Appendix-5. Other Relevant Data

Technical Notes

Basic Design Study

on

the Project for Reconstruction of Umi Bridge Along the Highlands Highway

in

Papua New Guinea

In compliance with Item (1) of Article 8 "Other Relevant Items " in the Minutes of Discussion signed by Both Sides on August 22, 1997, this technical note has been prepared by the team to confirm the various design criteria and bridge type to be applied in the study.

After a series of discussions with the concerned officials of the DoTW and the study team, both sides have finally agreed and confirmed the main items described in the attachments.

This agreement is subject to final approval by JICA Headquarters.

Port Moresby, August 29, 1997

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ATTACHMENTS

(1) Geometrical Criteria

Referring to Part 2 of Road Design Manual by the Department of Works and the geometrical standards of Ramu Highway Upgrading Project and National Road Improvement Project financed by the European Union and by OECF respectively, the following geometrical criteria to be applied in the study have been formulated by the team.

Geometrical Elements	Applicable Criteria	Remarks
-Road classification	National Highway	
-Design speed	Mini. 80 km/h	Traffic category is heavy (400 vpd)
-Horizontal curves	Desirable R=340 m Minimum R=250 m	
-Gradient	General max. 6% Absolute max. 8%	
-Crossfall	3%	Sealing Surface
-Superelevation	Max. 7%	When radius is less 300m and more than 100m
-Superelevation transition length	65 m	When V=80,Wh=6.5,SR=0.07
-Number of lanes	one each way	
-Lane width	3.25 m wide with bituminous surface treatment	
-Shoulder width	2 m wide	As same as the existing

(2) Typical Cross Sections

The typical cross sections of the road and bridge as shown in Figure-1 have been determined based on above geometrical criteria, those of the similar projects and the existing conditions of the Highlands Highway.

(3) Basic Configurations of Proposed Bridge

The basic configurations such as the bridge location, approximate bridge length, minimum span required are examined as follows;

(a) Bridge Location

The new Umi bridge will be located 15 m down stream side from the center line of the existing bridge in parallel with the existing bridge based on the following reasons:

- The river bank at just up stream side of the Lae side abutment has been extensively eroded. Provision shall be made for extensive bank protection to the abutment.
- The existing abutments can be used as river bank protection for the new bridge.

(b) Desirable Total Bridge Length

In general, a desirable total bridge length depends on flood peak discharge with an appropriate return period. To estimate this figure, several empirical formulas as stipulated below are published by various agencies.

$L = 0.5^{/1} \sim 0.8^{/2} \cdot Q^{3/4}$ ------------(1) By Sabo Standard by MOC in Japan

$L = 3.3^{/1} \sim 4.9^{/2} \cdot Q^{1/2}$ -------------(2) Lacey's formula

Where: Q= Flood Peak Discharge

L = Desirable bridge length

/1- Applicable to a river with stable water course

/2- Applicable to a river with unstable water course

Based on the above two formulas, the desirable bridge length of Umi bridge for which the water course is unstable with peak discharge of about 1,200m^3/sec is approximately 160 m.

(c) Minimum span length

In order to prevent water way becoming clogged, a minimum span length is also given by the following formula for reference purpose.

$L = 30^{/1} + 0.005*Q$, where L= minimum span length,

Q= peak discharge

/1 Instead of 20 stipulated in Sabo Standard by MOC in Japan, 30 is applied taking in account the long logs deposited in the river.

From the above formula, it is concluded that the span length of Umi bridge shall be more than 36m.

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(4) Optimum Bridge Type Selection

(a) Bridge Alternatives

Taking into account the basic configurations assessed above and the need for earthquake resistant structure (Bridge type A, ductile and fully monolithic) as recommended in Earthquake Engineering for Bridges in Papua New Guinea, 1985 Revision, following bridge alternatives are formulated.

Bridge Alternative	Total Bridge Length	Span Arrangement
A-3 spans continuous steel box girder	160m	55m+50m+55m
B-3 spans continuous steel plate girder	160m	55m+50m+55m
C-3 spans continuous steel truss	160m	55m+50m+55m
D-3 spans continuous P.C. box girder	160m	55m+50m+55m
E-4 spans continuous P.C. I section girder	160m	4@40m

The evaluation of each alternative is carried out as shown in Figure- 2.

(b)Selection of the Optimum Bridge Type

The present situation with the existing bridges and the bridge construction practice in PNG are as follows:

- The only cement factory in PNG is the one available in Lae city which produces normal portland cement. However, the test quality results are widely scattered and high early strength cement which is a requisite for prestressed concrete is not available.
- The major bridge construction materials such as steel plates, reinforcing bars, PC cables & tendons are not available locally at all.
- The main type of bridges existing in PNG are steel bridges, which are selected as a consequence of better quality control and earthquake proof aspects.
- No local contractors with P.C. bridge construction experience.

Based upon the above mentioned construction situation in PNG and the results of alternative evaluations, Alt-B i.e. the 3 spans continuous steel plate girder type of bridge is selected as an optimum bridge type for Umi bridge.

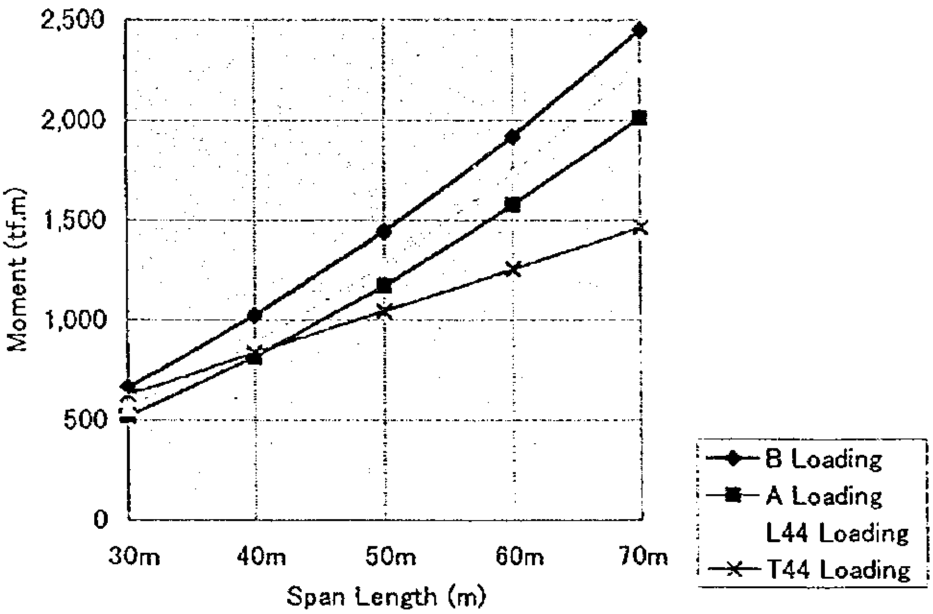
It is noted that the final span arrangement to be applied in the basic design will be adjusted based on final topographic survey map to a scale of 1: 500.

(5) Bridge Design Criteria

As agreed in the Minutes of Discussions dated on August 22, 1997, the bridge structure shall be mainly designed using "the Japanese Bridge Specification " except those due to local conditions such as thermal and seismic effects.

- Applicable live load shall be "B Loading" stipulated in the Japanese Specification. It is prudent that application of the "B Loading", which is about 14% heavier at a span of 50m than L44 lane loading in the "92 Austroads Bridge Design Code" as shown in figure below, is appropriate taking into account that most of the heavy trucks passing the highway are overloaded.

