JAPAN INTERNATIONAL COOPERATION AGENCY (JICA)

STATE SECRETARIAT OF PLANNING AND GENERAL COORDINATION,
PARANÁ STATE, THE FEDERATIVE REPUBLIC OF BRAZIL

THE MASTER PLAN STUDY ON THE UTILIZATION OF WATER RESOURCES IN PARANÁ STATE IN THE FEDERATIVE REPUBLIC OF BRAZIL

FINAL REPORT

SECTORAL REPORT VOLUME J
SOIL EROSION AND FOREST

December, 1995

Yachiyo Engineering Co., Ltd.
Tokyo, Japan

and

Nippon Koei Co., Ltd.
Tokyo, Japan

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COMPOSITION OF FINAL REPORT

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   II. Master Plan for Iguaçu River Basin
   III. Master Plan for Tibagi River Basin

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IN THE FEDERATIVE REPUBLIC OF BRAZIL

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CEPA	:	State Commission for Agricultural Planning *Comissão Estadual de Planejamento Agrícola*
COMEC	:	Coordination of the Metropolitan Area of Curitiba *Coordenação da Região Metropolitana de Curitiba*
CONAMA	:	National Council of Environment *Conselho Nacional do Meio Ambiente*
COPATI	:	Inter Municipal Concessionaire for the Environmental Protection of the Tibagi River Basin *Consórcio Intermunicipal para a Proteção Ambiental de Bacia do Rio Tibagi*
COPEL	:	Energy Company of the State of Paraná *Companhia Pananaense de Energia*
CORPRERI	:	Permanent Regional Commission Against Floods in the Iguaçu River *Comissão Regional Permanente Contra as Cheias do Rio Iguaçu*
DAGRI	:	Agricultural Operation Department *Departamento Operacional da Agricultura*
DEPEC	:	Livestock Department *Departamento de Pecuária*
DERAL	:	Economy Department *Departamento de Economia*
DNAEE	:	National Department of Water and Electric Energy *Departamento Nacional de Águas e Energia Elétrica*
ELETROBRAS	:	Brazilian Central Electric Joint-stock Company *Centrais Elétricas Brasileiras S.A.*
ELETROSUL	:	Electric Center of the South *Centrais Elétricas do Sul do Brasil S.A.*
EMATER	:	Paraná State Technical Assistance and Rural Extension Company *Empresa Paranaense de Assistência Técnica e Extensão Rural*
EMBRAPA	:	Brazilian Agriculture and Livestock Research Company *Empresa Brasileira de Pesquisa Agropecuária*

FAMEPAR	:	Institute for Municipal Assistance of Paraná State *Instituto de Assistência aos Municípios do Estado do Paraná*
FAO	:	Food and Agriculture Organization *Fundo das Nações Unidas para Alimentação e Agricultura*
IAP	:	Environmental Institute of Paraná *Instituto Ambiental do Paraná*
IAPAR	:	Agricultural Research Institute of Paraná *Instituto Agronômico do Paraná*
IBAMA	:	Brazilian Institute of Environment and Renewable Natural Resources *Instituto Brasileiro do Meio Ambiente e de Recursos Naturais Renováveis*
IBDF	:	Brazilian Forest Development Institute (current IBAMA) *Instituto Brasileiro de Desenvolvimento Florestal*
IBGE	:	Brazilian Institute of Geography and Statistic *Instituto Brasileiro de Geografia e Estatística*
IPARDES	:	Economic and Social Development Institute of the State of Paraná *Instituto Paranaense de Desenvolvimento Econômico Social*
JICA	:	Japan International Cooperation Agency *Agência de Cooperação Internacional do Japão*
MERCOSUL	:	South Common Market in Brazil, Argentina, Uruguay and Paraguay *Merca do Cone Sul*
MINEROPAR	:	Paraná State Mineral Company *Minerais do Paraná S/A*
PROSAM	:	Environmental Sanitation Program for Curitiba Metropolitan Region *Programa de Saneamento de Região Metropolitan de Curitiba*
SANEPAR	:	Sanitation Company of the State of Paraná *Companhia de Saneamento do Paraná*
SEAB	:	State Secretariat of Agriculture and Supply *Secretaria de Estado da Agricultura e do Abastecimento*
SEDU	:	State Secretariat of Urban Development *Secretaria de Estado do Desenvolvimento Urbano*

SEFA	:	State Secretariat for Treasury Secretaria de Estado da Fazenda
SEID	:	State Secretariat for Industry, Commerce and Economic Development *Secretaria de Estado da Indústria, Comércio e do Desenvolvimento Econômico*
SEMA	:	State Secretariat of Environment *Secretaria de Estado do Meio Ambiente*
SEPL	:	State Secretariat of Planning and General Coordination *Secretaria de Estado do Planejamento e Coordenação Geral*
SETR	:	State Secretariat of Transport *Secretaria de Estado dos Transportes*
SIMEPAR	:	Meteorological System of Paraná *Sistema Meteorológico do Paraná*
SETI	:	State Secretariat of Science, Technology and Higher Education *Secretaria de Estado da Ciência, Technologia e Ensino Superior*
SUCEAM	:	Superintendency of Erosion Control and Environmental Sanitation *Superintendência do Controle de Erosão e Saneamento Ambiental*
SUREHMA	:	Superintendency of Water Resources and Environment *Superintendência dos Recursos Hidricos e Méio Ambriente*
UEL	:	State University of Londrina *Universidade Estadual de Londrina*
UNDP	:	United Nation Development Program *Programa das Nações Unidas para o Desenvolvimento*

CHAPTER 1 STUDY OBJECTIVES AND METHODOLOGY

1.1 Study Objectives

The study consists of two phases, one for the strategy concerning the whole Paraná state and another for the master plan concerning the selected pilot river basins. The following objectives are common to both phases.

1) to identify soil erosion degree and factors inducing soil erosion

2) to propose countermeasures to suppress soil erosion in order to improve the water environment

1.2 Methodology

Characteristics of soil erosion in Paraná and its countermeasures were studied as shown in the flow chart, Figure-1.1. The study was divided in 4 steps, recognition of current situations, future projection, countermeasure proposal and cost estimate. The flow shows two phases, one for the strategy study and another for the master plan study in pilot river basins; however, the study process is basically same.

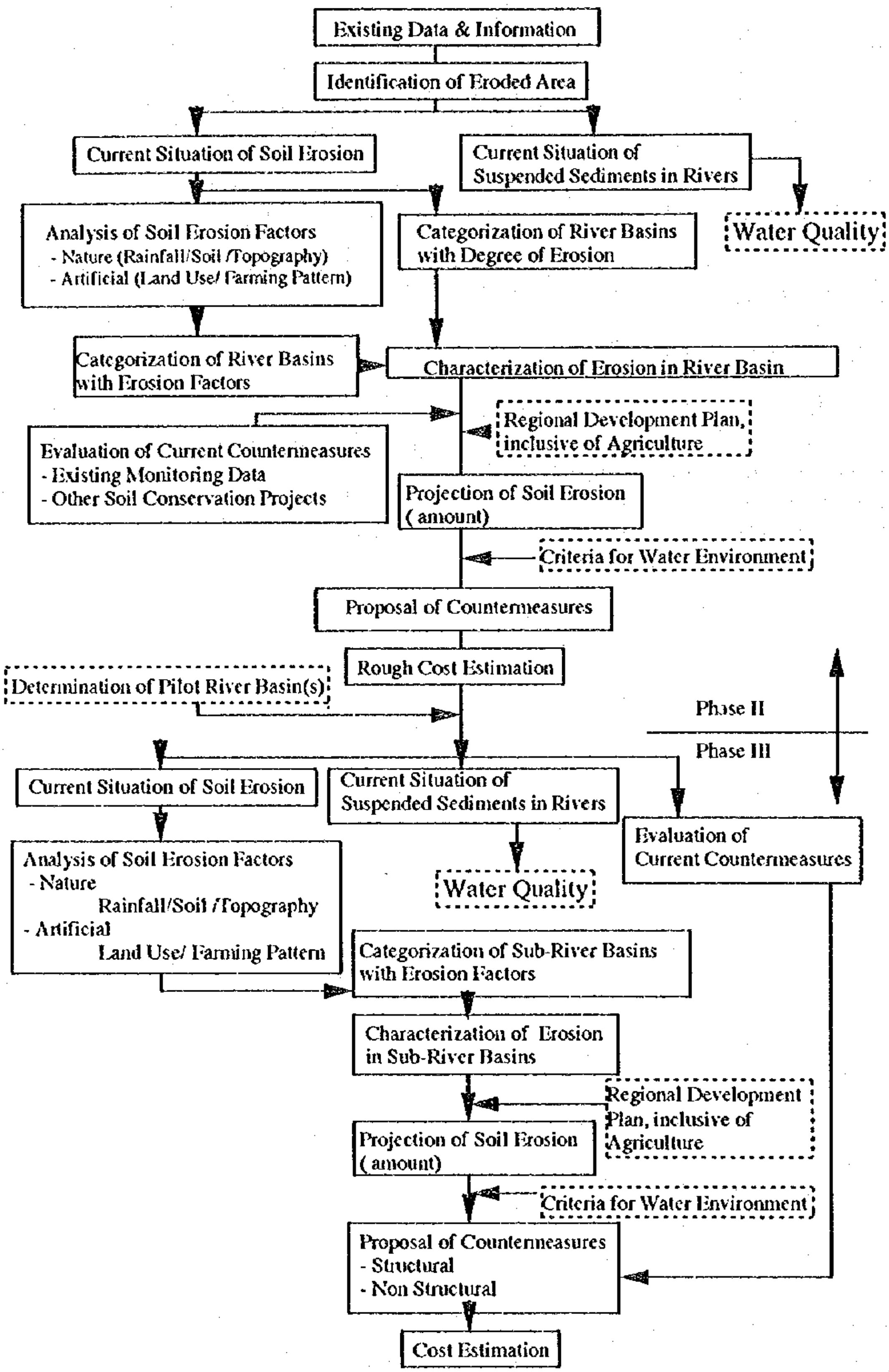
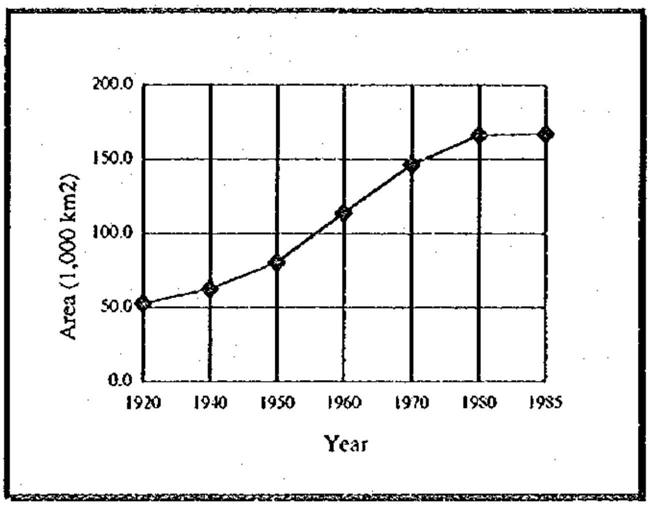


Figure-1.1 Conceptual Flow Chart of Study of Soil Erosion

CHAPTER 2 CURRENT SITUATION OF SOIL EROSION

2.1 Background

Paraná state is one of the leading states in Brazilian Agriculture. The agriculture development in Paraná has started since 17 century; however, the agricultural land has spread over the state rapidly in the last 50 years, especially from 1950's, as shown in Figure-2.1. Large expansion of farm land demolishing the natural forest, improper application of mechanization, inadequate farming system and so on during the rapid development, has caused severe soil erosion resulting in loosing soil fertility and degrading water quality in downstream rivers with sediment and agricultural chemicals.



Year	Area (1,000 km2)
1920	53.0
1940	62.5
1950	80.3
1960	113.8
1970	146.3
1980	166.1
1985	167.0

Figure-2.1 Change in Area of Farm Land

There is another kind of soil erosion in vicinity of city, especially the northwestern region in Paraná state where sandy soil (Arenito Caiúa) is dominant. As population increases, the city expands to farm land and the rapid development of residential area leaves lots of bare soil surface, such as unpaved roads and poor vegetation. Once there is a rain, bare soil is eroded since erodibility of sandy soil is very high. Another factor to accelerate soil erosion in such region is insufficient drainage system of rain water due to the rapid expansion of the urban area. During the rain, unpaved roads become drainage for the excess water and consequently gully erosion is induced.

2.2 Erosion Control Works

The Brazilian government requested "erosion control in the north-west of Paraná state" from the Organization of American States (OAS) at the end of 1960's. In response to the request, the executive commission, consisting of National Department of Sanitation Works (DNOS, Brazilian authorities), South Region Developing Superintendent (SUDESUL, Brazilian authorities) and Regional Development Office (EDR, OEA), was established in order to carry out the study of erosion control in the northwestern region. The study was divided in two phases, 1st Phase from 1970 to 1972 and 2nd phase from 1973 to 1974. In 1st phase, causes of soil erosion and its effect on environment, socio-economy, etc. was analyzed so as to determine short and medium term countermeasures for soil erosion in the rural and urban areas. Since soil erosion is the result of human activities, in other words development plans, in 2nd phase the regional development plan was formulated for the better achievement of erosion control. After the study, several micro-river basins, such as Cedro and Perola in the northwestern region, were selected and the application of the study result was tried as a demonstration project by ACARPA (now EMATER-PR), SUCEAM and SEMA.

The Soil and Water Integrated Management Program (PMISA) was launched in 1983 by Paraná state for soil conservation. The program focused on 600 micro-river basins applying non structural measures, rather than costly structural measures or mechanical measures. The implementation organization, Microcatchment State Commission (CEMH), consists of SEAB, EMATER-PR, banks, cooperatives, farmers and rural workers. The assistance from UNDP/FAO started in 1982, has emphasized to increase soil cover and preserve organic matters of soil in accordance with PMISA.

Paraná state has launched a new land management project, Paraná Rural, with a loan of US$ 63.0 million from the World Bank and US$ 75.3 million at state's own expense. The actual implementation of the project was started in 1989 and will be ended in 1995. 2,100 micro-river basins, inclusive of 300 achieved under PMISA, has been supported by Paraná Rural. The total area is 5 million ha, equivalent to 21 % of the state area and distributed among 311 municipalities. Paraná Rural consists of the following items.

1) Adaptive research for improving soil cover and soil structure

2) Rural extension

3) Incentive program for land management, soil conservation and pollution control

4) Erosion control along rural roads

5) Lime distribution facilities

6) Forestry development and environmental studies

7) Land use monitoring and control

8) Project administration, monitoring and evaluation

9) Training

Although tremendous efforts and investment have been put in Paraná state for erosion control, it is still one of main environmental issues in Paraná. So far, the importance of erosion control have been considered from an agricultural point of view, such as maintenance of soil fertility and improvement of crop productivity; however, there is a movement to suppress soil erosion for not only agriculture but also the water environment. For example, since soil erosion degrades the water quality of the downstream rivers, the countermeasures of erosion control have to be determined considering the use of water and natural preservation at downstream.

2.3 Factors Inducing Soil Erosion

Universal Soil Loss Equation, USLE, expresses soil loss due to erosion as a function of rainfall erosivity, soil erodibility, slope length and steepness, crop cover management and erosion control practice, as shown in equation (1). These factors were evaluated one by one to identify the erosion characteristics of Paraná and summarized in the following section.

$$A = R \cdot K \cdot LS \cdot C \cdot P \quad \text{..} \quad (1)$$

where A: annual gross erosion (ton / ha)

R: rainfall factor ($\frac{MJ \cdot mm}{ha \cdot hr}$)

K: soil erodibility ($\frac{ton \cdot ha \cdot hr}{ha \cdot MJ \cdot mm}$)

LS: slope length and steepness factor (dimensionless)

C: cover and management factor (dimensionless)

P: support practice factor (dimensionless)

(1) Rainfall Erosivity

Annual rainfall erosivity, rainfall factor, varies with location. Rufino, Biscaia and Merten (1993) determined rainfall erosivity and an isoerodent map in Paraná state ranging from 5,500 to 12,000 MJ·mm/ha·h·year. Their result shows high erosivity in the western region, decline to the east until the coast mountain range and high again in the coastal region as shown in Figure-2.2. The details are discussed in the section 3.1.1.

Unit: MJ·mm/ha·hr

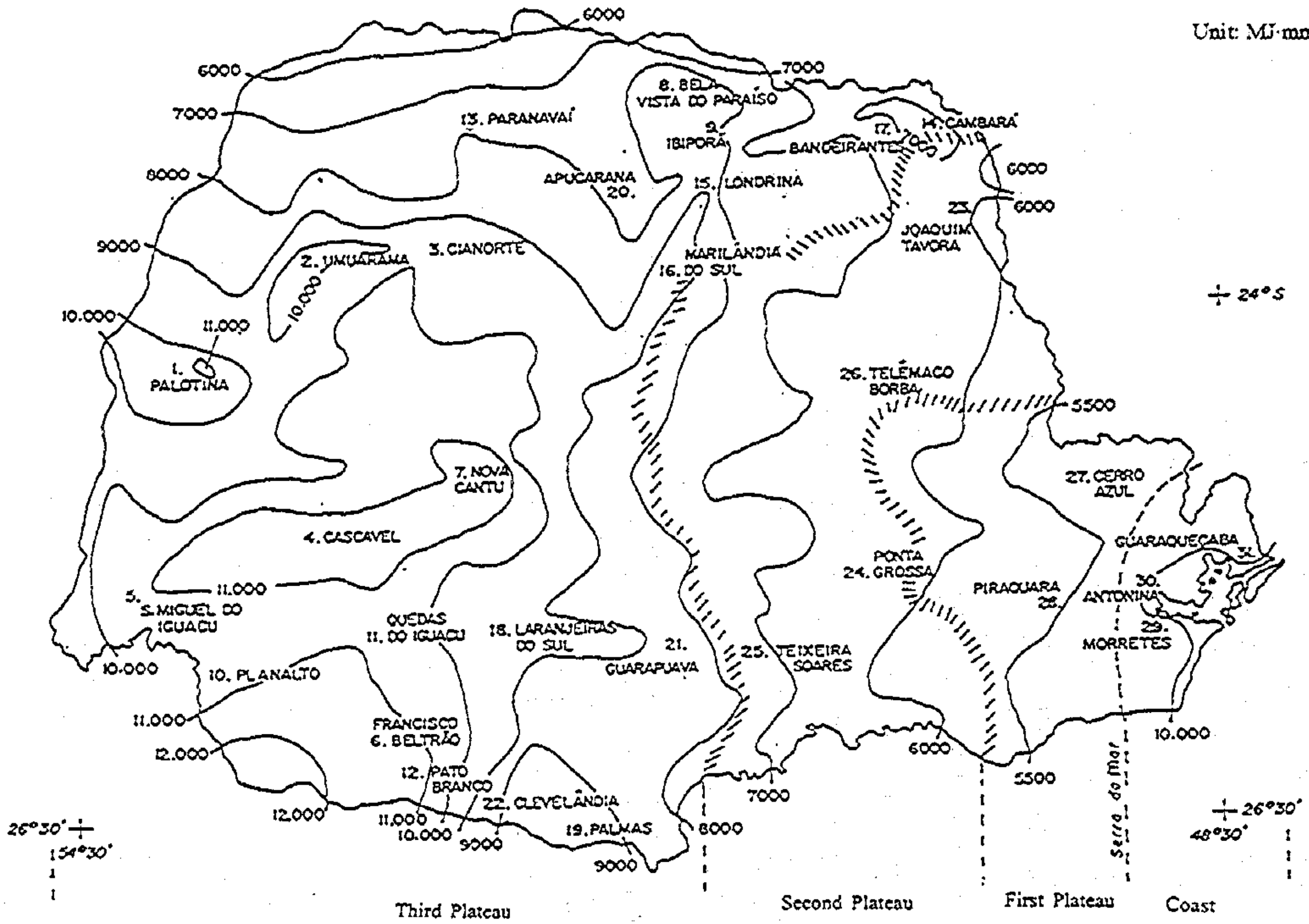


Figure-2.2 Isoerodent Map determined by Rufino et. al.(1993)

(2) Soil Erodibility

Technical Manual of Paraná Rural (SEAB, 1989) describes the characteristics, use and management of the dominant soil classes in Paraná. In Table-2.1, the information is summarized to show the erodibility of each soil class. 8 soil classes cover 83 % of the state area. Since a specific soil occurs in a specific topography, soil erodibility in the Table depends on not only the soil properties of each class but also the steepness. Cambissolos, Podzolico Vermelho Escuro, Podzolico Vermelho Amarelo and Litolico are highly erodible, while Latossolo Vermelho Escuro clay, Latossolo Roxo and Latossolo Bruno are resistant to soil erosion as long as the proper management is practiced. High erodible soil covers 37 % of the total state area.

Table-2.1 Erodibility of Dominant Soil in Paraná

Soil Classification	Occurrence		Occupation in the state	Soil Erodibility
	Slope	Location		
Latossolo Vermelho Escuro, clay	level and gentle	Ponta Grossa, Arapoti regions	12%	resistant
Latossolo Vermelho Escuro, sand	level and gentle	Northwest region near Ponta Grossa		medium
Latossolo Roxo	level and gentle	third plateau region	15%	resistant
Latossolo Bruno	level and gentle	third plateau and center-South regions	2%	resistant
Terra Roxa Estruturada	rolling landscape	third plateau	17%	medium
Cambissolos	rolling and steep	first and second plateau	7%	high
Podzolico Vermelho Escuro and Podzolico Vermelho Amarelo	rolling	Seacoast, first, second and third Plateau	15%	high
Litolico	steep, mountainous	distributed all of the state	15%	high

Source: Parana Rural (1989)

(3) Slope Steepness and Length

A slope steepness map in Paraná is not available and its mapping is beyond the Study objectives. Two maps, altitude and geomorphology, are available in the Atlas of Paraná state (SEAB and ITCF, 1987), and EMBRAPA (1984) has issued a Map for Limitation of Soil Utilization in terms of Soil Erodibility determined by slope steepness and soil characteristics. Comparing these maps, the effect of slope steepness on soil erosion is roughly grasped. The followings show the location and altitude of where soil erodibility is high in Paraná.

- the first plateau altitude ranging between 800 - 1200 m
- the boundary between the first and second plateau
  altitude ranging between 800 - 1000 m
- the southern part of the third plateau
  altitude ranging between 800 - 1200 m

It implies that the higher the altitude is, the steeper the slope is. These regions require the well conservation practices. Plateaus and contour lines in Paraná are shown in Figure-2.3.

