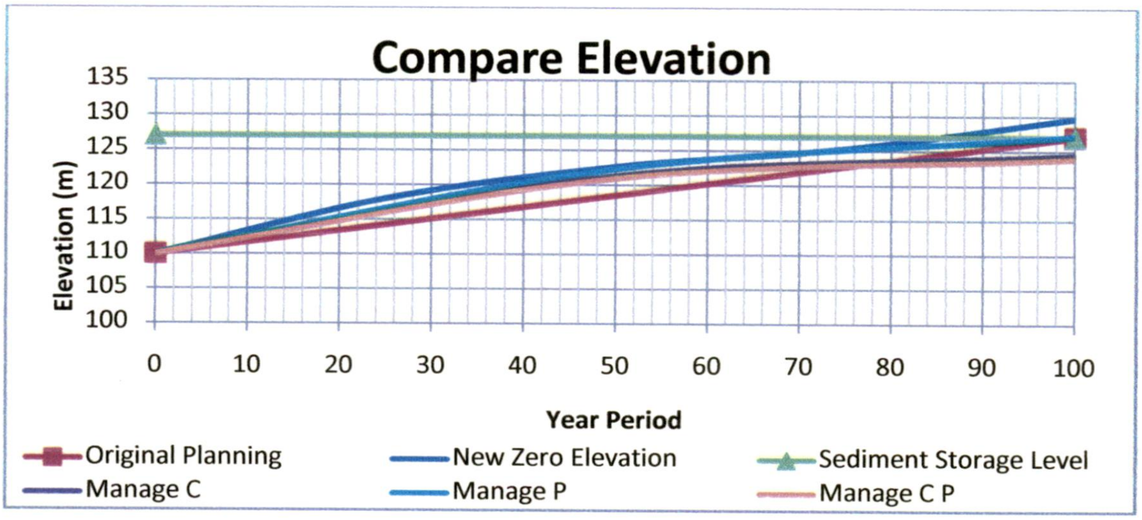


Figure 6.6 Comparisons of Elevation Changes Due To Management Tools

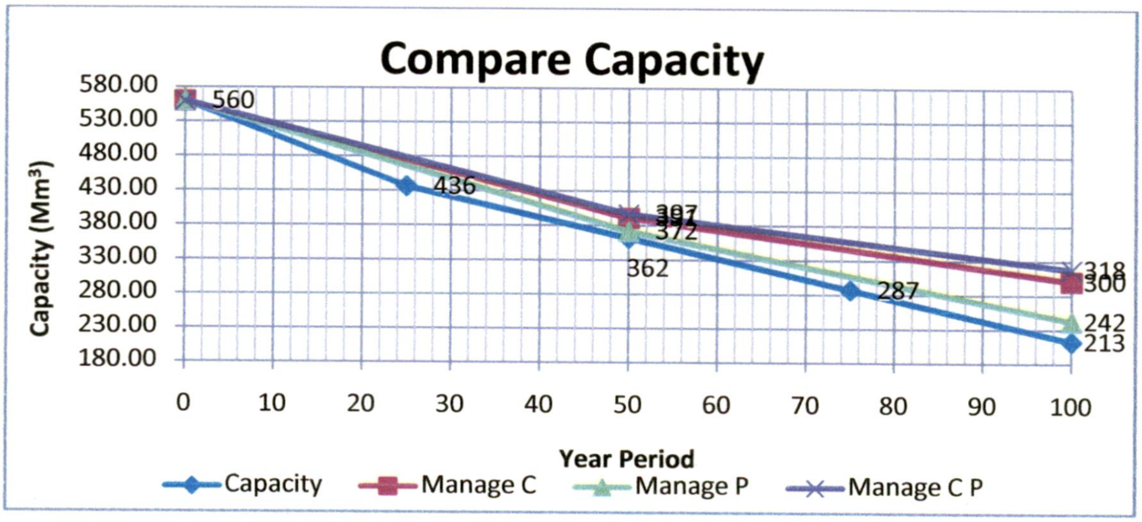


Figure 6.7 Comparisons of Capacity Changes Due To Management Tools

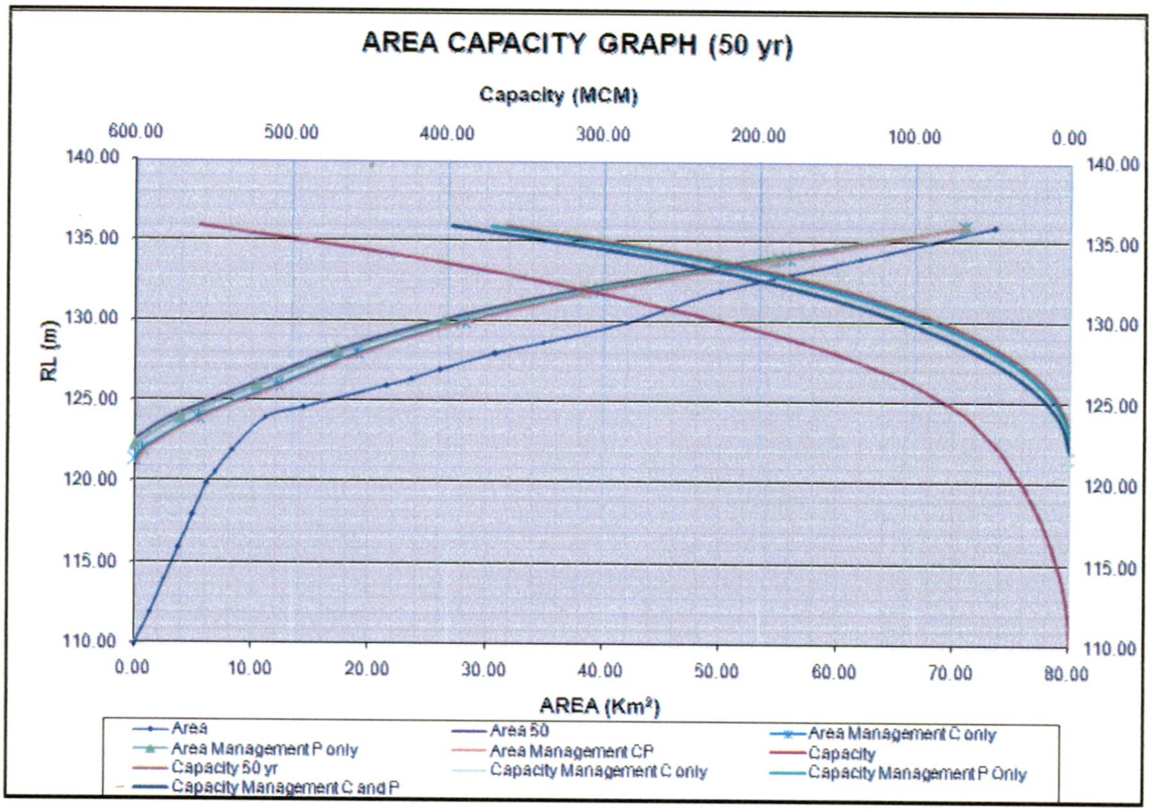


Figure 6.8 Comparison Area Elevation Capacity 50 Yr

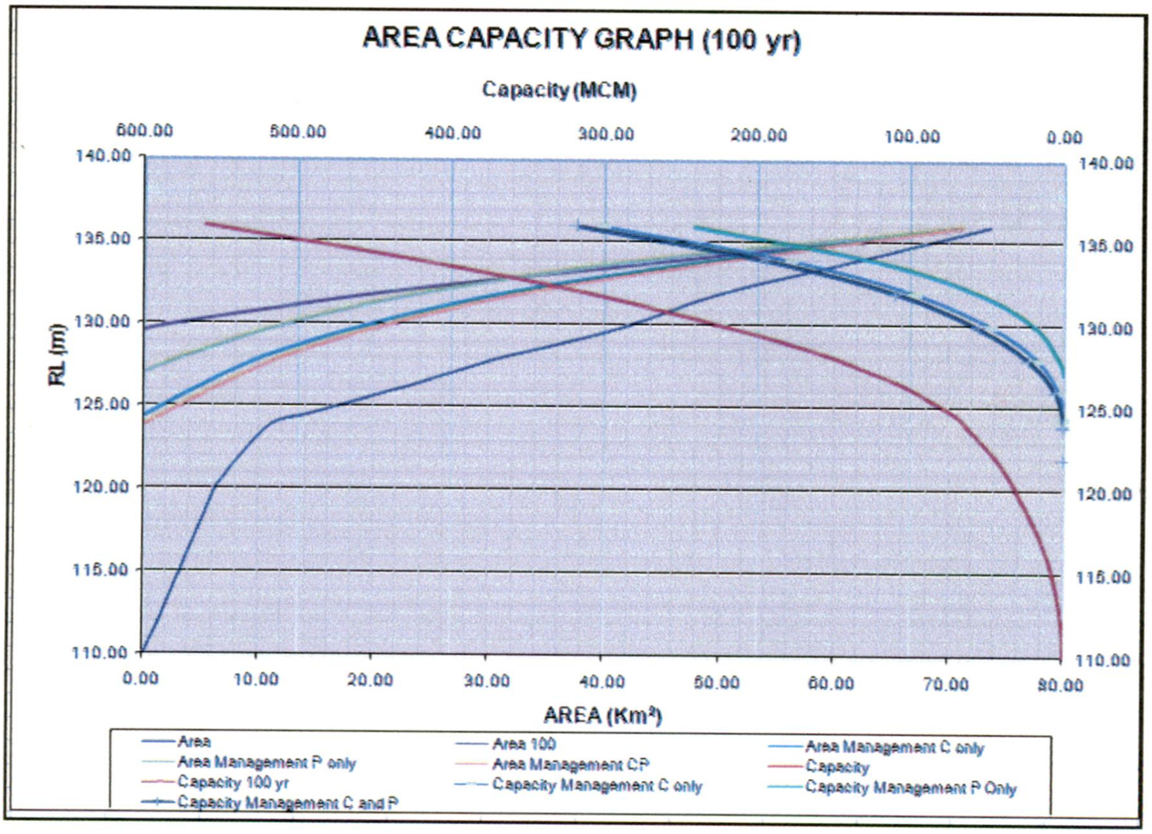


Figure 6.9 Comparison Area Elevation Capacity 100 Yr

6.5 CONCLUSION

The erosion is associated with most of the soils in the catchment, except for those under natural forest. It appears to exceed the soil loss values (high) above which serious damage to land productivity would occur. The estimated erosion impacts are even more severe for shallower soils whose soil loss tolerance limits are much lower than the value assumed for the deep soils. Clearly, natural vegetation must be left undisturbed on all the shallow soils and even on some of the deep soils. When socioeconomic factors force alternate land uses, these must be planned carefully to incorporate the most feasible precaution for reducing hazard. Favorable results can be obtained if agronomic measures that reduce the C and P factor values are adopted. Cost-effective soil conservation on steep croplands can be implemented through well designed, stable, and well maintained bench terraces.