Comparison Of Bending Moment Due To Varirous Live Loads



- The Heavy Load Platform Loading specified in the Austroads Bridge Code shall not apply.
- Superimposed dead load of 1.0 kN/m^2 on the completed carrigeway shall be considered for an asphalt overlay of 5 cm thickness.
- Design for Earthquake Forces shall be to the requirements of Earthquake Engineering for Bridges in Papua New Guinea, 1985 Revision.
- The effective temperature gradient (T) shall be 20^{o}C for all areas of PNG.

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- Forces due to Log Impact shall be calculated in accordance with Article 2.10.6 of the Austroads Bridge Code
- Where concrete decked bridges are not provided with an additional deck wearing surface, the concrete cover to the carriageway surface shall be increased by 10 mm.

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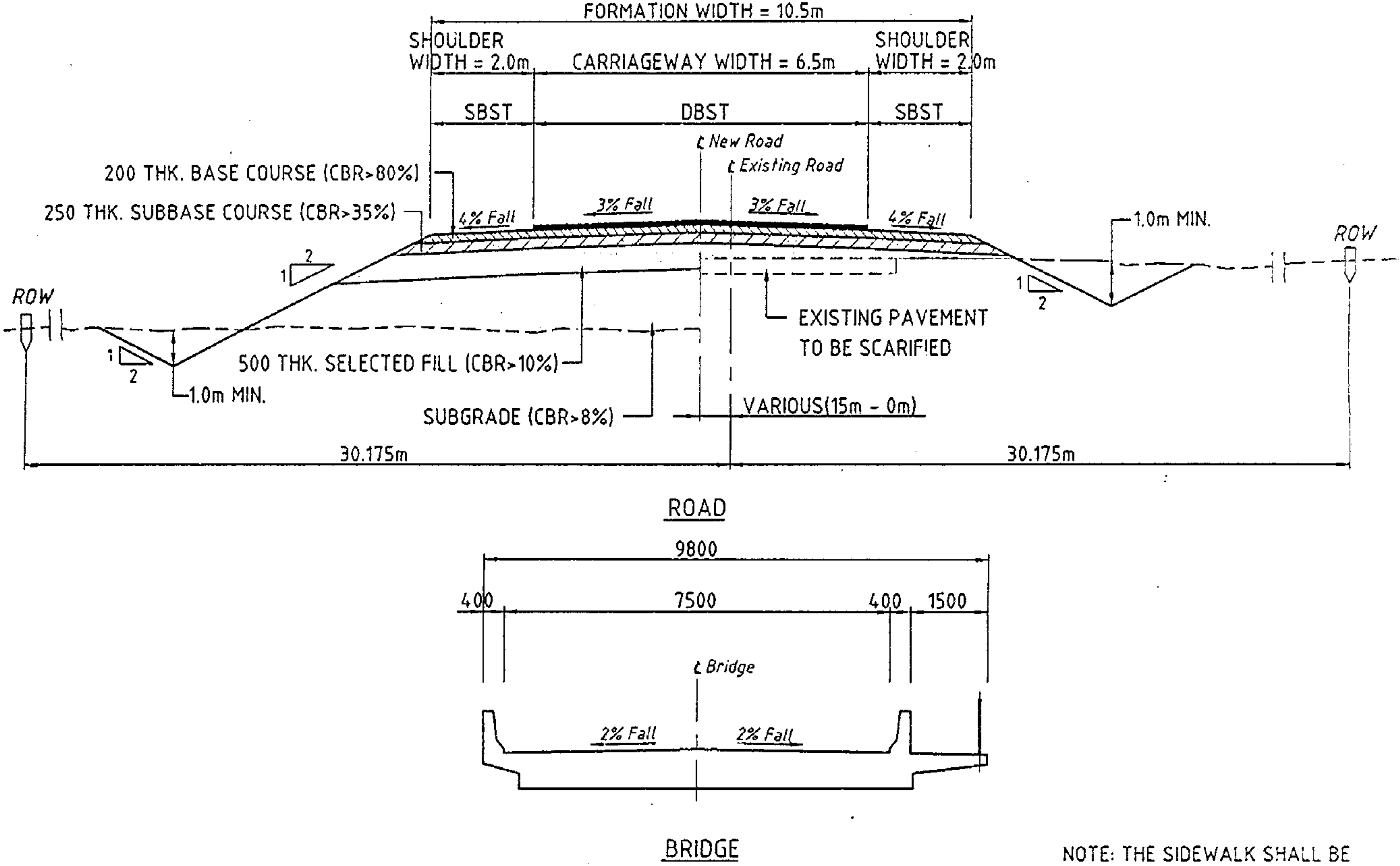
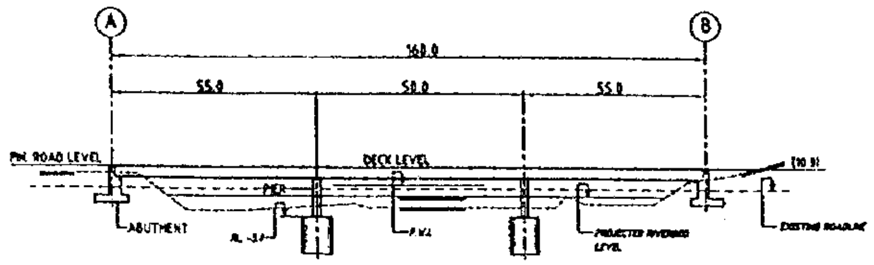
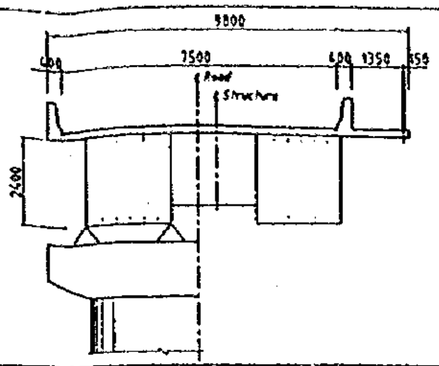
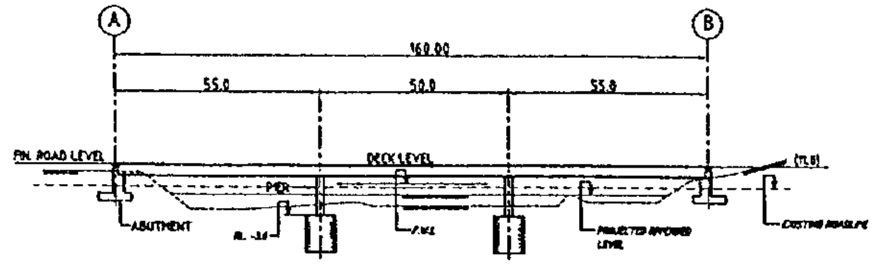
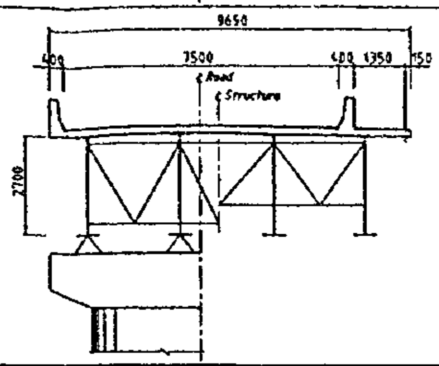
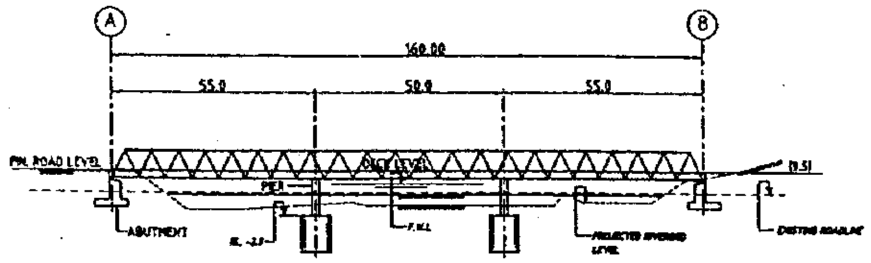
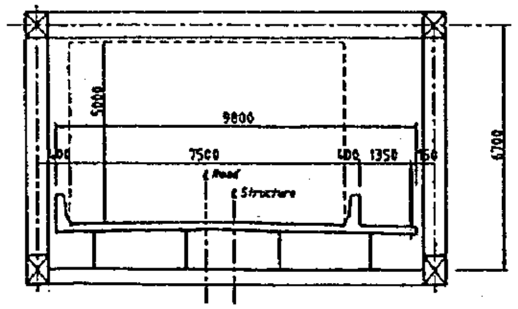
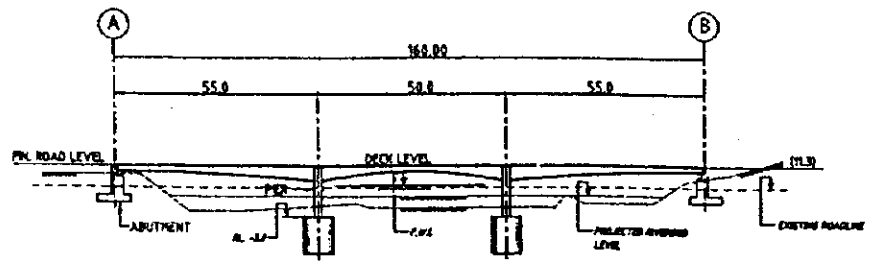
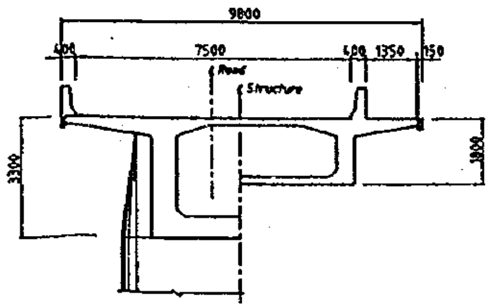
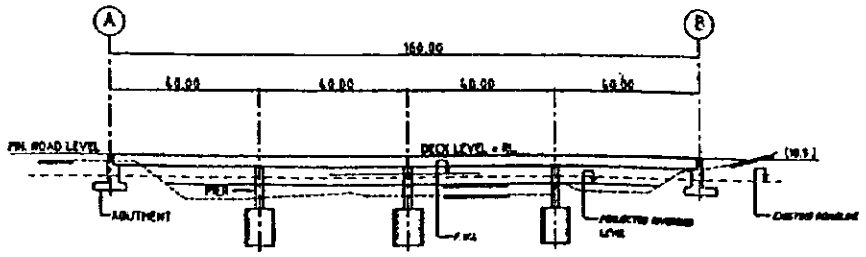
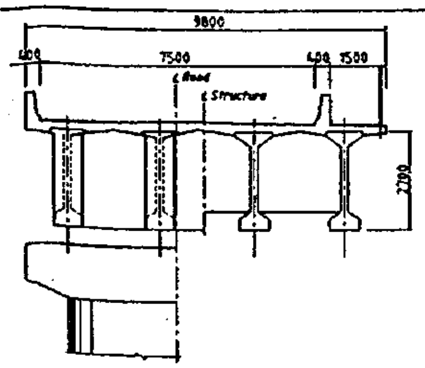