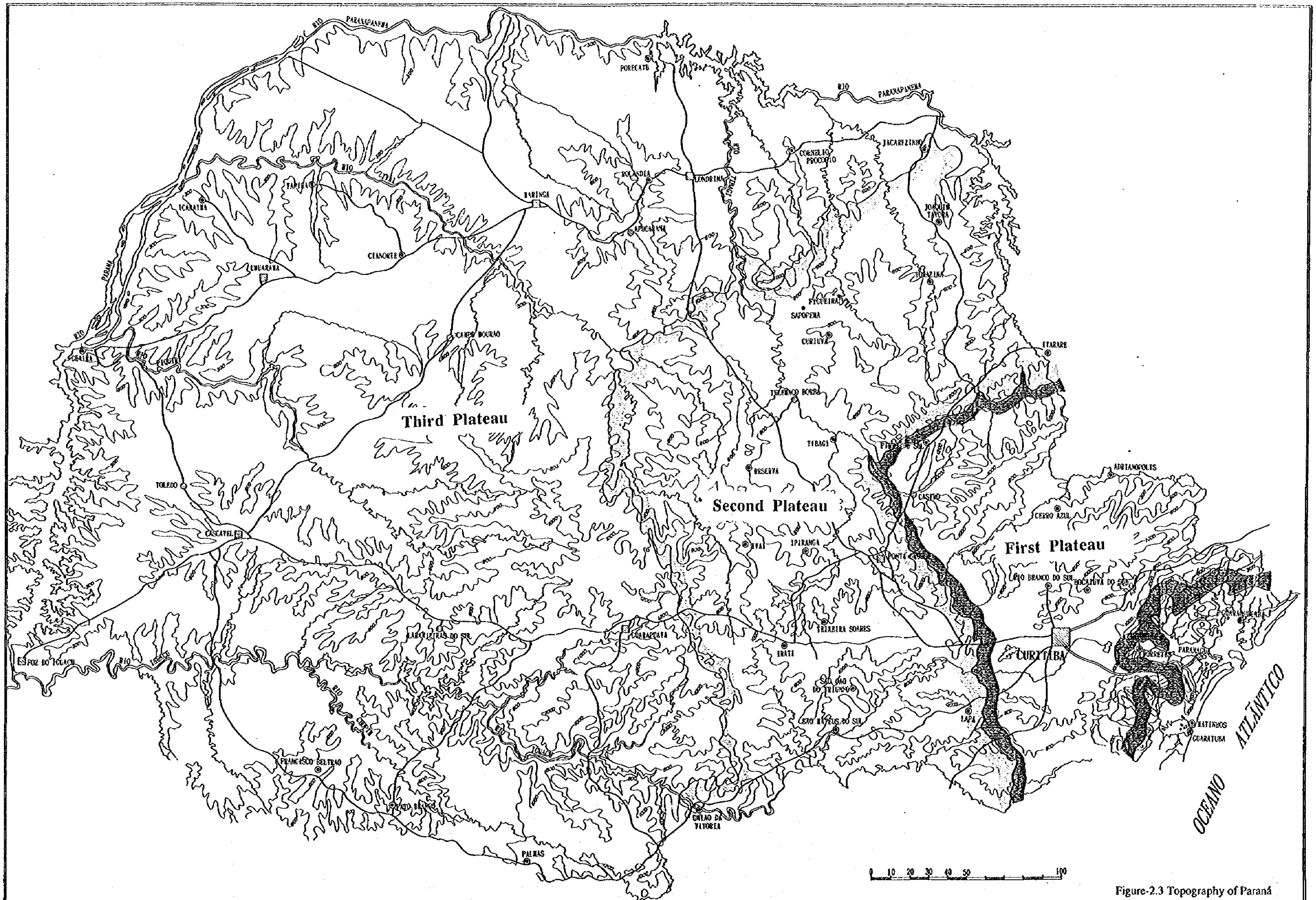


Figure-2.3 Topography of Paraná

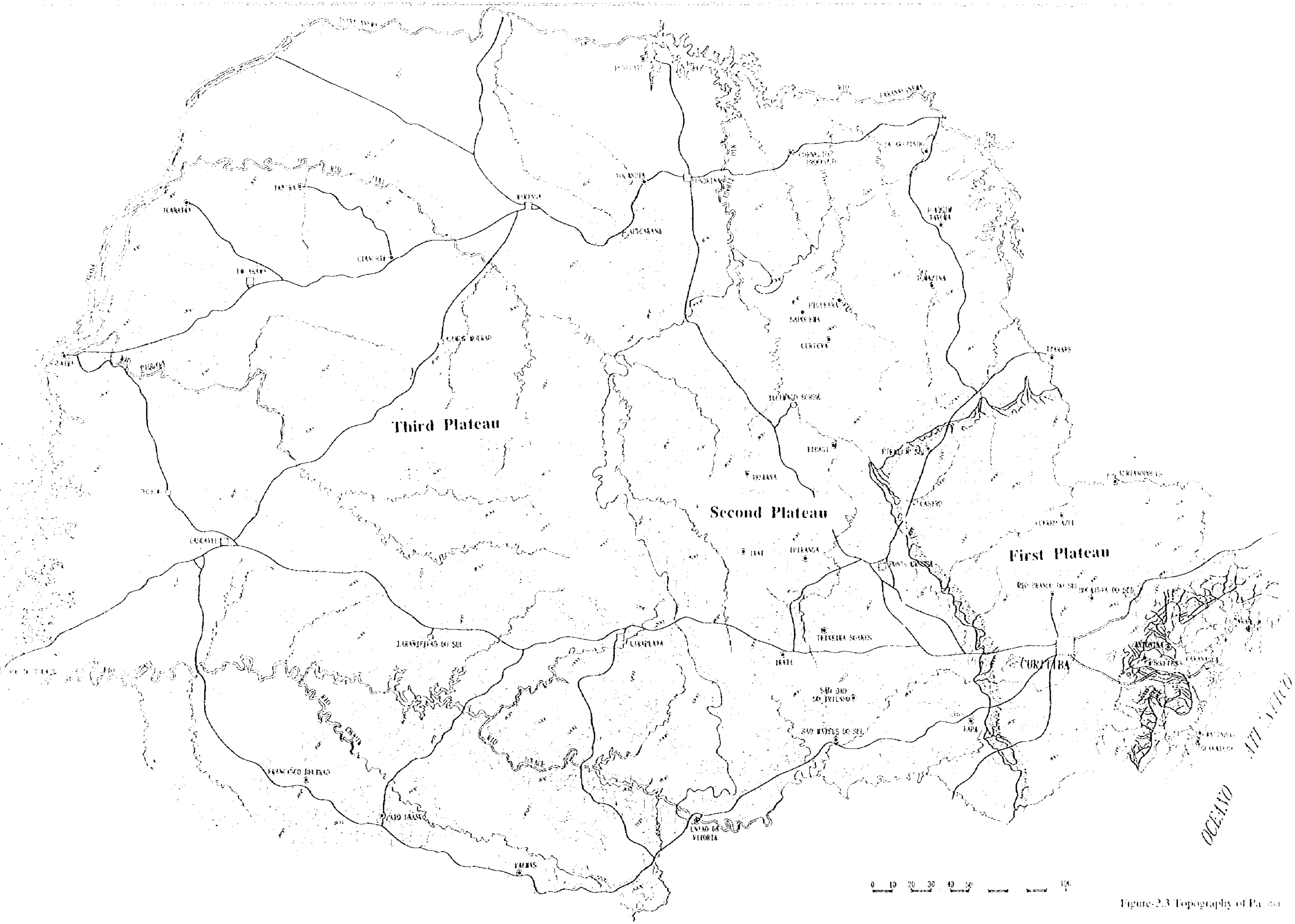


Figure-2.3 Topography of Paraná

(4) Cover and Management

Biscaia and Osaki (1994) summarized the effect of different crop cultivation on soil loss measured in IAPAR experimental field. The size of the experimental field is 3.5 m wide and 11 m long, and the measurement was carried out for three to eight years depending on a crop. Slope steepness was approximately 9 % and the way to cultivate was the common practice for each crop in Paraná. The soil loss from different crop fields is compared in Table-2.2.

Table-2.2 Soil Loss of Different Crop Cultivation

Type of Crop	Soil Loss (ton/ha/year)
Bare Soil (no culture)	up to 80
Potato	60 - 70
Cotton	50
Coffee	30
Maize	10 - 20
Soybeans	10 - 20
Wheat	5 - 10
Pasture	10
Type of Cultivation	
Subsistence Agriculture	10 - 30
Non Tillage	0.1 - 5

Source: Biscaia and Osaki (1994)
Subsistence Agriculture: small farming for self sufficiency with low input

The potato culture is the worst due to the heavy mechanization and no conservation practices such as terracing, while the soil loss of corn and soybean cultures is considerably low as a result of conservation management such as, contour cropping, terracing etc. Once soil is degraded with erosion due to improper management, it reduces crop yield. And then, the reduction of biomass production causes low cover of soil surface resulting in chemical, physical and biological degradation of soil. As a result, the erosion is accelerated and the crop yield declined more. The cover of soil surface is crucial and one of the targets of soil conservation. The proper management guarantee the high yield and low input.

The erosion degree of different soil class with different cover is shown in Table-2.3. Even erosion resistance soil, it would be eroded highly with the improper management, while the erosive soil needs a special care to utilize it. For example, Litolico should not be used for pasture and any crop cultivation, except annual crops by means of non tillage method. It is recommended to shorten the slope length of a crop field with increasing the slope steepness. This table gives us an idea how to utilize and conserve soil.

Table-2.3 Erosion Degree of Each Soil Type with Different Cover Management

Soil Classification		Forest	Pasture (high cover)			Annual crops											
						no tillage			good management			bad management					
												slope length					
												0-100m		100-250m		>250m	
		any	slope %			slope %			slope %			slope %		slope %		slope %	
name	abbreviation	slope	0-7	7-20	>20	0-7	7-20	>20	0-7	7-20	>20	0-7	7-20	0-7	7-20	0-7	7-20
Latossolo Vermelho Escuro, clay	LE (clay)	1	1	2	3	1	1	2	1	2	3	3	4	5	6	6	6
Latossolo Roxo, clay	LRa (clay)	1	1	2	3	1	1	2	1	2	3	3	4	5	6	6	6
Latossolo Bruno, clay	LBa (clay)	1	1	2	3	1	1	2	1	2	3	3	4	5	6	6	6
Terra Roxa Estruturada	TRe	1	1	2	3	1	1	2	1	2	3	3	4	5	6	6	6
Cambissolos	Ca	1	1	2	3	1	1	2	1	2	3	3	4	5	6		
Latossolo Vermelho Escuro, sand	LE (sand)	1	3	4	5	2	2	3	2	3	4	4	5	6	6	6	6
Latossolo Roxo, sand	LRa (sand)	1	3	4	5	2	2	3	2	3	4	4	5	6	6	6	6
Podzolico Vermelho Escuro and Podzolico Vermelho Amarelo	PV	1	4	5	5	2	2	3	4	5	5	5	6	6	6	6	6
Litolico	Ra	1	4	5	5	2	2	3	5	5	5	5	6	6	6	6	6

Soil Classification		Perennial crops					Pasture (low covere)			
		sugarcane	coffee							
			slope length		slope length		slope length		slope length	
		any	0-50m		>50m		0-100m		>100m	
		slope	slope %		slope %		slope %		slope %	
name	abbreviation		0-7	7-20	0-7	7-20	0-7	7-20	0-7	7-20
Latossolo Vermelho Escuro, clay	LE (clay)	2	3	4	5	6	4	6	6	6
Latossolo Roxo, clay	LRa (clay)	2	3	4	5	6	4	6	6	6
Latossolo Bruno, clay	LBa (clay)	2	3	4	5	6	4	6	6	6
Terra Roxa Estruturada	TRe	2	3	4	5	6	4	6	6	6
Cambissolos	Ca	3	5	6	6	6	5	6	6	6
Latossolo Vermelho Escuro, sand	LE (sand)	3	5	6	6	6	5	6	6	6
Latossolo Roxo, sand	LRa (sand)	3	5	6	6	6	5	6	6	6
Podzolico Vermelho Escuro and Podzolico Vermelho Amarelo	PV	NA	5	6	6	6	5	6	6	6
Litolico	Ra	NA	5	6	6	6	5	6	6	6

Source: Lanteri et al. (1992)

Erosion Rate
1 No erosion
2
3
4
5
6 Severe erosion

(5) Erosion Control Practice

Erosion control practice or soil conservation consists of structural measures and non structural measures. The effectiveness and cost vary with a countermeasure. Terracing seems to be the most popular tool in Paraná and non tillage method has spread recently. The area of soil conservation measures applied for primary crops by 1993 is available in EMATER, as shown in Appendix-1. Since EMATER divides Paraná state in 20 regions (Figure-2.4), the data is summarized in EMATER division wise. Table-2.4 shows the coverage of soil conservation measures for primary crops based on Appendix-1. According to EMATER, soil conservation measures here mainly consists of the following items.

1) Terracing

2) Contour bunds and buffer strips

3) Improvement of farm road

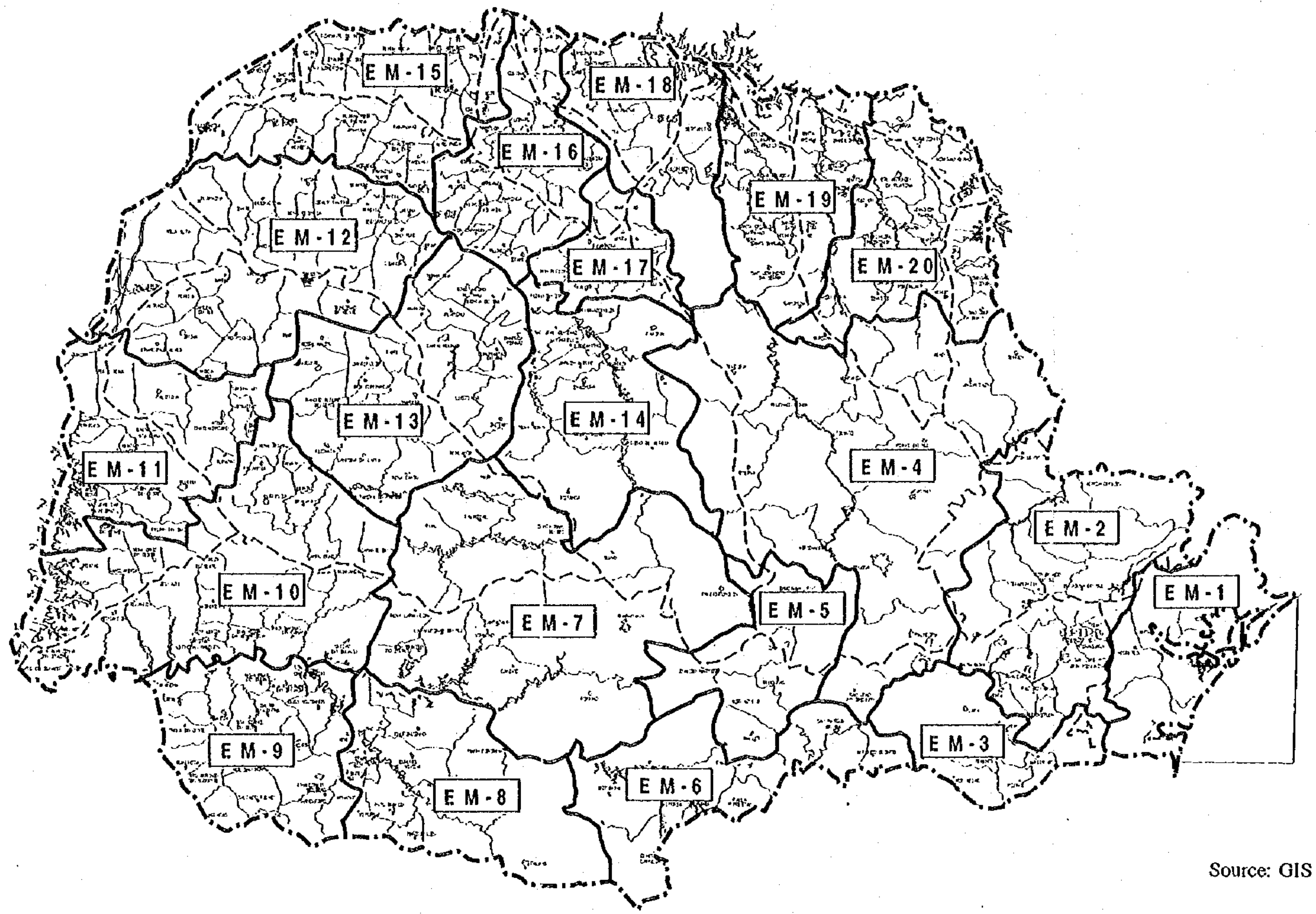
4) Amendment of soil properties by means of green manuring, liming, and so on

5) Adequate use of agriculture machinery

Soybean, wheat and sugarcane fields are well conserved since more than 80 % of their area on an average is covered by the proper soil conservation measures. On the other hand, the application of soil conservation measures in pasture (both natural and planted) and potato fields is very low compared to other crop cultivation. Although 48 % of potato field in Francisco Beltrao region (EM-9) is conserved, the coverage of conservation in other regions is very small resulting in 9.4 % for summer cultivation and 5.7 % for winter cultivation on an average. The figures in the Table corresponds well to Table-2.2. Except, soybean, wheat and sugarcane, crop fields in Paraná still require the large investments for soil conservation.

In Table-2.5, the area of conservation measures applied exclusive of non tillage is shown in the region base, EMATER division, and the coverage of conservation in each region by 1992 was calculated. By 1992, the soil conservation measures have been most practiced in Toledo region (EM-11) and its coverage is approximately 62.7 % of the total region area. However, the coverage of soil conservation measures in other regions is low and there is still lots of area remained in Paraná without any soil conservation. Soil conservation has been practiced in only 22.8 % of the total state area.

Non tillage was first introduced to Paraná in 1972. According to EMATER, non tillage cultivation was applied to 37.9 % in the area of the summer crop land in 1993. In detail, 37.9% consists of 21.3% for soybean, 13.7% for maize and 2.9% for beans. For the winter crop, it was applied to 30.2 % of wheat land. So far, non tillage has been spread gradually mainly in small and medium farm scale. Since the future target of non tillage practices is not only small or medium farmers but also big farmers, non tillage is expected to expand more rapidly.



EMATER Division

EM-1	Paranagua
EM-2	Curitiba
EM-3	Lapa
EM-4	Ponta Grossa
EM-5	Irati
EM-6	Uniao da Vitoria
EM-7	Guarapuava
EM-8	Pato Branco
EM-9	Francisco Beltrao
EM-10	Cascavel
EM-11	Toledo
EM-12	Umuarama
EM-13	Campo Mourao
EM-14	Ivaipora
EM-15	Paranavai
EM-16	Maringa
EM-17	Apucarana
EM-18	Londrina
EM-19	Cornelio Procopio
EM-20	Jacarezinho

Legend

------ Boundary of River Basin

—— Boundary of EMATER Division

Scale 1:2,500,000

Source: GIS Digitization by SANEPAR (1994)

Figure-2.4 EMATER Division

Table-2.4 Coverage of Soil Conservation Measures for Primary Crops

Unit %

No.	Region	Beans	Beans (winter)	Cassava	Coffee	Cotton	Maize	Maize (safrinha)	Pasture (natural)	Pasture (planted)	Potato	Potato (winter)	Rice (upland)	Rice (paddy)	Soybean	Soybean (safrinha)	Sugarcane	Wheat
1	Paranagua			10.7														
2	Curitiba	5.5	6.9	1.9			5.6		0.1	3.0	7.8	7.4	14.3					
3	Lapa	35.3		0.0			26.9		51.2	89.2	7.1		13.7		52.6			39.2
4	Ponta Grossa	31.4	68.6	19.5			49.7	47.7	4.0	23.2	20.7		38.0		86.7	98.4		88.9
5	Irati	25.0	55.1	19.4			26.6		0.0	6.6	24.1		8.6		78.6			69.3
6	Uniao da Vitoria	12.2	24.8	4.0			20.7		0.0	1.0	1.1		11.4		52.8			17.6
7	Guarapuava	22.0	28.0	0.0			39.3	8.2	0.0	1.8	4.6	1.0	26.1		95.0		13.0	94.5
8	Pato Branco	33.8	38.9	23.1			38.6	25.1	0.0	8.8	21.1		32.2		73.9		49.7	62.7
9	Francisco Beltrao	42.6	25.3	45.7	31.3		43.3	45.6	4.3	9.0	48.0		41.8		73.6		25.8	63.4
10	Cascavel	49.8		70.1		74.6	65.6	87.9		7.2	NA		62.1		91.2	82.3	54.2	90.7
11	Toledo	61.2		80.2	4.9	80.7	86.8	89.4	11.8	32.1			62.1	68.5	87.8	92.3		83.7
12	Umuarama	31.6	31.4	58.8	26.4	71.9	57.6	74.2		18.9			36.2	92.4	91.8		98.5	78.2
13	Campo Mourao	51.1	16.7	70.8	29.9	66.5	73.7	78.5	34.1	17.7			51.7		85.8	92.9	93.4	85.5
14	Ivaipora	33.9	74.3	13.2	15.4	63.9	35.9	45.7	3.4	2.9			21.9		76.5		91.8	77.1
15	Paranavai	58.5	89.7	82.5	35.4	84.1	77.1	66.7	34.3	28.8			45.4	98.3	87.1		99.1	100.0
16	Maringa	71.0		65.7	38.9	77.2	78.1	73.2	4.6	23.9			53.2		90.4	100.0	86.2	89.7
17	Apucarana	48.4			27.8	66.6	57.3	58.3	0.4	5.4			33.7		70.2		93.2	82.9
18	Londrina	93.5	90.3	79.0	50.6	85.4	87.5	54.3	0.0	15.6			74.2	95.9	85.4	95.2	74.4	89.7
19	Cornelio Procopio	30.2	63.3		44.3	71.4	67.6	83.9	6.4	6.9			60.0	23.7	79.2	86.9	85.3	70.6
20	Jacarezinho	40.0	61.3	26.2	50.4	62.3	43.8	43.1	3.3	11.6			23.6	91.9	95.8		64.5	97.4
	Average	30.9	53.7	62.5	34.8	72.4	49.1	68.4	6.5	17.1	9.4	5.7	33.5	76.0	85.3	91.4	82.9	83.1

NA: Not Available

Source: EMATER

Table-2.5 Conserved Area in 1992

NO.	EMATER Region	Total area (ha)	Micro-basin worked	Producers involved	Area conserved (ha)	Ratio* (%)
EM-1	Paranagua	559,447	17	895	77,517	13.9
EM-2	Curitiba	1,581,548	119	10,073	205,660	13.0
EM-3	Lapa					
EM-4	Ponta Grossa	2,452,078	125	7,294	297,039	12.1
EM-5	Irati	583,151	46	3,109	41,298	7.1
EM-6	Uniao da Vitoria	736,639	39	3,012	68,421	9.3
EM-7	Guarapuava	1,914,218	81	6,339	187,499	9.8
EM-8	Pato Branco	946,239	83	7,191	196,270	20.7
EM-9	Francisco Beltrao	771,754	112	13,493	277,792	36.0
EM-10	Cascavel	1,442,024	118	12,664	393,187	27.3
EM-11	Toledo	785,435	117	24,615	492,217	62.7
EM-12	Umuarama	1,543,020	109	9,034	344,808	22.3
EM-13	Campo Mourao	1,210,470	102	10,699	495,903	41.0
EM-14	Ivaipora	1,077,621	78	8,479	198,304	18.4
EM-15	Paranavai	1,003,907	86	5,169	248,838	24.8
EM-16	Maringa	656,517	124	8,765	289,541	44.1
EM-17	Apucarana	322,101	55	4,462	82,099	25.5
EM-18	Londrina	702,906	79	4,793	296,808	42.2
EM-19	Cornelio Procopio	751,758	113	7,946	198,048	26.3
EM-20	Jacarezinho	815,345	100	9,833	135,169	16.6
	Total	19,856,178			4,526,418	22.8

Source : EMATER-PR/CPLAN and SEAB/DAGRI
Ratio = Area conserved/Total area *100
Lapa is included in Curitiba.
According to EMATER definition, conserved area exclude the area of non tillage.

