THE DEVELOPMENT OF THE NEW SEDIMENT YIELD MAP OF SOUTHERN AFRICA

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ABSTRACT

This document deals with the technical aspects concerning the preparation of the new sediment yield map.

Information on sediment yield values for southern Africa was derived mainly from reservoir re-surveys performed by the Department of Water Affairs, and also from a number of South African river gauging stations and recorded sediment data for Lesotho, collected by Makhoalibe (1984).

Using the capabilities available on GIS, maps of various physical and geographical features of southern Africa which influence sediment yields were prepared and placed on GIS. These included:

(i) A basic erosion index map indicating the basic yield of different regions.

(ii) A land use map based on the value of agricultural products sold in 1975.

(iii) An average slope map depicting the energy gradients for defining sediment transport capacities.

(iv) A rainfall erosivity map based on EI_{30} values compiled by Smithen (1981) for a ten year return period.

Analysis or calibration of data for southern Africa as a whole is not possible due to the geographical diversity of the sub-continent. The region was therefore divided into nine relatively homogeneous sub-regions.

Various methods were used in an attempt to calibrate the new sediment yield map.

(i) With the aid of multiple linear regression techniques, an attempt was made to link sub-areas with differing yield potential and land-uses to their observed sediment yields. This attempt failed due to the lack of significance of overall model results as well as of individual variables, intercorrelation between independent variables, large standard errors and physically insignificant results.

(ii) A mathematical model developed by Rooseboom (1992) describes turbulent transport of sediments through catchments but could not be calibrated due to the fact that sediment availability rather than transporting capacity proves to be the limiting factor in determining sediment yields in practically all cases.

(iii) Statistical analysis was eventually performed on a regional basis in order to overcome the wide variability observed in sediment yields. The fundamental assumption here was that sediment availability is the determining factor in sediment yield processes across southern Africa. Yield values were standardized for all regions and the log generalised extreme value distribution with a negative skew was found to provide the best fit of the data. The relationship between yield and catchment size was examined. Mean values and confidence bands of sediment yield values showed a strong tendency to converge to a regional mean value with increasing catchment size.

A method for estimating sediment yields from ungauged catchments based on the results of the statistical analysis is presented which allows for confidence limits to be affixed to estimated yields from ungauged catchments.

All the original main objectives of the research project viz to

(i) collate all information relevant to sediment yields and to re-asses earlier data

(ii) investigate relationships between yields and the variables that determine yield.

(iii) develop a new yield map making use of the GIS system and to calibrate this map.

(iv) compile a background document (Rooseboom 1992)

have been covered in the project.

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LIST OF SYMBOLS

A	=	empirical coefficient related to sediment availability
A_H	=	Size of area consisting of soils with higher sediment yield potential
A_m	=	Size of area consisting of soils with medium sediment yield potential
A_L	=	Size of area consisting of soils with lower sediment yield potential
A_T	=	Total catchment area
$A_{T1} \ldots A_{TN}$	=	Subareas within a catchment
b_o	=	regression coefficient
$b_1 \ldots b_k$	=	regression coefficients
B	=	coefficient related to sediment carrying capacity
C	=	runoff coefficient
e	=	residual error
E	=	raindrop energy
F_H	=	high yield potential factor
F_m	=	medium yield potential factor
F_L	=	low yield potential factor
i	=	rainfall intensity

I_N	=	n-minute rainfall intensity
k	=	number of independent variables
N	=	number of uniquely defined subareas
q	=	unit run-off
q_S	=	sediment flow
R^2	=	multiple coefficient of determination
S	=	catchment slope
t	=	time (years)
T	=	total annual catchment sediment load
V_t	=	sediment volume after t years
V_w	=	reservoir storage volume
V_{50}	=	sediment volume after 50 years
Y_c	=	estimated catchment sediment yield value
$Y_T...Y_N$	=	annual unit sediment yields for subareas
Y_s	=	standardized sediment yield value
Z	=	measure of hydraulic sediment transport capacity

1. INTRODUCTION

Research was undertaken during 1990 and 1991 at the request of the Water Research Commission to develop a new sediment yield map for southern Africa.

This document deals with the technical aspects concerning the development of the new sediment yield map. The development went through a number of distinguishable phases as outlined below:

i) A data base of recorded sediment yield values was established.
ii) Information on relevant geographical and environmental factors which influence sediment yield values of catchments, was gathered. The main input in this respect is a map developed by Professor E. Verster of the University of South Africa and his associates, depicting the relative erodibility of soils for the southern African region.
iii) To facilitate the coordination of all the available information, the GIS System of the Institute of Cartographic Analysis at the University of Stellenbosch was used. The system was used to produce all the maps included in the research and provided the facility of a database linked to each map.
iv) Various attempts were made to calibrate the new sediment yield map. Methods used included multiple linear regression, the development of a mathematical model and further statistical analysis of available data.
v) A methodology for estimating sediment yields in catchments was developed, based on the results of the statistical analysis of the data. This methodology provides the user with risk linked estimates of sediment yields from a catchment, based on both the location and size of the catchment.

For more comprehensive background on sediment transport technology in South Africa, the reader is referred to Rooseboom (1992) which serves as a background document to be read in conjunction with this report.

Whilst small scale reproductions of maps developed during the research are included in the report, the reader is also referred to the higher quality, larger scale reproductions that are available.

It must be stressed that observed sediment yields in southern Africa show a high measure of variability due to the complex interaction of factors influencing sedimentation processes. For this reason, this document should not be used rigidly.

Skilled assessment of conditions in catchments are required where estimates of yields, that might have significant implications, need to be made.

2. RECORDED SEDIMENT YIELD VALUES

For the development of the new sediment yield map, information on sediment yield values for southern Africa was derived mainly from three sources. The most important source consists of the reservoir re-surveys which are performed on a regular basis by the Department of Water Affairs. Secondly, recorded suspended sediment load records are available for a number of South African river gauging stations which were operational for limited periods of time after 1928. A third main source of information is the recorded sediment data collected in Lesotho during the mid seventies (Makhoalibe, 1984).

2.1 RESERVOIR SEDIMENT DEPOSIT RE-SURVEYS

The main source of sediment information currently available in South Africa consists of the reservoir re-survey records of the Department of Water Affairs (DWA). Many of the existing reservoirs in South Africa have been re-surveyed by the Hydrographic Survey Section of the DWA in order to determine the capacity of these reservoirs and the loss of storage capacity due to sedimentation. Re-surveys are undertaken at intervals depending on the importance of a reservoir and the sediment yield of its catchment. The listed information on reservoirs which is published by the Department includes historical information on each reservoir at completion, as well as subsequent modifications together with the results of hydrographic surveys (Department of Water Affairs, 1988).

Sediment volumes can be calculated from the observed decrease in reservoir storage volumes. In order to determine the sediment yields of catchments, the sediment volumes have to be converted to annual sediment yields per unit catchment area. For this purpose, the surveyed sediment volumes are converted to equivalent 50 year volumes by means of an equation proposed by Rooseboom (1975).

$$\frac{V_t}{V_{50}} = 0.376 \ln \frac{t}{3.5}$$

with V_t = sediment volume after t years

V_{50} = sediment volume after 50 years

t = time (years)

To convert the 50 year sediment volume to a 50 year sediment mass, a density of 1,35 t/m^3 has been used. This value was found suitable for South African reservoirs (Rooseboom 1975). In order to convert the 50 year sediment mass to an annual mass, the assumption is made that the average sediment yield is constant with time. Although evidence to the contrary exists (Rooseboom, 1992), the available data base is not comprehensive enough to identify such changes in all but a few cases.

For the calculation of annual sediment yield per unit area, the effective size of a catchment is used.

Certain situations had to be treated with circumspection:

i) Some reservoirs trap only a fraction of incoming sediments. These reservoirs were identified by examining the ratios

$$\frac{V_W}{MAR}$$

and

$$\frac{V_W}{ECA}$$

with V_W = Storage volume of each reservoir

MAR = Mean annual run-off from its catchment

ECA = Effective catchment area.

The values of these ratios were compared to the values of ratios for those reservoirs with significant trap efficiencies. Reservoirs with much smaller trap efficiencies were discarded as unreliable data sources.

Reservoirs with borderline values were closely examined. For these reservoirs, minimum flow velocities (near the outlet) were estimated to ascertain whether most incoming sediments would be deposited.

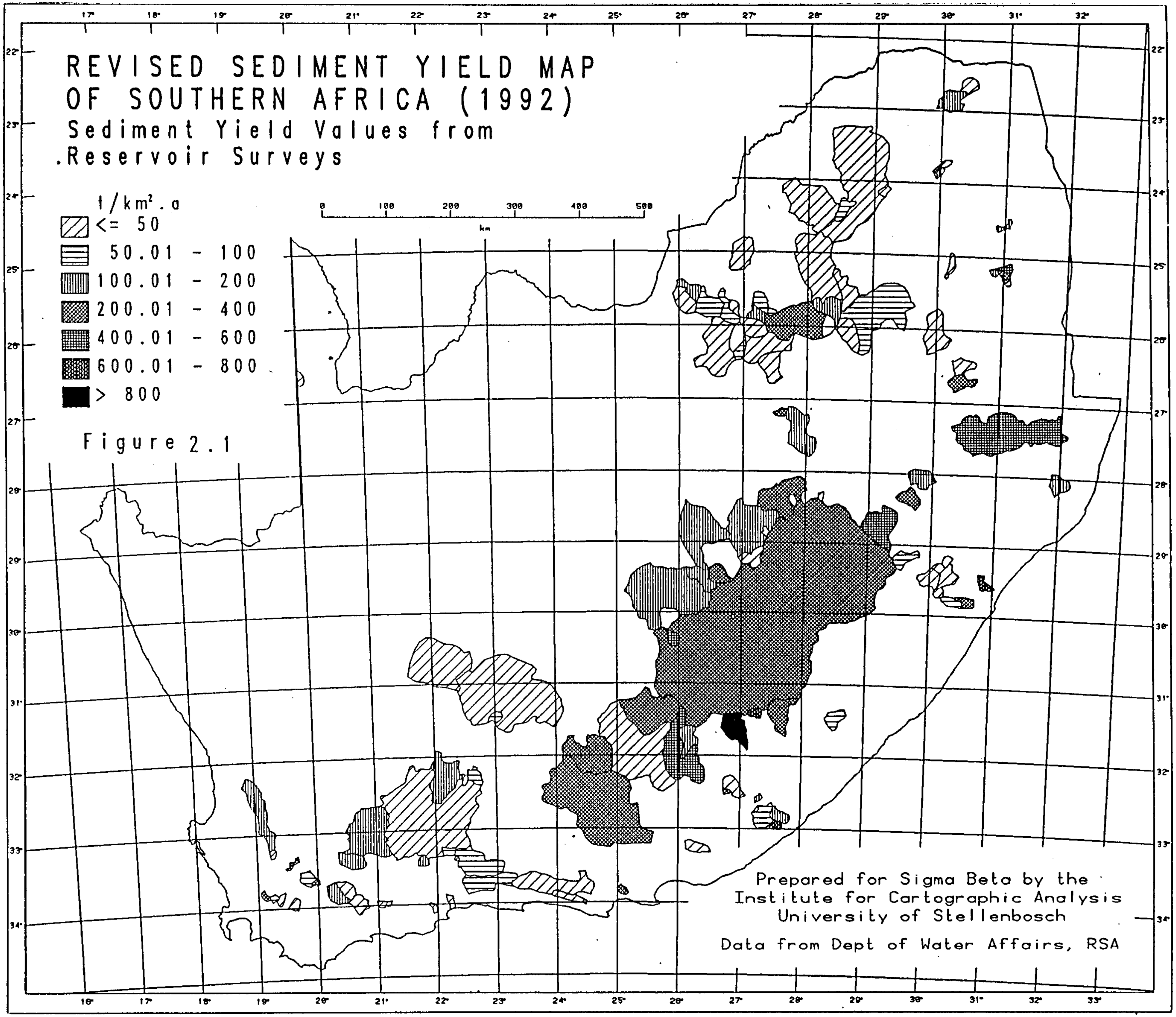
ii) Some dam structures were altered after original construction. In certain cases where no hydrographic survey was undertaken between construction and alteration, it was impossible to determine the accumulated sediment volumes. Where the reservoirs were surveyed at least once before alteration, it was often possible to determine the sediment deposit volumes.