NOTE: THE SIDEWALK SHALL BE PROVIDED AT THE DOWNSTREAM SID[illegible]

Figure 1 TYPICAL CROSS SECTIONS

FIGURE 2 COMPARATIVE STUDY OF ALTERNATIVE BRIDGE TYPES

ALTERNATIVES	CROSS SECTION	EVALUATION ITEM	EVALUATION	OVERALL RATING
ALTERNATIVE A - THREE (3) SPANS CONTINUOUS STEEL BOX GIRDER 		STRUCTURAL ASPECT	STABLE STRUCTURE	FAIR
		CONSTRUCTION COST	THE MOST EXPENSIVE AMONG STEEL BRIDGES (1.15 RATIO AGAINST THE COST OF ALTERNATIVE B)	
		CONSTRUCTION PERIOD	THE MOST SHORTEST CONSTRUCTION PERIOD AMONG 5 ALTERNATIVES (ABOUT 15 MONTHS)	
		FIELD WORK ASPECT	ENSURED PROGRESS AND QUALITY CONTROL	
		MAINTENANCE	PERIODICAL CLEANING AND REPAINTING OF HANDRAIL AND GIRDERS ARE REQUIRED	
		ASEISMICITY	HIGH ASEISMICITY DUE TO LIGHT SUPERSTRUCTURE	
		HYDRAULIC ASPECT	NO SPECIFIC PROBLEMS	
		OTHER ASPECT		
ALTERNATIVE B - THREE (3) SPANS CONTINUOUS STEEL PLATE GIRDER 		STRUCTURAL ASPECT	STRUCTURALLY UPPER LIMIT SPAN LENGTH OF PLATE GIRDER TYPE	EXCELLENT
		CONSTRUCTION COST	THE 2nd MOST ECONOMICAL FOLLOWING ALT. E AMONG FIVE ALTERNATIVES (1.00 RATIO AGAINST THE COST OF OTHER ALTERNATIVES)	
		CONSTRUCTION PERIOD	RELATIVELY SHORT CONSTRUCTION PERIOD AMONG 5 ALTERNATIVES (ABOUT 16 MONTHS)	
		FIELD WORK ASPECT	ENSURED PROGRESS AND QUALITY CONTROL	
		MAINTENANCE	PERIODICAL CLEANING AND REPAINTING OF HANDRAIL AND GIRDERS ARE REQUIRED	
		ASEISMICITY	HIGH ASEISMICITY DUE TO LIGHT SUPERSTRUCTURE	
		HYDRAULIC ASPECT	NO SPECIFIC PROBLEMS	
		OTHER ASPECT		
ALTERNATIVE C - THREE (3) SPANS CONTINUOUS STEEL TRUSS 		STRUCTURAL ASPECT	THE LOWEST FINISH GRADE DUE TO THROUGH TYPE BRIDGE	POOR
		CONSTRUCTION COST	THE 3rd ECONOMICAL BRIDGE AMONG OTHER BRIDGES (1.05 RATIO AGAINST THE COST OF ALTERNATIVES B)	
		CONSTRUCTION PERIOD	THE LONGEST CONSTRUCTION PERIOD AMONG STEEL BRIGGE ALTERNATIVES (ABOUT 18 MONTHS)	
		FIELD WORK ASPECT	ENSURED PROGRESS AND QUALITY CONTROL	
		MAINTENANCE	MOST COSTLT MAINTENANCE REQUIRED BECAUSE OF RELATIVELY WIDER PAINTING AREA THAN STEEL BRIDGES	
		ASEISMICITY	HIGH ASEISMICITY DUE TO LIGHT SUPERSTRUCTURE	
		HYDRAULIC ASPECT	NO SPECIFIC PROBLEMS	
		OTHER ASPECT	POSSIBLE MEMBER DEFORMATION DUE TO OVERSIZED VEHICLE COLLOSION AND DIFFICULTY OF BRIDGE WIDENING IN FUTURE	
ALTERNATIVE D - THREE (3) SPANS CONTINUOUS P.C. BOX GIRDER 		STRUCTURAL ASPECT	HIGH DUCTILE AND FULL MONOLITHIC BRIDGE	VERY POOR
		CONSTRUCTION COST	THE MOST EXPENSIVE BRIDGE AMONG OTHE BRIDGES (1.35 RATIO AGAINST THE COST OF ALTERNATIVE B)	
		CONSTRUCTION PERIOD	THE LONGEST CONSTRUCTION PERIOD AMONG 5 ALTERNATIVES (ABOUT 20 MONTHS)	
		FIELD WORK ASPECT	DIFFICULTY OF AND QUALITY AND PROGRESS CONTROL	
		MAINTENANCE	ONLY MINIMAL MAINTENANCE	
		ASEISMICITY	HIGH ASEISMICITY	
		HYDRAULIC ASPECT	NO SPECIFIC PROBLEMS	
		OTHER ASPECT		
ALTERNATIVE E - FOUR (4) SPANS CONTINUOUS P.C I SECTION GIRDER 		STRUCTURAL ASPECT	STANDARD STRUCTURE OF P.C. GIRDERS	POOR
		CONSTRUCTION COST	SLIGHTLY MORE ECONOMICAL THAN ALTERNATIVE B (0.95 RATIO AGAINST THE COST OF ALTERNATIVES B)	
		CONSTRUCTION PERIOD	RELATIVELY LONG CONSTRUCTION PERIOD AMONG 5 ALTERNATIVES (ABOUT 18 MONTHS)	
		FIELD WORK ASPECT	DIFFICULTY OF QUALITY AND PROGRESS CONTROL	
		MAINTENANCE	ONLY MINIMAL MAINTENANCE	
		ASEISMICITY	HIGH ASEISMICITY	
		HYDRAULIC ASPECT	REDUCED BRIDGE OPENING AND HIGH FLOW OBSTUCTION RATIO (6%). HIGH RISK OF BRIDGE OPENING TO BE CLOGGED DUE TO SHORT DISTANCE (LESS THAN 25m) BETWEEN NEW AND OLD PIERS DURING THE CONSTRUCTION	
		OTHER ASPECT		