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CHAPTER 3 CURRENT GROSS SOIL LOSS

USLE is a popular tool to estimate annual soil loss from the land surface; however the use of the model is limited to the small area. The result computed with USLE will be the most accurate for medium-textured soils, slope lengths of less than 400 ft (122 m), gradients of 3 to 8 % . For its application, the large area like a subject area of the Study should be divided in the small areas in accordance with soil properties, rainfall characteristics, vegetation, slope and so on. Besides, it requires a log term experiments or observation to determine each factor in USLE.

Considering the time allowed and the objectives of the Study, USLE was applied roughly to grasp gross erosion and examine the effectiveness of soil conservation practices. The result was compared with suspended sediment load to determine sediment delivery ratio of each river basin.

3.1 Current Gross Soil Erosion by USLE

3.1.1 Determination of USLE Factors

(1) R

The rainfall factor is a function of kinetic energy of rainfall and rainfall intensity. Wischmeier and Smith (1978) formulated an equation to obtain the kinetic energy of rainfall with the intensity of rainfall as shown in Equation (2).

$$E = 210 + 89 \log_{10}(I) \quad \cdots\cdots (2)$$

where E: kinetic energy (ton·m/ha·cm of rain)

I: rainfall intensity (cm/hr)

Raindrop size increases with rain intensity. The grater the raindrop size is, the faster the terminal velocities of free falling raindrops; however, they noticed that raindrop size does not continue to increase after rain intensities exceed 3 inch/hr, 7.62 cm/hr. Therefore, the rainfall factor depends on size and intensities of individual rainstorm and not annual rainfall.

Rufino et al. (1993) correlated rainfall factor with the rainfall coefficient, Rc.

$$R = a + b \cdot Rc \quad \cdots\cdots (3)$$

$$Rc = p^2 / P$$

where R; rainfall factor

a, b: coefficient

Rc: rainfall coefficient

p: average monthly rainfall (mm)

P: average annual rainfall (mm)

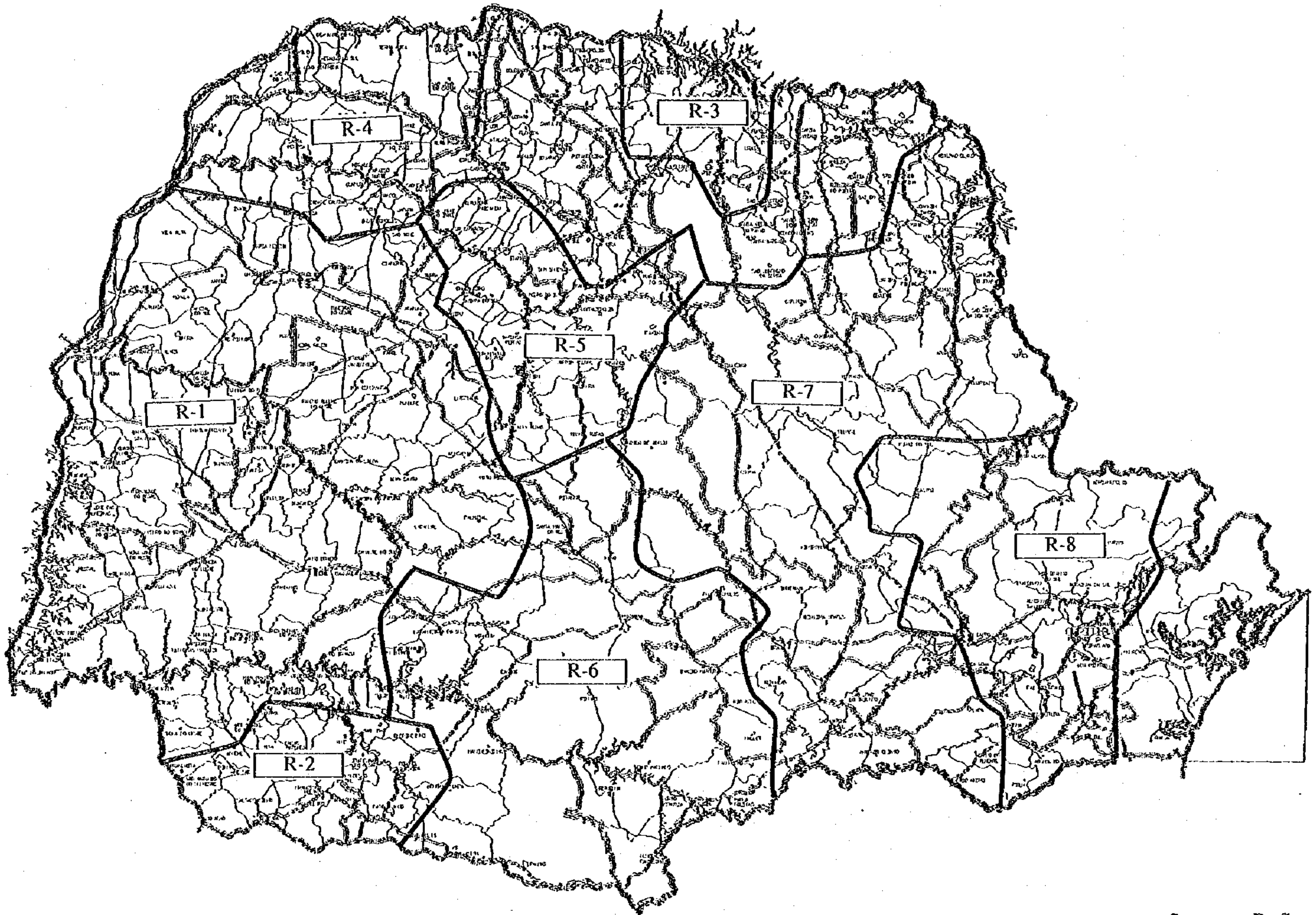
They computed the rainfall factor using the equation of Castro et al. (1982) which is basically a similar expression of Wischmeier and Smith (1978), and the rainfall coefficient based on the data from the pluviometer network of IAPAR. Their result shows the well correlation between the rainfall factor and coefficient. It implies that the rainfall factor can be computed by average monthly and annual rainfalls obtained from the pluviometer data instead of intensities of individual rainstorm. It also does not require the measurement of rainfall at short intervals, such as 30 minutes or shorter as required for the ordinal computation of the rainfall factor.

Based on the correlation computation, Rufino et al. (1993) drew the map of rainfall factor division in Paraná state dividing the state in 9 regions as shown in Figure-3.1. Their map was applied to determine the rainfall factor. One meteorological station among 33 stations for the meteorological analysis (see Figure-3.2) was selected as a representative for each river basin in each rainfall factor division. The conditions to select the representative meteorological station are as follows.

1) select the station located within an object river basin in each rainfall factor division.

2) select the station nearby an object river basin if no station located within that basin.

Average monthly and annual rainfalls from the selected meteorological stations were used to compute the rainfall factor. The result is shown in Table-3.1. The computed values are slightly different from the computation by Rufino et al. due to the difference in time interval of the data. The values of R determined vary from 5,167 to 11,723 MJ·mm/ha·hr depending on the location. Since the largest value in the United States is about 10,000 MJ·mm/ha·hr (Foster et al., 1981), Paraná state has higher erosive rain.



Legend

Federal Road
State Road
Boundary of Municipality
EMATER Division
Boundary of River Basin
Rainfall Factor

Rainfall Division	Equation
R-1	R=182.9+56.21Rc
R-2	R=146.6+55.62Rc
R-3	R=216.3+41.30Rc
R-4	R=164.1+39.44Rc
R-5	R=191.8+48.46Rc
R-6	R=107.5+46.89Rc
R-7	R=93.29+41.20Rc
R-8	R=33.26+40.71Rc

Source: Rufino et al. (1993)

$Rc=p^2/P$

R: Rainfall Factor

Rc: Rainfall Coefficient

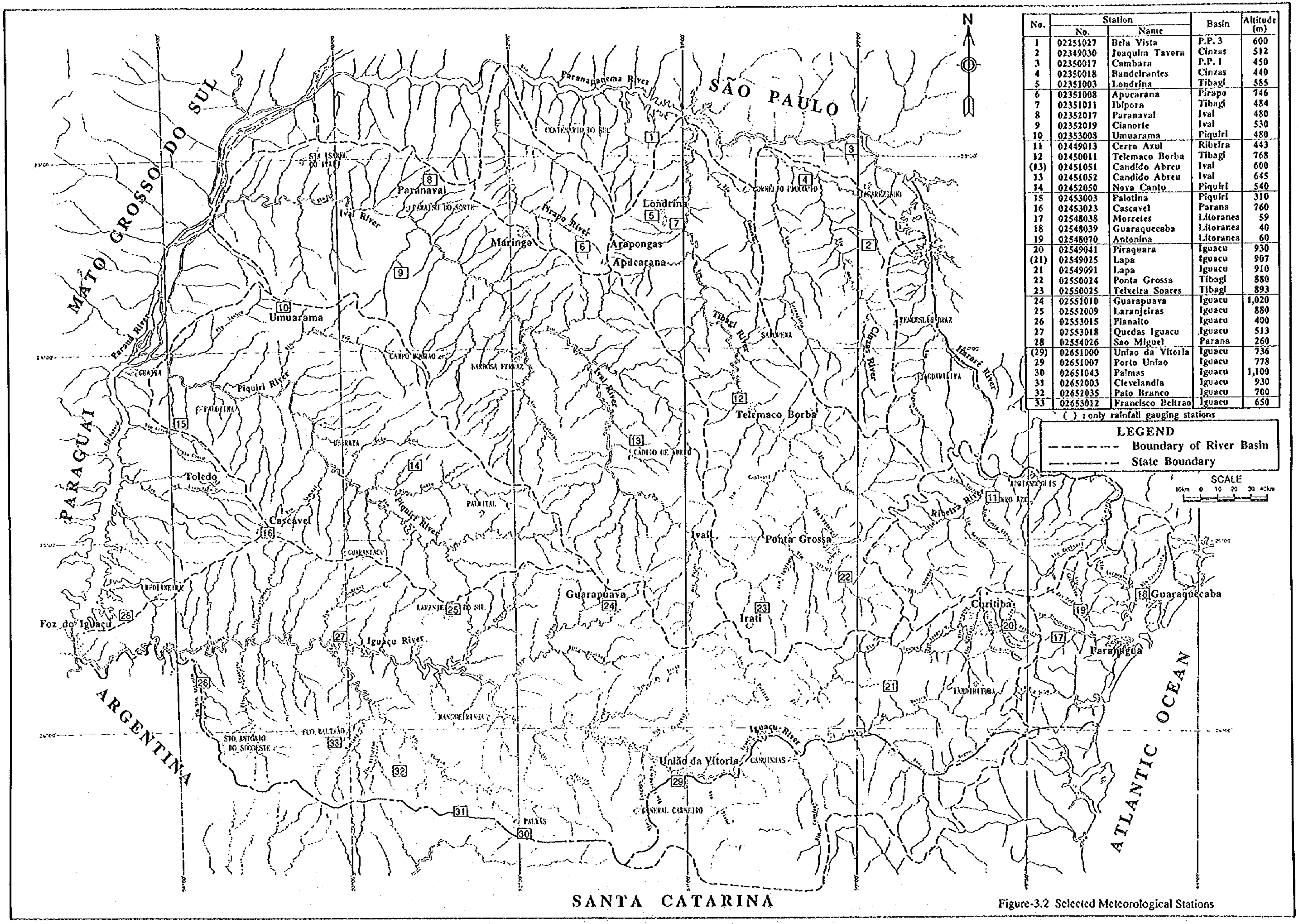
p: Average Monthly Rainfall

P: Average Annual Rainfall

Scale: 1: 2,500,000

Source: Rufino et al. (1993) for Rainfall Factor Division
GIS Digitization by SANEPAR (1994)

Figure-3.1 Rainfall Factor Division



No.	Station		Basin	Altitude (m)
	No.	Name		
1	02251027	Bela Vista	P.P. 3	600
2	02349030	Joaquim Tavora	Cinzas	512
3	02350017	Cambara	P.P. 1	450
4	02350018	Bandeirantes	Cinzas	440
5	02351003	Londrina	Tibagi	585
6	02351008	Apucarana	Pirapo	746
7	02351031	Ibipora	Tibagi	484
8	02352017	Paranavai	Ival	480
9	02352019	Cianorte	Ival	530
10	02353008	Umuarama	Piquiri	480
11	02449013	Cerro Azul	Ribeira	443
12	02450011	Telemaco Borba	Tibagi	768
(13)	02451051	Candido Abreu	Ival	600
13	02451052	Candido Abreu	Ival	645
14	02452050	Nova Canto	Piquiri	540
15	02453003	Palotina	Piquiri	310
16	02453023	Cascavel	Parana	760
17	02548038	Morretes	Litoranea	59
18	02548039	Guaraquecaba	Litoranea	40
19	02548070	Antonina	Litoranea	60
20	02549041	Piraquara	Iguacu	930
(21)	02549025	Lapa	Iguacu	907
21	02549091	Lapa	Iguacu	910
22	02550024	Ponta Grossa	Tibagi	880
23	02550025	Teixeira Soares	Tibagi	893
24	02551010	Guarapuava	Iguacu	1,020
25	02552009	Laranjeiras	Iguacu	880
26	02553015	Planalto	Iguacu	400
27	02553018	Quedas Iguacu	Iguacu	513
28	02554026	Sao Miguel	Parana	260
(29)	02651000	Uniao da Vitoria	Iguacu	736
29	02651007	Porto Uniao	Iguacu	778
30	02651043	Palmas	Iguacu	1,100
31	02652003	Clevelandia	Iguacu	930
32	02652035	Pato Branco	Iguacu	700
33	02653012	Francisco Beltrao	Iguacu	650

( ) : only rainfall gauging stations

Figure-3.2 Selected Meteorological Stations

Table-3.1 R Factor Computation

Rainfall Division	Equation	River Basin	Station		Month 1	2	3	4	5	6	7	8	9	10	11	12	Annual
R-1	y=182.9+56.21x	Iguacu	Planalto(Cfa)	Rainfall	179.8	143.2	123.3	163.8	181.4	157.4	117.2	124.0	144.4	188.3	182.8	173.1	1878.7
				Rainfall Factor	1,150	796	638	986	1,167	924	594	643	807	1,244	1,183	1,079	11,211
		Ivai	Cianorte(Cfa(h))	Rainfall	189.1	142.0	139.5	134.4	162.7	110.7	66.6	75.8	134.1	143.7	136.8	211.1	1646.5
				Rainfall Factor	1,404	871	847	800	1,087	601	334	379	797	888	822	1,704	10,534
		Piquiri	Nova Cantu(Cfa)	Rainfall	166.5	178.1	144.2	167.8	195.8	136.1	109.4	99.1	145.1	196.8	185.3	220.0	1944.2
				Rainfall Factor	984	1,100	784	997	1,291	718	529	467	792	1,303	1,176	1,582	11,723
R-2	y=146.6+55.62x	Iguacu	Francisco Beltrao(Cfa)	Rainfall	171.6	166.9	127.2	157.8	197.9	154.1	143.1	117.1	153.5	209.7	194.1	163.8	1956.8
				Rainfall Factor	984	938	606	854	1,260	822	729	536	816	1,397	1,217	909	11,068
R-3	y=216.3+41.30x	Tibagi	Ibipora	Rainfall	199.9	160.7	155.4	111.6	115.3	90.2	55.8	50.8	117.0	131.2	173.6	225.7	1587.2
				Rainfall Factor	1,256	888	845	540	562	428	297	283	572	664	1,000	1,542	8,877
R-4	y=164.1+39.44x	Cinzas	Bandeirantes(Cfa(h))	Rainfall	179.9	160.1	160.2	90.4	110.9	79.7	49.6	46.3	105.3	122.7	166.3	211.4	1482.8
				Rainfall Factor	1,025	846	847	381	491	333	230	221	459	565	900	1,353	7,651
		Ivai	Paranavai(Cfa(h))	Rainfall	184.1	145.0	130.2	110.0	123.7	101.4	54.5	54.8	127.2	163.1	122.0	185.3	1501.3
				Rainfall Factor	1,054	716	609	482	566	434	242	243	589	863	555	1,066	7,419
		Pirapo	Apucarana(Cfa(h))	Rainfall	190.3	154.6	151.5	112.7	151.0	112.2	69.2	66.2	128.6	153.6	159.1	211.3	1660.3
				Rainfall Factor	1,024	732	709	466	706	463	278	268	557	725	765	1,225	7,918
		Tibagi	Londrina(Cfa(h))	Rainfall	189.5	165.5	157.7	120.9	117.8	90.5	62.5	53.1	118.9	136.8	179.1	242.4	1634.7
				Rainfall Factor	1,030	825	764	517	499	362	258	232	505	616	938	1,582	8,128
R-5	y=191.8+48.46x	Ivai	Apucarana	Rainfall	190.3	154.6	151.5	112.7	151.0	112.2	69.2	66.2	128.6	153.6	159.1	211.3	1660.3
				Rainfall Factor	1,249	889	862	563	857	559	332	320	675	880	931	1,495	9,612
		Tibagi	Apucarana(Cfa(h))	Rainfall	190.3	154.6	151.5	112.7	151.0	112.2	69.2	66.2	128.6	153.6	159.1	211.3	1660.3
				Rainfall Factor	1,249	889	862	563	857	559	332	320	675	880	931	1,495	9,612
R-6	y=107.5+46.89x	Iguacu	Laranjeiras(Cfb)	Rainfall	167.1	175.4	120.0	154.8	188.3	150.6	140.4	115.6	152.7	209.6	180.1	181.7	1936.3
				Rainfall Factor	784	853	456	688	966	657	585	431	672	1,171	893	907	9,063
		Ivai	Guarapuava	Rainfall	182.0	147.1	146.8	143.7	196.1	141.4	128.6	107.8	156.4	183.9	174.4	184.2	1892.4
				Rainfall Factor	928	644	641	619	1,060	603	517	395	714	945	861	948	8,875
		Piquiri	Laranjeiras(Cfb)	Rainfall	167.1	175.4	120.0	154.8	188.3	150.6	140.4	115.6	152.7	209.6	180.1	181.7	1936.3
				Rainfall Factor	784	853	456	688	966	657	585	431	672	1,171	893	907	9,063
R-7	y=93.29+41.20x	Cinzas	Telemaco Borba(Cfa)	Rainfall	181.0	155.3	139.1	102.6	150.8	98.5	87.3	74.1	131.7	150.6	151.4	205.4	1627.8
				Rainfall Factor	922	704	583	360	669	339	286	232	532	667	673	1,161	7,128
		Iguacu	Lapa(Cfb)	Rainfall	159.0	138.0	120.8	86.4	142.5	107.2	109.4	98.3	119.9	146.1	127.7	158.6	1513.9
				Rainfall Factor	781	612	490	296	646	406	419	356	485	674	537	778	6,480
		Itarare	Joaquim Tavora(Cfa)	Rainfall	179.3	141.0	141.2	87.5	128.2	80.2	54.5	52.3	100.2	122.8	123.2	189.6	1400
				Rainfall Factor	1,039	678	680	319	577	283	181	174	389	537	540	1,151	6,548
		Ivai	Candido de Abreu(Cfa)	Rainfall	178.0	149.9	118.6	100.1	157.5	102.1	98.8	77.7	131.8	155.9	129.4	159.1	1558.9
				Rainfall Factor	931	687	465	358	749	369	351	253	552	736	536	762	6,749
		Tibagi	Telemaco Borba(Cfa)	Rainfall	181.0	155.3	139.1	102.6	150.8	98.5	87.3	74.1	131.7	150.6	151.4	205.4	1627.8
				Rainfall Factor	922	704	583	360	669	339	286	232	532	667	673	1,161	7,128
R-8	y=33.26+40.71x	Iguacu	Piraquara(Cfb)	Rainfall	161.3	135.8	125.3	86.4	119.5	88.5	92.8	73.2	109.7	127.2	122.4	146.2	1388.3
				Rainfall Factor	796	574	494	252	452	263	286	190	386	508	473	660	5,334
		Itarare	Cerro Azul(Cfa)	Rainfall	156.1	135.1	120.0	73.0	116.2	80.8	75.6	66.6	101.0	120.3	105.8	157.1	1307.6
				Rainfall Factor	792	602	482	199	454	237	211	171	351	484	382	802	5,167
		Ribeira	Cerro Azul(Cfa)	Rainfall	156.1	135.1	120.0	73.0	116.2	80.8	75.6	66.6	101.0	120.3	105.8	157.1	1307.6
				Rainfall Factor	792	602	482	199	454	237	211	171	351	484	382	802	5,167
		Tibagi	Ponta Grossa(Cfb)	Rainfall	163.2	133.7	140.3	105.0	157.4	98.1	105.1	85.0	128.4	136.3	126.5	151.7	1530.7
				Rainfall Factor	742	509	557	326	692	289	327	225	472	527	459	645	5,770

Rainfall: mm, Rainfall factor: MJ·mm/ha·hr
Koeppen Classification: Cfa, Cfa(h), Cfb

(2) K

Soil erodibility is the rate of soil loss per unit of the rainfall factor for a specified soil measured on a unit plot, which is a 72.6 feet (22.1 m) long with uniform slope of 9 % in clean tilled fallow. In general, a soil with more fraction of clay is less erodible and organic matter content is a second dominant factor to control soil erodibility after the particle size distribution. Since the erodibility of a specified soil depends on the complex interaction of physical and chemical properties of the soil, the determination of the soil erodibility requires a long term field experiment.