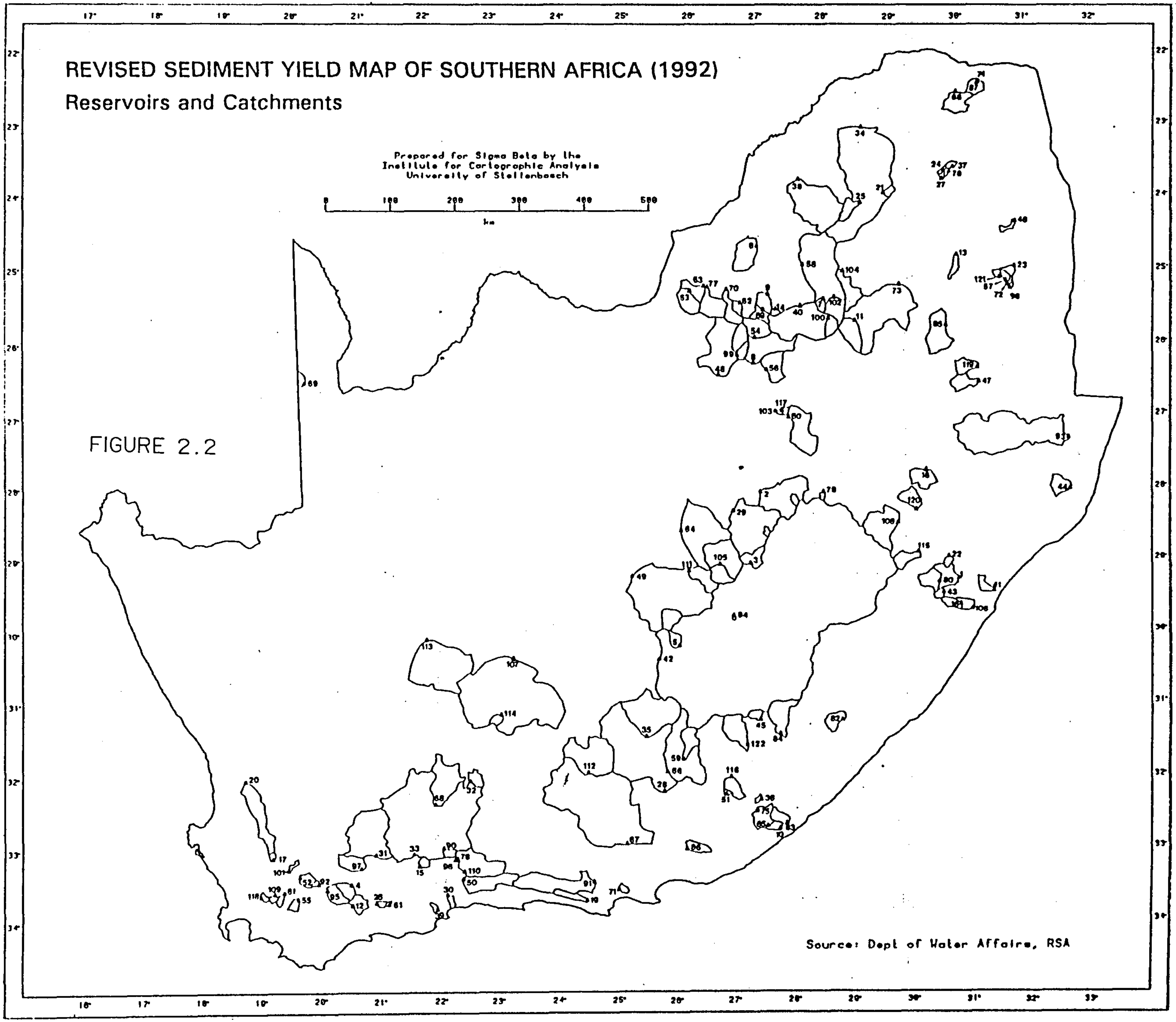
iii) A few dams were built within catchments of existing reservoirs. Due allowance had to be made in calculating the yields for the downstream reservoirs.

iv) Where deposits were younger than 8 years, the data was ignored as being unreliable.

All the reservoirs appearing in the Department of Water Affairs List of Reservoirs were considered for possible inclusion in the sediment yield data base. Many could not be used because of insufficient information. Some reservoirs were not included, because of the abovementioned factors, i.e. some reservoirs are ill-defined sediment traps, some were altered before surveys were done and some had short records. Information on some 120 reservoirs was eventually included in the data base for the calibration of the new sediment yield map. Information on the Camperdown Dam was obtained from the Mgeni Water Board. The data for the Windsor Dam was obtained from an unpublished report by Rooseboom to DWA. The areas covered by the catchments of the reservoirs are shown in **Figure 2.1**.

The full list of reservoirs is included in **Table 2.1**. The positions of the reservoirs are shown in **Figure 2.2**. **Table 2.2** contains a list of reservoirs which were excluded, together with reasons for their exclusion. Reservoirs not appearing in the tables, but listed in the 1988 List of Reservoirs, were excluded from the current data base where the information regarding sediment accumulation was deemed to be insufficient.


REVISED SEDIMENT YIELD MAP
OF SOUTHERN AFRICA (1992)
Sediment Yield Values from
.Reservoir Surveys
t/km².a
<= 50
50.01 - 100
100.01 - 200
200.01 - 400
400.01 - 600
600.01 - 800
> 800
Figure 2.1
0 100 200 300 400 500
km
Prepared for Sigma Beta by the
Institute for Cartographic Analysis
University of Stellenbosch
Data from Dept of Water Affairs, RSA



Reservoir Names

1 Albert Falls
2 Allemanskraal
3 Armenia
4 Bellair
5 Bethulie
6 Bierspruit
7 Bon Accord
8 Boskop
9 Bospoort
10 Bridle Drift
11 Bronkhorstspruit
12 Buffeljags
13 Buffelskloof
14 Buffelspoort
15 Calitzdorp
16 Camperdown
17 Ceres
18 Chelmsford
19 Churchill
20 Clanwilliam
21 Coebrink
22 Craigie Burn
23 Da Gama
24 Dap Naude
25 Doorndraai
26 Duivenhoks
27 Ebenezer
28 Elandsdrift
29 Erfenis
30 Ernest Robertson
31 Floriskraal
32 Gamka
33 Gamkapoort
34 Glen Alpine
35 Grassridge
36 Gubu
37 Hans Merensky
38 Hans Strydom
39 Hartebeeskuil
40 Hartebeespoort
41 Hazelmere
42 Hendrik Verwoerd
43 Henley
44 Hluhluwe
45 Indwe
46 Jan Wassenaar
47 Jericho
48 Johan Neser
49 Kalkfontein
50 Kammanassie
51 Kalrivier
52 Keerom
53 Klein-Maricopoort
54 Klerkskraal
55 Klipberg
56 Klipdrift
57 Klipkopjes
58 Klipvoor
59 Kommandodrift
60 Koppies
61 Korentepoort
62 Koster
63 Kromellenboog
64 Krugersdrift
65 Laing
66 Lake Arthur
67 Lake Mentz
68 Leeu Gamka
69 Lewubu
70 Lindleyspoort
71 Loerie
72 Longmere
73 Loskop
74 Luphephe
75 Maden
76 Magoebaskloof
77 Marico-Bosveld
78 Melville
79 Menin
80 Midmar
81 Moordkuil
82 Mtata
83 Nahoon
84 Ncora
85 Nooitgedacht
86 Nuwejaars
87 Nuwedal
88 Nzhelele
89 Olifantsnek
90 Oukloof
91 Paul Sauer
92 Pietersfontein
93 Pongolapoort
94 Poortjie
95 Poortjieskloof
96 Prinskop
97 Prinsrivier
98 Raubenheimer
99 Rietspruit
100 Rietvlei
101 Roode Elsberg
102 Roodeplaat
103 Roodepoort
104 Rust de Winter
105 Rustfontein
106 Shongweni
107 Smartt
108 Spioenkop
109 Stettynskloof
110 Stompdrift
111 Tierpoort
112 Van Ryneveldspas
113 Van Wyksvlei
114 Victoria-Wes
115 Wagendrift
116 Waterdown
117 Weltevrede
118 Wemmershoek
119 Woolee
120 Windsor
121 Witklip
122 Xonxa

TABLE 2.1 RESERVOIR LIST

BRANCH	LOCATION NUMBER	DAM NAME	REGION	PERIOD	V_W (END) (10^6 m^3)	V_T (10^6 m^3)	V_{60} (10^6 m^3)	ECA (km^2)	YIELD ($t/km^2.a$)	V_T/V_W (%)	V_W/MAR	V_W/ECA
Limpopo	A210-02	Hartebeespoort	1	1923-1979	194.627	35.884	34.422	3633	256	15.6	1.19	53572
Sterkstroom	A210-03	Buffelspoort	1	1935-1980	10.329	0.356	0.371	119	84	3.3	0.79	86794
Hennops	A210-05	Rietvlei	1	1934-1977	12.197	0.674	0.714	479	40	5.2	0.79	25463
Hex	A220-02	Olifantsnek	1	1928-1988	14.200	2.075	1.920	492	105	12.7	1.04	28862
Koster	A220--3	Koster	1	1964-1980	12.176	0.215	0.375	280	36	1.7	1.13	43486
Elands	A220-05	Lindleyspoort	1	1938-1980	14.417	2.018	2.159	705	83	12.3	0.73	20450
Hex	A220-07	Bospoort	1	1953-1969	18.900	0.943	1.650	600	63	4.8	0.89	32143
Pienaars	A230-01	Roodeplaat	1	1959-1980	43.691	1.797	2.667	684	105	4.0	1.53	63876
Pienaars	A230-02	Klipvoor	1	1970-1987	42.578	1.443	2.429	4585	14	3.3	0.35	9286
Apies	A230-08	Bon Accord	1	1925-1980	4.293	2.146	2.072	315	178	33.3	-	13629
Bierspruit	A240-04	Bierspruit	1	1960-1980	3.498	0.634	0.967	1330	20	15.3	0.33	2630
L/Marico	A300-02	Kromellenboog	1	1955-1983	9.375	2.309	2.953	606	132	19.8	0.68	15470
L/Marico	A300-03	Klein Maricoprt	1	1934-1983	7.073	0.911	0.918	1180	21	11.4	0.62	5994
G/Marico	A300-04	Marico-Bosveld	1	1933-1977	27.813	2.223	2.336	1219	52	7.4	0.96	22816
Mogol	A400-02	Hans Strydom	1	1975-1988	149.000	0.869	1.762	4319	11	0.6	4.07	34499
Sterk	A600-03	Doorndraai	1	1953-1979	47.255	1.582	2.098	579	98	3.2	2.06	81614
Mogalakwena	A600-04	Glen Alpine	1	1967-1979	21.928	1.868	4.031	10713	10	7.8	0.16	2047
Dorps	A600-05	Combrink	1	1964-1978	0.951	0.049	0.094	174	15	4.9	1.30	5465
Sterk	A600-09	Welgevonden	1	1954-1977	0.679	0.026	0.037	166	6	3.7	-	4091
Nzhelele	A800-01	Nzhelele	1	1948-1979	57.274	3.050	3.718	842	119	5.1	-	68021
Nwandezi	A800-04	Nwanedzi	1	1963-1979	5.533	0.032	0.056	109	14	0.6	-	50762
Luphephe	A800-05	Luphephe	1	1963-1979	15.019	0.115	0.201	150	36	0.8	0.53	100127
Bronkhorst	B200-01	Bronkhorstspruit	1	1948-1983	58.902	1.954	2.257	1263	48	3.2	1.27	46637