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1. OUTLINE OF THE STUDY AREA

The total area of the Umi watershed is about 700 sq. km. And the elevation change from 400 meters at the bridge site to about 4000 meters above sea level. Due to excessive landslide activities in this watershed as a consequence of earthquakes or other, the discharge of sediment to the Markham valley is very high. Therefore, the bridge site and the road in this section is highly vulnerable to debris and mudflows. A recent earthquake registering 7.1 on the Ritcher Scale occurred in this area killing more than 37 inhabitants. It was said that the aftermath of this earthquake was considerable, causing large number of landslides, flooding and discharging heavy sediment load in the down stream. It was said that these high discharge could irrevocably alter the river planform, which have to be thoroughly investigated in structural development in the Highway system.

Considering these disastrous activities in the mountain region and consequences in the river valley, it was attempted to estimate the annual soil production that could discharge at the bridge site in the study.

2. ACQUISITION OF REMOTE SENSING DATA

Consideration was made to two aspects of the present study in acquiring remote sensing data. The purpose of the present study is to estimate the annual soil production with limited data that is available for the present study area and for most of the watersheds in the Study Area. Specifically, data were screened out to find out usable sets to estimate the consequences of 1993 landslide.

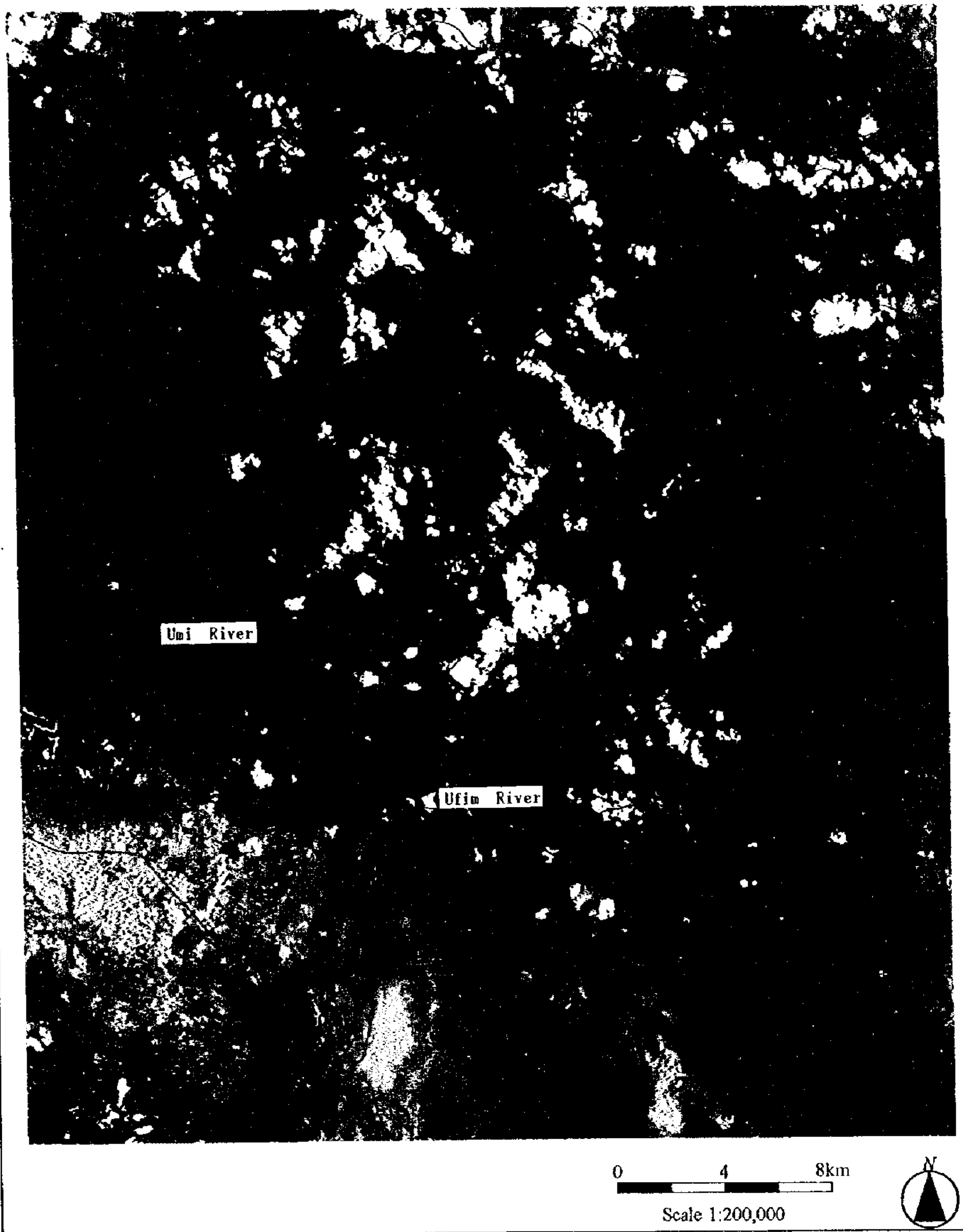
The following information of the selected datasets.

Sensor	Date	Comment
Landsat TM	1993 September 19	Before the earthquake
Landsat TM	1994 July 20	After the earthquake
Landsat TM	1996 April 20	Identify changes in 94-96
SPOT P	1994 April 4	Identify finer landslides

Field visits were carried out in 1997 August. Due to difficulty in access, field investigation was carried out only up to few kilometers of Ufim river, and Umi river. During this investigation, photographs were taken to compare with satellite data in establishing land cover type and the condition of the riverbed. Further, riverbed materials were investigated and the general material properties were observed.

In addition to satellite data the following data were collected for the present study.