Wischmeier and Smith (1978) created the soil erodibility nomograph based on tremendous research works in the USA; however, the use of the nomograph is limited to the USA. The direct applications of the nomograph in other countries show the unsatisfied results. Henklain et al. (1983) concluded that the determination of the soil erodibility with the nomograph is not applicable in Paraná state. This means that the soil erodibility should be determined through the long term experiments.

Based on the field experiments, Mondardo et al. (1979) and Biscaia et al. (1981) determined the erodibilities of some of the soils in Paraná state as shown in Table-3.2. In the table, the original unit, ton·ha·hr/ha·m^2·ton, was converted dividing by 9.8 ton·ha·hr/ha·MJ·mm so as to adjust the unit to the equation (1). Foster et al. (1981) approximates K values of low, moderate and high erodible soil in the USA after converting the US customary units to SI units as follows. Since the conversion factor from the US customary units to SI units is a multiplication of 0.1317, a maximum value of the soil erodibility, 1 in the US customary units, is on the order of 0.1 ton·ha·hr/ha·MJ·mm in SI units.

low erodible soil	0.01 ton·ha·hr/ha·MJ·mm
moderate erodible soil	0.03 ton·ha·hr/ha·MJ·mm
high erodible soil	0.06 ton·ha·hr/ha·MJ·mm

Table-3.2 K Factor for Some Soil in Paraná and USA

Unit: ton·ha·hr/ha·MJ·mm

Type of Soil	Location	K
Latossolo Roxo Distrofico (long term use for soybean and wheat)	Londrina	0.039 a
Latossolo Roxo Distrófico (recent use for soybean and wheat)	Londrina	0.015 a
Latossolo Vermelho Escuro (medium texture)	Paranavai	0.007 a
Latossolo Vermelho Escuro (clayey texture)	Ponta Grossa	0.008 a
Latossolo Roxo	Campinas	0.012 a
Dark Red Latossolo	Parana	0.024 b
Dusky Red Latossolo	Parana	0.027 b
Low erodible soil	USA	0.010c
Moderate erodible soil	USA	0.030c
High erodible soil	USA	0.060c

Souce: a Mondardo et al. (1979); b Biscaia (1981); c Foster et al.(1981)

Note: Original units of Mondardo and Biscaia are converted to ton·ha·hr/ha·MJ·mm

Available values of the soil erodibility in Paraná state are only for two soil classifications, Latossolo Roxo and Latossolo Vermelho Escuro. These soils are characterized as resistant to erosion and the values obtained from the experiment ranges between 0.007 and 0.012 corresponding to the low erodible soil in the classification of Foster et al. Considering the availability of the experimental data and accuracy required for the erosion estimation at the strategy study level, soils in Paraná state were classified in three categories in terms of the erodibility and K values approximated by Foster et al. were adopted, as shown in Table-3.3.

Table-3.3 K Factor Adopted

Soil Group	K	Erodibility
Latossolo Vermelho Escuro, clay (LE clay)	0.01	resistant
Latossolo Roxo (LRa)	0.01	resistant
Latossolo Bruno (LBa)	0.01	resistant
Latossolo Vermelho Escuro, sand (LE sand)	0.03	moderate
Terra Roxa Estruturada (TRe)	0.03	moderate
Podzolico (PV)	0.06	high
Cambissolo (Ca)	0.06	high
Litolicos (Ra)	0.06	high

(3) LS

The slope length and steepness factor is dimensionless value and is equal to 1 for an unit plot which is a 72.6 foot length (22.1 m) of uniform 9 % slope. Once the slope length and steepness are obtained, there are tables available to assess LS in Agriculture Handbook Number 537, the United States Department of Agriculture (Wischmeier and Smith, 1978).

Usually, the slope steepness in the specified area is determined through the analysis of contour maps (1/10,000) or direct field measurement; however, since the target area of the Study is about 200,000 km^2, none of them is feasible unless contour maps are digitized so as to enable GIS computation. Only feasible way to assess the slope steepness is to use the soil map. Each class of soil is located in specific slope steepness. For example, 62 % of Latossolo Vermelho Escuro exists on the slope with 0 to 8 % gradient. The slope steepness where each soil class is located is available in Agricultural Land Aptitude of Paraná (Ministry of Agriculture, 1981). Eight soil groups were selected as dominant soils in Paraná and the area weighted average of steepness was computed for each group. The result is shown in Table-3.4.

Table-3.4 Slope Steepness of Dominant Soil Groups

Soil Group	Slope Steepness (%)	Occupation in the state (%)
Latossolo Vermelho Escuro	4	12
Latossolo Roxo	6	15
Latossolo Bruno	6	3
Terra Roxa Estruturada	6	14
Terra Bruna	10	2
Podzolico	10	16
Cambissolo	10	10
Litolicos	30	21

Source: adopted and enlarged from Agricultural Land Aptitude of Paraná

Regarding the slope length of different land use, the field survey should be carried out for ordinal USLE application; however, this is not feasible for the whole Paraná state. Therefore, the following assumption was made for the computation sake.

1) Slope length of terracing for crop field and pasture depends on its steepness

6 % slope	30 m length
8 % slope	25 m length
10 % slope	20 m length
20 % slope	15 m length

2) Slope lengths of forest and secondary vegetation are 100 m, regardless of their steepness.

3) Slope length of crop field where only contouring is practiced follows the slope length limits of the contouring described in Agriculture Handbook Number 537 (Wischmeier and Smith, 1978). The values depend on the steepness.

After determining the slope steepness and length, LS was assessed entering the table or figure of LS in Agriculture Handbook Number 537 (Wischmeier and Smith, 1978).

(4) C

The cover and management factor is the ratio of soil loss from cropping land under certain conditions to the soil loss from clean-tilled continuous fallow. Since C is an integrated value of vegetation cover on soil surface and management practices to grow crops, it is dependent on many factors as follows. Therefore, C for a particular cropping varies with location.

Vegetation cover	combination of cover, crop sequence, particular stage of growth, development of vegetal cover at the time of the rain, etc.
Management	crop canopy, residue mulch, incorporated residues, tillage, land use residuals, etc.

The values of C is only obtainable through the field measurement and they are not available in Paraná state so far. Table-2.2 shows the soil losses from the bare soil surface and cropping fields of some of typical crops in Paraná state. Dividing the soil loss from each crop by the loss from bare soil, C value of each crop was approximated. Neglecting the spatial variation of C values, the obtained values were applied for the whole Paraná state with the following assumptions.

1) Cassava has the same C value as cotton.

2) All crops, except potato, cotton, cassava and coffee, have the same C values as maize.

3) Since wheat in Paraná is usually a second crop after soybean, annual C value of soybean - wheat crop sequence is the same as C value of soybean.

4) Effect of the rainfall factor on a particular stage of crop development is neglected.

5) Crop sequence is neglected. Therefore, the C values obtained are used as annual values of crop fields represented by 9 major crops selected.

6) C for forest and secondary vegetation are obtained from Agriculture Handbook Number 537 (Wischmeier and Smith, 1978).

C values of different vegetation adopted for the USLE computation are summarized in Table-3.5.

Table-3.5 C Factor

Crop	C
potato	0.750
cotton & cassava	0.625
coffee	0.375
other crops	0.250
pasture	0.125
forest	0.001
secondary vegetation	0.003

(5) P

The support practice means to reduce the velocity of surface runoff and consequently decrease the amount of soil carried by the runoff. And the support practice factor is the ratio of the soil loss with a specified support practice to the loss with up-and-down-slope culture. In Agriculture Handbook Number 537 (Wischmeier and Smith, 1978), P values of dominant support practices, such as contouring, contour stripcropping and terracing, are available.

EMATER has classified the crop land either conserved or not conserved. The conserved area means; a) terracing, b) contour bunds and buffer strips, c) improvement of rural roads,, d) soil improvement with green manure and lime, e) reforestation, f) guidance of adequate use of machinery.

For the computation sake of USLE, it was assumed that terracing with contouring is implemented in the whole conserved area in EMATER classification and only contouring is a conservation measure practiced in non conserved crop land. Entering the tables in Agriculture Handbook Number 537 (Wischmeier and Smith, 1978) with the assumptions mentioned above, P values for different slope steepness were obtained. P values for pasture not conserved, forest and secondary vegetation are 1.0 due to their natures.

(6) Land Use

Based on the result of satellite imagery analysis by IAP and GIS calculation by SANEPAR, the land use of each river basin was summarized in Figure-3.3. Secondary vegetation in the legend means where natural bush grows after the cultivation by means of land clearing with burning is ceased. These ratios of different land use were applied to determine the area of each land use as shown in Table-3.6. Although the satellite imagery analysis is based on the data in 1989 and 1990, it was assumed that the current landuse does not vary from one in 1989 and 1990.

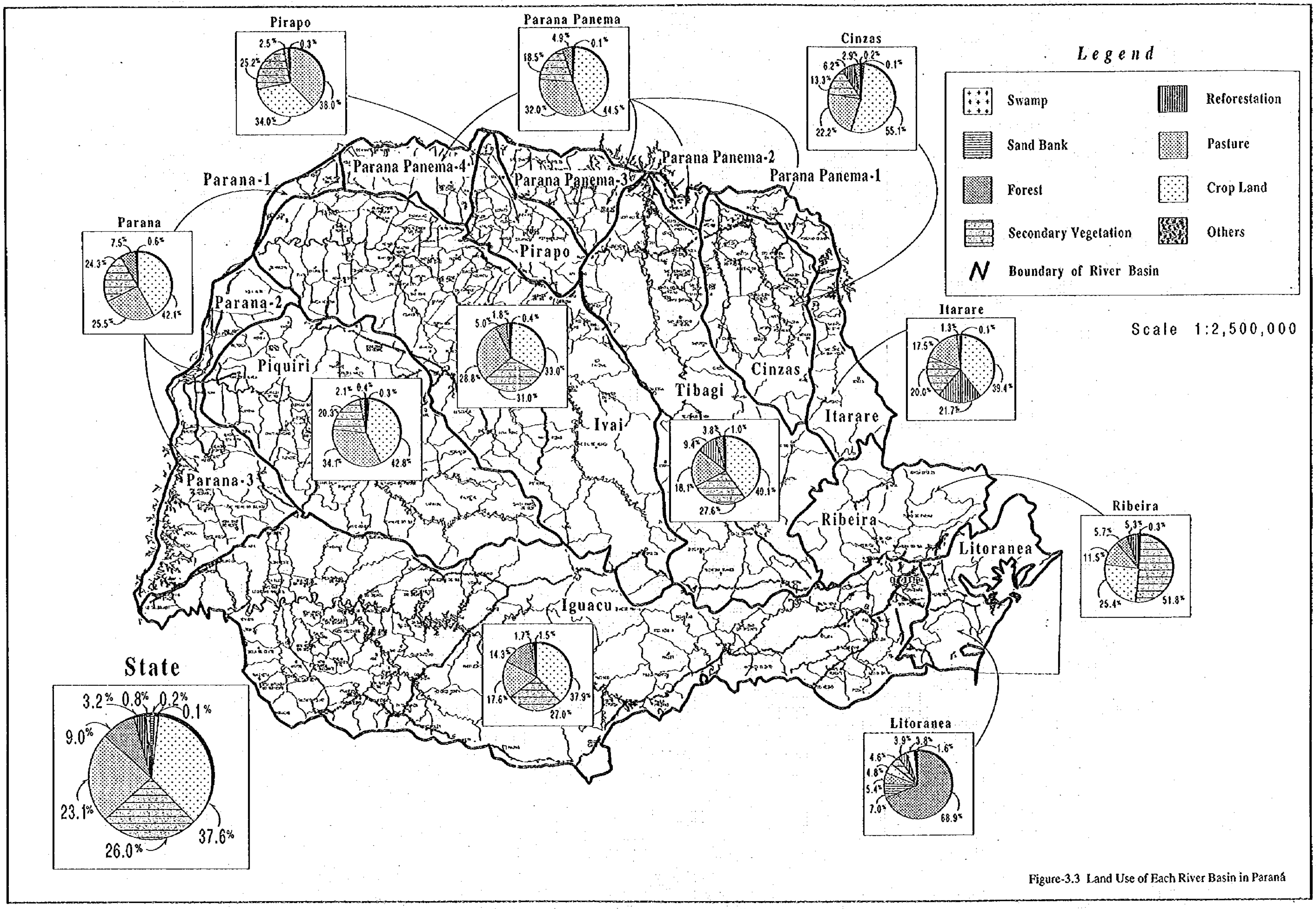


Figure-3.3 Land Use of Each River Basin in Paraná

Table-3.6 Ratio and Area of Land Use in 11 River Basins

	Total Area (km^2)	Landuse (%)							
		Swamp	Sand Bank	Forest	2nd Veg.	Reforest.	Pasture	Crop Land	Others
State	197882.0	0.1	0.2	9.0	26.0	3.2	23.1	37.6	0.8
Cinzas	9290.7	0.0	0.1	2.9	13.3	6.2	22.2	55.1	0.2
Iguacu	55318.0	0.0	0.0	14.3	27.0	1.7	17.6	37.9	1.5
Itarare	5197.7	0.0	0.0	1.3	20.0	21.7	17.5	39.4	0.1
Ivai	35878.9	0.0	0.0	5.0	31.0	1.8	28.8	33.0	0.4
Litoranea	5766.0	3.8	7.0	68.9	4.6	3.9	5.4	4.8	1.6
Parana	13156.3	0.0	0.0	7.5	24.3	0.0	25.5	42.1	0.6
Paranapnema	9797.0	0.0	0.0	4.9	18.5	0.0	32.0	44.5	0.1
Piquiri	24707.9	0.0	0.0	2.1	20.3	0.3	34.1	42.8	0.4
Pirapo	5005.9	0.0	0.0	2.5	25.2	0.0	38.0	34.0	0.3
Ribeira	9129.3	0.0	0.0	5.7	51.8	5.3	11.5	25.4	0.3
Tibagi	24634.7	0.0	0.0	3.8	27.6	9.4	18.1	40.1	1.0

2nd Veg.: Secondary Vegetation, Reforest.: Reforestation

Source: SANEPAR GIS computation based on IAP satellite imagery analysis (1990 &1994)

To categorize the crop land with specific crops, EMATER data for the year of 1993 associated with ratios of specific crop area and ratios of conserved area was used (refer to Appendix-1). Since the data is EMATER division wise, it was necessary to convert the data by means of the area weighted average to the river basin and rainfall factor division wise. Finally, the areas of different crops and their conserved area with rainfall factor division wise in each river basin were determined. Only dominant crops in terms of area were extracted through the above procedure. The details are in Appendix-2.

3.1.2 Result of USLE Computation

The process and computation of USLE equation are summarized in Appendix-2 and the result of USLE approximation for the gross soil erosion is shown in Table-3.7. The average gross soil erosion from 8 river basins is 28 ton/ha-year. This is a rough approximation; however, the value is considered as adequate accuracy to describes the current situation of Paraná state. Cinzas, Ivai and Ribeira river basins are ranked as high gross soil erosion. The gross erosion of Itarare river basin is low compared to other basins due to the low rainfall erosivity.

Table-3.7 Current Gross Soil Erosion

River Basin	Soil Loss from Whole Basin (1000 ton/year)	Area (1,000 ha)	Gross Soil Erosion (ton/ha-year)
Cinzas	33,066	929	36
Iguacu	154,804	5,532	28
Itarare	2,439	520	5
Ivai	115,309	3,588	32
Piquiri	66,328	2,471	27
Pirapo	9,387	501	19
Ribeira	27,471	913	30
Tibagi	58,568	2,464	24
Total	467,372	16,918	–
Average	–	–	28

Area of River Basin is only within Parana

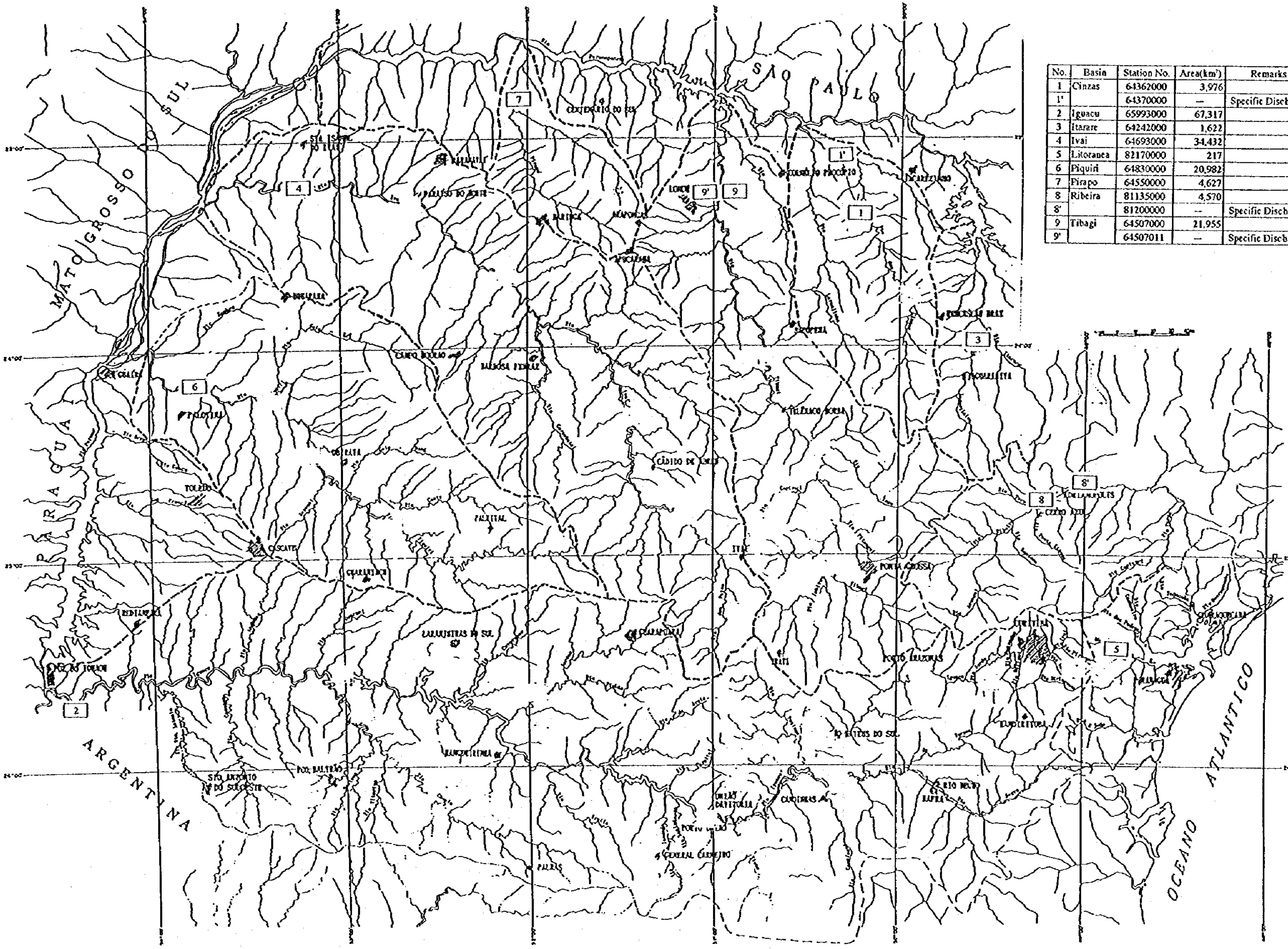
3.2 Suspended Sediment

3.2.1 Computation of Suspended Sediment Load

The eroded soil is transported downward with runoff and some is deposited more flat place due to the reduction of flow velocity while some reaches to a stream and moves further as suspended sediment and bed load. A correlation between suspended sediment and discharge was examined in order to assess the average annual suspended sediment yield of each river basin.

The data of suspended sediment measured is available in IAP, DNAEE and COPEL. The observation stations for computation of suspended sediment were selected with the following conditions. The selected observation stations are shown in Figure-3.4.

- the number of data available
- location as much close as the downstream end of a river basin
- same location as discharge measurement or nearby



No.	Basin	Station No.	Area(km²)	Remarks
1	Cinzas	64362000	3,976	
1'		64370000	—	Specific Discharge
2	Iguacu	65993000	67,317	
3	Itarare	64242000	1,622	
4	Ivai	64693000	34,432	
5	Litoranea	82170000	217	
6	Piquiri	64830000	20,982	
7	Pirapo	64550000	4,627	
8	Ribeira	81135000	4,570	
8'		81200000	—	Specific Discharge
9	Tibagi	64507000	21,955	
9'		64507011	—	Specific Discharge

Figure-3.4 Selected Stations of Suspended Sediment

The measured sediment in concentration was converted to sediment in mass per time, multiplying the measured sediment by the average discharge. The sediment in mass per time and discharge were then plotted in logarithm. Logarithm of suspended sediment, S (g/s), somehow correlates linearly to logarithm of discharge, Q (m^3/s). The relation between S and Q of each river basin was obtained in the following expression.

$$\text{Log } S = a \text{ Log } Q + b$$

The linear regression of Q vs. S for each river basin is shown in Appendix-2 and its result is summarized in Table-3.8.