A management practice depends on agro climate of the area and cost of the measures USLE can be used to identify suitable measures so that soil erosion is within permissible limit. Thus USLE can be used as an important tool to analyse management through manipulating of C and P factor. The conservation projects will be carried out over about change condition Composite/Ridge Terrace to Traditional Terrace for Management P Value and or combination cropping plant (Rain-fed Paddy-Soybean-Cassava)-orchard/plantation (low density-medium density) for C value

With management of C factor, the erosion decrease by 57.79 t/ha/yr. With management of P factor, the erosion decrease by 21.22 t/ha/yr. And with management of C and P factor, the erosion decrease by 70.51 t/ha/yr.

CHAPTER 7

PREDICTION OF TRIANGULAR DEPOSITION PROFILE

7.1 GENERAL

Mirarki GD (1983) have proposed a method for determining the deposition profile assuming it to be triangular. The method is based on analysis of deposition profile in some reservoirs in India

The upstream slope Su, downstream slope Sd, and maximum deposition Zp are depletion definition sketch figure 7.1.

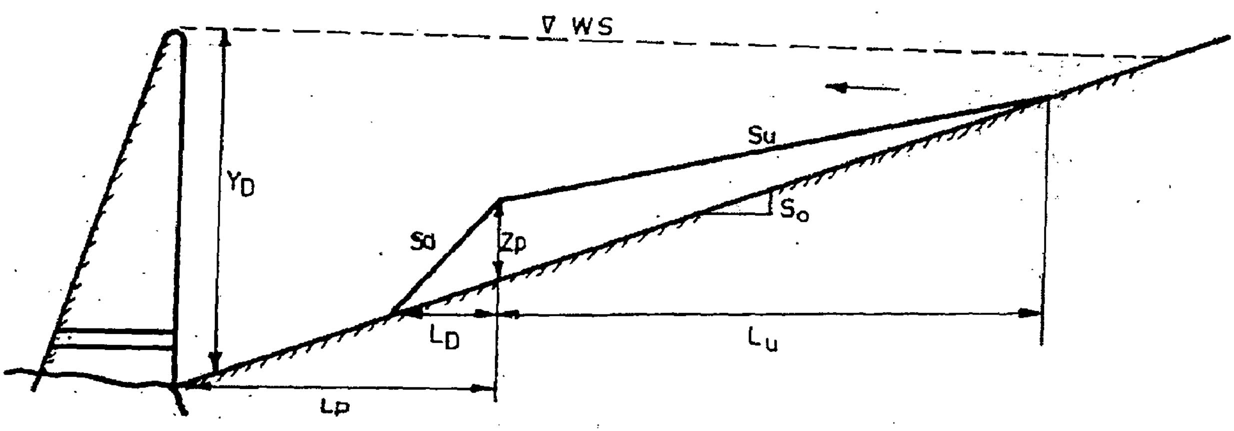


Fig. 7.1 Sketch of Triangular Profile

This method explained as below:

1. Compute corresponding value of absolute sediment yield (V_{SAB}) in volume unit.
2. Obtain annual s absolute sediment deposited in reservoir (V_{SABD})
3. Apparent volume of deposited sediment at the end of T years. ($V_{SAPD(T)}$)

   $$(V_{SAPD(T)}) = \frac{26}{\gamma av(T)} \sum_{I}^{T} V_{SABD}$$

   In present study ($V_{SAPD(T)}$) obtained from data 1980, 1993 and 2005
4. Determine number of years in which the reservoir will fill completely if all sediment coming into the reservoir (To) using equation below

$$To = \frac{\text{Reservoir Capacity}}{\text{Annual Sediment Deposited}}$$

5. Obtain Su, Sd and Zp for known T using equation below :

$$\frac{Su}{So} = 0.34\left(\frac{T}{To}\right)^{-0.08}$$

$$\frac{Sd}{S0} = 3.85(\frac{T}{To})^{0.20}$$

$$\frac{Zp}{Yd} = 0.717(\frac{T}{To})^{0.285}$$

6. Knowing reservoir characteristic obtain relationship for average W.S width Bs as function of water depth y.
7. Volume of sediment deposited under profile will be VSD(T) = (Lu+LD) Zp Bs/2
8. If VSD(T) is not equal to VSAPD(T) value of Su is adjusted

7.2 DATA

Value of absolute sediment yield (VSAB) and absolute sediment deposited in reservoir (V_{SABD}) calculated in chapter 5 and 6. Values of annual absolute sediment deposited in reservoir (VSABD) have different value for different management condition. Value of "To" are also different. The value of VSABD and "To" shown in table below:

Table 7.1 "To" for Different Condition

Condition	Life of Reservoir (Annual Sediment Deposited)			To	VSAPD (50 yr)	VSAPD (100yr)
	1980-1993 13 yr	1993-2005 12 yr	2005-(100 yr) 75 yr			
	(MCM/yr)	(MCM/yr)	(MCM/yr)		(MCM)	(MCM)
"To" (original)	6.737	2.984	2.984	161.31	197.97	347.16
"To" management of C factor	6.737	2.984	1.814	215.86	168.73	259.43

"To" management of P factor	6.737	2.984	2.593	176.18	188.206	317.854
"To" management of C and P factor	6.737	2.984	1.580	231.54	162.87	241.86

Value of Slope of reservoir is calculated from Original River of reservoir in upstream. The value of slope is 0.000968

7.3 ANALYSIS OF SEDIMENT PROFILE

Table 7.2 shows calculation of sediment deposition profile under various conditions.

Sediment profile of reservoir after 50 years and 100 yr are shown in figure 7.2. The profile sediment deposited after 50 at entry mouth of reservoir (original condition) shows the top elevation of sediment to be near to FRL of reservoir (EL. 136 m). But after 100 yr (original condition) the elevation of sediment exceeds Extend Flood Water Level of reservoir (EL. 139.1 m). Width of sediment profile (BS) after 50 yr and 100 yr will be 1031.26 m and 1304.70 m

The profile of sediment deposited after 50 yr (change of C factor condition) shows the top elevation of sediment below of FRL of reservoir (EL. 136 m). But after 100 yr (change of C factor condition) shows the elevation of sediment to be near Extend Flood Water Level of reservoir (EL. 139.1 m). Width of sediment profile (BS) after 50 yr and 100 yr will be 1005.04 m and 1119.68 m.

The profile of sediment deposited after 50 yr (change of P factor condition) shown the elevation of sediment below FRL of reservoir (EL. 136 m). This profile is above sediment profile with Change of C factor for 50 yr profile nd below of original profile 100 yr. Width of sediment profile (BS) after 50 yr and 100 yr will be 1021,21 m and 1245.88 m.

Table 7.2 Calculation Of Sediment Deposited Profile

No		No Management		Manage C		Manage P		Manage C and P	
		Years		Years		Years		Years	
		50	100	50	100	50	100	50	100
1	To	161.31	161.31	215.86	215.86	176.18	176.18	231.54	231.54
2	VSAPD (Mm3)	197.98	347.16	168.73	259.43	188.21	317.85	162.87	241.86
3	So	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
4	Yd (m)	26	26	26	26	26	26	26	26
5	Su	0.000361	0.000342	0.000370	0.000350	0.000364	0.000344	0.000372	0.000352
6	Sd	0.002948	0.003386	0.002781	0.003195	0.002896	0.003327	0.002742	0.003150
7	Zp (m)	13.35	16.27	12.29	14.97	13.02	15.86	12.04	14.67
8	Lp	7000	7000	7000	7000	7000	7000	7000	7000
9	Ld (m)	6742.49	6726.11	6776.29	6723.01	6750.85	6723.76	6787.18	6724.34
10	Lu	22015.36	25988.34	20550.17	24229.94	21559.85	25441.64	20213.80	23826.30
11	Bs (m)	1031.26	1304.70	1005.04	1119.68	1021.21	1245.88	1001.66	1078.93
12	VSD(T) (Mm3)	197.98	347.16	168.73	259.43	188.21	317.85	162.87	241.86

The profile sediment deposited in 50 (change of C and P factor original condition) shown the elevation of sediment below of FRL of reservoir (EL. 136 m). Profile sediment deposited in 100 yr (change of C and P factor condition) shown the top elevation of sediment below Extend Flood Water Level of reservoir (EL. 139.1 m). Width of reservoir (BS) in 50 yr and 100 yr will be 1001.66 m and 1078.93 m.

The above analysis shows that sediment deposition at the month of reservoir can be reduces by management C and P factors otherwise choking of mouth will occurs.