BRANCH	LOCATION NUMBER	DAM NAME	REGION	PERIOD	V_W (END) (10^6 m^3)	V_T (10^6 m^3)	V_{50} (10^6 m^3)	ECA (km^2)	YIELD ($t/km^2.a$)	V_T/V_W (%)	V_W /MAR	V_W /ECA
Elands	B310-01	Rust de Winter	1	1934-1977	28.483	1.303	1.382	1147	33	4.4	0.65	24832
Olifants	B320-01	Loskop	1	1939-1977	348.100	11.238	12.533	5820	58	3.1	0.84	59811
Watervals	B400-01	Buffelskloof	1	1972-1987	5.384	0.111	0.203	278	20	2.0	0.22	19367
Klaserie	B700-09	Jan Wassenaar	1	1960-1979	5.779	0.470	0.739	165	121	7.5	0.34	35024
G/Letaba	B800-02	Ebenezer	1	1959-1986	70.029	0.690	0.898	156	155	1.0	1.59	448903
Politsi	B800-06	Magoebaskloof	1	1970-1986	4.915	0.102	0.179	64	76	2.0	0.13	76797
Broederstroom	B800-17	Dap Naude	1	1961-1987	1.936	0.140	0.185	14	357	6.7	-	138307
Ramadiepa	B800-21	Hans Merensky	1	1935-1987	1.234	0.082	0.081	88	25	6.2	-	14024
Mooi	C230-01	Klerkskraal	3	1969-1982	8.249	0.423	0.858	1335	17	4.9	0.13	6179
Mooi	C230-04	Boskop	3	1959-1981	20.854	0.400	0.579	1952	8	1.9	0.24	10684
Loop	C230-06	Klipdrift	3	1918-1977	13.065	1.330	1.252	881	38	9.2	2.46	14830
Schoonspruit	C240-01	Rietspruit	3	1955-1989	7.772	0.774	0.905	375	65	9.1	-	20725
Schoonspruit	C240-05	John Neser	3	1915-1977	5.672	0.160	0.148	4200	1	2.7	-	1350
Sand	C400-02	Allemanskraal	3	1960-1989	182.512	40.255	50.632	2655	373	8.1	2.35	68743
G/Vet	C400-03	Erfenis	3	1959-1987	215.129	20.072	25.672	4000	173	8.5	1.57	53782
Riet	C510-04	Kalkfontein	6	1938-1979	321.416	36.173	39.095	8647	122	10.1	-	37171
Kaffir	C510-10	Tierpoort	6	1922-1979	34.343	4.042	3.853	922	113	10.5	1.72	37248
Modder	C520-02	Krugersdrift	3	1970-1989	75.527	12.423	19.531	3355	157	14.1	0.81	22512
Modder	C520-03	Rustfontein	6	1955-1981	72.654	4.738	6.284	600	283	6.1	2.88	121091
Renoster	C700-02	Koppies	3	1911-1978	40,715	11.983	10.797	2147	136	22.7	-	18964
Leeu	C700-03	Roodepoort	3	1896-1978	0.909	0.952	0.802	80	271	51.2	0.78	11356
Leeu	C700-05	Weltevrede	3	1907-1978	1.842	1.072	0.880	63	377	36.8	-	29244
Matjesvlei	C800-18	Menin	3	1922-1978	0.691	0.135	0.129	80	44	16.3	0.53	8638
Leeu	D200-04	Armenia	3	1951-1987	14.167	0.544	0.621	529	32	3.7	0.60	26780

BRANCH	LOCATION NUMBER	DAM NAME	REGION	PERIOD	V_W (END) (10^6 m^3)	V_T (10^6 m^3)	V_{50} (10^6 m^3)	ECA (km^2)	YIELD ($t/km^2.a$)	V_T/V_W (%)	V_W /MAR	V_W /ECA
Blaasbalk	D200-17	Poortjie	6	1925-1981	5.408	1.993	1.912	450	115	26.9	-	12018
Oranje	D350-02	Hendrik Verwoerd	6	1971-1979	5673.778	274.989	884.691	67845	352	4.6	0.66	83629
Bethulie	D350-04	Bethulie	6	1921-1979	1.969	4.542	4.302	255	455	69.8	0.34	7720
Swartbas	D420-01	Leeubos	2	1949-1983	0.998	0.129	0.151	259	16	11.4	0.72	3854
Van Wyksvlei	D540-01	Van Wyksvlei	5	1884-1979	143.081	2.248	1.300	1339	26	1.5	-	106857
Ongers	D600-01	Smartt	5	1912-1980	100.287	2.217	1.987	13114	4	2.2	2.48	7647
Dorp	D600-06	Victoria-Wes	5	1924-1954	3.660	0.440	0.545	280	53	10.7	-	13071
Olifants	E100-02	Clanwilliam	8	1935-1980	124.092	9.715	10.117	2033	134	7.3	0.32	61039
Olifants	E100-04	Bulshoek	8	1922-1980	6.298	0.486	0.460	736	17	7.2	0.01	8557
Wemmershoek	G100-13	Wemmershoek	8	1957-1984	58.797	1.102	1.434	125	310	1.8	-	470373
Stettynskloof	H100-18	Stettynskloof	8	1954-1984	15.543	0.088	0.109	55	54	0.6	0.33	282600
Koekedouw	H101-51	Ceres	8	1953-1981	0.347	0.018	0.023	50	12	4.9	-	6968
Sanddrif	H200-07	Roode Elsburg	8	1968-1983	7.744	0.373	0.682	59	202	4.6	0.39	131247
Groot	H300-01	Poortjieskloof	8	1957-1979	9.960	0.247	0.358	94	103	2.4	1.38	105952
Keisies	H300-02	Pietersfontein	8	1968-1981	2.062	0.570	1.155	116	269	21.7	4.48	17774
Nuy	H400-02	Keerom	8	1954-1981	7.398	0.946	1.232	378	88	11.3	1.03	19571
Konings	H400-06	Klipberg	8	1964-1983	1.996	0.002	0.002	54	1	0.1	1.80	36967
Hoeks	H400-10	Moordkuil	8	1950-1985	1.520	0.048	0.056	176	9	3.1	-	8634
Buffeljags	H700-02	Buffeljags	8	1966-1983	5.736	0.090	0.152	601	7	1.5	0.05	9543
Duiwenhoks	H800-03	Duiwenhoks	8	1965-1979	6.406	0.058	0.112	148	20	0.9	0.22	43283
Korinte	H900-03	Korentepoort	8	1965-1983	8.296	0.028	0.045	37	33	0.3	-	224224
Buffels	J110-01	Floriskraal	6	1957-1981	51.951	15.486	25.000	4001	169	23.0	2.49	12985
Brak	J120-02	Bellair	8	1920-1981	10.077	0.933	0.700	558	34	8.5	0.45	18059
Prins	J120-04	Prinsrivier	8	1916-1981	1.262	4.189	3.813	757	136	76.9	0.37	1667

BRANCH	LOCATION NUMBER	DAM NAME	REGION	PERIOD	V_W (END) (10^6 m^3)	V_T (10^6 m^3)	V_{50} (10^6 m^3)	ECA (km^2)	YIELD ($t/km^2.a$)	V_T/V_W (%)	V_W /MAR	V_W /ECA
Gamka	J210-01	Gamka	5	1955-1980	2.165	0.187	0.253	98	70	7.9	0.50	22092
Leeu	J220-01	Leeu Gamka	5	1959-1981	14.154	7.478	10.818	2088	140	34.6	0.49	6779
Cordiers	J230-01	Oukloof	5	1929-1984	4.222	0.293	0.283	141	54	6.5	1.13	29945
Gamka	J250-01	Gamkapoort	5	1969-1981	43.836	10.122	21.849	17076	35	18.8	1.09	2567
Nels	J250-02	Calitzdorp	8	1917-1981	4.817	0.997	0.850	170	135	17.2	0.67	28334
Olifants	J330-01	Stompdrift	8	1965-1981	55.316	6.438	11.265	5235	58	10.4	2.27	10567
Kammanassie	J340-02	Kammanassie	8	1923-1981	35.855	3.584	3.000	1505	54	9.1	0.98	23824
L/Le Roux	J350-04	Raubenheimer	8	1973-1984	9.203	0.005	0.011	43	7	0.1	0.52	150875
L/Le Roux	J350-05	Melville	8	1945-1984	0.466	0.001	0.001	18	1	0.2	-	25900
Hartenbos	K100-02	Hartebeeskuil	8	1969-1981	7.162	0.011	0.024	100	7	0.2	4.07	71615
G/Brak	K100-06	Ernest Robertson	8	1955-1985	0.419	0.004	0.004	10	12	0.9	0.11	41940
Krom	K900-01	Churchill	8	1943-1987	35.678	0.122	0.128	357	10	0.3	-	99939
Koega	L820-1	Paul Sauer	8	1969-1986	128.490	1.515	2.549	3887	18	1.2	0.64	33056
Loerie	L900-01	Loerie	8	1971-1984	3.362	0.752	1.524	147	280	18.3	0.08	22869
Sondags	N120-01	Van Ryneveldspas	9	1925-1978	47.426	31.397	27.500	3544	210	39.8	1.40	13382
Sondags	M230-01	Lake Mentz	9	1922-1978	191.758	135.670	130.140	12987	271	41.4	1.09	14765
Nuwejaars	P100-01	Nuwejaars	9	1958-1981	4.622	0.057	0.081	531	4	1.2	-	8704
G/Brak	Q130-01	Grassridge	9	1924-1984	49.576	41.252	38.610	4325	241	45.4	0.55	11463
Tarka	Q410-01	Kommandodrif	9	1956-1985	58.800	14.663	21.000	3623	157	20.0	1.68	16230
Tarka	Q440-01	Lake Arthur	9	1924-1985	29.255	68.059	63.331	3450	496	69.9	0.46	8480
G/Vis	Q500-01	Elandsdrift	9	1973-1981	9.720	2.459	7.912	8042	27	20.2	-	1209
Kat	Q940-01	Katrivier	9	1969-1988	24.873	1.887	2.966	258	310	7.6	1.18	96319
Buffels	R200-02	Laing	9	1950-1981	21.035	1.708	2.400	862	75	7.5	0.34	24403
Buffels	R200-05	Bridle Drift	9	1968-1981	73.509	5.146	10.430	375	751	6.5	0.71	196023