Table-3.8 Q vs. S Relation

Log S=aLogQ+b

River Basin	a	b
Cinzas	1.728	0.569
Iguacu	1.269	0.487
Itarare	1.839	0.589
Ivai	2.191	-1.423
Litoranea	1.162	1.089
Pirapo	1.957	0.208
Piquiri	1.762	-0.229
Ribeira	2.360	-0.734
Tibagi	1.167	1.193

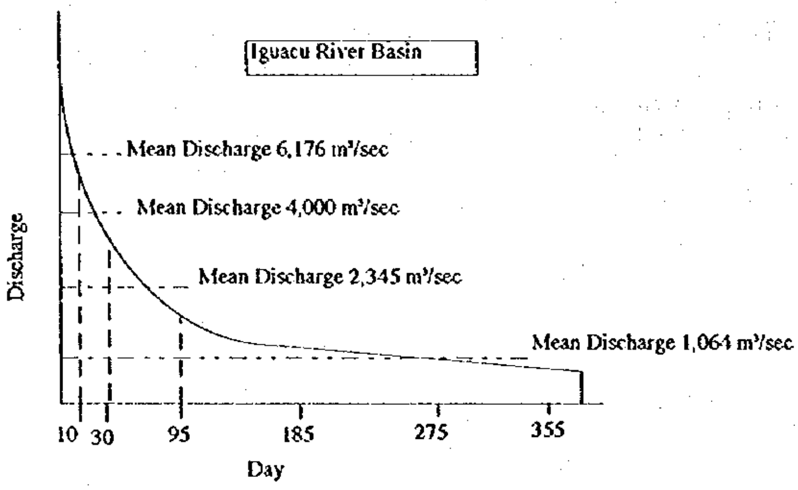
Flow regime of each river basin is available as a result of the hydrological analysis in the last 20 years (see Sectorial Report-B, Meteorology, Hydrology and Surface Water Resources, and Data Book). From the flow regime, the mean discharge of a specific period in a year is obtainable. Annual unit suspended sediment ($ton/km^2 \cdot year$) of each river basin was computed applying S and Q relation to the flow regime shown in Appendix-2. The result is summarized in Table-3.9.

Each river basin was compared to others in terms of unit suspended sediment per year, $ton/km^2 \cdot year$. As a result of computation, Ivai, Piquiri, Itarare and Cinzas yield suspended sediment higher than others. The annual suspended sediment in the Iguaçu river basin is low on the contrary to the expectation. The reason is that there are several dams in Iguaçu river basin and some of suspended sediment is deposited in dam reservoirs. Since no estimation of sediment deposit in the reservoirs is available, the effect of reservoirs on sediment transport is not predictable despite the fact that the computation result includes the effect.

Table-3.9 Annual Suspended Sediment Computed

Basin	Station No.		SS calculation					AS	UAS
Iguacu 67317 km²	65993000	Days	10	20	65	270			
		Q(m³/s)	6176	4000	2345	1064			
		S(ton/day)	17166	9890	5022	1842		1193	18
Tibagi 21955 km²	64507011* 64507000	Days	10	10	75	270			
		q (m³/s·km²)*	0.0895	0.0569	0.0342	0.0143			
		Q(m³/s)	1965	1249	751	314			
		S(ton/day)	9375	5526	3052	1104		676	31
Ivai 34432 km²	64693000	Days	10	20	65	270			
		Q(m³/s)	3422	2000	1139	512			
		S(ton/day)	180244	55575	16190	2809		4725	137
Piquiri 20982 km²	64830000	Days	5	5	20	65	270		
		Q(m³/s)	4595	2500	1500	776	362		
		S(ton/day)	144111	49320	20055	6280	1639	2219	106
Pirapo 4627 km²	64550000	Days	10	10	30	45	270		
		Q(m³/s)	272	175	125	90	59		
		S(ton/day)	8097	3416	1769	930	407	320	69
Cinzas 3976 km²	64370000* 64362000	Days	10	20	65	270			
		q (m³/s·km²)*	0.128	0.053	0.026	0.010			
		Q(m³/s)	509	211	103	40			
		S(ton/day)	15208	3321	962	188		332	84
Itarare 1622 km²	64242000	Days	10	50	95	270			
		Q(m³/s)	183	75	42	24			
		S(ton/day)	4864	943	325	116		158	97
Ribeira 4570 km²	81200000* 81135000	Days	10	25	60	270			
		q (m³/s·km²)*	0.0816	0.0414	0.0229	0.0141			
		Q(m³/s)	373	189	105	64			
		S(ton/day)	18652	3750	937	291		415	57
Litoranea 217 km²	82170000	Days	10	15	70	270			
		Q(m³/s)	70	40	22	9			
		S(ton/day)	148	77	38	14		9	41

*: Specific Discharge
AS: Annual Suapended Sediment (1000 ton/year)
UAS: Unit Annual Suspended Sediment (ton/km²/year)
Days: a period in a year, the sum of days is 365 days.
Q: the average discharge in a period obtained from the flow regime
S: the average suspended sediment in a period computed by Q and S relation
Area indicated in Basin cell is not the area of river basin. It is the area which each station covers.



Example of Discharge Estimation from Flow Regime

3.2.2 Sediment Delivery Ratio

The sediment yield is defined as the total sediment, the sum of suspended sediment and bed load, delivered to a certain point of a river basin from its upstream area and the sediment delivery ratio is a fraction of the sediment yield to the gross erosion. Since there is few theoretical equation verified to estimate the sediment delivery ratio, the best way to obtain either sediment yield or sediment delivery ratio is direct measurements.

The United States Soil Conservation Service (1971), USSCS, has formulated the general relationship between suspended sediment and river basin area; however, its application is limited to the case which no time is available to measure and establish the sediment delivery ratio, because the ratio is considered as an intrinsic value of a river basin. It implies that the sediment delivery ratio varies with location. The relationship established by USSCS is as follows.

$$SDR = 0.3320\,x^{-0.2236}$$

where SDR: sediment delivery ratio

x: river basin area (km^2)

Since the measurement of bed load has not been conducted periodically in Paraná state and to establish the sediment relationship of individual river basin is not the Study objective, the above equation was applied to approximate SDR of each river basin in terms of river basin area. SDR was also computed by means of the fraction of suspended sediment to gross erosion, assuming that the bed load is not significant compared to suspended sediment. Suspended sediment yield of each river basin was computed multiplying unit annual suspended sediment by the river basin area.

The result of SDR computation and SDR by USSCS are compared in Table-3.10. Although SDR computed excludes the bed load and SDR by USSCS is just area dependable, those figures are similar order magnitude, except Itarare and Iguaçu. It implies that sediment yield in a large scale is more dependent on area due to sediment deposition. Since the characteristics of gross erosion and sediment yield in Itarare deviates from other river basins, SDR computed is much greater than SDR by USSCS. SDR of Iguaçu river basin is low due to reservoirs.

Table-3.10 Estimation of Sediment Delivery Ratio

River Basin	GSL (1000 ton/year)	SS (1000 ton/year)	SDR	Area (km^2)	SDR US
Cinzas	33,066	780	0.024	9,290.7	0.043
Iguacu*	154,804	996	0.006	55,318.0	0.029
Itarare	2,439	504	0.207	5,197.9	0.049
Ivai	115,309	4,915	0.043	35,878.9	0.032
Piquiri	66,328	2,619	0.039	24,707.9	0.035
Pirapo	9,387	345	0.037	5,005.9	0.049
Ribeira	27,471	520	0.019	9,129.3	0.043
Tibagi	58,568	764	0.013	24,634.7	0.035

GSL: Gross Soil Loss, SS: Suspended Sediment for the whole river basin, SDR: Sediment Delivery Ratio
SDR US: Sediment Delivery Ratio estimated by USSCS relation
*: SDR in Iguacu is low due to reservoirs.
Area: River basin area within Parana

3.3 Erosion Susceptibility of River Basins

Erosion susceptibility of 8 river basins was evaluated based on estimations of gross soil erosion and suspended sediment as shown in Table-3.11. Since USLE is expressed as factors inducing soil erosion, the quantitative value of gross soil erosion describes well erosion susceptibility of land.

Ivai and Piquiri river basins show the highest magnitude in erosion susceptibility and suspended sediment yield. Although the gross erosion in Cinzas is high, suspended sediment yield is medium. It implies that more sediment is deposited in Cinzas compared to other basins. The reservoir effect on sediment deposit is obvious in Iguaçu. The suspended sediment yield in Iguaçu is the lowest despite of high gross erosion.

Most of river basins in Paraná, except Itarare, are suffered from exceeding permissible level of soil erosion and contamination of water with sediment. Among them, Ivai, Piquiri and Cinzas are ranked at high erosion susceptibility and high negative effect on the water environment. Therefore, proper land management and urgent implementation of countermeasures are required, especially in those basins.

Table-3.11 Evaluation of Erosion Susceptibility of River Basins

River Basin	GE	SS
Cinzas	5	3
Iguacu	4	1
Itarare	1	4
Ivai	5	5
Piquiri	4	4
Pirapo	3	3
Ribeira	4	2
Tibagi	3	2
Rank		
1 tolerant	0 - 8	0 - 30
2 moderate	9 - 16	31- 60
3 medium	17 - 24	61 - 90
4 severe	25 - 31	91 - 120
5 very severe	32≤	121≤
unit	ton/ha	ton/km²·year

GE: gross erosion

SS: suspended sediment

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CHAPTER 4 STRATEGY FOR SOIL CONSERVATION

The effects of soil erosion on the Water Environment vary from different points of view according to a specific discipline or field. Soil degradation in terms of physical and chemical is a main concern for soil science, reduction of soil fertility due to soil erosion is for agronomy and contamination of water due to suspended sediment, pesticide, fertilizer etc. is for water quality and ecology. Therefore, it is necessary to identify not only factors inducing the soil erosion but also its effect on the environment. Since countermeasures for zero soil erosion is not feasible, determination of objectives through the problem identification is essential to formulate the strategy for soil conservation.

Since the subjected area for the Strategy is the whole Paraná state, about 200,000 km^2, the detailed designs of countermeasures are not involved. The strategy at this scale should take account of the following matters..

1) identification of problem regions

2) examination of factors inducing soil erosion

3) examination of effects of soil erosion

4) estimation of current and future soil loss

5) proposal of measures excluding detail design

6) rough estimation of cost and benefit

4.1 Effect of Soil Erosion

Problems associated with soil erosion in Paraná are summarized as follows. Although each problem interacts with one another, simple identification was tried to figure out main problems.

at field

1) low crop productivity induced by soil degradation

2) increase in fertilizer application resulting higher cost

3) abandonment of land and stimulation of migration to urban area

in a river basin

1) high sediment yield

2) degradation of ecosystem

3) water contamination

According to Paraná Rural technical manual (SEAB, 1989), an average soil loss from the cropping area is 20 ton/ha-year. It would be equivalent to the surface soil loss of 1.5 mm depth/year if the specific weight of soil was 1.3 ton /m^3. At this rate of erosion, Paraná Rural project also estimates annual fertilizer loss from the field due to soil erosion at US$ 60 million/year for nitrogen and US$ 5 million/year for potassium. That amount of money is inputted to field as fertilizers to maintain soil fertility. Runoff water carries sediment to a river and some is deposited within a river basin while other flows to further downstream as bed load and suspended sediment. According to SANEPAR, the cost of sediment removal and turbidity reduction at purification plants is US$ 217 thousand/year.

4.2 Criteria to Determine Threshold of Erosion Control

The soil conservation is to control the erosion below a threshold level depending on a specific object. The theoretical threshold is a state of equilibrium between the amounts of erosion and soil formation On the other hand, the practical threshold generally applied is a less severe level to maintain soil fertility in the medium term (20 to 25 years) allowing soil amendment with fertilizer, green manure, lime etc. The practical threshold satisfies the requirements from an agronomy point of view, such as crop productivity; however, the contamination of water quality is often not considered.

The size of the target area is another factor to influence the determination of the threshold. Many researches show that dominant factors to control the soil erosion and sediment yield depend on the size of the area concerned. The larger the target area, the more sources of erosion are involved. On the other hand, the more places for sediment deposition in the larger area. Due to this, the permissible gross erosion per unit area is high for small areas and decreases with enlarging areas. Based on worldwide researches, Morgan (1980) approximated the appropriate values of the maximum permissible soil loss as follows.

field size	25 ton/ha·year
medium-scale	11 ton/ha·year
areas above 10 km^2	2 ton/ha·year

Rainfall energy and soil properties of the target area are other factors to be considered during the determination of the threshold. A single occurrence of rainfall in 100 year return period may induce the greater erosion than that in 50 year return period. Besides, the magnitude of rainfall probability to cause the soil erosion is a spatial variable. Since various soil properties show the different erosion susceptibilities, the permissible soil erosion varies with dominant soil class in the target area. When determining the erosion threshold at the field level, these factors should be taken account; however, at the strategy level targeting the large area, analyses and consideration of these factors are not feasible.

Threshold depends on criteria. Threshold which only maintenance of soil fertility is considered as criteria will be different from one which both soil fertility and water environment are considered. Since one of objectives of this study is to improve the water environment, it is necessary to suppress the effect of soil erosion on the downstream. However, criteria to determine the threshold of erosion control are not available in either Brazil or Japan. In Japan, soil erosion phenomena is not as common as in Paraná state. Most of sedimentation in Japan is supplied by land slide or collapsing of mountain flank due to it's steep mountainous characteristics in topography. However, in Okinawa prefecture, the southernmost islands in Japan, there is an erosion control project to not only maintain fertility in sugarcane and pineapple fields but also protect coral reefs at river mouth. Considering these criteria, the threshold of erosion control was determined as follows.

1) Allowable soil erosion depth is less than 1 mm/year

2) Allowable sediment load in river is less than 200 mg/liter

These threshold are not directly applicable to Paraná due to the difference in natural conditions of both areas. Therefore, it requires some approximation of the threshold. Since the areas of subjected river basins in Paraná ranges from 5,000 to 55,000 km^2, 2 ton/ha·year is a threshold from a view pint of a large river basin. However, this value is considered as too strict to be implemented in next twenty years. Therefore, a widely acceptable value, 11 ton/ha·year, was adopted as the threshold of soil loss to propose the strategy by the year of 2015 and 2 ton/ha·year will be achieved successively. Assuming the specific weight of soil as 1.3 ton/m^3, 11 ton/ha·year is converted to surface soil loss of 0.8 mm/year. This value at field is considered to be compensated by soil formation.

4.3 Countermeasures

The final goal of studies on soil erosion is to adopt and apply the suitable soil conservation measures; however, their selection relies on empirical procedures due to research lag on conservation measures compared to research on mechanism on soil erosion. Therefore, measures proposed hereunder were determined from countermeasures popularly practiced.

Soil conservation measures consist of agronomic measures, soil management and mechanical measures. Agronomic measures and soil management are effective on detachment and transport of soil particles, while mechanical measures are mostly effective on transport. The combination of agronomic measures and soil management usually results in successful soil conservation, and mechanical measures without agronomic measures are rarely effective to soil conservation. In general, agronomic measures are superior to mechanical measures from the following points of view.

1) low cost

2) no requirements of specific equipment and heavy machinery

3) less maintenance

4) easily adopted to current farming system

As long as the soil conservation at micro scale, field level, is concerned, agronomic measures or combination with soil management may be adequate to control soil loss and productivities; however, the integrated conservation system combining above three measures is required if medium or macro scale, such as river basins, is considered. Morgan (1980) summarized the effect of each type of measures on soil conservation as shown in Table-4.1.

Table-4.1 Effectiveness of Soil Conservation Practices

Practice	Effectiveness			
	Rainsplash		Runoff	
	D	T	D	T
Agronomic Measures				
Covering soil surface	*	*	*	*
Increasing surface roughness	—	—	*	*
Increasing surface depression storage	+	+	*	*
Increasing infiltration	—	—	+	*
Soil Management				
Fertilizers, manures	+	+	+	*
Subsoiling, drainage	—	—	+	*
Mechanical Measures				
Contouring, ridging	—	+	+	*
Terraces	—	+	+	*
Waterways	—	—	+	*

—: no control, +: moderate control, *: strong control
D: detachment, T: transport
Source: Morgan (1980)

In USLE, rainfall factor and soil erodibility are locally fixed values and not changeable with any countermeasures. Since to alter slope steepness is very costly, it is generally considered as rarely changeable factor. Slope length is modified only by mechanical measures, while cover and management factor, and erosion control practice are improved by agronomic measures and soil management.

4.3.1 Mechanical Measures

Terracing is a strong measure to reduce runoff velocity and induce sediment deposition in the drains. As a result, sediment yield from a field decreases. Besides, terracing has a multiplicative effect on erosion by means of reducing slope length. The effect of terracing is examined in Table-4.2 assuming that slope is 8 %, soil erodibility is moderate, K=0.03, and no cover and management factor, C=1. During the procedure, the slope length limit is determined in accordance with maximum slope length of each slope suggested in Agriculture Handbook Number 537 (Wischmeier and Smith, 1978). Three cases of rainfall erosivity, 5,000, 8,000 and 10,000 MJ·mm/ha·h·year, were applied.

Table-4.2 Soil Erosion with Different C Factor

slope=8%, C=1, K=0.03

Practice	R	P	slope length limit	LS	A
contouring	5000	0.5	61	1.410	106
contouring + terracing	5000	0.1	25	0.896	13
contouring	8000	0.5	61	1.410	169
contouring + terracing	8000	0.1	25	0.896	22
contouring	10000	0.5	61	1.410	212
contouring + terracing	10000	0.1	25	0.896	27

R: rainfall factor (MJ•mm/ha•hr•yr), P: support practice factor
LS: slope steepness and length, A: gross soil erosion (ton/ha)
C: cover and management factor, K: soil erodibility (ton•hr/MJ•mm)

Application of terracing drastically reduces gross soil erosion compared to contouring alone. Regardless of rainfall energy, the rate of reduction is about 87 % because of its multiplicative effect. Terracing combined with other measures, such as agronomic measures and contouring is more effective, and commonly practiced. According to EMATER, several types of terracing has been currently applied to 3,000,000 ha of crop land, about 50 % of the total area. By the year of 2015, 100 % cover of terracing is essential for soil conservation.

There are various types of terracing and the determination of type depends on slope steepness. Since the detailed design of soil conservation measures is not the study objective, recommendation of its type and design were not considered. Paraná Rural Technical Manual (SEAB, 1989) well describes its type with slope steepness as shown in Table-4.3 and accounts taken for design. Although the design of terracing is out of the study, the impoundment type terrace system with underground outlets is recommended where necessary to minimize sediment yield.

Table-4.3 Type of Terrace with Slope Steepness

Slope Steepness(%)	Type of Terrace Recommended
2 - 8	Broad base terrace
8 - 12	Steep backslope terrace and medium base terrace
12 - 18	Narrow base terrace
18 - 50	Bench terrace

Source: Parana Rural Technical Manual (SEAB, 1989)

Other mechanical measures should be considered for the soil conservation in Paraná are as follows. Their quantitative effectiveness on the reduction of gross erosion and sediment yield is not discussed because its estimation involve the detailed design. However, it is obvious that those measures should be included for the soil conservation strategy.

1) Contour Bunds and Buffer Strips, especially where sandy soil is dominant and terracing does not work well

2) Contouring

During the assessment of current gross erosion, it was assumed that contouring is practiced in the whole crop land. If some land is left without contouring, it should be implemented. Terracing without contouring does not achieve the expected effect on controlling soil erosion.

3) Road Improvement

Main problems associated with roads are induced by the excess runoff generated from road itself because farm roads are usually left unpaved, bare soil surface, and water cannot infiltrate into soil profile due to compacted surface. As a result, farm roads become drainage during the rain and cause severe erosion. The maintenance of roads is often required and is costly. Therefore, the improvement of farm roads with proper surface cover and drainage system is essential.

4) Gully Erosion Control

Gully erosion is induced by the concentration of runoff. Therefore, runoff must be reduced by land use management and controlled by well drainage system in order to suppress gully erosion at the river basin scale. Land use management is mulches, grasses, trees and their combination to decrease flow velocity with surface roughness and increase infiltration. These measures are effective to control surface erosion. In the northwestern region of Paraná, the gully erosion in urban areas is a serious problem due to the improper drainage system. In these areas, drain water from a town must be conducted to several outlets if possible to avoid the concentration of drainage and measures to reduce flow velocity, such as energy dissipator at an outlet, must be applied.

5) Sediment Settlement Pond

For the river basin management, sediment settlement ponds located at downstream end of a field are effective to reduce sediment yield. Eroded soil with runoff is conducted to the pond with drainage system and runoff is retained in the pond to allow sediment settled. Consequently, water with less sediment is drained downstream. Concrete lining ponds are easy to clean sediment settled. This measure is costly and only recommended to where other measures do not satisfy the permissible sediment yield.

4.3.2 Agronomic Measures and Soil Management

The aim of agronomic measures is to increase surface cover and infiltration. As a result, surface runoff is minimized and permissible soil loss is achieved. Since mechanical measures must be combined with agronomic measures as mentioned before, agronomic measures are crucial factors for soil conservation.

The main objectives of soil management are to maintain soil fertility, stabilize aggregate and avoid drainage problem in soil profile. Agronomic measures and soil management interact each other. For example, the maintenance of soil fertility increases the vegetation coverage on soil surface.

Agronomic measures and soil management are all related to C factor; however, since C factor is a local variable, researches on their quantitative effects in Paraná are still ongoing and thus unknown. Table-4.4 shows the gross erosion of a specific rainfall energy with different C factor as an example of effectiveness of agronomic measures and soil management.

Table-4.4 Soil Erosion with Different P Factor

LS=0.896, P=1, K=0.03 unit: ton/ha

R	C								
	0.01	0.10	0.20	0.30	0.40	0.50	0.60	0.80	1.00
5000	1.3	13.4	26.9	40.3	53.8	67.2	80.6	107.5	134.4
8000	2.2	21.5	43.0	64.5	86.0	107.5	129.0	172.0	215.0
10000	2.7	26.9	53.8	80.6	107.5	134.4	161.3	215.0	268.8
12000	3.2	32.3	64.5	96.8	129.0	161.3	193.5	258.0	322.6

R: rainfall factor (MJ•mm/ha•hr•yr), P: support practice factor
LS: slope steepness and length
C: cover and management factor, K: soil erodibility (ton•hr/MJ•mm)

Agronomic measures and soil management vary with crop, rainfall energy, land relief and so on. Therefore, the determination of countermeasures involves the careful evaluation of each factor associated with soil erosion. However, this evaluation is beyond the study objective at strategy level. Common agronomic measures and soil management are summarized hereunder and the detailed is not discussed.