Geographical Maps 1:250,000
Geographical Maps 1:100,000
Climatic Records
Reports on Landslides and Earthquakes



REMOTE SENSING AND GEOGRAPHICAL INFORMATION SYSTEM (GIS) ANALYSIS

Figure 1 Landsat TM false color image
(September 19, 1993)

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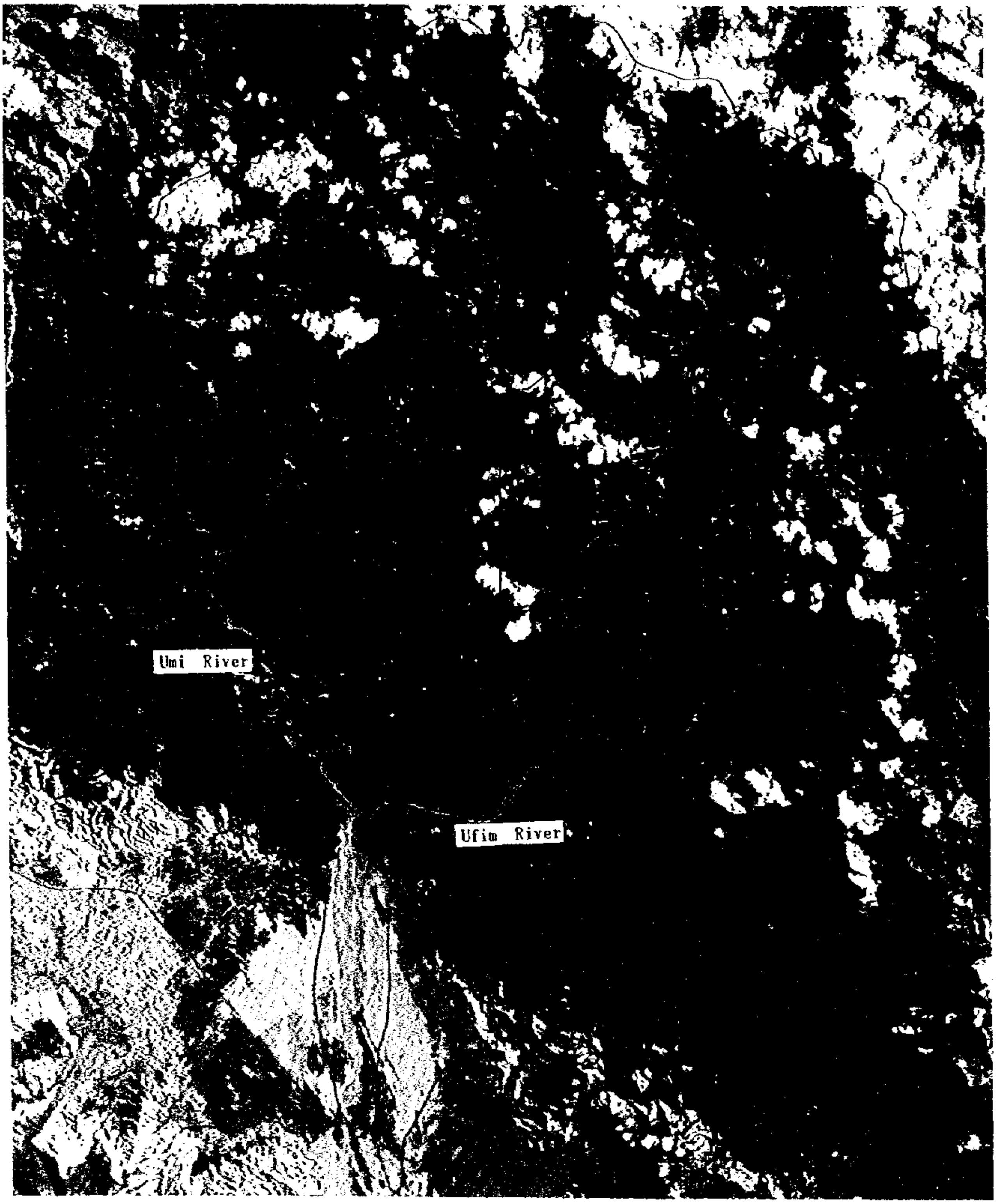

REMOTE SENSING AND GEOGRAPHICAL INFORMATION SYSTEM (GIS) ANALYSIS

Figure 2 Landsat TM false color image (July 20, 1994)

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REMOTE SENSING AND GEOGRAPHICAL INFORMATION SYSTEM (GIS) ANALYSIS	Figure 3 Landsat TM false color image (April 20, 1996)
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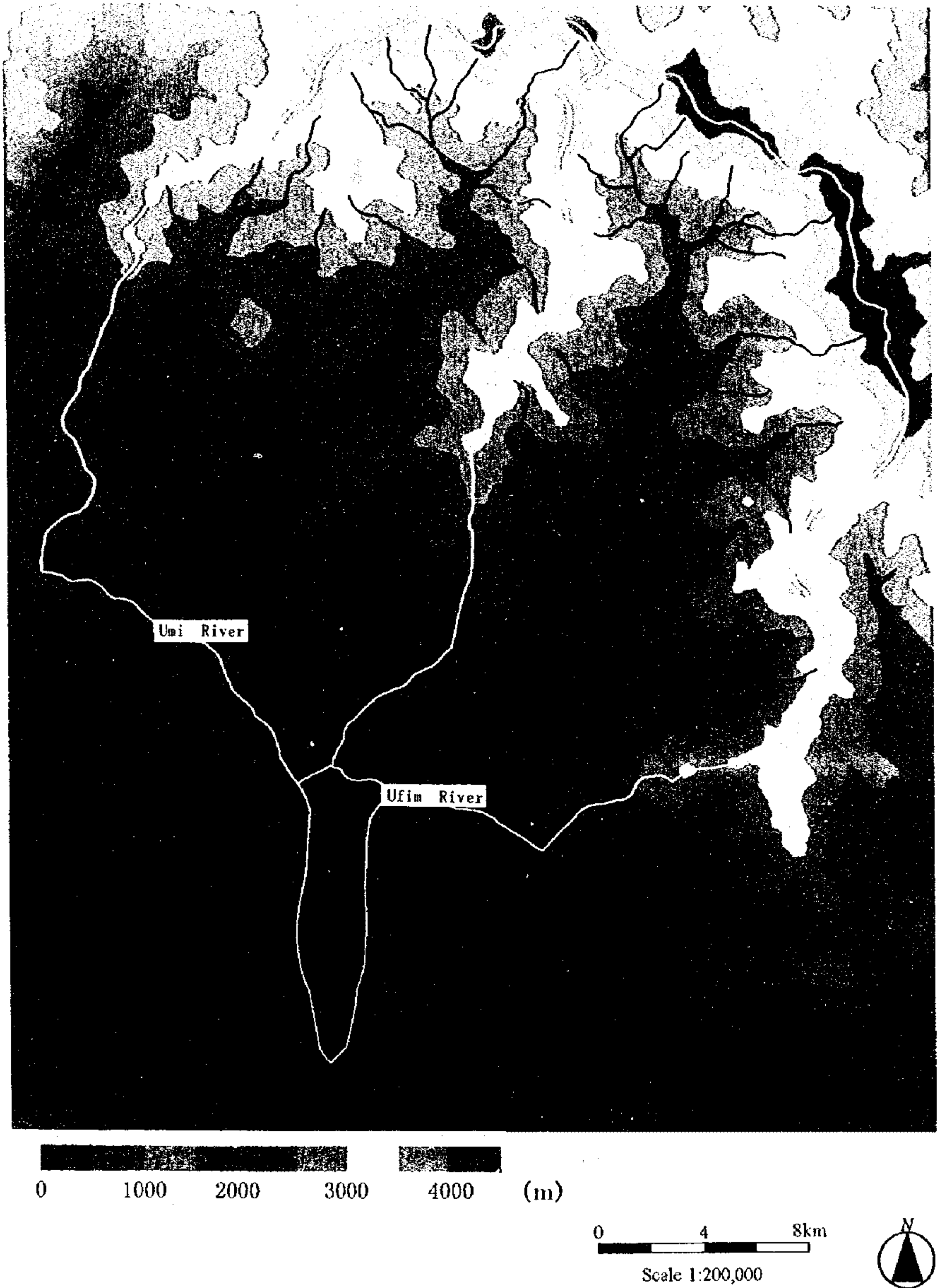