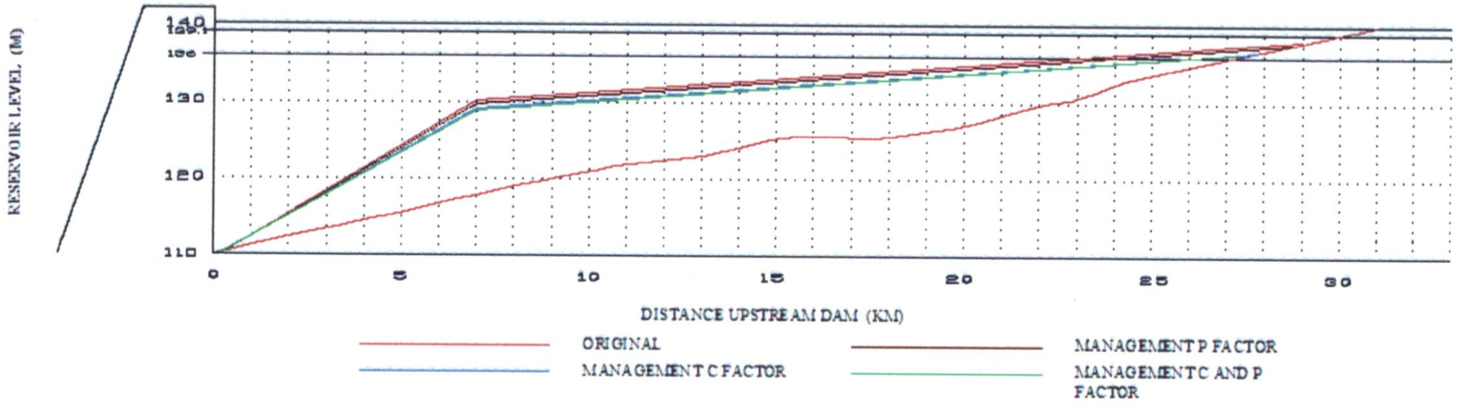
7.4 CONCLUSION

Deposition profile in a reservoir can be empirically found using Area Reduction Method as discussed in chapter 4. Mirarki GD (1983) and Garde et al (1983) have proposed a method for determining the deposition profile assuming it tobe triangular. Method was attempted for Wonogiri Reservoir to find deposition profile under following condition:

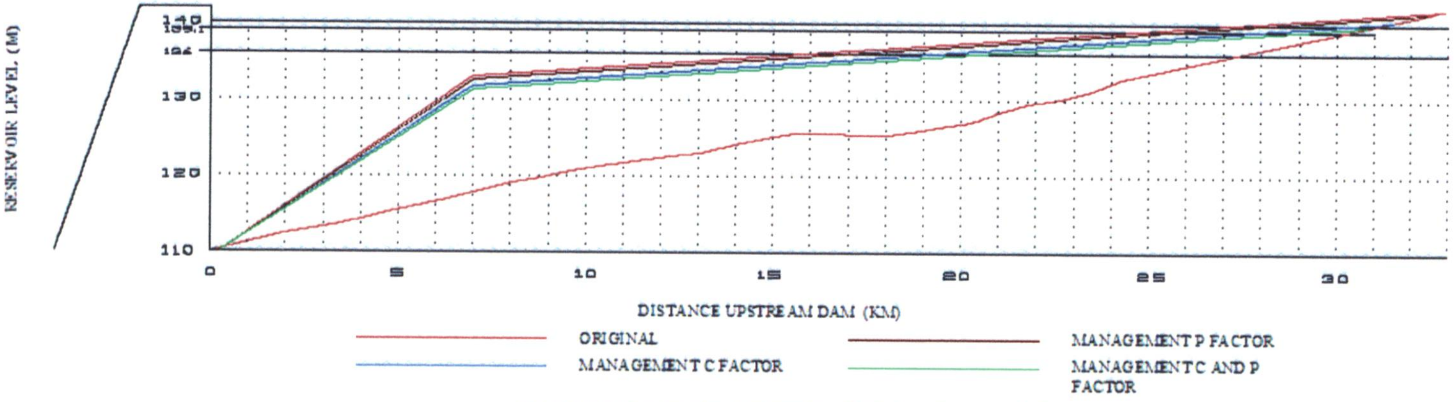
i. Without management and at end of 50 yr and 100 yr
ii. With management of C factor and at end of 50 yr and 100 yr
iii. With management of P factor and at end of 50 yr and 100 yr
iv. With management of C and P factor and at end of 50 yr and 100 yr

Lowest profile is obtained with management of C and P. Management of both C and P is necessary to control sediment deposit at mount of reservoir. Value of Zp is unreasonably high further studies are needed.

Limitation of the method lies in the fact that profile is assumed to be triangular. If the sediment brought into the reservoir is finer, the mechanism and pattern of disposition profile is likely to be different and hence the method is likely give inaccurate result.



PREDICTION OF SEDIMENT DEPOSITED PROFILE IN RESERVOIR
(COMPARE 50 YR)



PREDICTION OF SEDIMENT DEPOSITED PROFILE IN RESERVOIR
(COMPARE 100 YR)

Figure 7.2 Prediction of Sediment Deposited Profile 50 yr and 100 yr

CHAPTER 8

SUMMARY AND CONCLUSIONS

Worldwide loss of storage capacity due to sedimentation is estimated to be 45 km^3 per year i.e 45 billion cubic meters (Palmiery et al-2003). In india loss of live storage capacity per year is estimated to be 1.3 billion cubic meters per year (GOI-NCIWRD report-1999).

This dissertation work deals with GIS based assessment of soil erosion from the catchment of Wonogiri Reservoir (Indonesia) under various conditions (without management and with management of C and P factors) and effect of sediment deposition in the Wonogiri reservoir on its elevation-area-capacity relation.

8.1 WONOGIRI RESERVOIR

The Bengawan Solo River is the largest river on the island of Java in Indonesia. The basin geographically extends between 110°18' and 112°45' of east longitude and between 6°49' and 8°08' of south latitude. Its catchment area is 16,100 km^2 lying on both Central and East Java provinces, covering approximately 12% of the total area of the Java. The river originates from the Sewu mountain range and flows into the Java Sea to the north of Surabaya after travelling about 600 km.

The Bengawan Solo (BS) river basin can be divided into two main reaches, the Upper Solo and Lower Solo River basins, at the confluence with the Madiun River. The former is further subdivided into the Upper Solo and Madiun basins and area of some 6,072 km^2 and 3,755 km^2 respectively, by Mt. Lawu located at its center. Both Upper Solo and Madiun Rivers have their source in the Sewu Range in the south of the basin.

The Upper Solo and Madiun Rivers flow gathering tributary flows from steep slopes of volcanic cone of Mt. Merapi, Mt. Merbabu and Mt. Lawu. The tributaries, which flow down carrying continuously a large quantity of eroded volcanic materials, contribute to high sediment load of the Bengawan Solo River.

The Wonogiri dam and reservoir area is underlain by volcanic breccia, tuff breccia, tuffaceous sandstone, calcareous sand and limestone of Miocene age belonging to the Southern Mountains Zone. Quaternary volcanic products of Solo Zone are distributed on the right bank of the Wonogiri Dam and the Keduang River.

The watershed is drained by the following eight rivers.

Table. 8.1 Watershed Area

Wonogiri Reservoir Watershed Rivers	Sub watershed Area km^2	Percent Area %
Keduang	420.98	33.86
Tirtomoyo	230.65	18.55
Temon	62.6	5.03
Upper Solo	205.53	16.53
Alang	169.4	13.62
Ngunggahan	82.4	6.63
Wuryantoro	44.1	3.55
Remnat	27.68	2.23
Total Area	**1243.3**	**100**

The Wonogiri multipurpose dam is the only large dam on the mainstream of the Bengawan Solo River in Indonesia. Dam was constructed in the late 1970s to early 1980s to provide flood control, irrigation water and hydroelectric power.

The Wonogiri multipurpose dam is the only large dam on the mainstream of the Bengawan Solo River. The Wonogiri Multipurpose Dam on the upper Bengawan Solo was constructed in the late 1970s to early 1980s to provide flood control, irrigation water and hydroelectric power. Impoundment of the reservoir was initiated on 29 December 1980. Since impoundment of the Wonogiri reservoir, the Wonogiri dam has much contributed to social welfare in the basin and has greatly benefited the country in both regional and national economic development.

8.2 EFFECT OF SEDIMENT DEPOSITION ON ELEVATION-AREA-CAPACITY RELATION

Analysis of sediment distribution in the Wonogiri reservoir has been analysed using Area Reduction Method. Analysed highlights the following important aspects:

a. Standard type of classification of a reservoir is not constant over entire project life. Due to change in standard type of classification, sediment distribution pattern will also change as per method of Borland and Miller. From beginning (project design) the reservoir behaves as Type II, from 25 years to 50 years, reservoir behaves as Type II, then it is Type I from 50 years to 75 years, Type III from 75 years to 100 years and Type I after 100 years Even if standard type classification does not change during a period, elevation-area-capacity curve will still undergo revision due to variation in new zero elevation, it is therefore, necessary to consider progressive change in elevation-area-capacity relationship in long term simulation study a reservoir.

b. In the conventional procedure as recommended by Central Water Commission in India, the reservoir would have been designed considering revised elevation-area-capacity curve obtained after sediment deposition during 50 years and assumed to apply uniformly over the entire project life (100 years). With the likely change in new zero elevation and elevation-area-capacity curve at regular interval say 25 years as shown in Fig 4.8 and Fig. 4.9 of Chapter 4., the use of conventional procedure would result in underestimation or overestimation of silt deposition in different time intervals.

c. Sedimet Deposition-Existing Reservoir

For the existing reservoir the hydrographic surveys at about 10 to 15 years interval provide most useful clues for improvement of prediction capabilities. Critical comparison of observed and initially assumed reservoir pattern could be made to find out extent of deviation from predicted deposition pattern. Depending upon various situations following measures are suggested for improving further prediction for sediment deposition.

   i. After each survey, the type of the reservoir must be rechecked by Borland and Miller procedure, using new depth-capacity relationship. If the type remains unchanged then compare observed deposition pattern with that assumed for the design. If these are in close agreement, further predictions should be made by following same reservoir type.

ii. If the observed deposition pattern follows the pattern other than that assumed during design then further computations may be made by adopting new pattern.

iii. If the curve for observed deposition pattern lies between the curves for any two standard types, the further computation may be done with appropriate interpolation between two standard types at different relative depths.

iv. If the curves for observed deposition pattern crosses some of the standard types, then further computations bay be done by following values interpolated between different standard type at different relative depths.

d. Sediment Deposition-Proposed Reservoir

In case of proposed reservoirs it is difficult to check whether the reservoir will behave as per type assumed for the design. The situation is more difficult when the value of parameter M indicating the type is close to the limit particular type. For example, if the value of M is 2.5, then it could be treated as type II or type III. This difficulty arises mainly because there is no transition between any two types. In reality the transition exists and if the value of M is 2.5, them after siltation, the reservoir with type III is likely to change to type II and a reservoir of type II with value of M at upper limit of 3.5 is likely to change to type I. So one needs to take care of such possibilities in advance when the values of type deciding parameter (M) are close to the limiting values.