1) proper spacing of crop strips
2) proper crop calendar
3) maintenance of soil fertility with application of fertilizers and green manure
4) intercropping
5) mulching and residue cover
6) permanent vegetation cover
7) stabilization of aggregate

   The larger aggregate is, the more tolerant to erosion.

8) tillage practices

   Soil tillage is practiced to pulverize a hard pan so as to provide a fine seed bed and increase infiltration; however, inadequate application of tillage induces negative effects on soil properties, such as generating a hard pan due to excess operation of heavy machinery, soil erosion due to excess clearing resulting in bare soil surface, and so on. Therefore, the proper management must be guided to farmers.

   In 1972, non tillage method was introduced in Paraná state with the area of 100 ha. According to Derpsch (1991), in 1984 non tillage was applied to 300,000 ha, about 5 % of the total area. At present, the area has expanded to approximately 760,000 ha which covers about 12 % of the crop land. United States Department of Agriculture (1985) estimated that 55 % of the total agriculture land in USA will be applied this tillage system by the year of 2010. Under this circumstance and considering the advantages, non tillage will expand more rapidly in Paraná state (say 50 % by the year of 2015). Main positive effect of non tillage on soil erosion is to maintain surface cover throughout the year. Advantages and disadvantages are summarized below.

Advantages

a) soil loss reduction to 20 % to 1 % compared to those under conventional tillage.

b) less evapotranspiration and more adequate water storage in soil profile

c) Maintenance of favorable physical soil properties, especially for Terra Roxa Estruturada and Latossolo Roxo

d) decrease in excess soil temperature

e) increase in soil biological activities

f) increase in carbon content and phosphorus availability in soil

Disadvantage

a) increase in frost damage

b) higher machinery costs

c) higher herbicide costs

d) more complex weed control

4.3.3. Assessment of Future Soil Erosion with Strategy

As a result of examination of countermeasures, the soil conservation strategy in Paraná state is summarized hereunder and the effect of the strategy was examined by USLE application. To achieve the final goal by the year of 2015, countermeasures of soil erosion above mentioned must be implemented through the close cooperation among persons and authorities concerned.

Soil Conservation Strategy by the year of 2015 are summarized below.

threshold 11 ton/ha·year

essential measures

1) 100 % application of terracing with contouring to crop land and pasture

2) improvement of farm roads with proper drainage

3) 50 % application of non tillage to crop land

4) application of agronomic measures and soil management depending on factors associated with erosion problem

5) proper land use

6) increase forest area

measures if required

1) sediment settlement pond

2) improvement of urban drainage system

3) drainage system with collecting channel, conduit and box at crop land

Since quantitative effects of some measures proposed on soil erosion are difficult to be assessed due to the lack of data, requirement of long term experiment and so on, the future gross erosion was estimated in terms of the following factors whose effects can be evaluated quantitatively. The details are discussed in Appendix-2.

100 % implementation of terracing with contouring to crop land and pasture

50 % implementation of non tillage to crop land where applicable

The result is shown in Table-4.5 with suspended sediment expected. The gross erosion from each river basin is drastically reduced to 32 % to 19 % of the current gross erosion. The rate of reduction varies with different land use of each river basin. Since other measures are not counted in estimation, the result is considered as an underestimation. It means that less gross erosion would be expected than estimated value if the strategy was implemented fully.

Assuming that the sediment delivery ratio does not vary with any soil conservation practices, the future sediment yield was computed. The reduction of suspended sediment load would contribute to better ecosystem and water quality. Consequently, achieving the healthy water environment, high productions of agriculture sector would be maintained.

Table-4.5 Gross Erosion and Suspended Sediment in 1994 and 2015

River Basin	Area (1,000 ha)	Erosion from Whole Basin (1000 ton/year)	Gross Soil Erosion (ton/ha·year)	Sediment Delivery Ratio	AS (1000 ton/year)
		1994			
Cinzas	929.1	33,066	36	0.024	780
Iguacu	5,531.8	154,804	28	0.006	996
Itarare	519.8	2,439	5	0.207	504
Ivai	3,587.9	115,309	32	0.043	4,915
Piquiri	2,470.8	66,328	27	0.039	2,619
Pirapo	500.6	9,387	19	0.037	345
Ribeira	912.9	27,471	30	0.019	520
Tibagi	2,463.5	58,568	24	0.013	764
Average			28		
		2015			
River Basin	Area (1,000 ha)	Erosion from Whole Basin (1000 ton/year)	Gross Soil Erosion (ton/ha·year)	Sediment Delivery Ratio	AS (1000 ton/year)
Cinzas	929.1	6,521	7	0.024	157
Iguacu	5,531.8	45,823	8	0.006	275
Itarare	519.8	678	1	0.207	140
Ivai	3,587.9	29,466	8	0.043	1,267
Piquiri	2,470.8	17,955	7	0.039	700
Pirapo	500.6	2,845	6	0.037	105
Ribeira	912.9	7,229	8	0.019	137
Tibagi	2,463.5	17,195	7	0.013	224
Average			8		

AS: annual suspended sediment
AS for 2015 was computed applying the same SDR for 1994.
Area: River basin area within Parana state

4.3.4 Cost and Benefit

(1) Cost

The costs for terracing in Paraná are available in EMATER as shown in Table-4.6. The costs vary with type of terracing and machinery applied. Impoundment terracing, terraces with underground outlets, is much more expensive than others because of its complexity of construction and larger volume of soil removed. Its use in Paraná is limited despite the fact that impoundment terraces are highly effective for sediment control. Even in next twenty years, its limited use is expected. Therefore, for the calculation sake, 40 US$/ha was adopted to estimate the cost for terracing.

Table-4.6 Cost for Terracing

Terrace Spacing	Type of Terracing	Machinery	Cost (US$/ha)
25 m	Large base terrace	Tractor	32
	Large base terrace	Motor grader	37
	Narrow base terrace	Motor grader	14
	Impoundment	Small bulldozer	121
	Impoundment	Large bulldozer	125
	Impoundment	Loader	93
20 m	Narrow base terrace	Tractor	19
	Impoundment	Small bulldozer	121
	Impoundment	Large bulldozer	125
	Impoundment	Loader	102

Source: EMATER

The cost for non tillage is mainly purchase of planters and herbicides. According to Derpsch et al. (1991), the costs for soybean and corn planters, 6 and 3 rows respectively, range from 4,700 to 7,900 US$, and farmers usually have two kinds of planters, one for narrow space planting and another for medium or wide space planting due to less efficiency of universal machinery. For the calculation sake, the following assumption was made.

1) Average machinery cost is US$ 6,500
2) Machinery lasts ten years. Therefore purchase within the next 20 years will be twice.
3) Universal machinery overcomes its less efficiency. Consequently, farmers have only one machinery.
4) Maintenance costs are negligible.
5) Farmers already adopting non tillage also purchase machinery twice by 2015.
6) The costs for herbicides is not considered.
7) Non tillage is applicable to primary crops, except coffee and pasture.
8) One machinery covers 200 ha planting in accordance with the average area of medium size farmers who are major to practice non tillage.

Area computation for terracing and non tillage is based on area for computation of gross erosion discussed before. The total cost for soil conservation measures in next twenty years is US$ 443 million as shown in Table-4.7. The total figures seem to be not affordable; however, the cost per year would be US$ 22 million if the measures were implemented evenly in next twenty years.

Table-4.7 Cost Estimation of Soil Conservation

Measures	Area involved (1,000 ha)	Area/Machinery (ha)	Number of Machinery Required (1,000 unit)	Unit cost (US$)	Total (million US$)
Terracing	6,022	—	—	40 US$/ha	241
Non tillage	3,147	200	31	6,500 US$/Unit	202

Note: Area involved for non tillage is the total area including ones already applied as of 1991 (760,000 ha).
Area involved for terracing is the area excluding ones already applied as of 1993.

(2) Benefit

Paraná Rural Program has estimated nutrient loss compensated by fertilizers assuming the average soil loss of 20 ton/ha·year and enrichment ratio of 1.0. Consequently, the losses in the whole Paraná state are US$ 60 million per year for nitrogen and US$ 5 million per year for potassium.

If soil conservation measures were implemented evenly in the next twenty years started from 1996 in accordance with the strategy, 28 ton/ha·year (state average) in 1994 would be reduced to 8 ton/ha·year (state average) in 2015. Applying simply the ratio of nutrient loss to average soil erosion, nutrient loss in 1994 and 2015 were compared.

1994	US$ 84 million per year for N	US$ 7 million per year for K
2015	US$ 24 million per year for N	US$ 2 million per year for K

The cost to compensate the nutrient loss will be reduced to 30 % of the current one. This saved cost is considered as the benefit. The state total cost was split into each river basin by means of multiplication of the state total cost with the ratio of annual soil loss from each river basin to the state total. Since the soil conservation will be implemented evenly in the next twenty years, the benefit from each river basin was approximated with the following manner and shown in Table-4.8.

benefit in 1996 = (cost in 1994 - cost in 2015) / 20 years

benefit in 1997 = (cost in 1994 - cost in 2015) / 20 years x 2

benefit in 2015 = (cost in 1994 - cost in 2015) / 20 years x 20

SANEPAR has estimated the annual cost to purify water due to the suspended sediment at US$ 217 thousand. The cost for water purification in 2015 was estimated by a comparison between the total annual suspended sediment in 1994 and 2015 assuming that US$ 217 thousand was spent for water purification in 1994.

1994	US$ 217 thousand
2015	US$ 57 thousand

The cost and benefit for water purification were approximated by the same way as the soil nutrient loss and the result is shown in Table-4.8.

The effect, total cost and benefit by the year of 2015 with the implementation of strategy are summarized in Table-4.8. The benefit is saved capital with soil conservation measures. The total benefits by the year of 2015 are US$ 683 million for fertilizer and US$ 2 million for water purification.

The increase in crop productivity is not analyzed; however, many researches show increase and stabilization of the productivity by means of soil conservation practices. The improvement of soil physical and chemical properties with soil conservation results in high productivity and less inputs, such as fertilizers.

(3) Conclusion

According to the Sectoral Report vol.E Agriculture , the gross income of agricultural sector is 3,955, 4,993 and 5,659 million US$ in the year of 1993, 2005 and 2015, respectively. Annual costs of conservation measures in 2005 and 2015 are 0.44 % and 0.39 % to the gross income. Therefore, the cost is considered as affordable level and lots of capital would be saved.

Although the benefit estimation is very rough, the result shows that soil conservation measures are worth to be implemented and cost can be compensated by capital saved and gained.

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Table-4.8 Effect, Cost and Benefit of Conservation Measures

River Basin	1994		Countermeasures (1,000 ha)		2015		Cost by 2015 (million US$)		Benefit by 2015 (million US$)		
	ASL	AS	Terracing	Non Tillage	ASL	AS	Terracing	Non-tillage	N	K	Purification
Cinzas	33,066	780	384	233	6,521	157	15.4	15	49.50	4.10	0.131
Iguacu	154,804	996	1,935	1,063	45,823	275	77.4	69	201.70	16.80	0.540
Itarare	2,439	504	176	97	678	140	7.0	6	3.30	0.30	0.009
Ivai	115,309	4,915	1,334	565	29,466	1,267	53.4	36	159.50	13.30	0.424
Piquiri	66,328	2,619	964	514	17,955	700	38.6	33	89.70	7.50	0.239
Pirapo	9,387	345	184	80	2,845	105	7.4	5	12.10	1.00	0.032
Ribeira	27,471	520	293	116	7,229	137	11.7	7	37.60	3.10	0.100
Tibagi	58,568	764	751	479	17,195	224	30.0	31	76.60	6.40	0.205
Total	467,372	11,443	6,021	3,147	127,712	3,005	241.0	202.0	630.00	53.00	2.000

ASL: annual soil loss (1,000 ton/year)

AS: annual suspended sediment (1,000 ton/year)

Unit cost: terracing = US$ 40/ha, non tillage = US$ 6,500/machinery

N: Nitrogen, K: Potassium

CHAPTER 5 CURRENT SOIL EROSION IN PILOT RIVER BASINS

Since Iguaçu and Tibagi were selected as pilot river basins, the following study was conducted only for Iguaçu and Tibagi river basins.

5.1 Simulation Model

At the Strategy study, the current and future soil loss from 8 river basins in Paraná was roughly estimated with USLE, Universal Soil Loss Equation. Since the main objectives of USLE application at Strategy is to grasp the magnitude of soil loss, the data with a large division wise was used and analyzed.

USLE was applied to pilot river basins again for the following objectives and Municipality wise data was used to determine each factor in USLE. The data regarding agriculture in 1994 was obtained from EMATER and GIS computation was conducted by SANEPAR based on the IAP satellite imagery analysis (1990 &1994).

1) To identify the location with high degree of soil erosion in order to formulate the soil conservation plan with location priority
2) To evaluate the effectiveness of the soil conservation plan proposed

5.1.1 Data Applied

To identify the landuse of Municipalities in pilot river basins, Iguaçu and Tibagi river basins, SANEPAR conducted GIS computation based on the landuse map resulting from the satellite imagery analysis (IAP, 1990 & 1994). Table-5.1 shows the landuse of river basin average and state average, while the landuse with Municipality wise is shown in Appendix-3.

The satellite imagery analysis is based on the data of 1989 and 1990. Since this is the most recent landuse available, it was adopted throughout the study assuming that the current landuse does not vary from one in 1990.

Table-5.1 Landuse in Iguaçu and Tibagi River Basin

	Total Area (km^2)	Swamp (%)	Sand Bank (%)	Forest (%)	2nd Veg.(%)	Ref. (%)	Pasture (%)	Crop (%)	Others (%)
Iguacu river basin	55,320	—	—	14.3	27.0	1.7	17.6	37.9	1.5
Tibagi river basin	24,630	—	—	3.8	27.6	9.4	18.1	40.1	1.0
Parana State	197,880	0.1	0.2	9.0	26.0	3.2	23.1	37.6	0.8

2nd Veg.: Secondary Vegetation, Ref.: Reforestation
Area of Iguacu river basin is only within Parana state.
Source: SANEPAR GIS Computation based on IAP Satellite Imagery Analysis (1990 & 1994)

Agricultural data as of 1994 was obtained from EMATER database. Since the model requires to characterize the crop land of the landuse classification for each Municipality in pilot river basins, the following Municipality wise data for dominant crops was extracted.

area, productivity, number of farmers involved, area mechanized, area where soil conservation measures are applied, area where non tillage is practiced and productivity with non tillage

There is discrepancy in the total crop area of each municipality between EMATER data and the result of SANEPAR GIS computation. Since the specific landuse of each municipality is identified by GIS computation, EMATER data was adjusted to the result of GIS computation. The data after the adjustment is attached in Appendix-3.

Either topography or slope steepness in pilot river basins is not digitized. Therefore, slope steepness was obtained from the agricultural aptness map available in Agriculture land Aptitude of Paraná (Ministry of Agriculture, 1981). Soil classes and their location were also obtained from the agricultural aptness map. For Tibagi, the agricultural aptness map digitized is available, while for Iguaçu area and location of each aptness class was obtained by means of visual and planimeter assessment.

Other local information necessary for the model was obtained from Erosion and Sediment Model for Paraná, ESPAR, which is currently being developed by Roloff, Federal University of Paraná.

5.1.2 Determination of USLE Factors

Compared to the simulation at the Strategy study, the simulation for pilot river basin was involved in much detail analysis of the data with Municipality wise and some factors of USLE were estimated applying RUSLE, Revised Universal Soil Loss Equation. The formulas to compute annual soil loss in both USLE and RUSLE are same as expressed in equation-1. The difference between them is the determination of factors in equation-1, especially C factor.

$$A = R \cdot K \cdot LS \cdot C \cdot P \qquad \text{..(1)}$$

where A: annual gross erosion (ton/ha)

R: rainfall factor (MJ·mm/ha·hr)

K: soil erodibility (ton·ha·hr/ha·MJ·mm)

LS: slope length and steepness factor (dimensionless)

C: cover and management factor (dimensionless)

P: support practice factor (dimensionless)

Since the above factors in USLE and RUSLE are local dependent variable, the improvement of model requires careful examinations of local data. Roloff, Federal University of Paraná, is currently developing Erosion and Sediment Model for Paraná, ESPAR, based in RUSLE combining with the database of local information. Its development is still on going, a final phase; however, it can be used at least for the determination of USLE factors. Therefore, the model was applied close cooperation with Roloff, especially the determination of K, LS and C factors. Since the description of each factor is mentioned in the section 3.1, only the way to determine USLE factors is discussed below.

(1) R Factor

Rufino et al. (1993) derived the following correlation equation of the rainfall factor, R, with the average monthly and annual rainfall. Their equation was applied to compute the rainfall factor of each Municipality.

$$R = a + b \cdot Rc$$

$$Rc = p^2 / P$$

where R: rainfall factor (MJ·mm/ha·hr)

a, b: coefficient

Rc: rainfall coefficient

p: average monthly rainfall (mm)

P: average annual rainfall (mm)

As a result of the meteorological analysis, Thiessen's polygon diagram was drawn to obtain the mean rainfall depth over area (See Sectoral Report Vol. B, Meteorology, Hydrology and Surface Water Resources). Identifying which Thiessen's polygon each Municipality belongs to, the average monthly and annual rainfall was obtained from meteorological stations assigned to Thiessen's polygons.

Based on the rainfall factor division determined by Rufino et al. (1993), Figure-3.1, a correlation equation for each Municipality was obtained. Selected meteorological stations and the result of R factor computation are shown in Appendix-4.

(2) K Factor

Roloff and Denardin (1994) developed regression equations to estimate K for soils in Paraná, based on existing soil survey data. K factors for soils in Paraná were determined by the following regression equations using the database of ESPAR.

$$Ko = 0.0437Mm^{0.5} - 0.035Fs - 0.0111As$$

$$Kt = 0.0917Mm^{0.5} - 0.0526Fs + 0.0176Af$$

$$Kd = 0.1038Mm^{0.5} - 0.0454As$$

$$Ks = 0.0049P + 0.0331Mm^{0.5}$$

where Ko: K for soils of oxic B horizon (ton·ha·hr/ha·MJ·mm)

Kt: K for soils of textural B horizon (ton·ha·hr/ha·MJ·mm)

Kd: K for other deep soils (ton·ha·hr/ha·MJ·mm)

Ks: K for other shallow soils (ton·ha·hr/ha·MJ·mm)

Mm: silt fraction (g/g)

Fs: iron fraction (g/g)

As: fraction of aluminum oxides extracted by sulfuric acid (g/g)

Af: amount of fine sand (g/g)

P: profile permeability code in Agriculture handbook No. 537 (Wishmeier and Smith, 1978)

Soil classes and their locations in pilot river basins were obtained from the agricultural aptness map available in Agricultural Land Aptitude of Paraná (Ministry of Agriculture, 1981). Dominant soils of each aptness class were read and an area weighted average of K factors were computed for each aptness class. The result is shown in Appendix-4.

(3) L and S Factors

The following equations in RUSLE different from USLE were applied to compute L and S factors.

$$L = \left(\lambda / 22.1\right)^{m}$$

$$m = \beta / (1 + \beta)$$

$$S = 10.8 \sin\left(\theta\right) + 0.03 \qquad \textit{steepness} < 9\%$$

$$S = 16.8 \sin\left(\theta\right) - 0.50 \qquad \textit{steepness} \geq 9\%$$

where λ : slope length (m)

β : a ratio of rill and interrill erosion

θ : slope angle

Slope steepness in pilot river basins were estimated from the agricultural aptness map available in Agricultural Land Aptitude of Paraná (Ministry of Agriculture, 1981). Since dominant soils in each aptness class have certain range of slope, taking a mid-point of the range S factors for dominant soils were computed. Successively, an area weighted average of S factors for each aptness class was computed.

L factors were computed assigning the typical slope length to each aptness class. The result is shown in Appendix-4.

(4) C Factor

Compared to USLE, the major advantage of RUSLE is the determination of C factor for crop land as a function of the effect of prior land use, canopy cover, surface cover and surface roughness. Since C determination with RUSLE requires crop and tillage database, agricultural data from EMATER and ESPAR was used.

Soil Loss Ratio, SLR, in RUSLE is computed by the following equation. SLR is the soil loss for a certain condition at a certain time and varies throughout the year as soil and cover conditions change. Combined SLRs with rainfall erosivity values for each crop stage are summed over an entire growth rotation in order to determine C factor, which is average annual value.

$$SLR = PLU \cdot CC \cdot SC \cdot SR$$

where *PLU*: effect of prior land use, *CC*: canopy cover, *SC*: surface cover, *SR*: surface roughness

Although the original RUSLE computes these subfactors using crop and tillage database, there is no such database available in Paraná. Therefore, the model was modified to compute each subfactor with the available data in Paraná as follows.

$$PLU = Cf \cdot \exp\left(-c \cdot Bu\right)$$

where *Cf*: effect of tillage induced surface density changes on soil erosion, *Bu*: amount of live and dead roots, and incorporated residue in the top 2.5 cm of soil (ton/ha), *c*: effectiveness of incorporated residue in reducing soil erosion

Cf varies from 1.0 for freshly tilled conditions to 0.45 after 7 years of no soil disturbance. Bu is computed by the above ground biomass, roots left by the previous crop and their decomposition based on average daily temperature and rainfall. The common assumption for c is the mixed rill-interrill resulting in c value of 3.18 ha·cm/ton.

$$CC = 1 - Fc \cdot \exp\left(-0.0304 \cdot H\right)$$

where *Fc*: fraction of canopy cover on soil surface obtained from leaf area index computed by the accumulated heat units, solar radiation, and day length, *H*: distance that raindrops fall after striking the canopy

$$SC = \exp\left[-b \cdot Sp \cdot \left(0.24 / Ru\right)^{0.08}\right]$$

where *b*: effectiveness of surface cover in reducing soil erosion, 0.035 for typical crop land, *Ru*: surface roughness (cm), *Sp*: percentage of soil surface covered by residue

Sp is computed by the following equation.

$$Sp = \left[1 - \exp\left(-\alpha \cdot Bs\right)\right] \cdot 100$$

where α: ratio of area covered by a piece of residue to mass of that residue (ha/kg), *Bs*: dry weight of residue on the soil surface (kg/ha)

Bs is computed by the yield and harvest index of previous crops, which is the above ground biomass and roots left by the previous crops. Their decomposition is estimated by the average temperature and rainfall.

$$SR = \exp\left[-0.26\left(Ru - 0.61\right)\right]$$

$$Ru = 0.61 + \left[Dr\left(Ri - 0.61\right)\right]$$

where *Dr*: roughness decay coefficient estimated using rainfall data, *Ri*: initial roughness (cm)

For perennial crops, reforestation, fallow or recent cut forest, C factor is estimated with the subfactor method developed by Dissmeyer and Foster (1981). The data required is cover by crop canopy and residue, type of soil surface, time after soil disturbance and so on.