BRANCH	LOCATION NUMBER	DAM NAME	REGION	PERIOD	V_W (END) (10^6 m^3)	V_T (10^6 m^3)	V_{50} (10^6 m^3)	ECA (km^2)	YIELD ($t/km^2.a$)	V_T/V_W (%)	V_W /MAR	V_W /ECA
Buffels	R200-07	Maden	9	1909-1981	0.266	0.053	0.047	30	42	16.8	-	8850
Nahoon	R300-01	Nahoon	9	1964-1981	20.759	1.201	2.021	474	115	5.5	0.52	43795
Wit Kei	S100-01	Xonxa	9	1974-1986	135.080	22.486	48.536	1487	881	14.3	-	90841
Doring	S200-01	Indwe	9	1969-1984	23.444	3.864	7.061	295	646	14.1	-	79471
Klipplaat	S300-06	Waterdown	9	1958-1988	38.200	0.213	0.264	603	12	0.6	0.72	63350
Tsomo	S500-01	Ncora	9	1976-1988	154.076	8.193	17.686	1772	269	5.0	-	86951
Gubu	S600-04	Gubu	9	1970-1981	9.254	0.059	0.137	23	161	0.6	2.16	402330
Mtata	T201-03	Mtata	9	1977-1987	257.097	1.129	2.859	868	89	0.4	-	296195
Umgeni	U200-01	Albert Falls	4	1974-1983	289.167	0.295	0.832	716	31	0.1	1.14	403864
Umgeni	U200-03	Midmar	4	1965-1983	177.114	0.204	0.330	928	10	0.1	1.01	190855
Umzinduzi	U200-09	Henley	4	1942-1987	5.407	0.355	0.370	238	42	6.2	-	22717
Mdloti	U300-01	Hazelmere	4	1975-1987	19.223	4.679	10.099	377	723	19.6	0.33	50989
Mlazi	U600-03	Shongweni	4	1927-1987	5.208	6.853	6.414	750	231	56.8	-	6945
Tugela	V100-01	Spioenkop	4	1972-1986	279.628	6.367	12.214	774	426	2.2	0.50	361276
Mnyamvubu	V200-02	Craigie Burn	4	1963-1983	23.446	0.108	0.164	152	29	0.5	0.88	154253
Ngagane	V300-04	Chelmsford	4	1961-1983	198.438	3.400	4.919	830	160	1.7	1.17	239081
Boesmans	V700-01	Wagendrift	4	1963-1983	58.362	1.639	2.500	744	91	2.7	0.28	78444
Hluhluwe	W300-03	Hluhluwe	4	1964-1985	28.775	2.517	3.736	734	137	8.0	0.72	39202
Pongola	W440-01	Pongolapoort	4	1973-1984	2445.258	55.656	129.262	7831	446	2.2	4.54	312254
Mpapa	W530-03	Jericho	4	1966-1983	59.834	1.011	1.701	218	211	1.7	1.32	274470
Usutu	W540-01	Westoe	4	1968-1980	61.011	0.044	0.096	531	5	0.1	1.35	114898
Komati	X100-09	Nooitgedacht	4	1962-1983	78.824	1.162	1.724	1569	30	1.5	1.39	50238
Wit	X200-04	Primkop	4	1970-1987	2.017	0.191	0.322	158	55	8.7	0.08	12763
Wit	X200-13	Longmere	4	1940-1979	4.347	0.227	0.250	27	250	5.0	0.26	161000

BRANCH	LOCATION NUMBER	DAM NAME	REGION	PERIOD	V_W (END) (10^6 m^3)	V_T (10^6 m^3)	V_{50} (10^6 m^3)	ECA (km^2)	YIELD ($t/km^2.a$)	V_T/V_W (%)	V_W /MAR	V_W /ECA
Sand	X200-20	Witteklip	4	1969-1979	12.972	0.150	0.379	64	160	1.1	0.78	202691
Wit	X200-23	Klipkopjes	4	1960-1979	11.866	0.430	0.676	78	234	3.5	-	152131
Witwaters	X300-02	Da Gama	4	1971-1979	13.653	0.404	1.300	62	566	2.9	1.10	220202
Klip	-	Windsor	4	-	-	-	1.087	2329	126	-	-	-
Mgeni	-	Camperdown	4	1901-1923	1.364	0.909	1.170	376	84	0.67	-	3628

REGION = SEDIMENT YIELD REGION (SECT 3.7)

V_W(END) = VOLUME OF RESERVOIR AT MOST RECENT SURVEY

V_T = VOLUME OF SEDIMENT DEPOSIT

V_{50} = EQUIVALENT 50 YEAR SEDIMENT DEPOSIT VALUE

ECA = EFFECTIVE CATCHMENT AREA

YIELD = ANNUAL YIELD PER UNIT AREA (MASS)

MAR = MEAN ANNUAL RUN-OFF

TABLE 2.2 Reservoirs excluded from database

LOCATION NUMBER	RESERVOIR	REASON FOR EXCLUSION
A220-01	Vaalkop	Short record
A230-07	Warmbad Irr Bd	Altered before survey
A300-05	Twyfelpoort Irr Bd	Altered before survey
A500-07	Susandale	Unreliable sediment trap
A500-08	Visgat	Unreliable sediment trap
A600-09	Welgevonden	Unreliable sediment trap
A800-02	Cross	Short record
A900-03	Albasini	Altered before survey
B100-04	Witbank	Altered before survey
B100-13	Middelburg	Altered before survey
B320-02	Rooikraal	Altered before survey
B400-12	Tonteldoos	Unreliable sediment trap
B600-02	Blyderivierspoort	Short record
B700-02	Phalaborwa	Unreliable sediment trap
B800-12	Prieska Weir	Unreliable sediment trap
C111-28	Amersfoort	Unreliable sediment trap
C210-02	P v/d M Haarhoff	Unreliable sediment trap
C230-07	Lakeside	Channel link from Boskop
C300-02	Schweizer Renecke	Unreliable sediment trap
C800-11	Driekloof	Short record
C801-10	Sterkfontein	Altered before survey
C900-02	Vaalharts Weir	Unreliable sediment trap
D140-02	JL de Bruyn	Unreliable sediment trap
D200-01	Welbedacht	Unreliable sediment trap
D310-01	P.K. Le Roux	Short record
D320-01	Krugerspoort	Altered before survey
D530-07	Rooiberg	Unreliable sediment trap
E400-01	Calvinia	Altered before survey
G100-03	Voëlvlei	Channel link
G203-64	Kleinplaas	Altered before survey
G400-18	Kromme Dam	Altered before survey

LOCATION NUMBER	RESERVOIR	REASON FOR EXCLUSION
H100-25	Brandvlei	Off channel storage
H402-48	Kwaggaskloof	Altered before survey
H600-10	Waterval	Altered before survey
K900-02	Elandsjagt	Short record
L300-01	Beervlei	Unreliable sediment trap
N300-03	Blyde	Altered before survey
R200-04	Rooikrantz	Altered before survey
T300-04	Mountain	Altered before survey
T500-01	Gilbert Eyles	Unreliable sediment trap
V100-02	Woodstock	Short record
V100-04	Driel Barrage	Unreliable sediment trap
V100-18	Kilburn	Short record
W210-12	Klipfontein	Short record
W530-02	Morgenstond	Short record
W600-01	Mnjoli	Short record
X100-02	Vygeboom	Effective catchment difficult to define

2.2 SUSPENDED SEDIMENT MEASUREMENT

2.2.1 South African Data

A number of suspended sediment measuring stations were in existence for periods after 1928. Most of these stations were situated in the major drainage areas in the country, such as the Orange, Tugela and Pongola river basins (Rooseboom and Maas, 1974). Due to major changes in sediment transport patterns in some South African rivers, notably the Orange River, the data available from these stations, do not represent the current state of affairs. Nevertheless, the data available from this source is of value as:

i) Some of the stations cover areas where no other information is available.

ii) The stations with long annual records provide insight into the variability of sediment yields with time. A good example is provided by the suspended sediment data for Prieska-Upington.

Although this data was not used for the calibration of the new sediment yield map, the data is useful for comparative purposes. The map in **Figure 2.3** indicates the positions of the measuring stations and the measured yield values for these stations are given in **Table 2.3** (Rooseboom and Maas 1974).

TABLE 2.3: AVERAGE SEDIMENT TRANSPORT YIELDS AT VARIOUS MEASURING STATIONS (ORANGE RIVER SYSTEM) ($t/km^2.a$) [ROOSEBOOM AND MAAS - 1974]

STATION	RIVER	ID	REG	TOTAL AREA	PERIOD				
					1929 - 1934	1934 - 1943	1943 - 1952	1952 - 1960	1960 - 1969
Oranjedraai	Orange	6	6	24876	-	-	-	-	402
Aliwal-North	Orange	5	6	37202	414	366	470	530	462
Jammersdrift	Caled.	9	6	13320	923	871	-	-	-
Bethulie	Orange	23	6	65151	646	536	657	669	560
Oranjerivierbrug	Orange	17	5	94464	630	493	562	-	-
Barrage	Vaal	22	3	45882	85	-	-	-	-
Paardeberg	Modder	15	3	14791	-	-	311	-	-
Leeuwkraal	Riet	16	3	11000	100	-	-	-	-
Prieska/ Upington		18/20	3	329582	311	196	183	161	119

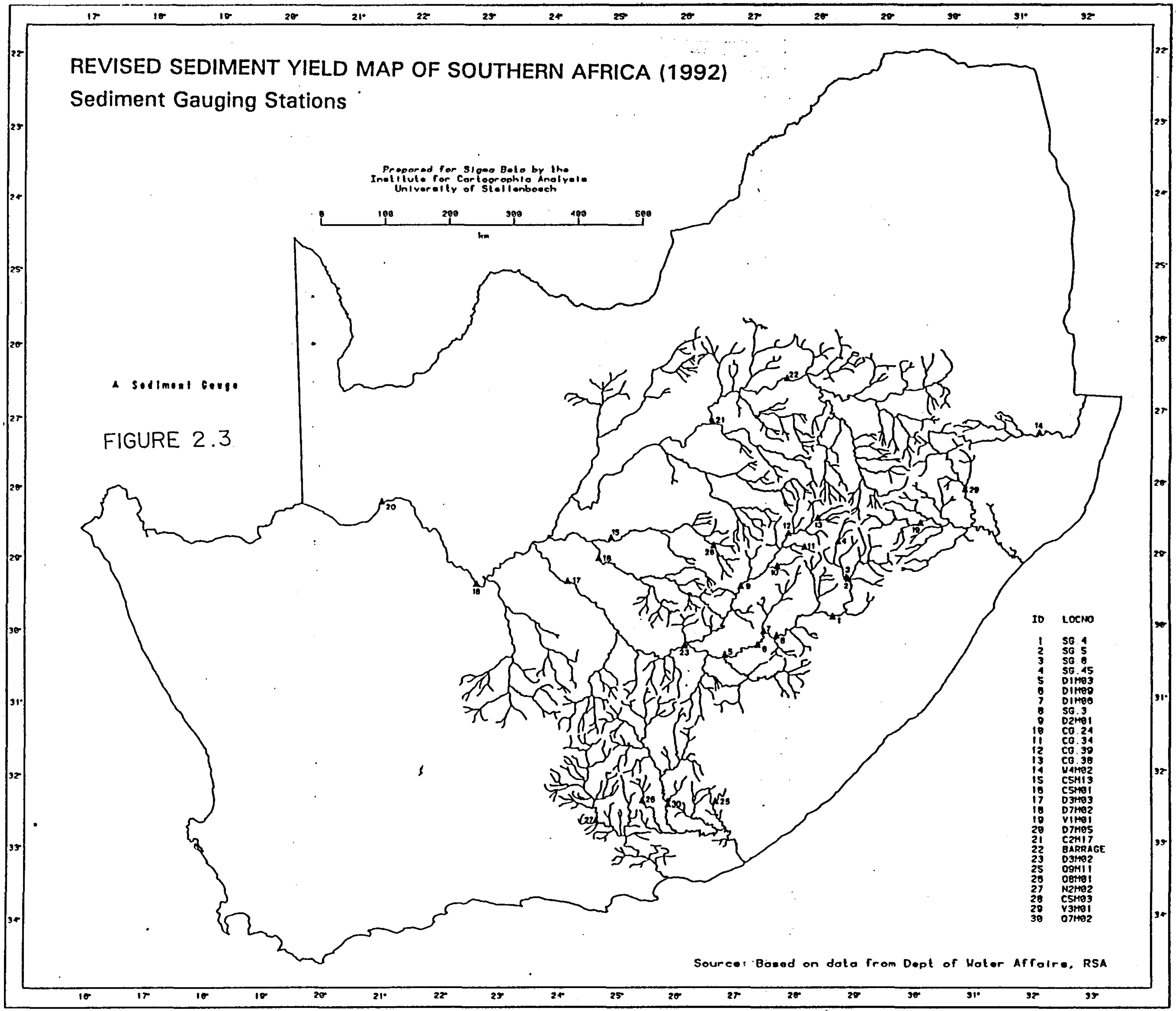

REVISED SEDIMENT YIELD MAP OF SOUTHERN AFRICA (1992)
Sediment Gauging Stations
Prepared for Sigma Beta by the
Institute for Cartographic Analysis
University of Stellenbosch
0 100 200 300 400 500
km
▲ Sediment Gauge
ID LOCNO
1 SG.4
2 SG 5
3 SG.6
4 SG.45
5 D1M03
6 D1M09
7 D1M06
8 SG.3
9 D2M01
10 CG.24
11 CG.34
12 CG.39
13 CG.38
14 W4M02
15 C5M13
16 C5M01
17 D3M03
18 D7M02
19 V1M01
20 D7M05
21 C2M17
22 BARRAGE
23 D3M02
25 Q9M11
26 Q8M01
27 N2M02
28 C5M03
29 V3M01
30 Q7M02
Source: Based on data from Dept of Water Affairs, RSA