8.3 GIS BASED STUDY OF EROSION IN CATCHMENT

There is high population density in the catchment. Poor land use of its catchment and intensive farming of annual crops using poor practices on the highly erosive and steep-sloped uplands as well as highly populated and intensely farmed areas are the main causes of the sedimentation of the Wonogiri reservoir.

R factor map, K factor map, the S factor map, C factor map and P factor map have been prepared using GIS.. These maps contain the geographic information on the R, K, LS, C, and P factor

Overlay technique has been used to combine R, K, LS, C , P factor maps to create a map of soil erosion A = (R . K . LS . C . P) as shown in Figure 5.8. Table 5.9 shows erosion classification of area s. This classification has been used to identify area according to degree erosion .

In the following paragraph, GIS calculation refers to GIS based study accounting spatial variation and analytical calculation refers to calculation without considering geographic variation

The erosion estimates in the subwatersheds using analytical calculation (excel software) and GIS Technique is compared in Table 5.10. Computation of erosion using GIS shows less amount of erosion compared to analytical calculation based tabular calculation. Estimate using GIS are more accurate because more detailed geographic variation in K factor, C factor, and P factor are considered in GIS. In tabular calculation weighted K, C, P factor are used which are assumed to be uniform over the subwatershed.

Table Classification Level of Erosion

Class	Total Erosion (ton/ha/yr)	Erosion Level
I	<15	Very Low
II	>15 - <60	Low
III	>60 - <180	Medium
IV	>180 - <480	High
V	>480	Very High

Source: Forestry Department of Indonesia Government

Erosion range for different subwatersheds is from 67.71 t/ha.yr in Alang subwatershed to 260.48 t/ha/yr in Tirtomoyo Watershed. Sediment erosion from catchment of Wonogiri reservoir is 19.798 Million Tons per year

Estimated soil erosion under existing condition from the entire catchment of Wonogiri Reservoir is 23.547 million ton per year (Analytical calculation) and 19.798 million ton per year (Arc GIS calculation). Soil erosion estimate using GIS is more accurate.

Rate of erosion is highest in Tirtomoyo sub watershed and lowest in Wuryantoro sub watershed with an average of 189.39 ton/ha/yr (Analytical calculation) and 159.24 ton/ha/yr (Arc GIS calculation) for entire catchment. Based on these results it can be concluded that the Wonogiri Watershed is undergoing Medium Level of erosion. Soil erosion in Upper Solo, Tirtomoyo and Remnant watershed are is of High Level and Tirtomoyo Watershed produces the largest erosion. But Keduang Watershed give contribute sediment to reservoir largest (1.167 MCM). The erosion from watershed causes sedimentation of reservoir and will reduce level capacity of reservoir and life of reservoir too.

Estimated erosion using GIS are more accurate because more detailed geographic variation in K factor, C factor, and P factor are considered in GIS.

8.4 COMPARISON WITH JICA STUDY

Study was carried out by Japan International Corporation Agency (JICA-2005). The results of sediment deposit by JICA are different for the results in this present study. Comparison of the results shown is in table below:

No	Subwatershed	Sediment Yield (1000 m^3/yr)	
		Present Study	JICA (2005)
1	Keduang	1,166.6	1,134
2	Tirtomoyo	587.23	470
3	Temon	64.8	61
4	Upper solo	722.1	591
5	Alang	354.6	327
6	Ngunggahan	220.6	194
7	Wuryantoro	66.8	104
8	Remnant	94.1	65
9	Total	3,277	2,947

There is a difference of 0.33 MCM/yr. This happened because of different calculation methods and different data sets.

- Different method for calculation of R factor (Rainfall Factor)
- Different method of calculation the LS factor (Length Slope Factor)
- Different in C Factor and P Factor due to difference interpretation of land use or land cover

8.5 GIS BASED USLE FOR MANAGEMENT OF C AND P FACTORS

Erosion control in Wonogiri Basin region can be improved by: (1) improvement of land, (2) improvement of farming patterns or land use, or (3) a combination of two of these. Procedures for erosion control improvements (improvement factor P) and the pattern of cultivation (factor C) are probably the most easily implemented measures. Soil improvement (improvement factor K) is not technically difficult, but it is expensive. Repair farming patterns, let alone improving land use, is one effort that is easily implementable in the reduction of erosion because the material is easily available and at cheap prices

Reduction of soil loss in the Wonogiri dam watershed is expected after implementation of the watershed conservation projects. USLE can be used as an important tool to analyse management through manipulation of C and P factor. The conservation measure used be change condition from Composite/Ridge Terrace to Traditional Terrace for Management P Value and or combination cropping plant (Rain-fed Paddy-Soybean-Cassava)-orchard/plantation (low density-medium density) for C value. The soil loss in the Wonogiri dam watershed can be significantly reduced by implementation of the improved P and C factors.

With management of C factor, the erosion decrease by 57.79 t/ha/yr. With management of P factor, the erosion decrease by 21.22 t/ha/yr. And with management of C and P factor, the erosion decrease by 70.51 t/ha/yr.

8.6 TRIANGULAR DEPOSITION PROFILE IN RESERVOIR

Deposition profile in a reservoir can be empirically found using Area Reduction Method as discussed in chapter 4. Mirarki GD (1983) and Garde et al (1983) have proposed a method for determining the deposition profile assuming it to be triangular. Method was attempted for Wonogiri Reservoir to find deposition profile under following condition:

i. Without management and at end of 50 yr and 100 yr
ii. With management of C factor and at end of 50 yr and 100 yr
iii. With management of P factor and at end of 50 yr and 100 yr
iv. With management of C and P factor and at end of 50 yr and 100 yr

Lowest profile is obtained with management of C and P. Management of both C and P is necessary to control sediment deposit at mouth of reservoir. Value of Zp (max depth of sediment) is unreasonably high. Further studies are needed.

Limitation of the method lies in the fact that profile is assumed to be triangular. If the sediment brought into the reservoir is finer, the mechanism and pattern of disposition profile is likely to be different and hence the method is likely to give inaccurate result.

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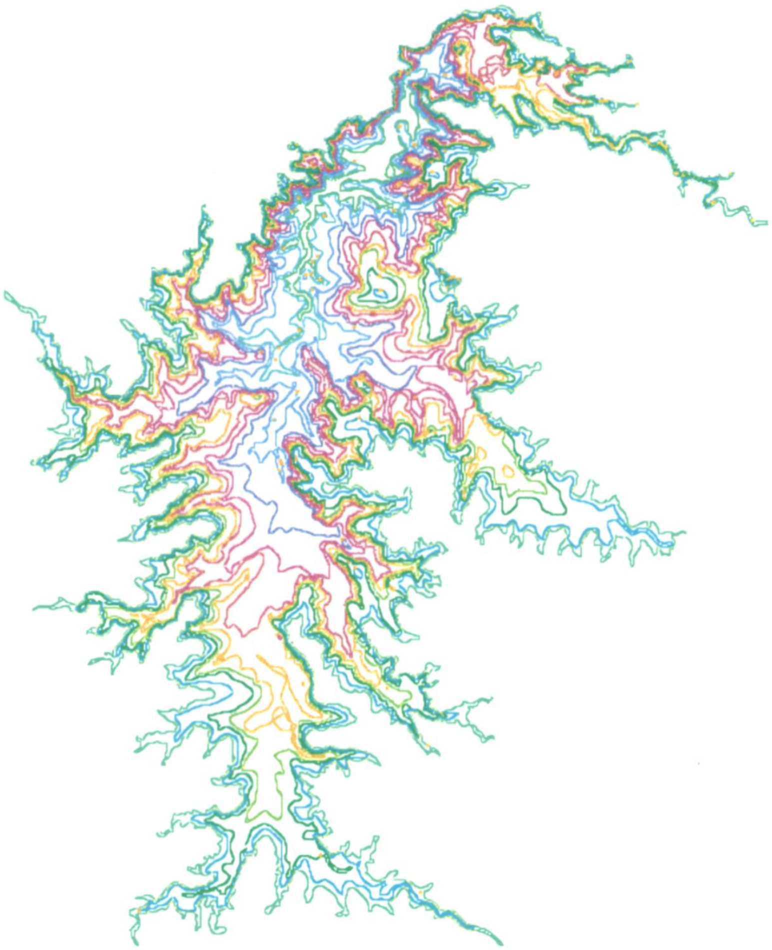
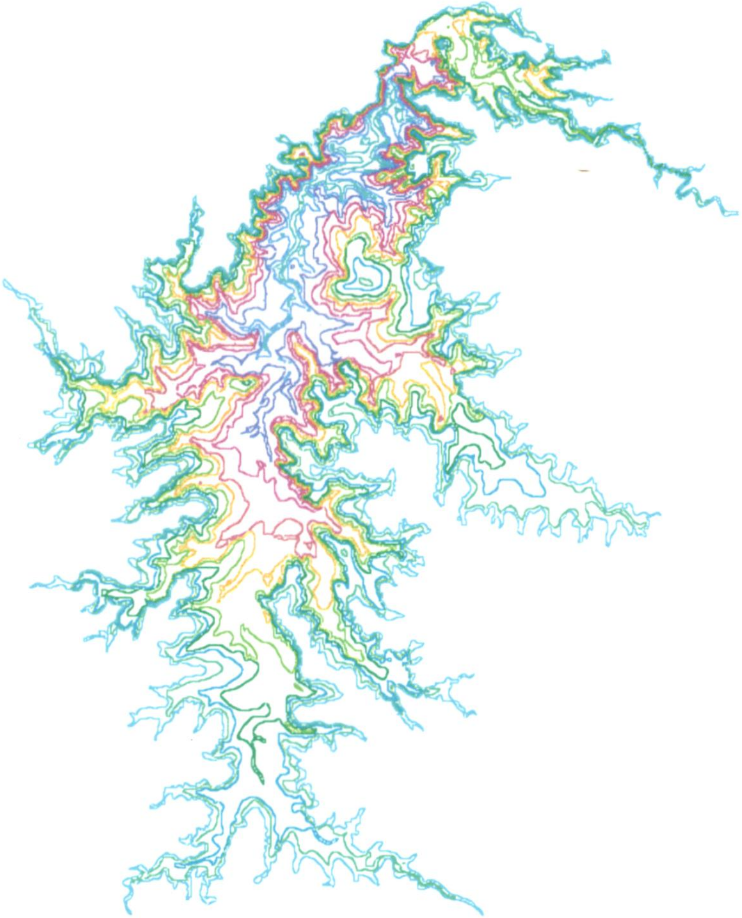
Appendix 1