For permanent pasture and forest, the tables in USLE (Wischmeier and Smith, 1978) is available to determine C factor because seasonal variation of surface cover is small and land is well conserved.

Based on the above equations, local dependent variable (C factors) in pilot river basins were determined by ESPAR (under the development by Roloff, Federal University of Paraná) using its own database and inputting the necessary information obtained from EMATER. C factor for each landuse in each Municipality was determined and shown in Appendix-4.

(5) P Factor

P factors were determined from the tables in USLE (Wischmeier and Smith, 1978). Three types of P factors are used throughout the simulation.

1) a value of 1.0 for land other than crop land, such as forest, reforestation and secondary vegetation

2) a value of 0.8 for crop land defined not conserved by EMATER because farmers there practice at least crop rows across the water flow but not exactly on contour

3) a value in combination of 0.6, which accounts contouring, and 0.05, which accounts terracing, for crop land defined conserved by EMATER

5.2 Result of Simulation

5.2.1 Iguaçu River Basin

Current gross soil loss estimated for each landuse classification in Iguaçu river basin is shown in Table-5.2 with municipality wise. The average soil loss over municipality is the highest in Santa Lucia, 99.6 ton/ha·year, and the lowest in Ceu Azul, 0.8 ton/ha·year. This large range of the average soil loss is due to the interaction of many factors, such as landuse, rainfall erosivity, soil erodibility, topography, cultivation method, and so on; however, the different soil loss between Santa Lucia and Ceu Azul is mainly due to the difference in landuse. In Ceu Azul, 87 % of the municipality area is preserved for the natural forest, while in Santa Lucia 64 % of its area is currently used as crop land.

In Table-5.2, it is obvious that soil loss vary with the different landuse. Soil loss from crop land is the highest, while one from the natural forest is the lowest. Since soil loss increases as soil surface is disturbed, it is necessary to apply the proper soil conservation measures to crop land.

The average soil loss of Municipalities was classified from low to high. Low means soil loss less than 10 ton/ha·year, Medium is between 10 and 20 ton/ha·year and High is more than 20 ton/ha·year. As shown in Figure-5.1, the most of area with high soil erosion is located on the left side in the downstream of Iguaçu river basin due to high rainfall erosivity and large crop area, while soil loss on the right side in the downstream is low because of the large area of forest preserved.

Figure-9.1 shows the location of forest and reforestation in Iguaçu river basin. Overlapping Figure-5.1 with Figure-9.1, the effect of landuse on soil erosion is distinct. The larger the area of forest and reforestation is, the lower the average soil loss over municipality is.

The soil loss from crop land ranges between 146.0 and 1.9 ton/ha·year depending on the spatial variation of rainfall erosivity, soil erodibility, topography, application of soil conservation measures, cultivation method and so on. Municipalities whose soil loss from crop land exceeds 100 ton/ha·year are Barracao, Boa Esperanca do Iguaçu, Campo Largo, Cantagalo, Honorio-Serpa, Itapejara D'Oeste, Nova Esperanca do Sudoeste, Nova Laranjeiras, Salgado Filho and Santa Lucia. The factors inducing the high soil loss in these municipalities are mainly the expansion of crop land to the unsuitable area where land is steep and soil is susceptible to soil erosion, and low application of soil conservation measures; however, they vary with location. For example, the high soil loss in Boa Esperance do

Iguaçu is mainly due to high soil erodibility (Litolico) and steep land, while one in Campo Largo is due to low application of soil conservation measures (1.6 % of the crop area).

Municipalities whose soil loss from crop land is less than 10 ton/ha·year are Ceu Azul, Guarapuava, Ibema, Mariopolis, Matelandia, Palmas, Palmeira and Porto Vitoria. The application of soil conservation measures in these municipalities is generally high, more than 80 %, except Palmas (66.3 %), Palmeira (76.2 %) and Porto Vitoria (59.5 %). Other reasons for low soil loss are low rainfall erosivity and low soil erodibility.

Table-5.2 Current Gross Soil Loss in Iguaçu River Basin

Unit: ton/ha/year

No.	Municipality	Area	1994						No.	Municipality	Area	1994					
		(km2)	Forest	2nd Veg.	Ref.	Pasture	Crop	Average			(km2)	Forest	2nd Veg.	Ref.	Pasture	Crop	Average
I-001	Campina Grande do Sul	79.2		3.2	1.3	1.6	19.0	4.6	I-052	Manopolis	232.1	0.3	2.9		3.4	2.8	2.9
I-002	Quatro Barras	99.5	0.1	4.6	1.5	6.0	14.3	6.6	I-053	Vitorino	326.1	0.1	1.4		4.1	53.7	29.7
I-003	Piraquara	171.9	0.2	4.7		11.4	24.3	10.7	I-054	Renascenca	434.7	0.3	7.1	3.2	4.0	18.1	11.2
I-004	Sao Jose dos Pinhais	674.2	0.1	3.7	1.3	7.4	19.9	11.8	I-055	Bom Sucesso do Sul	135.3		7.8		2.3	30.6	18.1
I-005	Colombo	127.6		1.5		1.5	18.5	4.0	I-056	Itapejara D'Oeste	246		9.5		2.4	102.3	57.2
I-006	Pinhais	98.2		0.5		1.6	18.6	10.7	I-057	Vere	345.6		9.5		24.2	51.2	36.9
I-007	Almirante Tamandare	189.3		4.0		5.8	19.2	7.7	I-058	Sao Joao	408.9	0.3	10.0		24.0	26.1	23.6
I-008	Curitiba	431.7		0.6		1.9	16.3	8.6	I-059	Sulina	158.5		10.1		26.3	79.8	53.3
I-009	Campo Largo	297.2		3.8	1.6	13.1	114.2	65.0	I-060	Saudade do Iguacu	147.8	0.3	7.8		20.6	27.3	21.8
I-010	Araucaria	503.7		1.7		1.5	22.9	13.8	I-061	Rio Bonito do Iguacu	459.3	0.2	0.8		7.0	45.8	6.8
I-011	Fazenda Rio Grande	110.9		0.5		1.7	19.1	10.8	I-062	Nova Laranjeiras	578.8	0.3	6.1	2.6	19.4	101.0	19.6
I-012	Mandirituba	392.3		3.3	1.1	10.2	16.5	11.3	I-063	Guaraniacu	495	0.3	10.1		28.2	82.7	32.4
I-013	Tijucas do Sul	422.6	0.2	3.1	1.5	4.0	18.4	5.8	I-064	Quedas do Iguacu	1192.9	0.2	0.7	0.2	5.4	28.1	7.0
I-014	Balsa Nova	319.7		2.2	1.1	2.0	29.7	8.3	I-065	Sao Jorge do Oeste	385.1	0.3	10.1		14.1	45.0	28.5
I-015	Contenda	222.2		3.3		4.2	30.2	18.7	I-066	Cruzeiro do Iguacu	96.6	0.3	9.1		11.4	55.4	34.1
I-016	Quitandinha	419.4	0.1	3.3	1.1	10.9	23.8	14.4	I-067	Boa Esperanca do Iguacu	249.4	0.3	10.1		33.7	120.9	77.1
I-017	Agudos do Sul	259.6	0.2	4.6	1.7	14.5	60.9	35.6	I-068	Dois Vizinhos	372.7		9.5		14.6	38.8	27.2
I-018	Pien	261.7	0.1	3.3	1.1	10.9	34.5	19.4	I-069	Eneas Marques	234.7		9.5		31.8	72.8	42.4
I-019	Rio Negro	603.2		4.3	1.7	12.4	33.1	11.0	I-070	Francisco Beltrao	696.7	0.3	9.5		7.3	52.9	31.5
I-020	Campo do Tenente	314	0.2	4.7	1.9	5.5	17.3	9.8	I-071	Marmeleiro	449.9	0.3	9.5	3.2	4.0	17.7	12.6
I-021	Lapa	2203.9	0.2	3.8	1.9	2.5	11.9	6.7	I-072	Flor da Serra do Sul	94.7		1.0		3.5	45.6	23.9
I-022	Porto Amazonas	153		1.5	0.5	5.1	19.2	8.1	I-073	Barracao	386.3		9.5		31.8	107.7	62.5
I-023	Palmeira	273.4	0.1	2.5	0.8	2.0	3.5	2.8	I-074	Salgado Filho	506.4		9.5		12.0	127.2	29.7
I-024	Sao Joao do Triunfo	708.1	0.1	2.6	0.5		17.8	4.9	I-075	Santo Antonio do Sudoeste	313.8		9.2		22.9	53.9	37.9
I-025	Antonio Olinto	482.5	0.2	2.7			29.6	12.0	I-076	Pranchita	297.1		8.6		10.5	37.3	23.8
I-026	Sao Mateus do Sul	1332.8	0.1	1.5	0.9		26.0	9.7	I-077	Pinhal de Sao Bento	107.6		7.8		9.1	46.6	14.0
I-027	Reboucas	498.9	0.1	4.0			44.5	27.5	I-078	Ampere	307.9		9.2		5.6	37.7	19.6
I-028	Irati	408.1	0.1	4.2	0.9		56.7	32.2	I-079	Nova Esperanca do Sudoeste	176.9	0.3	9.5		31.8	141.4	86.2
I-029	Rio Azul	642.6	0.0	3.6		14.8	51.3	26.6	I-080	Salto do Lontra	336.9	0.3	9.5		14.6	45.6	28.6
I-030	Mallet	672.8	0.1	4.7			77.2	34.4	I-081	Santa Izabel do Oeste	330.5	0.3	9.7	3.2	27.1	65.8	41.9
I-031	Paulo Frontin	377.5	0.0	0.7	0.3		12.1	7.1	I-082	Nova Prata do Iguacu	333	0.3	10.1		31.6	36.3	31.2
I-032	Paula Freitas	417	0.0	0.8	0.3		19.9	9.1	I-083	Perola do Oeste	330.1	0.3	9.7		24.4	79.8	50.5
I-033	Uniao da Vitoria	773.9	0.1	5.7		2.9	17.1	6.2	I-084	Planalto	337.1	0.0	9.7		32.2	43.3	35.9
I-034	Porto Vitoria	220.2	0.2	6.9		0.0	8.2	6.2	I-085	Realeza	351.9	0.3	9.7		29.4	50.3	40.2
I-035	General Carneiro	1063.7	0.2	5.0		2.6	22.7	7.4	I-086	Capanema	403.9	0.3	9.7		32.2	73.0	56.2
I-036	Bituruna	1209.7	0.2	5.1		2.3	24.3	7.6	I-087	Tres Barras do Parana	521.7	0.3	10.1	3.4	3.3	14.7	10.4
I-037	Cruz Machado	1500.5	0.2	5.9		2.3	24.5	12.1	I-088	Catanduvas	593.9	0.3	2.2	3.4	10.4	28.3	14.7
I-038	Inacio Martins	879.9	0.2	1.4		2.6	27.5	7.5	I-089	Ibema	148.3	0.3	8.0	3.4	10.6	5.3	7.2
I-039	Guarapuava	3402.7	0.3	7.4	2.6	4.7	1.9	3.2	I-090	Cascavel	1198.9	0.3	7.1	3.4	2.8	12.5	8.7
I-040	Pinhao	2875.2	0.3	4.2		2.5	14.1	6.5	I-091	Boa Vista da Aparecida	232.2		10.0		11.5	26.2	19.2
I-041	Palmas	3125.5	0.3	7.7		4.3	9.7	5.1	I-092	Capitao Leonidas Marques	279.8	0.3	9.7		25.7	29.5	26.2
I-042	Clevelandia	708.4	0.3	3.9		2.8	34.6	18.1	I-093	Santa Lucia	137.1	0.3			32.2	137.3	99.6
I-043	Honorio-Serpa	806.6	0.3	8.0		9.6	110.8	53.3	I-094	Lindoeste	273.2	0.3	10.1		26.9	88.6	59.5
I-044	Mangueirinha	801.3	0.3	7.8		14.3	13.2	10.4	I-095	Santa Tereza do Oeste	235.5	0.3	10.1	3.4	10.8	11.6	10.4
I-045	Candoi	999.8	0.3	7.8		24.6	28.3	19.1	I-096	Ceu Azul	937.2	0.2	2.2		7.4	5.9	0.8
I-046	Cantagalo	774.1	0.3	3.5		18.5	146.0	62.5	I-097	Matelandia	601.4	0.2	2.3		6.7	5.9	2.2
I-047	Virmond	198.4	0.1	3.7		26.1	68.2	39.0	I-098	Medianeira	621.1	0.2	2.4		6.7	14.3	5.6
I-048	Laranjeiras do Sul	1052.7	0.2	5.4		20.2	83.3	38.6	I-099	Sao Miguel do Iguacu	455.7	0.3	8.2	0.0	9.6	32.0	17.3
I-049	Chopinzinho	992.5	0.1	7.4	0.7	19.5	22.5	16.8	I-100	Santa Terezinha de Itaipu	162.1	0.0	0.7		3.9	16.7	10.2
I-050	Coronel Vivida	681.5	0.3	9.9	3.3	15.2	66.5	35.7	I-101	Foz do Iguacu	312.2	0.1	3.1		8.6	32.9	13.2
I-051	Pato Branco	570.2	0.3	3.7		4.1	73.3	34.9		Total	55776					Average	17.8

Area: = Total Area of Municipality - Area of Others in Landuse Classification   2nd Veg.: Secondary Vegetation, Ref.: Reforestation

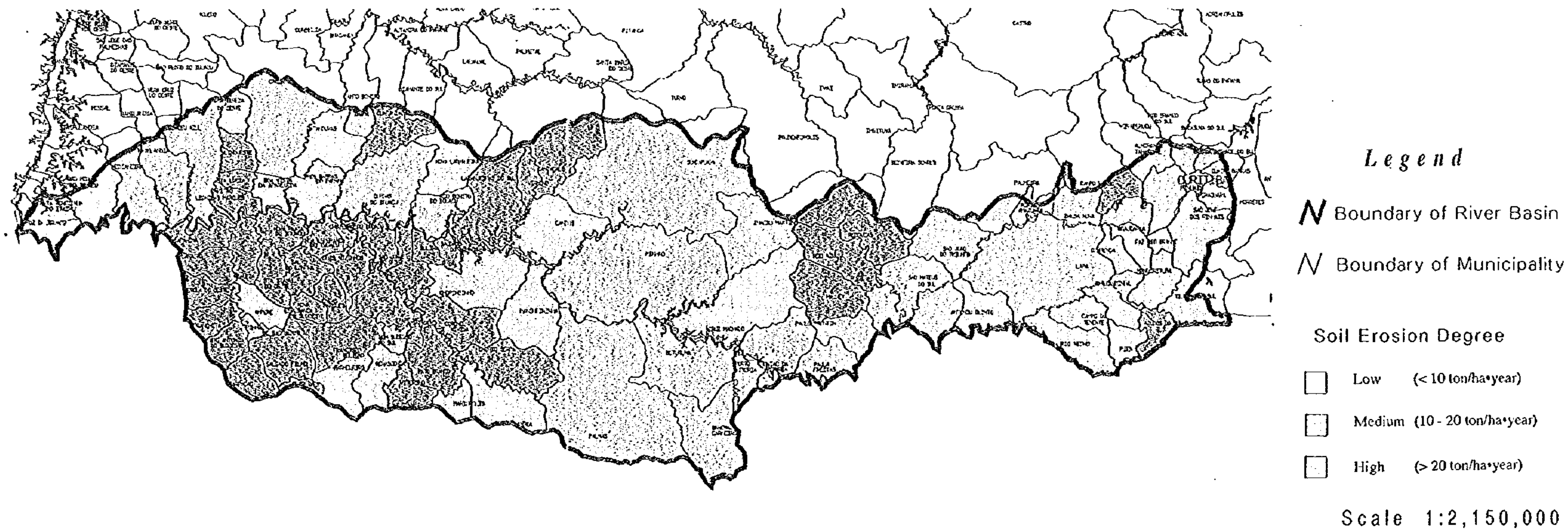


Figure-5.1 Local Variation of Soil Erosion in Iguaçu River Basin

5.2.2 Tibagi River Basin

Current gross soil loss estimated for each landuse classification in Tibagi river basin is shown in Table-5.3 with municipality wise. The average soil loss over municipality is the highest in Sao Jeronimo da Serra, 92.8 ton/ha·year, and the lowest in Telemaco Borba, 1.8 ton/ha·year. This large range of the average soil loss is due to the interaction of many factors, such as landuse, rainfall erosivity, soil erodibility, topography, cultivation method, and so on; however, the different soil loss between Sao Jeronimo da Serra and Telemaco Borba is mainly due to the difference in landuse. In Telemaco Borba, 82 % of the municipality area is reforested, while in Sao Jeronimo da Serra 71 % of its area is currently used as crop land.

The magnitude of soil loss depends on the vegetation on soil surface. As shown in Table-5.3, soil loss from crop land is the highest followed by one from pasture. The proper soil conservation measures are essential to crop land where soil surface is disturbed periodically with cultivation.

The average soil loss of municipalities was classified from low to high and shown in Figure-5.2. The upstream of Tibagi river basin is classified in low soil loss because of high rate of reforestation, while soil loss on the right side in the downstream is high due to the large expansion of crop land with the low coverage of soil conservation measures.

Figure-9.2 shows the location of forest and reforestation in Tibagi river basin. Comparing Figure-5.2 with Figure-9.2, the effect of reforestation on suppression of soil erosion is obvious.

The soil loss from crop land ranges between 128.0 and 0.1 ton/ha·year depending on the spatial variation of rainfall erosivity, soil erodibility, topography, application of soil conservation measures, cultivation method and so on. Municipalities whose soil loss from crop land exceeds 100 ton/ha·year are Sao Jeronimo da Serra and Sapopema. The main factor inducing the high soil loss in these municipalities is the expansion of crop land to the unsuitable area where slope steepness is high and soil is susceptible to soil erosion.

In almost half of municipalities in Tibagi river basin, soil loss from crop land is less than 10 ton/ha·year. One of the reasons is the high implementation of soil conservation measures. For example, soil conservation is practiced more than 90 % of crop land in Castro, Maua da Serra and Sertaneja. As a result, soil loss from these crop land is less than 2 ton/ha·year.

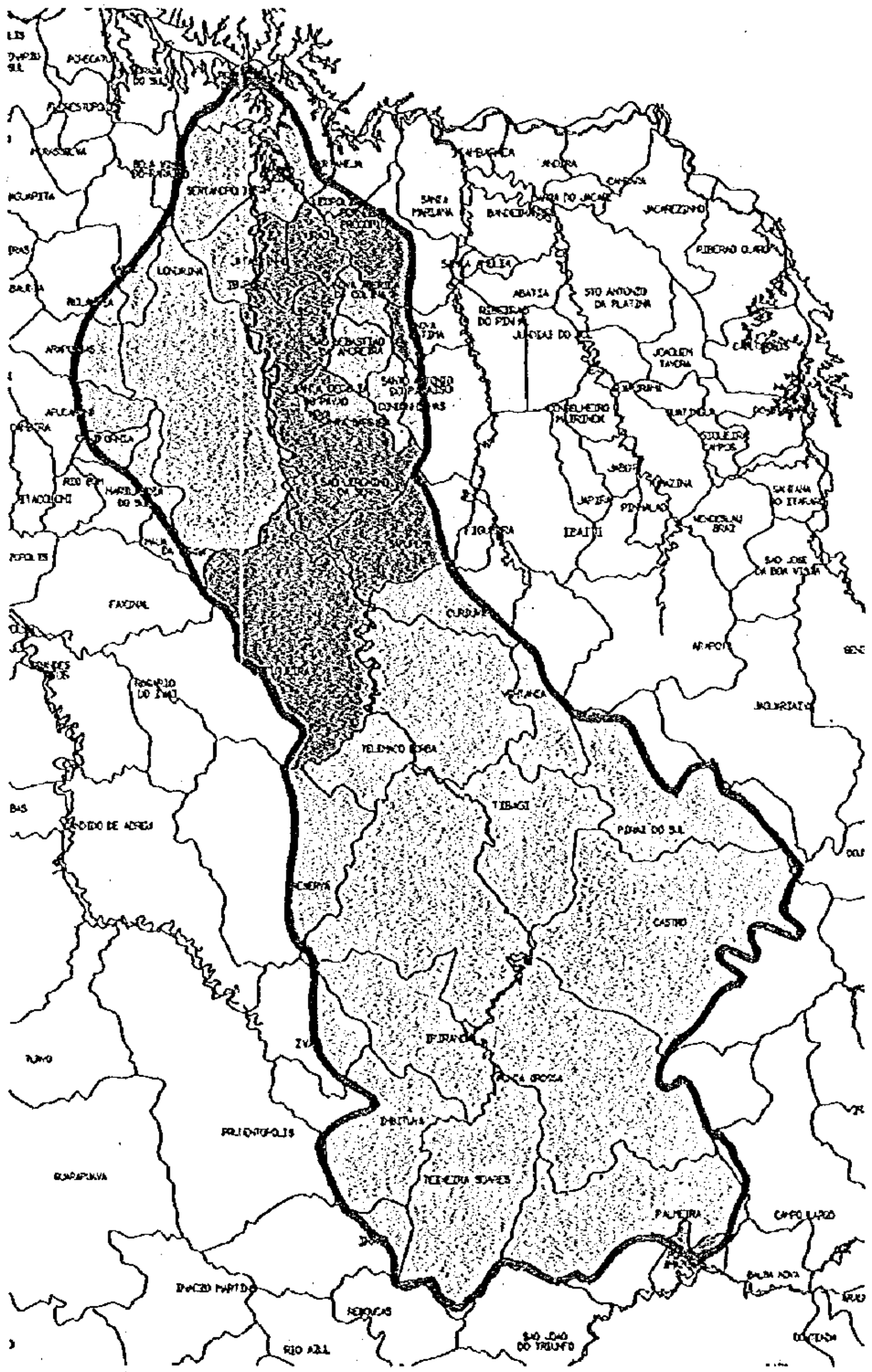
Dominant crops in Tibagi river basin are soybean and maize, which covers 44.4 % and 39.3 % of the total crop area, respectively. Since the average implementation rate of soil conservation is 86.9 % for soybean and 57.4 % for maize in Tibagi river basin, the soil loss from crop land is low compared to Iguaçu river basin.