FIGURE 2.3

TABLE 2.4: OTHER YIELD DATA DERIVED FROM STREAM SAMPLING RECORDS

STATION	RIVER	ID	REG	AREA km^2	YIELD $t/km^2.a$	PERIOD
Colenso	Tugela	19	4	4203	571	1950 - 1958
Intulembi	Pongola	14	4	7147	133	1928 - 1945
Burghersdorp	Stormberg	-	6	2370	762	1935 - 1948
Standerton	Vaal	-	3	8254	193	1929 - 1940
Vetrivierbrug	Vet	21	3	5504	279	1935 - 1947
Schweizer Reneke	Hartz	-	3	9251	7	1934 - 1956
Sannaspos	Modder	28	3	1650	304	1935 - 1943
Jansenville	Sondags	27	9	11560	136	1930 - 1948
Buffelsfontein	L/Fish	26	9	995	589	1931 - 1939
Hougham Abramson	G/Fish	30	9	18436	209	1930 - 1940
Upsher	Kat	25	9	554	499	1931 - 1948

REG = SEDIMENT YIELD REGION (SECTION 3.7)

2.2.2 Lesotho Data

A suspended sediment measurement programme was started in Lesotho in the mid seventies (Makhoalibe, 1984). The measuring stations cover almost the entire Lesotho. Although records are relatively short, the values obtained supplement longer term results downstream in South Africa.

The yield values obtained from the Lesotho stations were included in the data base for calibration purposes as they are considered to be reliable indicators of relative average yields.

The sediment yield values for Lesotho are given in **Table 2.5**.

TABLE 2.5: LESOTHO SEDIMENT YIELD VALUES (MAKHOALIBE - 1984)

LOC. No.	STATION	RIVER	ID	REG	AREA (km^2)	YIELD ($t/km^2.a$)	PERIOD
SG3	Seaka	Senqu	8	6	8975	295	1976-1982
SG4	Whitehill	Senqu	1	7	2950	329	1976-1982
SG45	Ha Lejone	Malibamatso	4	7	1157	9	1976-1982
SG5	Koma-Koma	Senqu	2	7	2198	89	1976-1982
SG8	Paray	Malibamatso	3	7	1018	175	1976-1982
CG24	Masianokeng	S. Phutiatsana	10	6	945	1382	1976-1982
CG34	Mapoteng	N. Phutiatsana	11	7	386	2050	1976-1982
CG38	Mashili	Caledon	12	6	1348	832	1976-1982
CG39	Mohlokagala	Caledon	13	6	3312	1055	1976-1982

REG = SEDIMENT YIELD REGION (SECTION 3.7)

The positions of Lesotho measuring stations are indicated on the map in **Figure 2.3**.

3. <u>THE SUBDIVISION OF SOUTHERN AFRICA INTO SEDIMENT YIELD REGIONS FOR CALIBRATION PURPOSES</u>

3.1 INTRODUCTION

One of the main purposes in the development of the new sediment map was to attempt to establish relationships between observed sediment yields and the physical and geographical features of southern Africa. For this purpose, maps with relevant information on soil erodibility, rainfall, steepness and land use were prepared during the course of the research and placed on the GIS system.

This chapter deals with the various maps (see **Table 3.1**), the use of the GIS system, as well as the subdivision of southern Africa into various sediment yield regions on the basis of available information.

3.2 THE USE OF GIS FOR RESEARCH PURPOSES

3.2.1 Introduction

The application of geographical information systems (GIS) to the problem of extrapolating sediment yield information in southern Africa marks a new phase in this type of analysis. The capabilities of GIS to capture, store, manipulate, maintain, analyze and display large volumes of geographically related data in a flexible and efficient manner holds great potential for analysis at regional, continental and even global scales.

Environmental problems such as erosion and sedimentation are particularly suited to analysis by means of GIS as these processes are inherently spatial by nature. A GIS facilitates analyses of large spatial datasets in many ways. Overlay analysis, for example, can be applied to compute area statistics for particular combinations of environmental characteristics. These statistics can be further employed in modelling or mapping procedures (Starr and Estes, 1990).

In this sedimentation study a GIS was used in a supportive role with more limited objectives, namely:

i) To create a sedimentation database for large reservoirs in southern Africa;

ii) To map spatial variations in observed sediment yield values and other related environmental characteristics per catchment area;

iii) To obtain area statistics of soil properties per catchment for modelling sediment yield values; and

iv) To facilitate the delineation of sediment yield regions for southern Africa.

The Institute for Cartographic Analysis at the University of Stellenbosch participated in the project by providing GIS support for achieving these goals.

3.2.2 Database Creation with GIS

A GIS stores spatial and non-spatial information for particular entities in its database. The geographical entities for which data can be entered are classified as points, lines or polygons. All three entity types are represented in the present study. Dams and sediment gauging stations, for which sediment yield values are obtainable, are examples of point features. Rivers, coastlines and national boundaries are represented by lines, whereas soil type, slope, rainfall erosivity and agricultural regions are instances of polygon features.

The GIS on which the sedimentation database was created is PC ARC/INFO Version 3.4D (ERSI, 1990). The system is currently operated on a 486 PC with a

600 Mb hard disk and VGA colour monitor under DOS Version 4.01. This system adequately handled the data volumes encountered in the project and imposed little restriction. The only exceptions were a limitation of 32 000 polygons when averaged slopes were created from point data and in mapping complex polygons when using the VGA graphics card.

A list of the datasets which were put into ARC/INFO is given in **Table 3.1.**

Each of the datasets entered into the GIS is described in term of its source, scale, projection, original entity type, derived entity type and derivation procedures. By providing information on the lineage of the data it should be possible for future users to evaluate the data quality and assess different levels of accuracy.

3.3 BASIC EROSION INDEX MAP (FIGURE 3.1)

3.3.1 Soil-Slope factors controlling sediment delivery potential

The sediment yield of a drainage basin is the net result of the processes of erosion, transportation and deposition. In this section, however, the erosional process and soil loss will not be dealt with in detail. Soil loss can be related to several controlling factors such as rainfall, soil erodibility, slope (length and steepness) and landuse. For the purpose of this part of the study, the soil and slope factors were analyzed separately in order to compile a broad-scale map (scale 1:1 500 00) of the sediment delivery potential of southern Africa.

Another relevant aspect is the availability of soil materials to yield sediments (sediment yield potential of soils) of a specific particle size range.

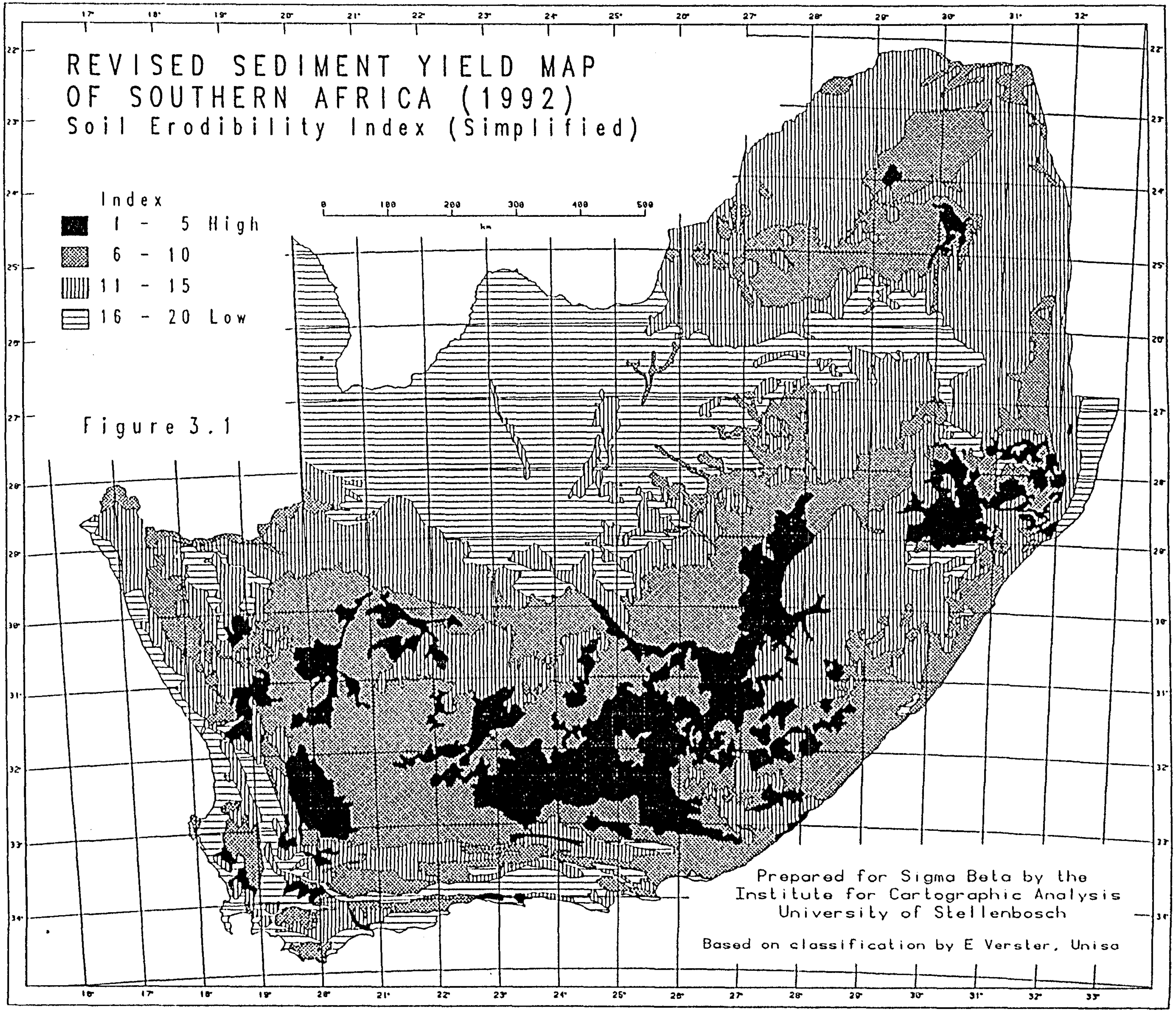

REVISED SEDIMENT YIELD MAP
OF SOUTHERN AFRICA (1992)
Soil Erodibility Index (Simplified)
Index
1 - 5 High
6 - 10
11 - 15
16 - 20 Low
0 100 200 300 400 500
km
Figure 3.1
Prepared for Sigma Beta by the
Institute for Cartographic Analysis
University of Stellenbosch
Based on classification by E Verster, Unisa