REMOTE SENSING AND GEOGRAPHICAL INFORMATION SYSTEM (GIS) ANALYSIS

Figure 4

Elevation distribution of the Umi watershed

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3. METHODOLOGY

The soil volume produced from the failure area by the earthquake were calculated by the Geological Survey of Papua New Guinea in 1995 from satellite images and aerial photographs. According to them, identification of failure zones is important to estimate the soil volume produced by the earthquake. False color image of Landsat Satellite images was used to identify the failure zones. The zones were estimated by subjective means from the hue of the image, which was zoomed to 1:100,000.As a result for the 1993 earthquake in Umi river basin, a failure area of 20km2 was identified. Present failure area is assumed as 25km2. The soil volume produced from the failure area by the earthquake was estimated the at 500 million cubic meters.

In our study, the analysis was carried out with the following themes;

- Amount of soil produced by the 1993 earthquake
- Amount of soil yield (volume) by remote sensing and GIS technology
- Vegetation recovery status

4. ESTIMATION OF SOIL YIELD DUE TO THE 1993 EARTHQUAKE

Identification and estimation of landslide areas, and the volume of soil production due to

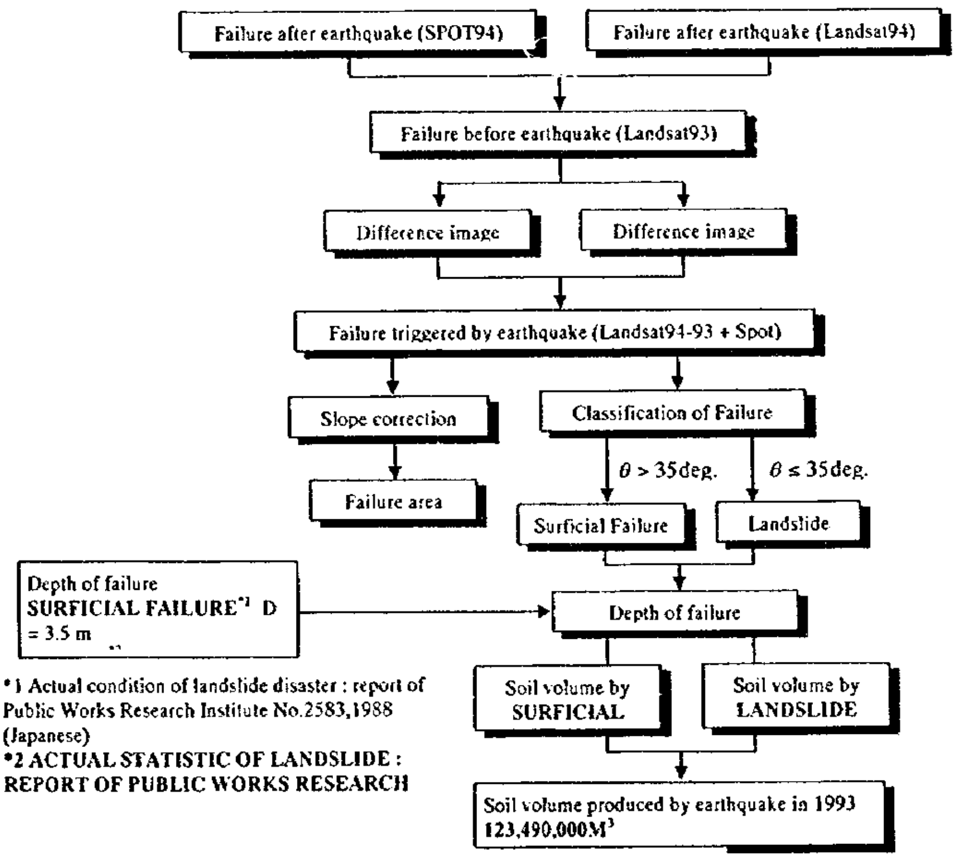


Fig.5 Flowchart of analysis

the 1993 earthquake, and the annual average soil loss was carried out using satellite data and topographical maps. These information were integrated into a GIS database and the analysis was carried out in the GIS environment. Further, reports published on the earthquake, photographs obtained over the damaged area were used as supporting information in the analysis process. The conceptual flowchart of the analysis is shown in Figure 5.

(1) Estimation of landslide area due to 93 earthquake

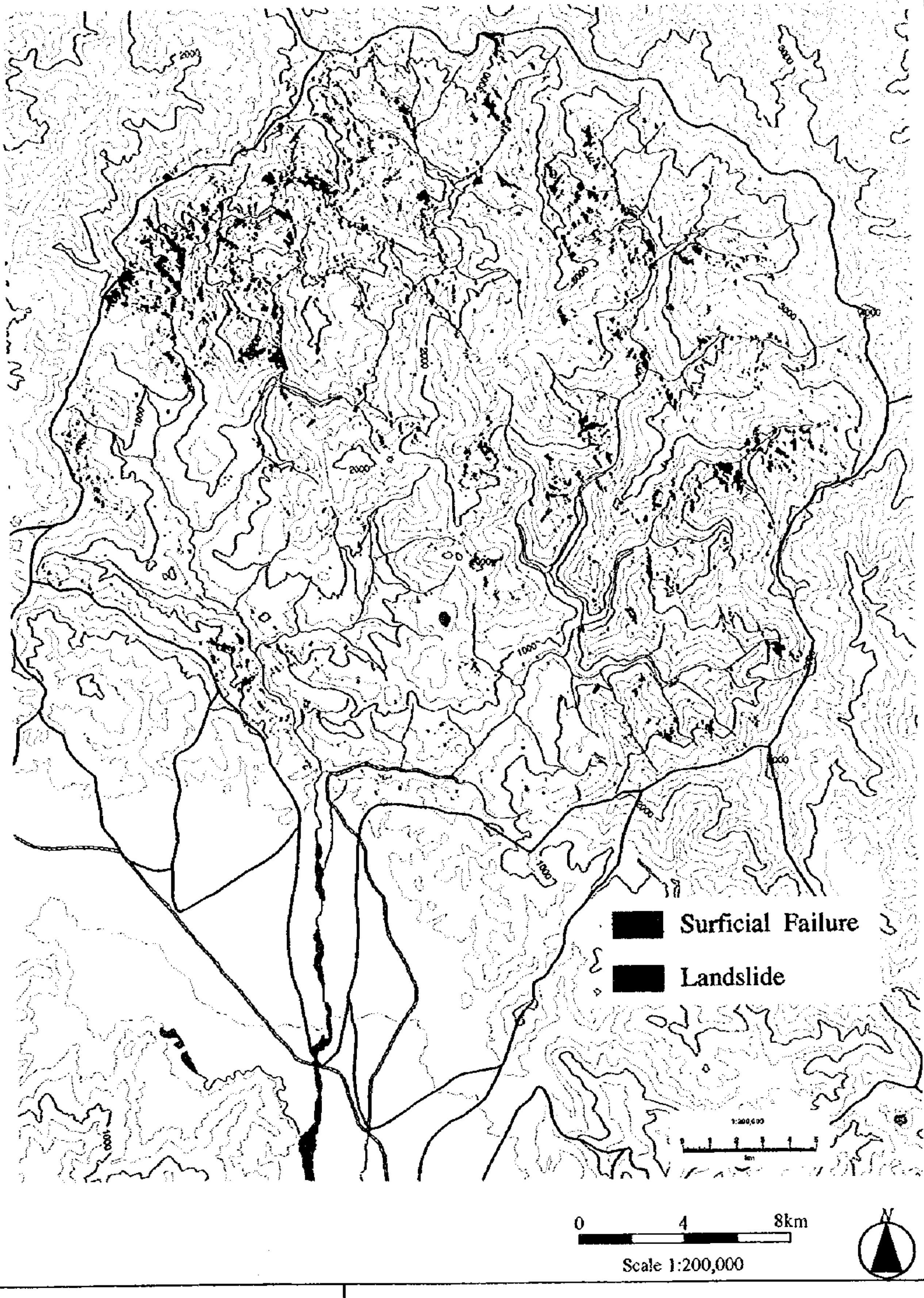
The landslide areas were estimated using Landsat Thematic Mapper (TM) data acquired before (1993.09.19) and after (1994.07.20) the earthquake. After pre-processing and geocording these two dates were analyzed as shown in Figure 5. Landslides on both of the satellite dataset were estimated, and a difference image was created with these analyzed datasets depicting the landslide areas due to the 1993 earthquake. Further, to identify finer failures, landslides identified on high resolution SPOT data (1994.04.04, after earthquake) was fused with Landsat TM before the earthquake. Both of these difference images were integrated in a GIS database, and landslide areas after the earthquake was extracted. Shifting cultivation, crop lands that resemble the spectral patterns of landslides were excluded from the above estimation using photographs obtained in the field. Surface area of each landslide identified with satellite data was rectified using surface slope, which was calculated using contour data integrated in the GIS database. Consequently, relationship of landslide area with the surface slope was established, and the landslide area within cloud cover portion was estimated based on this relationship. Figure 6 shows the distribution map of failure occurred after 1993 earthquake. The total surface area of the landslides occurred after the earthquake was estimated at 21.5 km^2, which is about 3% of the watershed area.