Topographic Reservoir Map (1993)



Topographic Reservoir Map (2005)



Appendix 2

Sediment Distribution Pattern after 75 Years Based on M Value at End of 25 Yr

Max Water Level	136 m	New zero elevation	125.3 m
Original Stream Bel Level	118 m	Area	13.2 km^2
Est of sediment vol during 50 years		Relative depth	0.408
	149.19 (Mm^3)	Ap	1.204
		K=Area/AP	11.0008

No	Elevation	Area 25 yr	capacity 25 yr	Depth (2)-118	Relative depth P (5)/26	Ap Type II	Sediment area Kap 11.0008 x (7)	Sediment volume	Accumulated sediment volume	Modified accumulated volume	Revised	
											Area (3)-(8)	Capacity (4)-(11)
	m	(km^2)	(Mm^3)	m			(km^2)	(Mm^3)	(Mm^3)	(Mm^3)	(km^2)	(Mm^3)
1	2	3	4	5	6	7	8	9	10	11	12	13
1	136.0	71.0	436.4	18.0	1.000	0.000	0.00	6.67	149.19	149.19	71.04	287.21
2	134.0	58.5	307.1	16.0	0.889	0.910	10.01	22.32	142.51	142.51	48.44	164.59
3	132.0	43.1	205.9	14.0	0.778	1.123	12.35	25.80	120.19	120.19	30.76	85.73
4	130.0	31.5	131.6	12.0	0.667	1.223	13.45	27.23	94.39	94.39	18.05	37.21
5	128.0	22.5	77.9	10.0	0.556	1.252	13.78	27.25	67.17	67.17	8.70	10.71
6	126.0	15.5	40.1	8.0	0.444	1.225	13.47	8.80	39.92	39.92	2.04	0.18
7	125.3	13.2	31.1	7.3	0.408	1.204	13.24	14.54	31.12	31.12	0.00	0.00
8	124.0	8.6	16.6	6.0	0.333	1.141	8.60	9.07	16.58	16.58	0.00	0.00
9	122.7	5.1	7.5	4.7	0.259	1.049	5.11	2.80	7.51	7.51	0.00	0.00
10	122.0	3.4	4.7	4.0	0.222	0.991	3.39	4.08	4.72	4.72	0.00	0.00
11	120.0	0.9	0.6	2.0	0.111	0.739	0.95	0.63	0.63	0.63	0.00	0.00
12	118.0	0.0	0.0	0.0	0.000	0.000	0.00	0.00	0.00	0.00	0.00	0.00

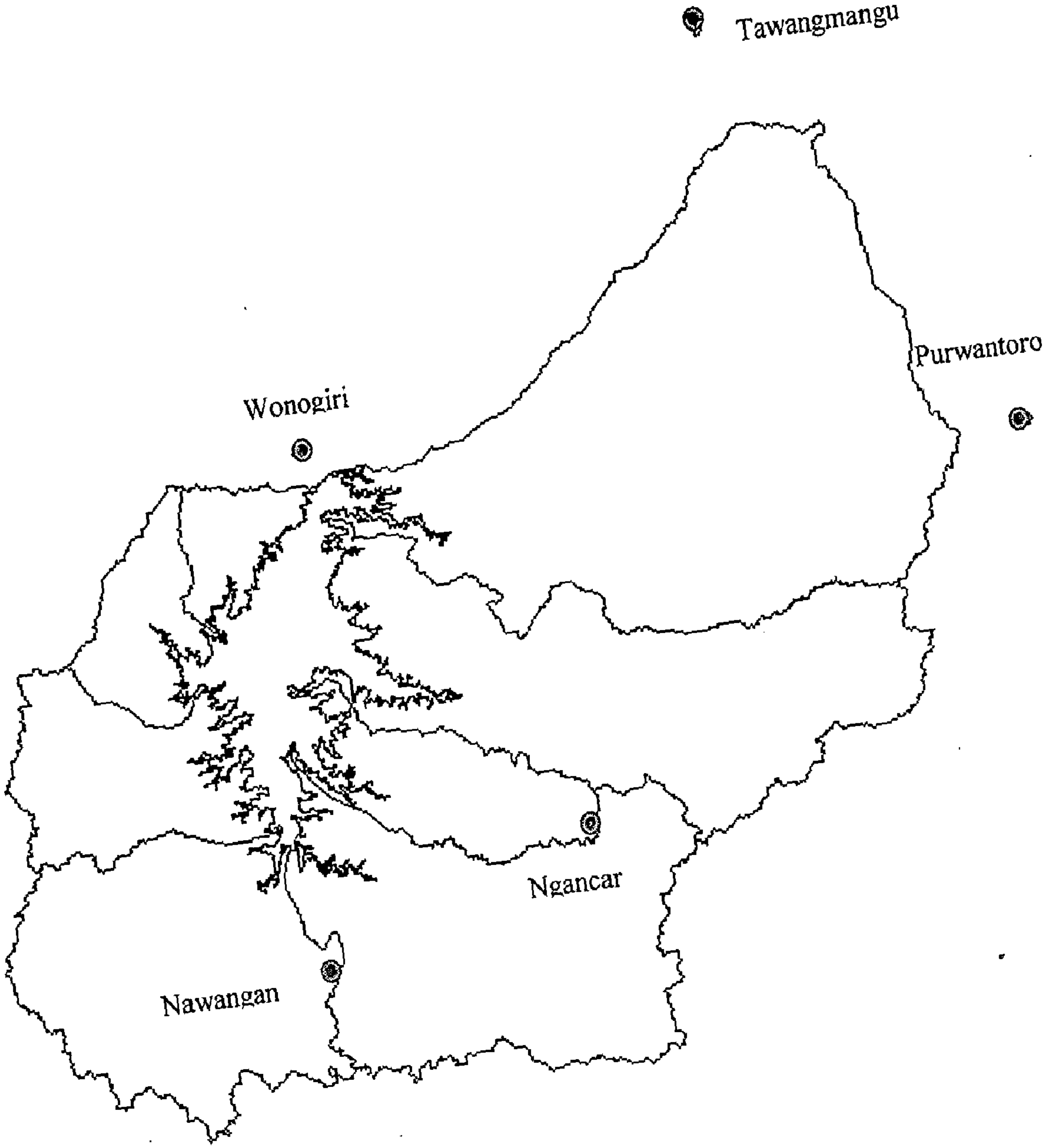
Sediment Distribution Pattern after 100 Years Based on M Value at End of 75 Yr

Max Water Level	136 m	New zero elevation	129.7 m
Original Stream Bel Level	125.3 m	Area	16.7 km^2
		Relative depth	0.410
Est of sediment vol during 25 yr	74.59 (Mm^3)	Ap	1.770
		K=Area/AP	9.4417

No	Elevation	Revised Area	Revised Capacity	Depth (2)-125.3	Relative depth P (5)/10.7	Ap Type III	Sediment area Kap 9.4417 x (7)	Sediment volume	Accumulated sediment volume	Modified accumulated volume	Revised	
											Area (3)-(8)	Capacity (4)-(11)
	m	(km^2)	(Mm^3)	m			(km^2)	(Mm^3)	(Mm^3)	(Mm^3)	(km^2)	(Mm^3)
1	2	3	4	5	6	7	8	9	10	11	12	13
1	136.0	71.04	287.21	10.7	1.000	0.000	0.00	1.70	74.59	74.59	71.04	212.62
2	134.0	48.44	164.59	8.7	0.812	0.269	2.54	11.20	72.90	72.90	45.90	91.69
3	132.0	30.76	85.73	6.7	0.625	0.994	9.38	25.17	61.69	61.69	21.38	24.04
4	130.0	18.05	37.21	4.7	0.437	1.704	16.09	4.71	36.52	36.52	1.96	0.69
5	129.7	16.7	33.4	4.4	0.410	1.770	16.71	21.38	31.80	33.40	0.00	0.00
6	128.0	8.70	10.71	2.7	0.249	1.782	8.70	9.97	10.42	10.71	0.00	0.00
7	126.0	2.04	0.18	0.7	0.062	0.642	2.04	0.45	0.45	0.18	0.00	0.00
8	125.3	0.00	0.00	0.0	0.000	0.000	0.00	0.00	0.00	0.00	0.00	0.00

Appendix 3

Figure Rainfall Station Map



Appendix 4

Rainfall Factor Calculate In Each Station (Thiessen)

Station	No	Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Thiessen
Nawangan	3a	Av. Monthly Rainfall (mm)	308	295	254	148	69	58	23	13	24	63	142	212	0.279
		Av. Max rainfall (mm)	62	63	58	43	29	32	10	10	12	18	44	49	
		Av. no of days	19	17	16	11	6	4	3	1	2	5	10	14	
		EI	252.908	254.5896	208.533	111.836	48.9293	48.093	10.715	8.71709	15.0483	36.1424	113.8	163.758	
		Re =	1273.1												
Station	No	Av. Monthly Rainfall (mm)	328	374	305	182	85	70	22	13	26	76	165	275	0.303
Ngancar	14	Av. Max rainfall (mm)	74	75	72	51	35	34	13	9	12	27	51	69	
		Av. no of days	19	20	19	13	7	5	3	1	2	6	12	16	
		EI	304.892	350.6744	276.36525	146.001	65.3773	60.0902	12.0798	6.45587	14.3663	51.9785	136.136	257.461	
		Re =	1681.9												
Station	No	Av. Monthly Rainfall (mm)	323	290	273	161	102	62	29	18	17	99	171	215	0.208
Wonogiri	21	Av. Max rainfall (mm)	61	64	54	43	42	23	14	12	9	30	51	53	
		Av. no of days	17	14	15	10	6	4	3	1	2	6	11	13	
		EI	279.612	275.7254	230.14921	129.583	93.0928	46.1351	16.8578	12.3741	8.56182	74.5702	147.346	183.105	
		Re =	1497.1												
Station	No	Av. Monthly Rainfall (mm)	300	270	242	205	77	62	31	21	28	97	222	230	0.136
	6	Av. Max rainfall (mm)	57	54	60	58	31	27	15	12	11	34	55	56	
Purwantoro		Av. no of days	18	17	16	13	6	4	3	2	2	6	12	14	
		EI	243.605	213.9552	205.22274	182.677	59.1726	46.8019	19.5825	13.9083	15.0659	77.3398	200.642	196.126	
		Re =	1474.1												
Station	No	Av. Monthly Rainfall (mm)	563	496	412	298	159	84	46	36	71	153	306	405	0.075
Tawangmangu	86	Av. Max rainfall (mm)	85	85	68	61	48	28	23	21	26	41	67	70	
		Av. no of days	24	21	21	18	10	7	4	2	5	10	17	20	
		EI	556.05	507.3	360.1	252.748	132.013	55.9819	31.4405	28.3231	52.2001	117.743	279.12	365.59	
		Re =	2738.6												