TABLE 3.1: GEOGRAPHICAL INPUT DATASETS FOR SEDIMENTATION DATABASE

	ENTITY	TYPE	SCALE	FORMAT	SOURCE
1.	Rivers	Lines	1 : 1 500 000	ARC/INFO	Dept. of Water Affairs, RSA
2.	Drainage Regions	Polygons	1 : 1 500 000	ARC/INFO	Dept. of Water Affairs, RSA
3.a	Reservoirs	Points	1 : 1 500 000	ARC/INFO	Dept. of Water Affairs, RSA
3.b	Reservoirs	Points		Tabular List	Dept. of Water Affairs, RSA
4.	Reservoir Catchment	Polygons	1 : 1 500 000	Map	Dept. of Water Affairs, RSA
5.	Sediment Gauging Stations	Points		Tabular List	Dept. of Water Affairs, RSA
6.	Sediment Gauging Catchment	Polygons	1 : 1 500 000	Map	Dept. of Water Affairs, RSA
7.	Rainfall Erosivity	Points		Tabular List	Smithen, (1981, University of Natal)
8.	Soil Erodibility	Polygons	1 : 1 500 000	Map	Verster, E. Prof. (1991), Dept. of Geography, University of South Africa
9.	Average Slope	Points	1 : 1 250 000	Digital File	Computing Centre for Water Research, University of Natal
10.	Agricultural Regions	Polygons	1 : 1 500 000	Map	Institute for Cartographic Analysis, University of Stellenbosch

Limited information is available on the particle size distribution of sediments occurring in South African dams. Unprocessed data available from the Department of Water Affairs and Forestry (Directorate of Hydrology) indicates that the sediment deposited during the period 1978 - 1982 near the wall of the Hendrik Verwoerd Dam is mainly finer than 0,006 mm whereas, near the inlet, it is finer than 0,05 mm. By contrast, the sediments in the Van Ryneveld Pass Dam are composed of 38% finer than 0,002 mm, 43% between 0,002- 0,05 mm, 16% between 0,05 - 0,147 mm, and 3% between 0,147 - 0,589 mm; and in the Grassridge Dam 13% finer than 0,002 mm, 27% between 0,002 - 0,05 mm, 29% between 0,05 - 0,147 mm, 26% between 0,147 - 0,589 mm, 2% between 0,589 - 2,0 mm and 3% coarser than 2,0 mm (Rabie 1968). Although it can be assumed that spatial variability is a feature of sediments' particle size distribution in dam basins, it seems likely that the soil size fractions clay, silt and very fine sand (i.e. finer than approximately 0,106 mm) are the major contributors to sediment yields. This is also substantiated by the size fractions of the sediment deposits from the Orange River on irrigated lands at Onseepkans during the flood of 1988 (Verster and Van Rooyen, 1988).

The basic map was prepared in two steps, viz the compilation of a macro soil-slope association map (scale 1:1 000 000) and the composition of a sediment delivery potential map (scale 1:1 500 000) based on the soil and slope factors.

All available information on the soil-slope conditions of southern Africa was collated as a first step. This was extracted from the published and unpublished land type maps and inventories as produced by the Soil and Irrigation Research Institute, Pretoria*: and from Murdoch (1970) for Swaziland, Soil Survey Conservation Division (1979) for Lesotho and the Department of Development Aid, Pretoria for the Transkei.

From an interpretation of the soil-slope map, the sediment delivery potential map was constructed taking two aspects into consideration, namely the soil erosion hazard and the availability of soil materials to yield sediments. The assessment of erosion hazard was based on percentage slope, leaching status of the soils, the soil erodibility factor (K-value) and the textural difference between the A and B horizons as described by Scotney et. al. (1991) for the soils of South Africa. In turn, the sediment yield potential was mainly based on soil type and the experience gained by the co-workers of the soil-site conditions. Finally, all the information was interpreted and grouped into 20 relative sediment delivery potential classes as follows:

TABLE 3.2

CLASS	**SEDIMENT DELIVERY POTENTIAL**
1 - 4	Very High
5 - 8	High
9 - 12	Moderate
13 - 15	Low
16 - 20	Very Low

The relative sediment delivery potential classes are shown on the larger scale full-colour map. A simplified version is shown in Figure 3.1.

*** Co-workers compiling a soil-slope map of South Africa using this information were A. Bennie, C. du Preez, F. Ellis, P. Le Roux, A. Oosthuizen, G. Paterson and D.Turner.**

The sediment yields from any area depends on many variables. Moreover, the broad scale approach of this study means that map units are not "pure", with the result that an assessment of potential reflects the average condition only. In view of these limitations, and the fact that it may be regarded as an impossible task to describe all the soil-slope-sediment delivery combinations covering the southern Africa landscape, only a general assessment of the sediment delivery potential of the broad soil patterns, as depicted on the land type maps, is summarised in **TABLE 3.3**.

The basic erosion index map at a scale of 1:1 500 000 was based on the Bonne projection. It was digitized, projected to geographical coordinates using the Department of Water Affairs computer programme and subsequently projected to Alberts Equal Area in a manner similar to that described in Section 2.4. The coverage contains 359 soil polygons to which are attached their computed area and soil erodibilty index.

TABLE 3.3: GENERAL SEDIMENT DELIVERY POTENTIAL CLASSES OF THE BROAD SOIL PATTERNS OF SOUTHERN AFRICA

BROAD SOIL PATTERN	SEDIMENT YIELD POTENTIAL OF SOILS	GENERAL SLOPE CLASS	SEDIMENT DELIVERY POTENTIAL CLASS
Red and yellow apedal freely drained soils:			
•Highly and moderately leached loams and clays; some with a humic horizon	High	Sloping to steep	9 - 18
•Mainly red high base status loams and clays	High	Level to sloping	9 - 16
•High base status mainly sands	Low	Level	16 - 20
Plinthic catena with upland duplex and margalitic soils rare:			
•Highly and moderately leached sands and loams	Moderate	Level to sloping	13 - 16
•Poorly leached sands and loams	Moderate	Level	13 - 18
Plinthic catena with upland duplex and margalitic soils common:			
•Loams and clays	High	Level to sloping	5 - 12
Duplex and paraduplex loams and clays	High	Level to sloping	1 - 8
Red and black structured clays	High	Level	12 - 16
Shallow soils on rock:			
•High rainfall areas	Moderate	Sloping to steep	9 - 12
•Low rainfall areas	Moderate	Level to steep	5 - 12
Deep grey sands	Low	Level to sloping	16 - 20
Undifferentiated deep alluvial loams	Moderate	Level	1 - 12
Rock areas with undifferentiated soils:			
•High rainfall areas	Low	Steep	13 - 16
•Low rainfall areas			
- Sands	Low	Sloping to steep	13 - 16
- Clays	Low	Sloping to steep	5 - 8
Rock areas with little or no soil:			
- Sand	Low	Sloping to steep	13 - 16
- Clays	Low	Sloping to steep	5 - 12

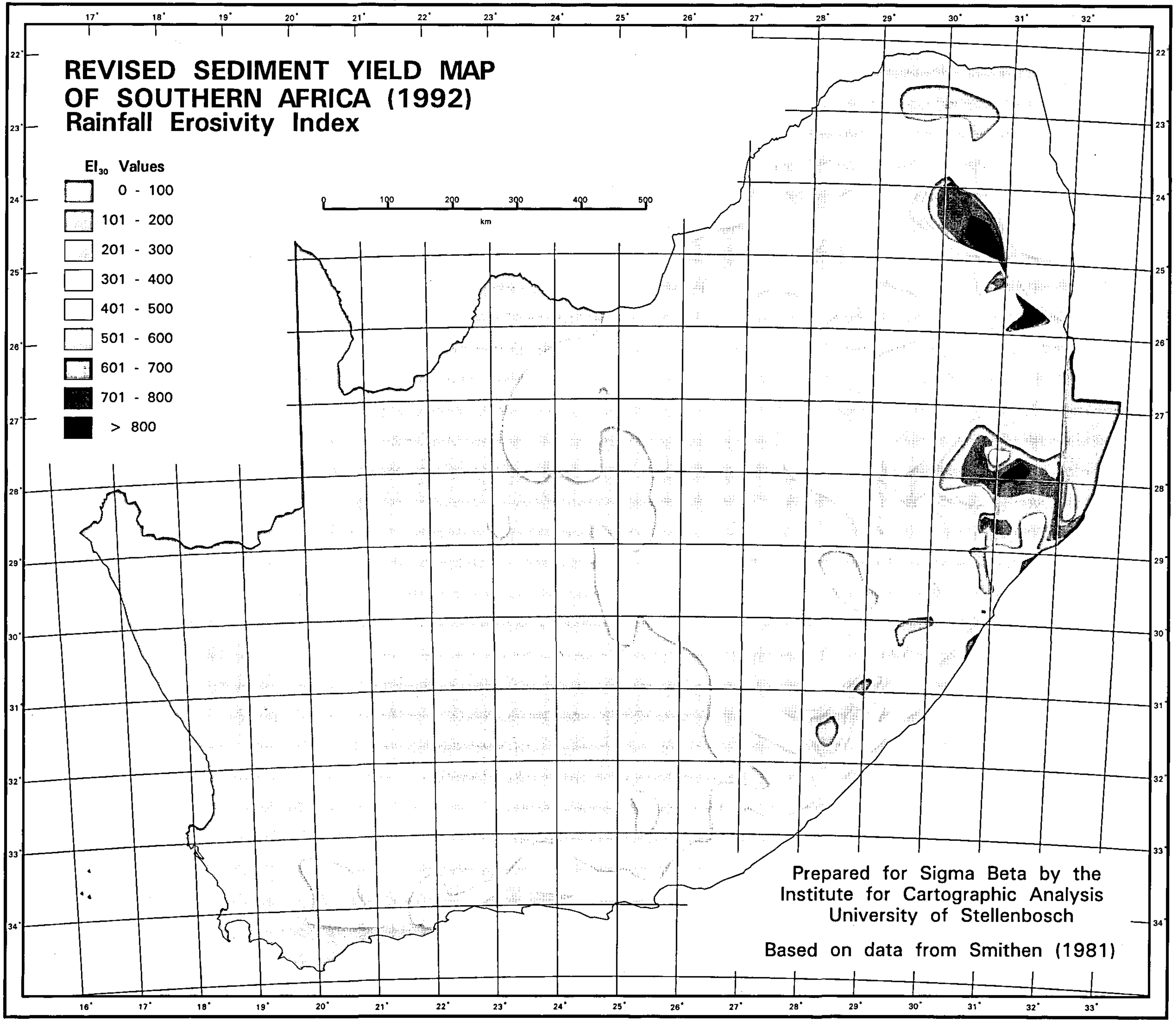
3.4 LAND USE MAP (FIGURE 3.2)

Due to the lack of land use information at a national scale it was decided to incorporate a surrogate measure in the form of an agricultural region classification. An existing map of Agricultural Regions produced by the Institute for Cartographic Analysis in 1979 was digitized. This map was based on the value of agricultural products sold by commercial farmers in 1975 (Republic of South Africa, 1976). Magisterial districts were classified according to predominant type of farming activity. It is assumed that general spatial patterns in agricultural production have not changed materially. Data of a similar nature have not been published by the Department of Statistics since 1976 and verification of this assumption is not possible without substantial effort. The coverage contains classification codes for ten major agricultural regions, i.e. grains (maize and wheat), sugar cane, vegetable gardening, fruit (deciduous, citrus and subtropical), cattle (beef and dairy), sheep (wool and mutton), diverse (poultry and pigs), subsistence farming and forestry. The 1975 records have the additional advantage of being in good agreement with the periods for which most of the sediment yield data is available.