(2) Estimation of Soil Yield due to 1993 Earthquake

Landslides occurred after 1993 earthquake could be considered in two types according to published reports, (BGC, 1995 and Tutton, 1995), and with reference to helicopter photographs obtained just after the earthquake. These tow types can be defined as *Surfacial Failure*, and *Landslides.* Failure depth, surface slope and the movement of these two types have different characteristics, Table 1. Landslide areas estimated by satellite data as explained earlier are subdivided into these two types.

GIS overlay was carried out, and the failures that had been occurred in areas where the slope angle is greater than 35 degrees were referred surfacial failures, and rest landslides. Failure depth of these two categories were defined and the total soil loss was estimated. The depth was defined as follows;

- Surfacial failure 3.5 meters
- Landslide Failures estimated by remote sensing were converted into polygon. *Width* of a failure was defined as the width of a square of that have same surface area of the polygon being considered. *Depth* was defined as 1/8 of the width. Further, *shape* of the slip surface is defined as spherical



REMOTE SENSING AND GEOGRAPHICAL INFORMATION SYSTEM (GIS) ANALYSIS	Figure 6 Failure occurred after 1993 earthquake
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Given the above condition, produced soil volume due to the earthquake was estimated at the sum of above two types. The total volume was estimated at 124,390,000 m^3, where 65,160,000 m^3 due to landslides, 59,230,000 m^3 by surfacial failure.

5. AVERAGE ANNUAL SOIL LOSS IN THE UMI WATERSHED

In the previous section, the volume of the soil produced due to the earthquake was estimated. Whole of this soil is not discharged at once into the floodplain. A portion is discharge with the water flow, and a part is accumulated in stream. These accumulated soil is discharge with the increase of water flow, or after reaching a certain surface slope that is unstable to hold the increasing deposit. These newly created landslide areas susceptible for surface erosion, increasing the discharge of the watershed.

Analysis of channel changes, and soil production of a watershed similar to Umi with about 703 km2 has to be carried out in two aspects; spatial change of river form and movement of sediment, and simulating these phenomena in time scale. In reality, these type of analysis is hard to carry out due to lack of accurate and continuous data. Further, these detailed calculation requires quite high investment. In this report, a method was established to estimate the erosion in a torrent river. It is assumed that the soil produced by failures and surface erosion accumulate in sub-streams, and discharge depending on the transport capacity of the water flow.

Generally, the annual sediment discharge of a torrent stream (E) can be represented as below;

$$E = E_s + E_f + E_{se}$$

E_s Average annual surface erosion
E_f Average annual soil volume due to failures
E_{se} Average annual riverside erosion

(a) Estimation of average annual surface erosion (E_s)

In calculating annual soil loss, USLE was used. This equation considers factors shown below, and the total annual soil loss is the sum of erosion produced from land cover categories, such as forest, grass lands, bare lands found in the watershed. According to USLE, the annual surface erosion can be estimated as below;

$$E_S = FR(S/10)^{.9}(L/72.6)^{.35}(P/1.375)^{1.75}$$

Here, F annual base erosion
R Conservation factor
S Surface slope
L Slope length
P Rain fall

In the present study, remote sensing data, topographical maps were used in estimating E_s. The annual surface erosion in the Umi watershed was estimated as 1,941,000 m^3/year.

(b) Annual soil production volume due to failures (E_f)

It was observed that some of the failures were establishing with natural re-vegetation. Also, it was found that failure rate is lesser than the re-establishing or re-vegetation rate. This factor is hard to estimate as no ground information is available, and the surface erosion factor E_s is partly explained the soil loss in the failure areas, the soil loss due to E_f was ignored in the present study. The following table shows the failures and re-vegetation in the Umi watershed.

	Area Analyzed (no cloud cover) 290.167 sq.km	Total Area (Analyzed & Extrapolated) 703.150 sq. km
failures observed in 1994, 96	4.379	10.612
failures in 1994, re-vegetation in 96	2.588	6.272
vegetation in 1994, failures in 96	1.354	3.280

(c) Average annual riverside erosion (E_{se})

This was estimated in the GIS environment calculating riverbed gradient using input elevation data. The riverbed gradient was divided into five categories, namely, (1) 0 to 3 degrees, (2) 3 to 10 degrees, (3) 10 to 15 degrees, (4) 15 to 30 degrees, (5) greater than 30 degrees. The width of the riverbed was defined as 0,1,3,12,15 cm, and the depth of erosion was assumed as 0.5 meters.

Figure 7 shows gradient map of Umi riverbed.