Annexure 5.1 Sediment Distribution Pattern after 50 yr Based on M Value At End of 25 Years (Management C Factor)

Max Water Level	136 m	New zero elevation	121.4 m
Original Stream Bel Level	118 m	Area	2.6 km^2
Est of sediment vol during 25 yr	45.35 (Mm^3)	Relative depth	0.187
		Ap	0.924
		K=Area/AP	2.8186

No	Elevation m	Area 25 yr (km^2)	Capacity 25 yr (Mm^3)	Depth (2)-118 m	Relative depth P (5)/18	Ap Type II	Sediment area Kap 2.8186 x (7) (km^2)	Sediment volume (Mm^3)	Accumulated sediment volume (Mm^3)	Modified accumulated volume (Mm^3)	Revised	
											Area (3)-(8) (km^2)	Capacity (4)-(11) (Mm^3)
1	2	3	4	5	6	7	8	9	10	11	12	13
1	136.0	71.04	436.39	18.0	1.000	0.000	0.00	1.71	45.35	45.35	71.04	391.04
2	134.0	58.45	307.10	16.0	0.889	0.910	2.56	5.72	43.64	43.64	55.89	263.46
3	132.0	43.12	205.92	14.0	0.778	1.123	3.17	6.61	37.92	37.92	39.95	168.00
4	130.0	31.50	131.60	12.0	0.667	1.223	3.45	6.98	31.31	31.31	28.06	100.29
5	128.0	22.47	77.88	10.0	0.556	1.252	3.53	6.98	24.33	24.33	18.94	53.54
6	126.0	15.52	40.10	8.0	0.444	1.225	3.45	6.67	17.35	17.35	12.07	22.75
7	124.0	8.60	16.32	6.0	0.333	1.141	3.22	6.00	10.69	10.69	5.39	5.63
8	122.0	3.39	4.73	4.0	0.222	0.991	2.79	1.73	4.68	4.68	0.59	0.05
9	121.4	2.6	3.6	3.4	0.187	0.924	2.61	2.32	2.96	3.55	0.00	0.00
10	120.0	0.95	0.63	2.0	0.111	0.739	0.95	0.63	0.63	0.63	0.00	0.00
11	118.0	0.00	0.00	0.0	0.000	0.000	0.00	0.00	0.00	0.00	0.00	0.00

Annexure 5.2 Sediment Distribution Pattern after 100 yr Based on M Value at End of 50 Years (Management C Factor)

Max Water Level	136 m
Original Stream Bel Level	121.4 m
Est of sediment vol during 50 years	90.699 (Mm^3)

New zero elevation	124.4 m
Area	6.9 km^2
Relative depth	0.211
Ap	0.970
K=Area/AP	7.0758

No	Elevation m	Revised Area (km^2)	Revised Capacity (Mm^3)	Depth (2)-121.4 m	Relative depth P (5)/14.6	Ap Type II	Sediment area Kap 7.0758 x (7) (km^2)	Sediment volume (Mm^3)	Accumulated sediment volume (Mm^3)	Modified accumulated volume (Mm^3)	Revised	
											Area (3)-(8) (km^2)	Capacity (4)-(11) (Mm^3)
1	2	3	4	5	6	7	8	9	10	11	12	13
1	136.0	71.04	391.04	14.6	1.000	0.000	0.00	4.59	90.699	90.699	71.04	300.34
2	134.0	55.89	263.46	12.6	0.863	0.974	6.89	15.21	86.104	86.104	49.00	177.36
3	132.0	39.95	168.00	10.6	0.727	1.179	8.34	17.18	70.893	70.893	31.61	97.10
4	130.0	28.06	100.29	8.6	0.590	1.250	8.84	17.54	53.711	53.711	19.22	46.58
5	128.0	18.94	53.54	6.6	0.454	1.229	8.70	16.64	36.173	36.173	10.25	17.37
6	124.4	6.9	9.4	3.1	0.211	0.970	6.86	2.71	8.009	9.420	0.00	0.00
7	124.0	5.39	5.63	2.6	0.180	0.911	5.39	5.18	5.304	5.632	0.00	0.00
8	122.0	0.59	0.05	0.6	0.044	0.477	0.59	0.13	0.126	0.045	0.00	0.00
9	121.4	0.00	0.00	0.0	0.000	0.000	0.00	0.00	0.000	0.000	0.00	0.00

Annexure 5.3 Sediment Distribution Pattern after 50 yr Based On M Value at End of 25 Years (Management P Factor)

Max Water Level	136 m	New zero elevation	122.3 m
Original Stream Bel Level	118 m	Area	4.3 km^2
Est of sediment vol during 25 yr	64.824 (Mm^3)	Relative depth	0.241
		Ap	1.022
		K=Area/AP	4.1733

No	Elevation m	Area 25 yr (km^2)	Capacity 25 yr (Mm^3)	Depth (2)-118 m	Relative depth P (5)/18	Ap Type II	Sediment area Kap 4.1733 x (7) (km^2)	Sediment volume (Mm^3)	Accumulated sediment volume (Mm^3)	Modified accumulated volume (Mm^3)	Revised	
											Area (3)-(8) (km^2)	Capacity (4)-(11) (Mm^3)
1	2	3	4	5	6	7	8	9	10	11	12	13
1	136.0	71.04	436.39	18.0	1.000	0.000	0.00	2.53	64.824	64.824	71.04	371.57
2	134.0	58.45	307.10	16.0	0.889	0.910	3.80	8.47	62.293	62.293	54.66	244.81
3	132.0	43.12	205.92	14.0	0.778	1.123	4.69	9.79	53.825	53.825	38.43	152.09
4	130.0	31.50	131.60	12.0	0.667	1.223	5.10	10.33	44.038	44.038	26.40	87.56
5	128.0	22.47	77.88	10.0	0.556	1.252	5.23	10.34	33.709	33.709	17.25	44.17
6	126.0	15.52	40.10	8.0	0.444	1.225	5.11	9.87	23.372	23.372	10.41	16.73
7	124.0	8.6	16.32	6.0	0.333	1.141	4.76	7.50	13.502	13.502	3.84	2.82
8	122.3	4.3	6.0	4.3	0.241	1.022	4.26	1.28	6.000	6.012	0.00	0.00
9	122.0	3.39	4.73	4.0	0.222	0.991	3.39	4.08	4.715	4.728	0.00	0.00
10	120.0	0.95	0.63	2.0	0.111	0.739	0.95	0.63	0.63	0.63	0.00	0.00
11	118.0	0.00	0.00	0.0	0.000	0.000	0.00	0.00	0.00	0.00	0.00	0.00

Annexure 5.4 Sediment Distribution Pattern after 100 yr Based on M Value at End of 50 Years (Management P Factor)

Max Water Level	136 m
Original Stream Bel Level	122.3 m
Est of sediment vol during 50 year	129.6 (Mm^3)

New zero elevation	127.2 m
Area	13.3 km^2
Relative depth	0.353
Ap	1.160
K=Area/AP	11.4359

No	Elevation m	Revised Area (km^2)	Revised Capacity (Mm^3)	Depth (2)-122.3 m	Relative depth P (5)/13.7	Ap Type II	Sediment area Kap 11.4359 x (7) (km^2)	Sediment volume (Mm^3)	Accumulated sediment volume (Mm^3)	Modified accumulated volume (Mm^3)	Revised	
											Area (3)-(8) (km^2)	Capacity (4)-(11) (Mm^3)
1	2	3	4	5	6	7	8	9	10	11	12	13
1	136.0	71.04	371.57	13.7	1.000	0.000	0.00	7.59	129.648	129.648	71.04	241.92
2	134.0	54.66	244.81	11.7	0.854	0.996	11.38	25.02	122.058	122.058	43.27	122.75
3	132.0	38.43	152.09	9.7	0.707	1.196	13.67	27.99	97.034	97.034	24.76	55.06
4	130.0	26.40	87.56	7.7	0.561	1.252	14.32	28.13	69.042	69.042	12.08	18.52
5	128.0	17.25	44.17	5.7	0.414	1.208	13.81	11.33	40.909	40.909	3.43	3.26
6	127.2	13.3	28.2	4.8	0.353	1.160	13.27	13.73	29.577	28.210	0.00	0.00
7	126.0	10.41	16.73	3.7	0.268	1.062	10.41	13.71	15.843	16.727	0.00	0.00
8	124.0	3.84	2.82	1.7	0.122	0.770	3.84	2.13	2.130	2.815	0.00	0.00
9	122.3	0.00	0.00	0.0	0.000	0.000	0.00	0.00	0.000	0.000	0.00	0.00

Annexure 5.5 Sediment Distribution Pattern after 50 yr Based on M Value at End of 25 Years (Management C and P Factor)

Max Water Level	136 m
Original Stream Bel Level	118 m
Est of sediment vol during 25 years	39.49 (Mm^3)

New zero elevation	121.0 m
Area	2.1 km^2
Relative depth	0.165
Ap	0.879
K=Area/AP	2.4305