Table-5.3 Current Gross Soil Loss in Tibagi River Basin

Unit: ton/ha•year

No.	Municipality	Area (km2)	1994 Forest	2nd Veg.	Ref.	Pasture	Crop	Average
T-001	Porto Amazonas	53.8		3.1		11.4	45.9	23.4
T-002	Palmeira	1227.4	0.2	3.1	1.0	2.7	4.9	3.7
T-003	Teixeira Soares	1303.5	0.0	0.7	0.2	2.3	9.4	3.4
T-004	Irati	139.6	0.2	4.8	1.7		16.6	11.4
T-005	Imbituva	811.3	0.2	1.5	0.5	2.4	7.2	2.9
T-006	Ipiranga	932	0.1	1.1	1.5	2.3	11.3	4.6
T-007	Ponta Grossa	1870.8	0.2	1.5	1.1	2.1	4.2	2.9
T-008	Castro	2278.4	0.2	3.9	1.7	1.9	1.1	2.2
T-009	Ivai	212.2	0.2	3.2		2.4	18.7	8.6
T-010	Reserva	555.9	0.1	6.1	1.4	4.1	21.5	11.8
T-011	Tibagi	2926.6	0.2	3.1	2.0	4.3	2.1	2.9
T-012	Pirai do Sul	965.2	0.2	4.3	2.1	2.4	10.0	4.7
T-013	Ventania	380.1	0.2	4.5	2.0	4.5	3.1	3.4
T-014	Telemaco Borba	1625.3		3.1	0.5	10.3	13.9	1.8
T-015	Ortigueira	1588.5	0.2	5.3	1.8	16.3	46.9	24.1
T-016	Curiuva	361.8	0.1	0.8	0.3	3.6	26.4	10.1
T-017	Sapopema	531.9	0.2	5.3		17.5	113.1	51.7
T-018	Sao Jeronimo da Serra	851.3	0.2	5.5		7.9	128.0	92.8
T-019	Maua da Serra	48	0.2	6.9		15.9	0.1	6.6
T-020	Marilandia do Sul	152.2	0.3	4.0		9.4	4.5	4.2
T-021	California	97.2	0.3	2.5		6.1	27.3	8.3
T-022	Apucarana	182.2	0.2	4.1		7.8	33.6	15.5
T-023	Arapongas	191.9	0.1	2.3		7.8	9.5	5.7
T-024	Londrina	2095.6	0.2	4.1		5.8	5.7	4.7
T-025	Nova Santa Barbara	112.2		2.5		8.0	15.2	14.1
T-026	Santa Cecilia do Pavao	68.5					32.1	32.1
T-027	Santo Antonio do Paraiso	151.9	0.2	6.0		7.6	6.7	6.8
T-028	Congonhinhas	104.6		5.6		7.4	8.2	7.9
T-029	Nova Fatima	83.5		6.6		22.0	37.1	29.8
T-030	Sao Sebastiao da Amoreira	217.4	0.2	2.0		5.1	3.1	3.3
T-031	Assai	450.5	0.3	7.8		9.4	32.2	28.2
T-032	Nova America da Colina	133.3		7.0		21.6	14.1	15.4
T-033	Cornelio Procopio	336.7	0.2	6.6		17.8	37.3	25.8
T-034	Urai	209.6	0.3	7.8		26.0	25.2	25.0
T-035	Jataizinho	199.1	0.3	7.8		26.0	41.4	34.2
T-036	Ibipora	295.4		6.2		5.7	7.1	6.8
T-037	Rolandia	57.4		1.5			5.5	4.1
T-038	Cambe	143.5	0.0	1.8			7.1	5.3
T-039	Sertanopolis	478.9	0.3	5.8		5.5	5.7	5.7
T-040	Rancho Alegre	187.4		7.5			2.4	2.4
T-041	Leopolis	68.9	0.3	7.8		26.0	16.0	16.4
T-042	Sertaneja	226.7	0.1	1.7			1.9	1.9
T-043	Primeiro de Maio	142.8		4.7			2.2	2.7
	Total	25051					Average	10.9

Area: = Total Area of Municipality - Area of Others in Landuse Classification
2nd Veg.: Secondary Vegetation, Ref.: Reforestation



Legend

Boundary of River Basin

Boundary of Municipality

Soil Erosion Degree

- Low (< 10 ton/ha•year)
- Medium (10 - 20 ton/ha•year)
- High (> 20 ton/ha•year)

Scale 1:1,750,000

Figure-5.2 Local Variation of Soil Erosion in Tibagi River Basin

5.2.3 Evaluation of Model

Current gross soil losses estimated for Iguaçu and Tibagi river basin at the Master plan study deviates from ones at the Strategy study. The average soil losses from Iguaçu and Tibagi river basin are 28 ton/ha·year and 24 ton/ha·year respectively at the Strategy study, while ones at the Master plan study is 18 ton/ha·year and 11 ton/ha·year, respectively. This discrepancy is mainly due to:

1) difference in scale of data

The Strategy study adopted agricultural data with EMATER division wise, which splits Paraná in 20 regions, while the Master plan study adopted agricultural data with Municipality wise in order to specify the crop land (the land use classification) with cropping pattern, tillage and cultivation methods, extension of soil conservation and so on.

2) difference in scale of analysis

The data analysis for the determination of USLE factors was conducted by EMATER division wise at the Strategy study, while USLE factors were determined for the specific land use in each Municipality at the Master plan study.

The accuracy of the model should be examined through the comparison between the result computed and real data; however, in Paraná neither USLE nor RUSLE has been tested enough. Since the USLE model at the Master plan study was involved in the detail analysis of data to compute factors of USLE, the results in Table-5.2 and Table-5.3 were adopted to propose the Master plan. The result of USLE at the Strategy study is considered to have at least enough accuracy to compare the magnitude of soil loss among river basins in Paraná.

5.3 Suspended Sediment Measurement at Micro River Basins

Suspended sediment measurement and analysis of river bed material were conducted by means of subcontracting with a local consultant in February, March and May, 1995, in order to grasp the effect of different landuse on soil erosion. Sites selected and period of measurement are shown in Table-5.4.

Table-5.4 Sites for Suspended Sediment Measurement

River Basin	Location	Micro-river Basin	Area Involved (ha)	Conditions	Measurement Period
Iguacu	Saudades	Paz	880	crop land with severe erosion	Feb.27 - Mar.9, '95
	Sulina	Areiao	1,425	crop land with soil conservation measures	Feb.27 - Mar.9, '95
	Mangueirinha	Cachoeirinha	1,350	forest with slash-burn agriculture	Feb.28 - Mar. 10, '95
Tibagi	Jataizinho	(Tibagi main stream)	2,195,500	mixture of different land use	Feb. 13 - Feb. 24 & May 13 - May 17, '95
	Congoinhas	Uru	908	crop land with soil conservation measures	Feb.15 - Feb. 25 & May 13 - May 17, '95
	Assai	Limoeiro	1,103	crop land with severe erosion	Feb. 14 - Feb. 24 & May 13 - May 17, '95
	Londrina	Godoy	86	forest	Feb. 15 - Feb. 24 & May 13 - May 17, '95

Three micro river basins with different landuse (forest, land with severe soil erosion and land conserved) were selected from each pilot river basin, Iguaçu and Tibagi river basins. During the site selection, it was tried to select sites where the landuse is as much unity as possible and where are as close as possible to other sites in each pilot river basin in order to distinguish the landuse effect on soil erosion clearly eliminating the spatial variation of natural conditions, such as climate, soil properties and so on. However, in reality, it was difficult to find sites with such conditions. Table-5.5 shows the landuse and implementation rate of soil conservation in each micro river basin.

Table-5.5 Landuse and Rate of Soil Conservation for Micro River Basins

River Basin	Micro-river Basin	Area Involved (ha)	Conditions	Landuse (%)				Soil Conservation Measures, (% to crop land area)
				Crop	Pasture	Forest	Others	
Iguacu	Paz	880	crop land with severe erosion	27	56	5	12	0
	Areiao	1,425	crop land with soil conservation measures	61	21	6	12	25 (terracing), 11 (buffer strips)
	Cachoeirinha	1,350	forest with slash-burn agriculture	10	--	70	20	0
Tibagi	Limoeiro	1,103	crop land with severe erosion	82	4	14	—	0
	Uru	908	crop land with soil conservation measures	65	35	—	—	87 (terracing)
	Godoy	86	forest	—	—	100	—	—

Source: EMATER

The site information and result of suspended sediment measurement are attached in Appendix-5. Besides, the result of particle size analyses for suspended sediment if possible and river bed material is also shown in Appendix-5.

During the suspended sediment measurement in May, there was no rain at all. Therefore, the data in May was excluded from the analysis and only the result of measurement is shown in Appendix-5.

5.3.1 Result of Measurement

As shown in Figure-5.3 for Iguaçu river basin and Figure-5.4 for Tibagi river basin, the effect of landuse on suspended sediment yield is obvious. For both river basins, Godoy and Cachoeirinha micro river basins (preserves of natural forest) show always low suspended sediment load, while Paz and Limoeiro micro river basins, where most of land is cultivated with low implementation of soil conservation, show the highest load most of time.

Although Areiao micro river basin is characterized as conserved micro river basin, the applications of terrace and buffer strips are only 25 % and 11 % of the total crop land, respectively. Thus, suspended sediment load from Areiao is slightly lower than one from Paz micro river basin, where the implementation of soil conservation is 0 %.

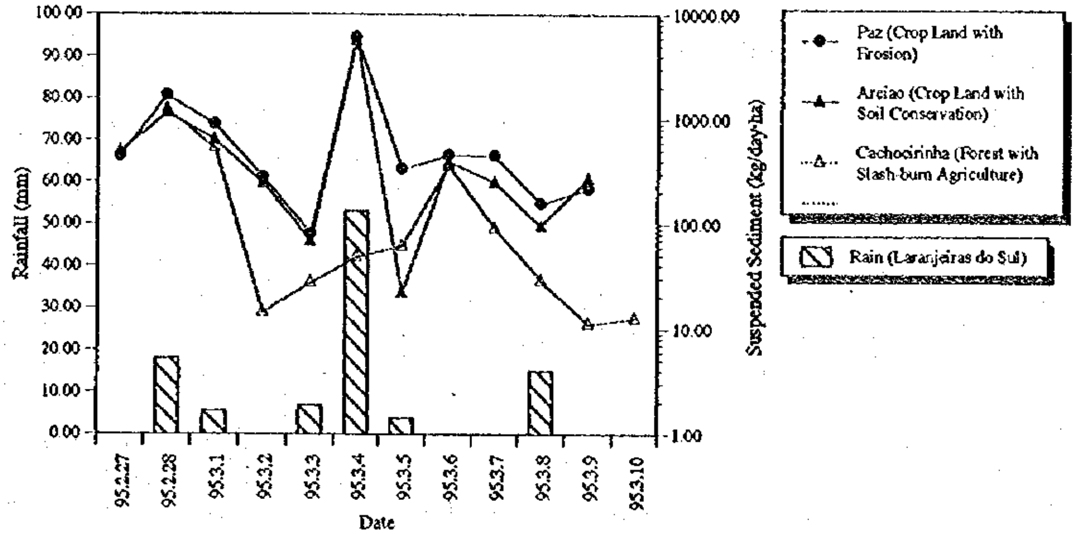


Figure-5.3 Suspended Sediment Load at Micro River Basins in Iguaçu River Basin

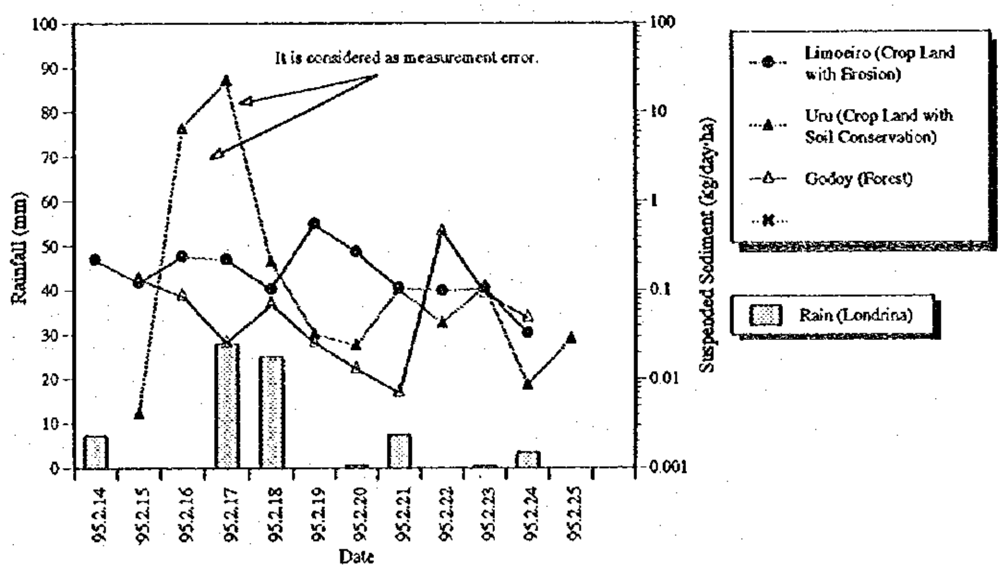


Figure-5.4 Suspended Sediment Load at Micro River Basins in Tibagi River Basin

In Uru micro river basin, the soil conservation is well practiced and terracing cover 87 % of the total crop land; however, the suspended sediment load deviates from the general rule, which sediment yield decreases with the implementation of soil conservation. Especially, February 16 and 17, 1995, suspended sediment from Uru micro river basin is much higher than Limoeiro micro river basin where the implementation of terracing is 0 %. This is considered as error during the measurement. The specific reason is unknown; however, unusual disturbance of soil surface , such as road construction, might have happened at the upstream of the measurement site. Excluding February 16, 17 and 18, 1995, suspended sediment load from Uru micro river basin follows the general rule.

5.3.2 Soil Loss Simulation

Applying USLE and RUSLE, soil loss from micro river basins during the suspended sediment measurement was computed. Data necessary for the determination of USLE factors was obtained from EMATER and IAPAR. The data obtained from EMATER is location map, landuse, topography, soil map, rate and type of soil conservation implementation, dominant crops, scale of farmers and so on. Rainfall data at Laranjeiras do Sul and Londrina was obtained from IAPAR for micro river basins in Iguaçu and Tibagi river basins, respectively. Although both rainfall stations are miles away from sites, they are the most closest stations available.

The determination of USLE factors is same as the soil loss computation for the whole Iguaçu and Tibagi river basins described in the section 5.1, except rainfall factor (R factor). Since the period during the suspended sediment is only 10 days, the correlation equation of R with mean monthly and annual rainfall determined by Rufino et al. (1993) is not applicable to the soil loss simulation for micro river basins. Thus, R factor was computed by RUSLE.

The difference between USLE and RUSLE in R factor determination is only computation of kinetic energy of rainfall. Reading every 10 minute rainfall per incident of rain, kinetic energy of rainfall was computed by the following equation.

$$KE = 0.29\left[1 - 0.72\exp\left(-0.05I\right)\right]$$

where KE: kinetic energy of rainfall (MJ/ha·mm), I: rainfall intensity (mm/hr)

Table-5.6 explains the computation of R factor. Kinetic energy per mm of rainfall is computed above equation with rainfall intensity and successively kinetic energy per increment of rainfall, "KE*rain", is computed multiplying KE with rainfall (mm). The maximum amount of rainfall in any 30 minute period is enclosed with line in the table. The total kinetic energy of rain over the rain incident multiplied by the intensity of the maximum rainfall in 30 minute is R factor.

KE per mm of rainfall(6:50) = 0.2843 MJ/ha·mm

KE per increment (6:50) = 0.2843 x 12 mm = 3.4115 MJ/ha

R factor = sum(KE per increment) x Intensity of maximum amount of rain in any 30 minutes

= 4.0627 x (12 + 2.9 + 0.3) x 2 = 123.51 MJ·mm/ha·hr

Table-5.6 Example of R Factor Computation

DATE	TIME	RAIN (mm)	Intensity (mm/h)	KE*Rain (MJ/ha)
1-Mar	6:30 am	0.000	0	0
	6:40 am	0.100	0.6	0.0087
	6:50 am	12.000	72	3.4115
	7:00 am	2.900	17.4	0.5873
	7:10 am	0.300	1.8	0.0298
	7:20 am	0.100	0.6	0.0087
	7:30 am	0.100	0.6	0.0087
	7:40 am	0.010	0.06	0.0008
	7:50 am	0.010	0.06	0.0008
	8:00 am	0.010	0.06	0.0008
	8:10 am	0.010	0.06	0.0008
	8:20 am	0.010	0.06	0.0008
	8:30 am	0.010	0.06	0.0008
	8:40 am	0.010	0.06	0.0008
	8:50 am	0.010	0.06	0.0008
	9:00 am	0.020	0.12	0.0016
Total		15.600	*R factor*	123.51

After the computation of soil loss during the measurement period, sediment deliver ratio for each micro river basin was obtained. The details of soil loss computation for micro river basins is shown in Appendix-5 with USLE factors determined. In Table-5.7, the result of soil loss simulation for micro river basins is summarized.

Table-5.7 Soil Loss from Micro River Basins

River Basin	Micro-river Basin	Area Involved (ha)	Soil Loss (kg/ha)	Suspended Sediment Yield (kg/ha)	Sediment Delivery Ratio
Iguacu	Paz	880	20,919	11.49	0.0005
	Areiao	1,425	47,621	5.93	0.0001
	Cachoeirinha	1,350	158	1.77	0.0110
Tibagi	Limoeiro	1,103	2,591	1.70	0.0006
	Uru	908	824	22.87	0.0277
	Godoy	86	29	0.68	0.0237

Soil loss is the total over the sampling period.
Suspended sediment yield is the total sediment of a certain period assumed that rain during the measurement is effective to yield suspended sediment.

As expected, Godoy micro river basin, whose area is totally covered by natural forest, has the lowest soil loss rate and suspended sediment yield. Although Cachoeirinha micro river basin was selected as forested area, presence of crop land and fallow, 30 % of the basin area, causes higher soil loss rate and suspended sediment yield.

Areiao micro river basin is categorized as the basin with soil conservation measures, while Paz micro river basin is categorized as the basin with severe soil erosion. In Areiao micro river basin, terracing and buffer strips are implemented 25 % and 11 % of the total crop area, respectively, and in Paz micro river basin there is no soil conservation measures applied. However by contraries soil loss rate from Areiao micro river basin is higher than one from Paz micro river basin. This is due to the different landuse. In Areiao micro river basin, 61 % of the land is used for crop, while in Paz micro river basin pasture covers 56 % of the basin area and only 27 % of the basin is used for crop.

As mentioned before, there is some errors in the suspended sediment measurement for Uru micro river basin and thus, suspended sediment yield is the highest despite the fact that 87 % of the crop land is terraced. Since the reason for this error is unknown, the data of Uru micro river basin was excluded from the analysis.

In spite of the several assumptions and uncertainty of data, the effects of landuse on suspended sediment yield and soil erosion were analyzed. The result confirms that the dense vegetation cover suppress soil erosion and reduce suspended sediment yield. Besides, USLE and RUSLE models reasonably estimate the soil loss.

Soil loss estimated was compared with suspended sediment, and areas of micro river basins were compared with sediment delivery ratio. The data of Uru micro river basin is excluded from the following analysis.

(1) Soil Loss vs. Suspended Sediment Yield

As shown in Figure-5.5, soil loss estimated is well correlate with suspended sediment yield observed. The higher soil loss is, the more suspended sediment yields. Therefore, the suppression of soil loss is essential to improve the water environment.

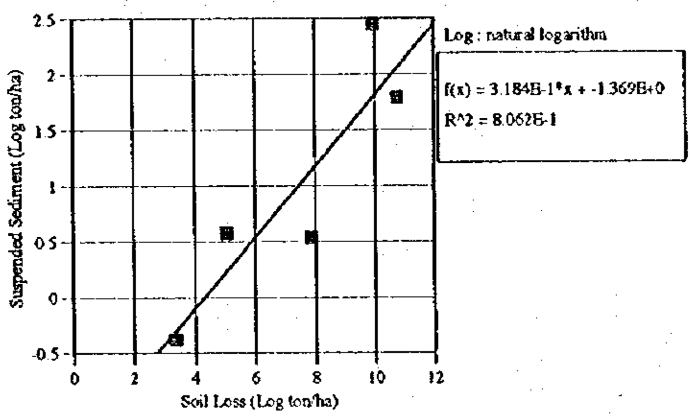


Figure-5.5 Soil Loss vs. Suspended Sediment Yield

(2) Basin Area vs. Sediment Delivery Ratio

As shown in Figure-5.6, sediment delivery ratio decreases with the increase of area. It implies that there is more area for the deposit of soil eroded with the larger basin area. This relationship confirms the equation of sediment delivery ratio with river basin area formulated by USSCS (1971), the United States Soil Conservation Services. This relationship reinforced by data from other many river basins would be useful to estimate sediment delivery ratio roughly when there is no time allowed for the measurement.

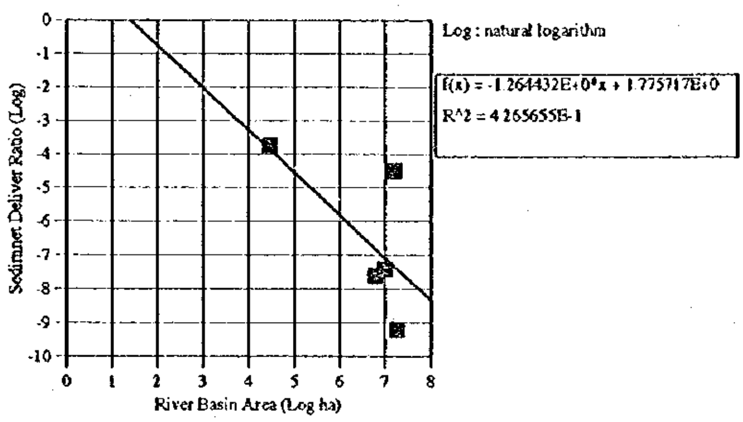


Figure-5.6 River Basin Area vs. Sediment Delivery Ratio

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