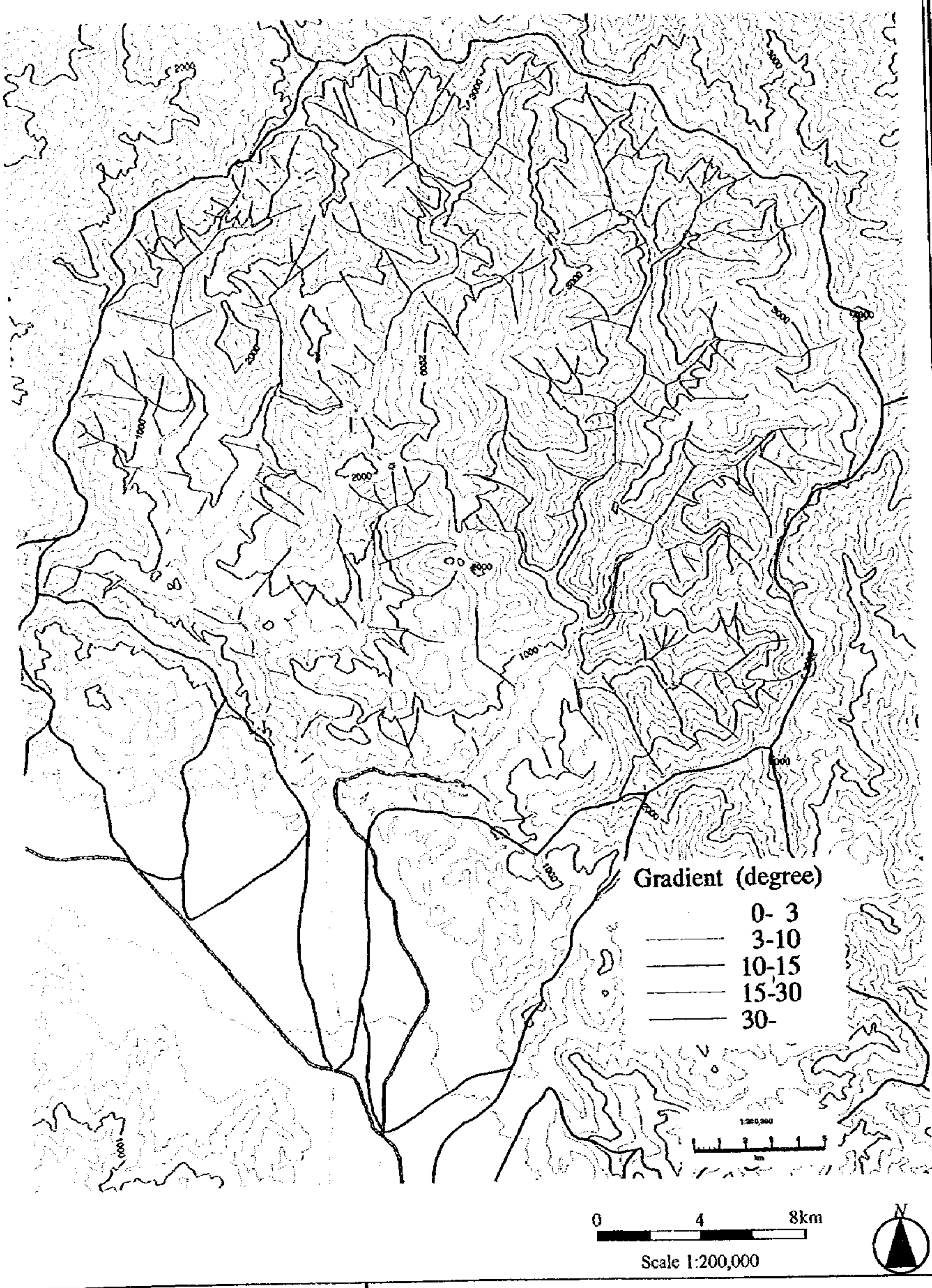
Then the estimated soil volume of riverside erosion was 28,000 m^3/year.

Following the above estimation described under (a), (b), (c), the total annual soil loss of the watershed is 1,969,000 m^3/year ($E_s + E_{se}$).

66. VEGETATION RECOVERY STATUS

In general, if surfacial failure occurs, the vegetation recovers rapidly in the tropical zone. Satellite image immediately before the earthquake in 1993 show that the catchment area is mostly covered with forest with negligible failure area, in spite of the fact that the earthquakes have occurred periodically the past time.

In this project, in order to evaluate the rate of vegetation recovery we analyzed the status of vegetation after earthquake in1993 with that in 1994 and 1996.



REMOTE SENSING AND GEOGRAPHICAL INFORMATION SYSTEM (GIS) ANALYSIS	Figure 7 Riverbed gradient map
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(1) Vegetation index

The Cells in plant leaves are very effective scatters of light because of the high contract in the index of refraction between the water-rich cell contents and the intercellular air spaces. Vegetation is very dark in visible (400-700 nm) and very bright in near-infrared (700-1300 nm).

The most commonly used vegetation index is the Normalized Difference Vegetation Index (NDVI).

(2) Situation of vegetation recovery

The following NDVI recovery model was applied to estimate vegetation after failure in Papua New Guinea.

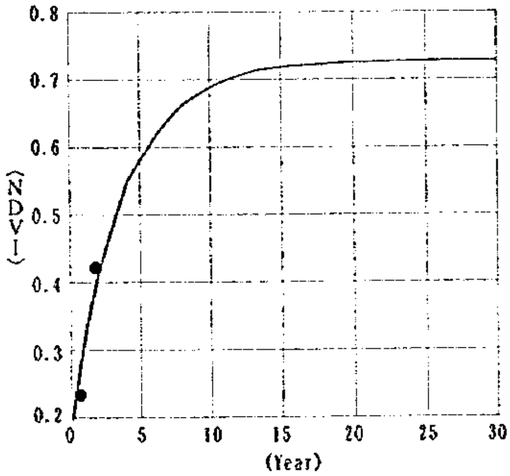
Here M : Value of maximum NDVI change

K : A constant number of recovery speed

$NDVI_0$: Value of NDVI after landslide

In general, the above growth curve formula, also called Mitscherlich growth law, was applied to estimate average tree diameter and average tree height (Nagumo(1987)).

In this study, the k parameter was estimated for 1994 and 1996 from the corresponding satellite images.



ANDVI = 0.228 + 0.528 * (1.0 - exp(-0.26*t))

As a result, it was estimated that most of the vegetation will recover within 20 years.

Figure 8 Result of regression analysis

Appendix-6. References

No.	Title of Reference Data	Publication by
	Development Plan	
1	1997 Estimates of Expenditure for the National Government Development Budget	NPO, 1997
2	1997 Estimates of Revenue & National Government Expenditure & Provincial Local level Governments Grants	NPO, 1997
3	The 1997 Budget Finance Statement 1997	NPO, 1997
4	Medium Term Development Strategy 1997 - 2002	NPO, 1997
	Environment	
5	Environmental Guidelines or Roads and Bridges	DEC, 1996
6	Environmental Planing Act General Guidelines for the Preparation and Content	DEC
7	Water Resources Act 1982	DEC
	Engineering	
8	Ramu Highway Upgrading Engineering Report Volume 1	DOTW, 1996
9	Ramu Highway Upgrading Engineering Report Volume 2	DOTW, 1996
	Technical	
10	Earthquake Engineering or Bridges in Papua New Guinea	DOTW, 1985
11	Road Design Manual	DOTW, 1994
12	A Guide to the Structural Design of Bitumen-Surfaced Roads in Tropical and Sub-Tropical Countries	DOTW, 1993
13	Specification for Road and Bridge works	DOTW, 1995
14	Manual or the Design of Drainage Structures for Rural Roads	DOTW
15	Flood Estimation Manual	DEC, 1990
16	Bridge Design Code, Austroads	DOTW, 1992
17	Waterway Design, Austroads	DOTW, 1994
18	An Appraisal o the condition and Stability o the Highlands Highway	DMP, 1995
19	Rapid Methods of Landslide Hazard Mapping	DMP, 1995
20	Climate of Papua New Guinea	NMB, 1983
21	Land Resources and Agricultural Potential	DA, 1973
	Others	
22	Land Resources and Agricultural Potential of the Markham Valley	DA, 1973
23	The Vegetation Map of Papua New Guinea	DA, 1975
24	Aerial Photos, scale = 1/25,000, 1975	NMB, 1975
25	Aerial Photos, scale = 1/36,000, 1973	NMB, 1973

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