No	Elevation m	Area 25 yr (km^2)	Capacity 25 yr (Mm^3)	Depth (2)-118 m	Relative depth P (5)/18	Ap Type II	Sediment area Kap 2.4305 x (7) (km^2)	Sediment volume (Mm^3)	Accumulated sediment volume (Mm^3)	Modified accumulated volume (Mm^3)	Revised	
											Area (3)-(8) (km^2)	Capacity (4)-(11) (Mm^3)
1	2	3	4	5	6	7	8	9	10	11	12	13
1	136.0	71.04	436.39	18.0	1.000	0.000	0.00	1.47	39.491	39.491	71.04	396.90
2	134.0	58.45	307.10	16.0	0.889	0.910	2.21	4.93	38.02	38.02	56.24	269.08
3	132.0	43.12	205.92	14.0	0.778	1.123	2.73	5.70	33.08	33.08	40.39	172.83
4	130.0	31.50	131.60	12.0	0.667	1.223	2.97	6.02	27.39	27.39	28.53	104.22
5	128.0	22.47	77.88	10.0	0.556	1.252	3.04	6.02	21.37	21.37	19.43	56.51
6	126.0	15.52	40.10	8.0	0.444	1.225	2.98	5.75	15.35	15.35	12.54	24.75
7	124.0	8.60	16.32	6.0	0.333	1.141	2.77	5.18	9.60	9.60	5.83	6.72
8	122.0	3.4	4.73	4.0	0.222	0.991	2.41	2.33	4.42	4.42	0.98	0.30
9	121.0	2.1	2.8	3.0	0.165	0.879	2.14	1.46	2.10	2.75	0.00	0.00
10	120.0	0.95	0.63	2.0	0.111	0.739	0.95	0.63	0.63	0.63	0.00	0.00
11	118.00	0.00	0.00	0.0	0.000	0.000	0.00	0.00	0.00	0.00	0.00	0.00

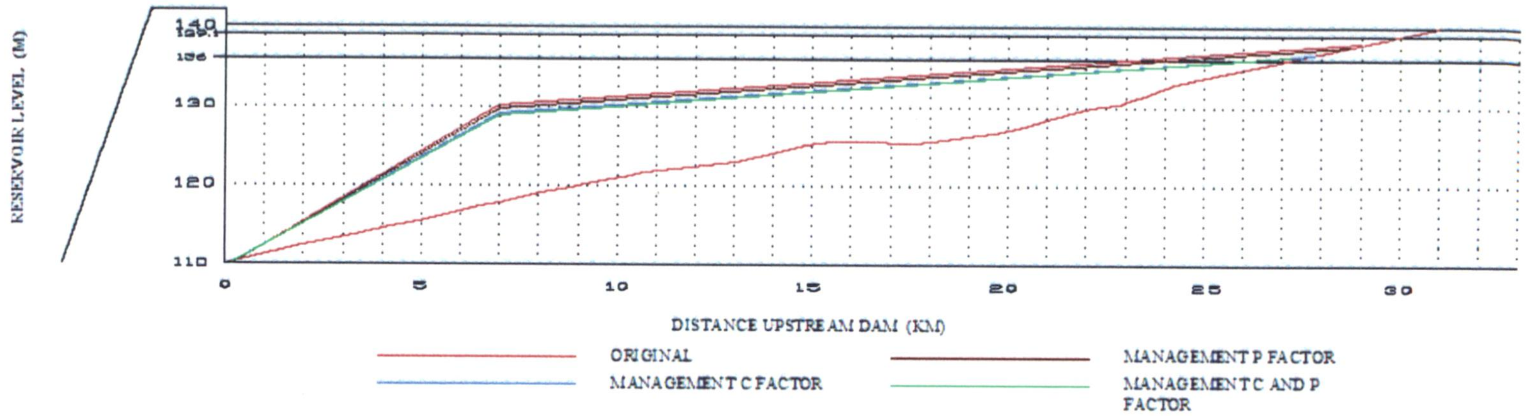
Annexure 5.6 Sediment Distribution Pattern after 100 yr Based on M Value at End of 50 Years (Management C and P Factor)

Max Water Level	136 m
Original Stream Bel Level	121.0 m
Est of sediment vol during 50 years	78.98 (Mm^3)

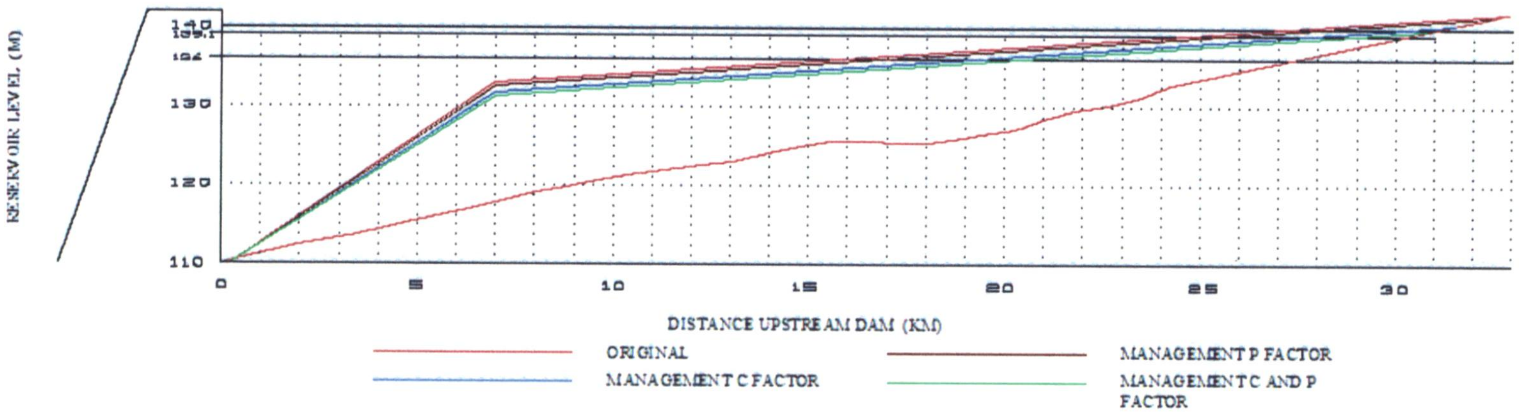
New zero elevation	123.9 m
Area	5.6 km^2
Relative depth	0.196
Ap	0.942
K=Area/AP	5.9636

No	Elevation m	Revised Area (km^2)	Revised Capacity (Mm^3)	Depth (2)-121 m	Relative depth P (5)/15	Ap Type II	Sediment area Kap 5.9636 x (7) (km^2)	Sediment volume (Mm^3)	Accumulated sediment volume (Mm^3)	Modified accumulated volume (Mm^3)	Revised	
											Area (3)-(8) (km^2)	Capacity (4)-(11) (Mm^3)
1	2	3	4	5	6	7	8	9	10	11	12	13
1	136.0	71.04	396.90	15.0	1.000	0.000	0.00	3.84	78.983	78.983	71.04	317.92
2	134.0	56.24	269.08	13.0	0.867	0.966	5.76	12.73	75.143	75.143	50.48	193.94
3	132.0	40.39	172.83	11.0	0.734	1.173	6.99	14.43	62.411	62.411	33.39	110.42
4	130.0	28.53	104.22	9.0	0.601	1.248	7.44	14.81	47.980	47.980	21.09	56.23
5	128.0	19.43	56.51	7.0	0.468	1.235	7.36	14.17	33.175	33.175	12.06	23.33
6	124.0	5.83	6.72	3.0	0.201	0.953	5.68	0.49	6.526	6.526	0.15	0.19
7	123.9	5.6	6.4	2.9	0.196	0.942	5.62	5.70	6.033	6.437	0.00	0.00
8	122.0	0.98	0.30	1.0	0.068	0.590	0.98	0.33	0.334	0.303	0.00	0.00
9	121.0	0.00	0.00	0.0	0.000	0.000	0.00	0.00	0.000	0.000	0.00	0.00

Annexure 6.1



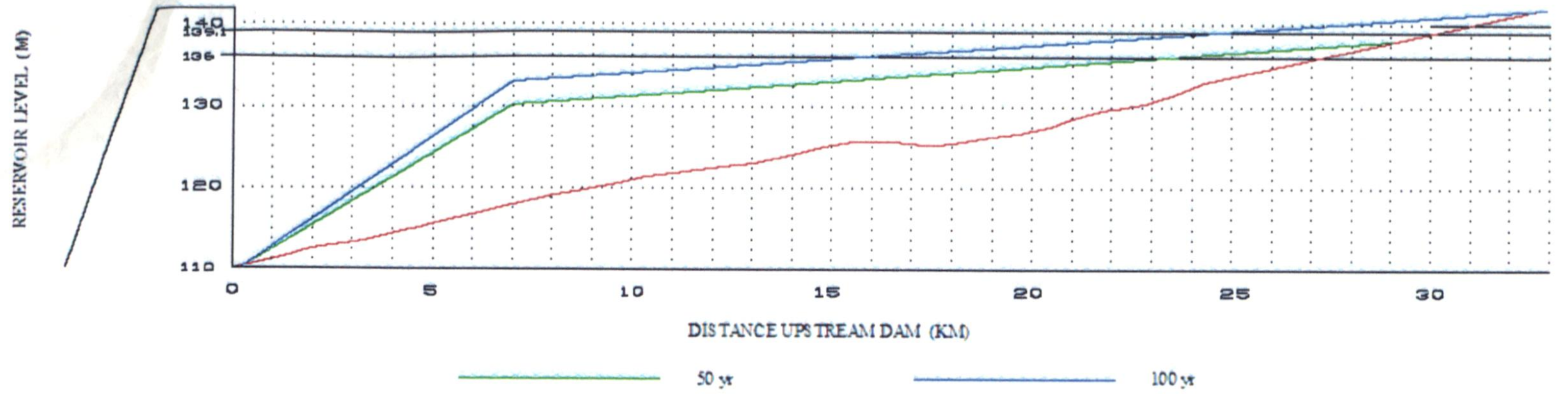
PREDICTION OF SEDIMENT DEPOSITED PROFILE IN RESERVOIR
(COMPARE 50 YR)