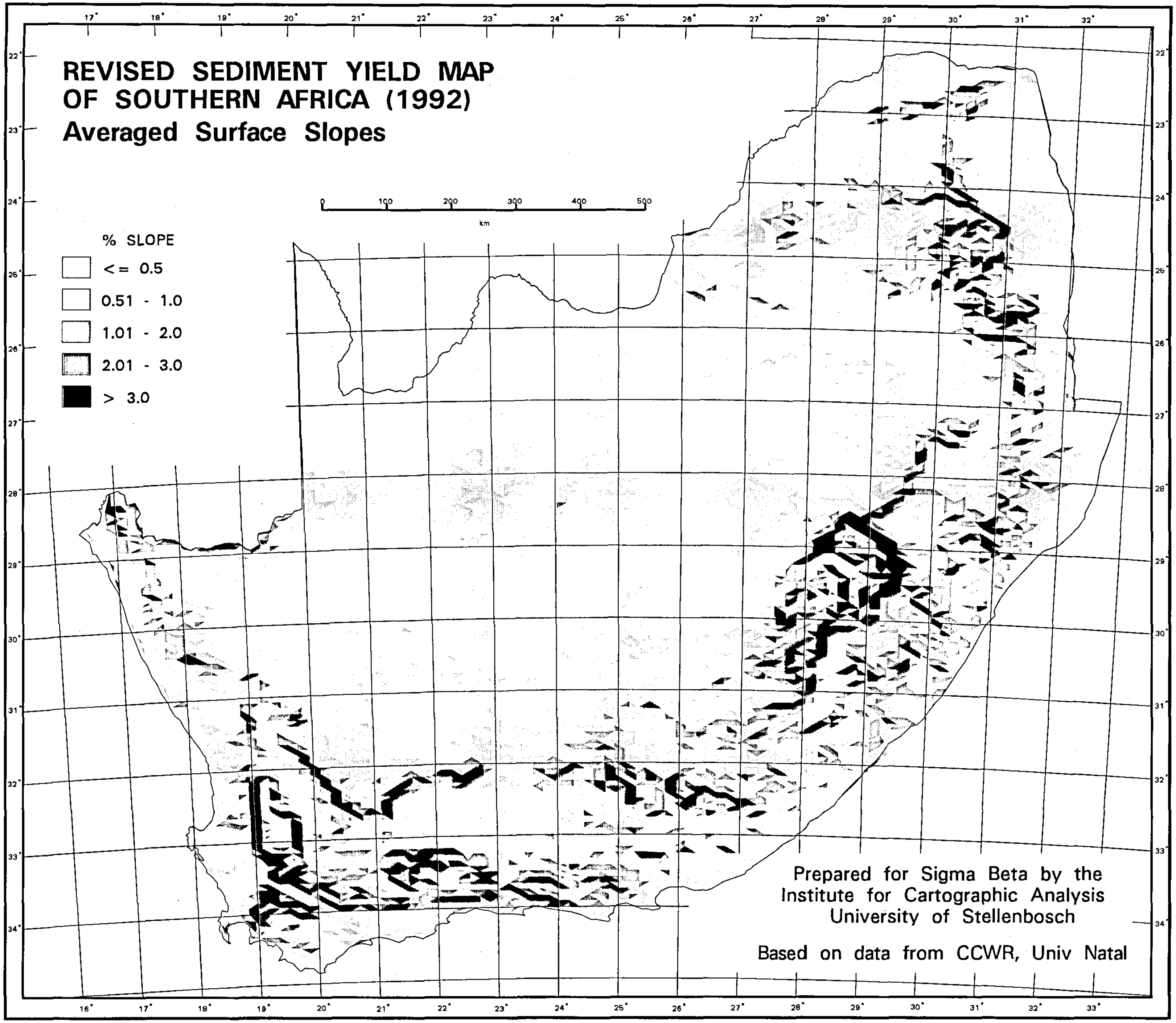
A more detailed map would not have been of much greater value as the limited sediment yield data base which is available does not warrant finer delineation of land use patterns.

3.5 AVERAGE SLOPE (FIGURE 3.3)

Slope represents the kinetic energy generated for sediment transport by such agents as running water and mass movements (De Ploey, 1990). Slope data for southern Africa were obtained from the Computing Centre for Water Research at the University of Natal in Pietermaritzburg. This data was on a magnetic tape and provided mean altitude values for a grid of 1′ x 1′ cells. The original dataset contained more than 450 000 altitude values. This level of detail was too great



/prj1ser4/plots/sedsch/rainfall.gra (Magenta)



REVISED SEDIMENT YIELD MAP
OF SOUTHERN AFRICA (1992)
Averaged Surface Slopes
0
100
200
300
400
500
km
% SLOPE
<= 0.5
0.51 - 1.0
1.01 - 2.0
2.01 - 3.0
> 3.0
Prepared for Sigma Beta by the
Institute for Cartographic Analysis
University of Stellenbosch
Based on data from CCWR, Univ Natal

for the purpose of this project, considering that most other data was derived from 1:1 500 000 scale maps. The altitude data was thus aggregated to a 5′ x 5′ grid which consisted of approximately 18 000 averaged altitude values. This was entered in ARC/INFO and a Triangulated Irregular Network model produced with the PC SEM software. This coverage consisted of more than 36 000 triangular shaped polygons each having a slope and aspect value. However, when attempting to convert this 3-D model into an ARC/INFO coverage the process failed due to a limitation of 32 000 polygons in the PC version of ARC/INFO. The problem was overcome by resampling the 5′ x 5′ grid and selecting every second value. This new dataset contained 9 207 altitude values and resulted in 17 210 polygons. Area, slope and aspect values were computed for each of these polygons by the GIS software. The actual values of percentage slope should be regarded as a relative measure due to the averaging method of computation.

3.6 RAINFALL EROSIVITY MAP (FIGURE 3.4)

In the early sixties, Smith and Wischmeyer developed the concept of the erosion index value (El_n), which is the product of raindrop energy (E) and the n - minute rainfall intensity (Mathewson, 1981). Rainfall erosivity index values (EI_{30}) for southern Africa were obtained from Smithen (1981). These values for a ten year return period were entered into the GIS by keypunching longitude and latitude values for 310 weather stations in the Republic of South Africa. Once entered into ARC/INFO, a triangular Irregular Network model was created using PC SEM developed by ERSI Germany. This 3-D of erosivity index values was subsequently interpolated at increments of 100 EI_{30} values and polygonized to produce **Figure 3.4.** The database currently contains a coverage of point locations with EI_{30} values and station names and a polygon coverage with broad class intervals of EI_{30} values.

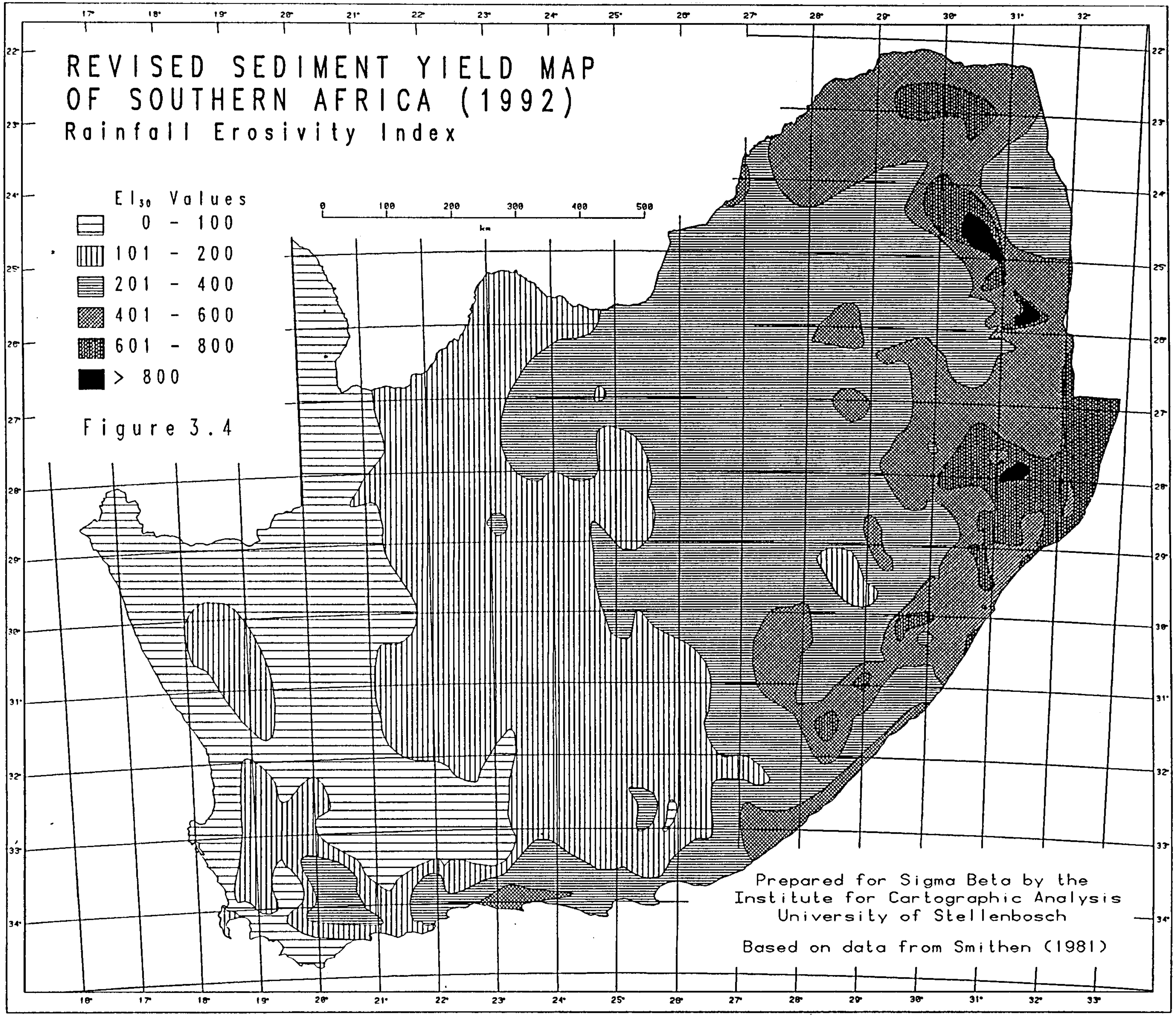

REVISED SEDIMENT YIELD MAP
OF SOUTHERN AFRICA (1992)
Rainfall Erosivity Index
EI_{30} Values
0 - 100
101 - 200
201 - 400
401 - 600
601 - 800
> 800
0 100 200 300 400 500
km
Prepared for Sigma Beta by the
Institute for Cartographic Analysis
University of Stellenbosch
Based on data from Smithen (1981)

Figure 3.4

3.7 REGIONALIZED YIELD MAP (FIGURE 3.5)

During the research, it became clear that analysis or calibration of data for the entire southern Africa as a whole was not possible due to the geographical diversity if the sub-continent. It was therefore necessary to sub-divide southern Africa into a number of relatively homogeneous sub-regions.

Apart from geographical considerations, the availability of data also played a role in determining the boundaries of the homogeneous regions. The final boundaries of the regions have been taken along watershed boundaries. Therefore, any single catchment under consideration should fall within a single sediment yield region.