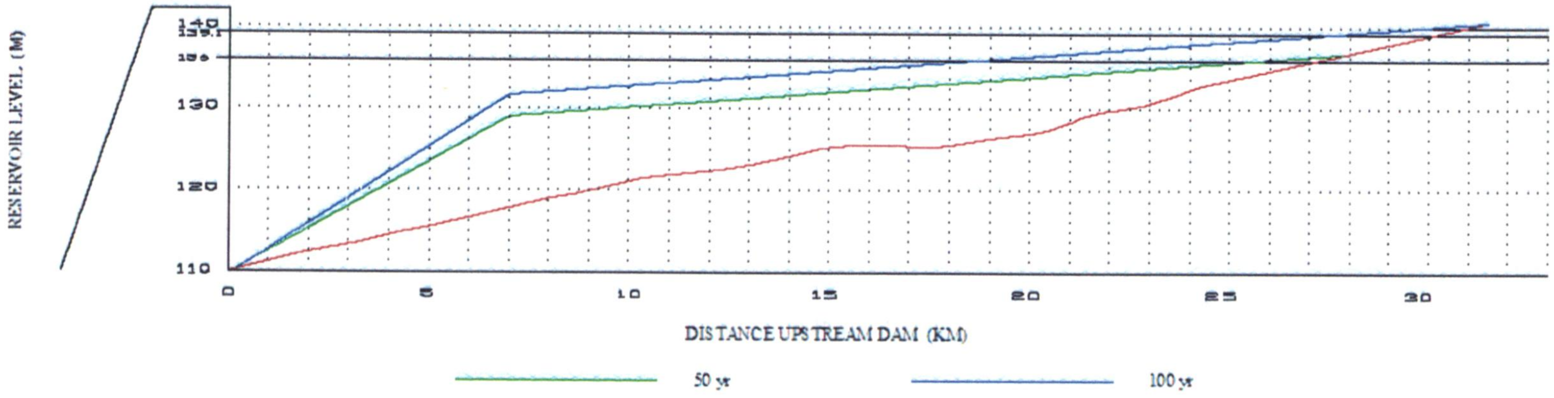
PREDICTION OF SEDIMENT DEPOSITED PROFILE IN RESERVOIR
(COMPARE 100 YR)

Figure Prediction of Sediment Deposited Profile 50 yr and 100 yr

Annexure 6.2



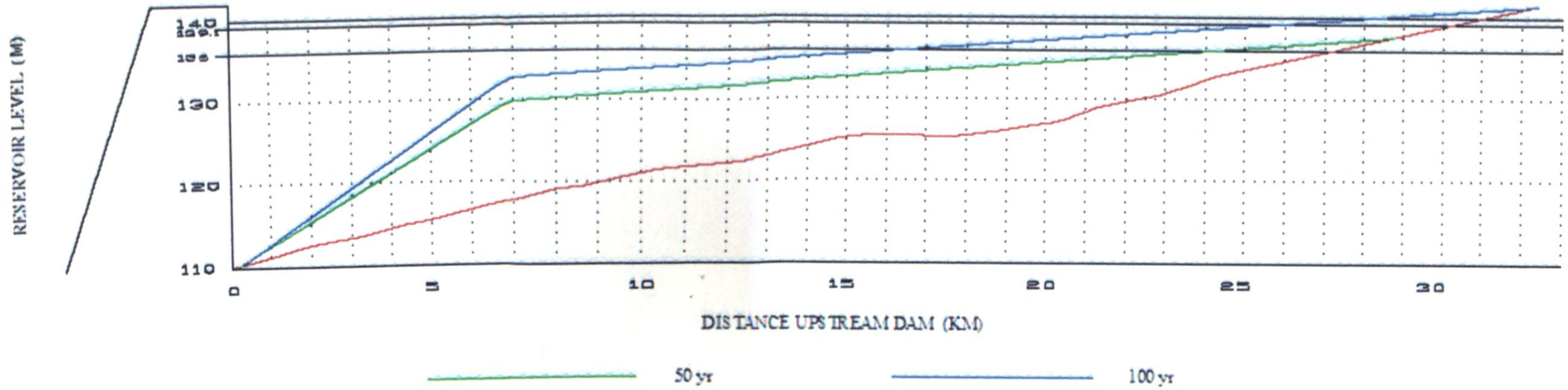
PREDICTION OF SEDIMENT DEPOSITED PROFILE IN RESERVOIR
(ORIGINAL SEDIMENT DEPOSITED)



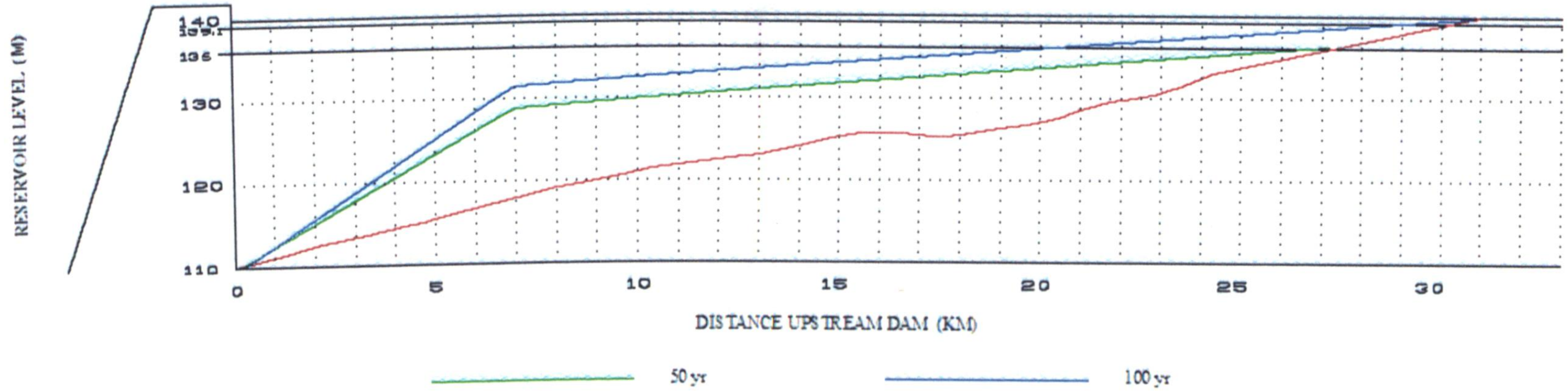
PREDICTION OF SEDIMENT DEPOSITED PROFILE IN RESERVOIR
(USING MANAGEMEN "C" FACTOR)

Figure Prediction of Sediment Deposited Profile No Management (Original) and Management C Factor (50 yr and 100 yr)

Annexure 6.3



PREDICTION OF SEDIMENT DEPOSITED PROFILE IN RESERVOIR
((USING MANAGEMEN "P" FACTOR)



PREDICTION OF SEDIMENT DEPOSITED PROFILE IN RESERVOIR
((USING MANAGEMEN "CP" FACTOR))

Figure Prediction of Sediment Deposited Profile Management P Factor and CP Factor (50 yr and 100 yr)

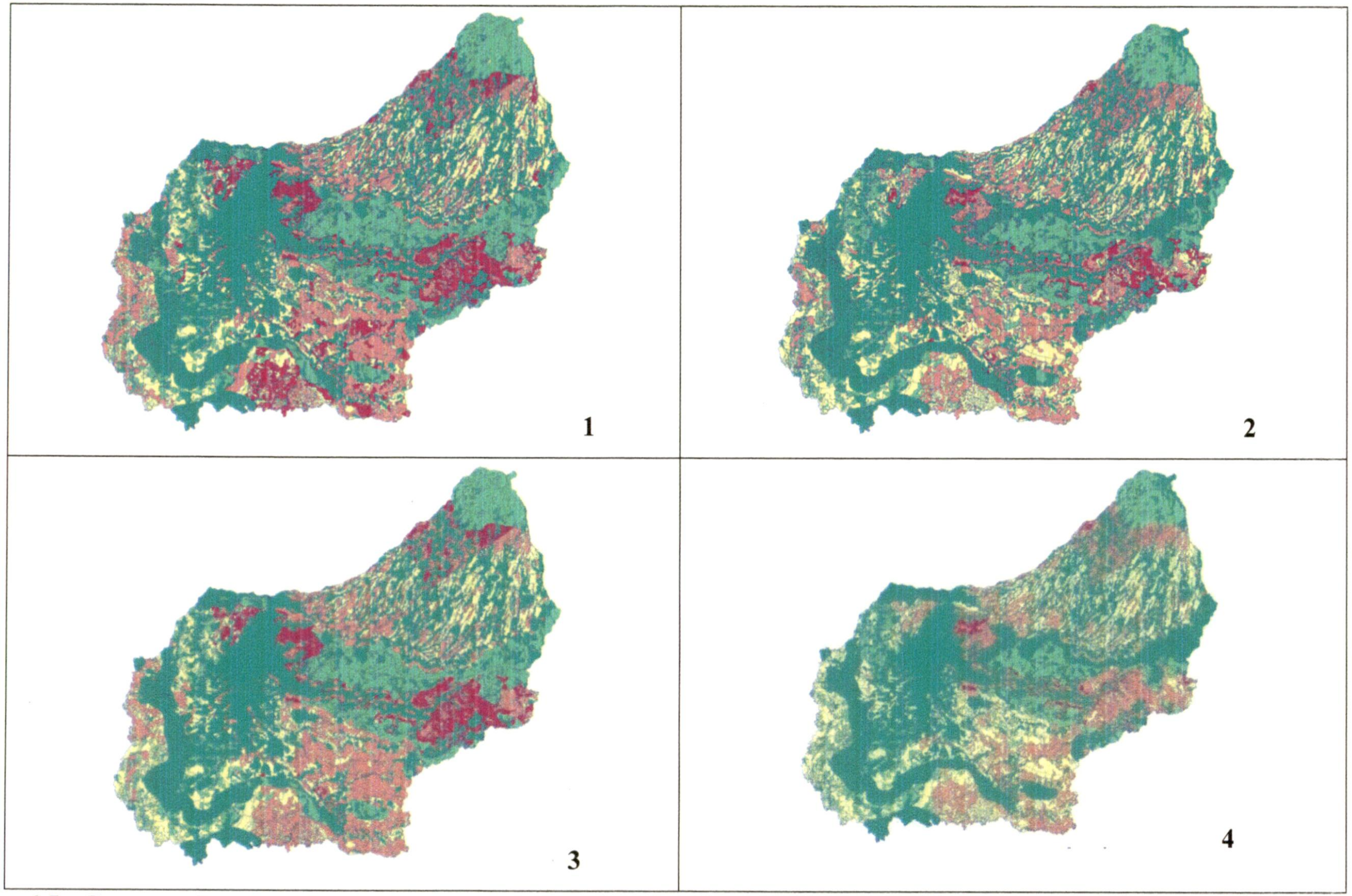


Figure 6.5 : Compare Erosion Map 1. Erosion Map; 2 Erosion Map with Management C; 3 Erosion Map with Management P 4. Erosion Map with Management C and P