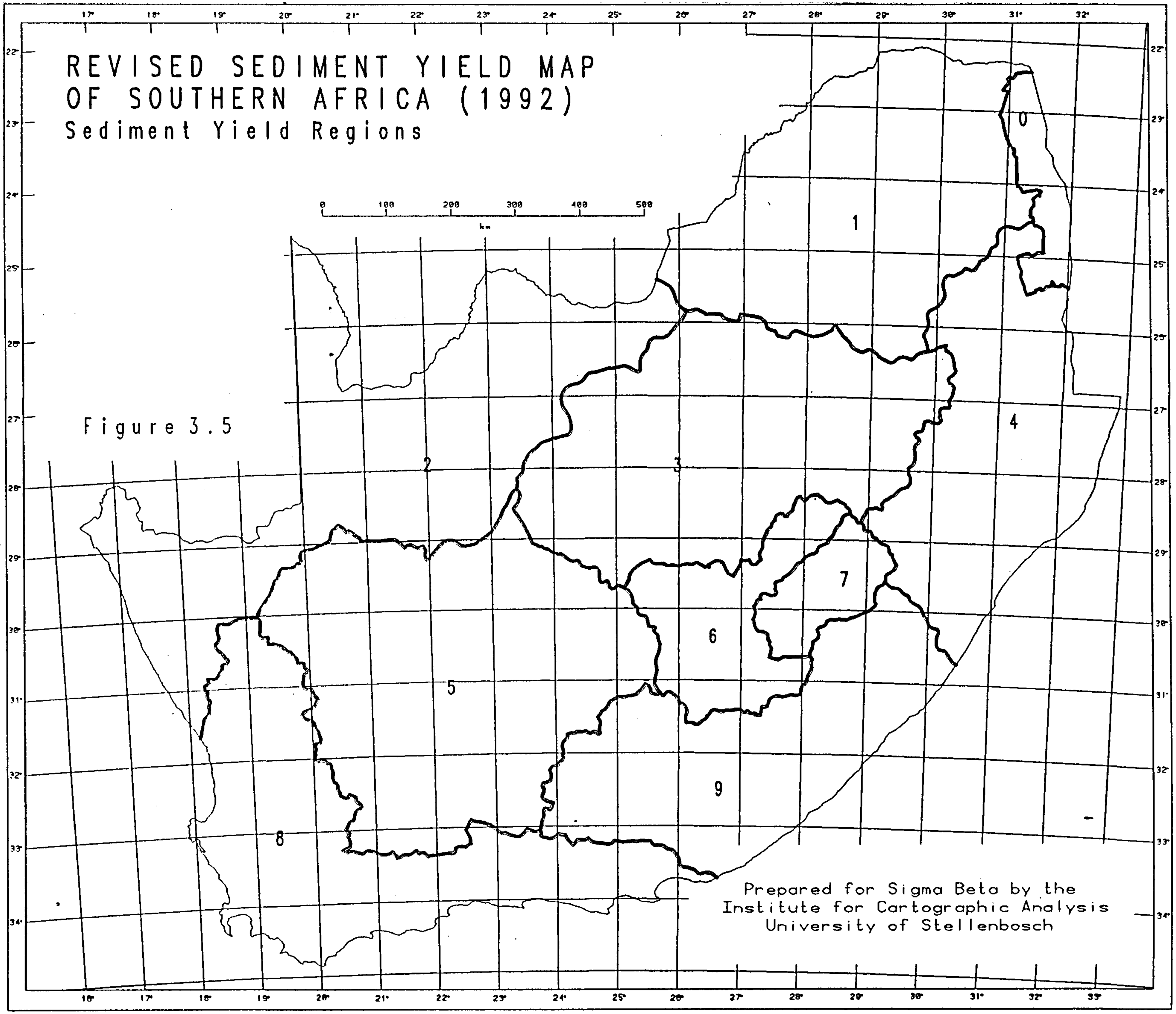
The regional boundaries are indicated in **Figure 3.5**. These boundaries were traced manually and entered into the GIS. Any analysis of sediment yields and related factors is of necessity dependent on the scale involved. This is also true of the regional boundaries which were chosen. Different boundaries might be more suitable at other scales. Nevertheless, the selected boundaries seem best suited to the amount and the detail of data which is currently available.

The nine regions may be categorized as follows:

Region 1

The region consists of drainage regions of the Transvaal rivers which flow to the Indian Ocean, mainly the tributaries of the Limpopo River.

A relatively good data base is available for the region. Sediment yield data obtained from reservoir surveys are available for 31 sites, with record lengths that vary from 12 to 60 years.


REVISED SEDIMENT YIELD MAP
OF SOUTHERN AFRICA (1992)
Sediment Yield Regions
Figure 3.5
0
100
200
300
400
500
km
0
1
2
3
4
5
6
7
8
9
Prepared for Sigma Beta by the
Institute for Cartographic Analysis
University of Stellenbosch

The majority of catchments for which sediment yield information is available are however situated in the upper regions of the Marico, Olifants and Crocodile river catchments. Little data is available for areas in the far northern Transvaal, along the main branch of the Limpopo.

The region is geologically diverse. Land use varies and includes highly urbanized areas, cattle and maize farming, as well as some subsistence farming areas.

Developing and highly urbanized and industrialized areas in this region have to be carefully considered, as these areas produce relatively high sediment yields. An example is the Hartebeespoort Reservoir. Even though this reservoir has a large catchment, the sediment yield is well above average for the region. This is attributed to the fact that the catchment contains part of Johannesburg and large areas in the process of urbanization.

Region 2

This region is situated along the lower reaches of the Orange River. The region is arid and slow draining. Although a large quantity of sediment is available for transport, the transporting capacity of run-off is low (little rainfall and small slopes). In this region, the transporting mechanism rather than the availability of sediment tends to be the limiting factor in determining yields.

Due to the fact that only a single yield value has been recorded in this region, no meaningful analysis of yield values has been possible.

However, this is a region with relatively low sediment yields and it is unlikely that many reservoirs will be constructed in this area because run-off is limited.

Region 3

Region 3 is situated within the catchment of the Vaal River. Reservoir sediment deposit survey data is available for 12 catchments and the recorded sediment yield values vary from less than 10 $t/km^2.a$ to 377 $t/km^2.a$. Although this region is geologically somewhat diverse, the land use is relatively homogeneous and includes the country's main grain production regions.

Region 4

Region 4 is situated mainly in Natal and includes Swaziland. Sediment yield information is available for 20 reservoirs. Measured sediment yield values vary between 5 $t/km^2.a$ and 723 $t/km^2.a$.

The reservoirs for which information is available, are not homogeneously distributed through the region. Most of the reservoirs are situated in the area between the coast and Lesotho, within the catchments of the Mgeni and Tugela rivers. Little data is available in and around Swaziland.

The area is geologically varied. Land use varies from cattle farming in the Natal midlands to sugar cane farming along the coast, with large areas of subsistence farming scattered throughout the region. Sugar cane production areas, which have high sediment yield potential, are not well represented in the available data.

Region 5

This region covers the central Karoo and is geologically one of the more homogeneous regions. Sheep farming is the dominant land use.

Only 8 reservoirs with surveyed sediment records are available for the region. Measured sediment yields vary from 4 $t/km^2.a$ to 169 $t/km^2.a$.

Region 6

The region consists of the upper Orange and Caledon catchments down to the Verwoerd Dam, including the south eastern part of Lesotho. Some of the highest sediment yielding areas in the country are situated in this region, mainly within the Caledon River catchment. Sediment surveys for 6 reservoirs are available. Some data obtained from suspended sediment yield measuring stations in Lesotho was also used. Measured sediment yield values range from 113 to 1382 $t/km^2.a$. The Verwoerd Dam catchment is the largest effective catchment in the country for which reservoir survey information is available and covers an area of 68 000 km^2.

Region 7

Region 7 consists mainly of the basaltic regions of Lesotho situated along the upper Orange (Senqu) River. Information on sediment yields in this region was obtained from a number of suspended sediment measuring stations with short records, mainly about 6 years.

Region 8

Region 8 is situated in the Western Cape. Fruit farming is the main land use, and the area consists of most of the winter rainfall areas in southern Africa.

Sediment surveys are available for 25 reservoirs. Observed sediment yields are between 1 $t/km^2.a$ and 310 $t/km^2.a$.

Catchment sizes in this region are relatively small, which lead to relatively small total sediment loads.

Bush fires which increase the resistance of soils to water penetration and change the soil texture, play a role in increasing surface run-off, flow velocities and sediment yields in this region (Scott, Schulze and Kunz, 1991).

Region 9

Region 9 covers the South Eastern Cape and Transkei. Sediment survey information for 18 reservoirs is available. Measured sediment yield values are between 4 $t/km^2.a$ and 881 $t/km^2.a$.

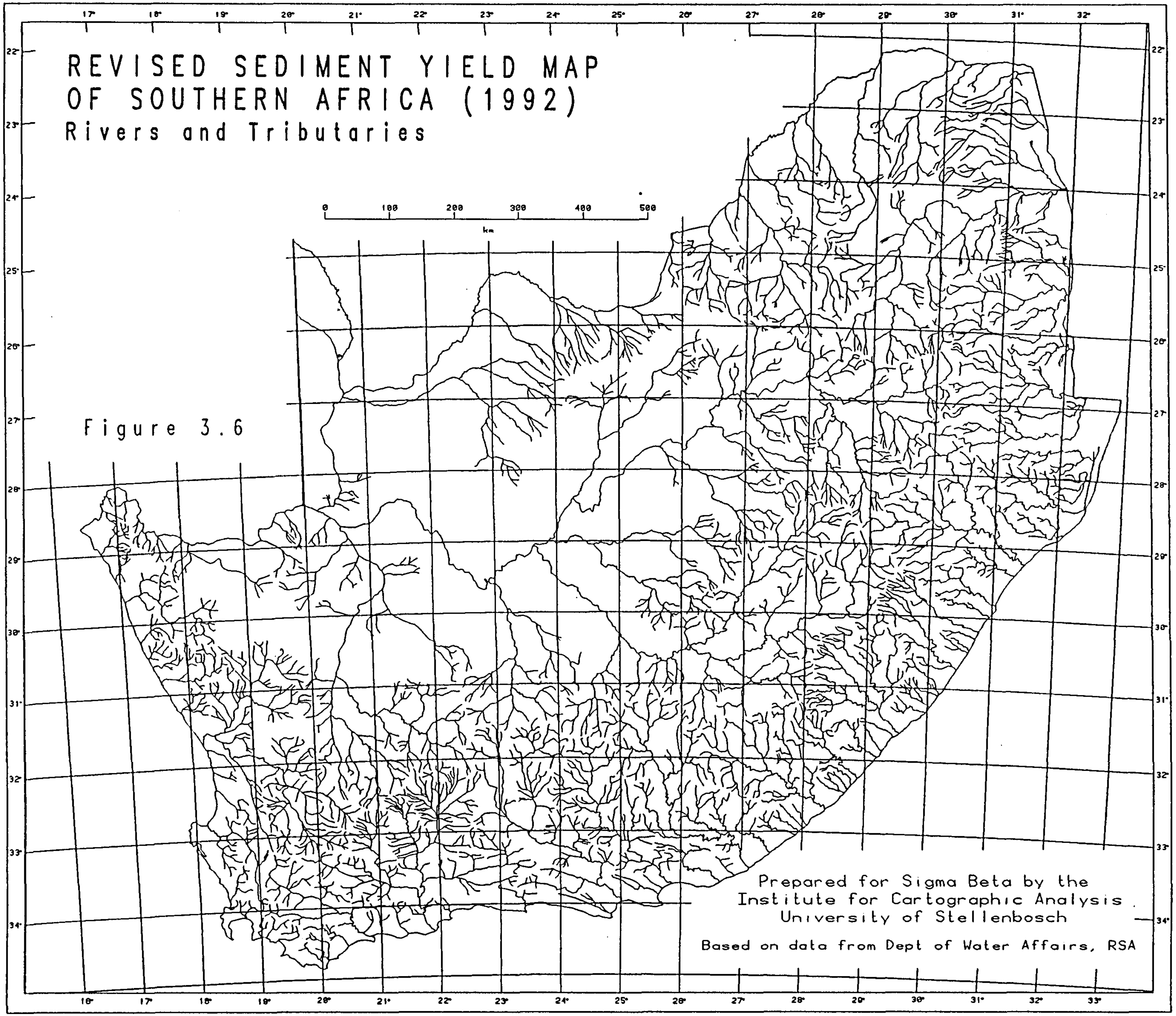
3.8 VARIOUS OTHER DATA SETS CAPTURED ON GIS

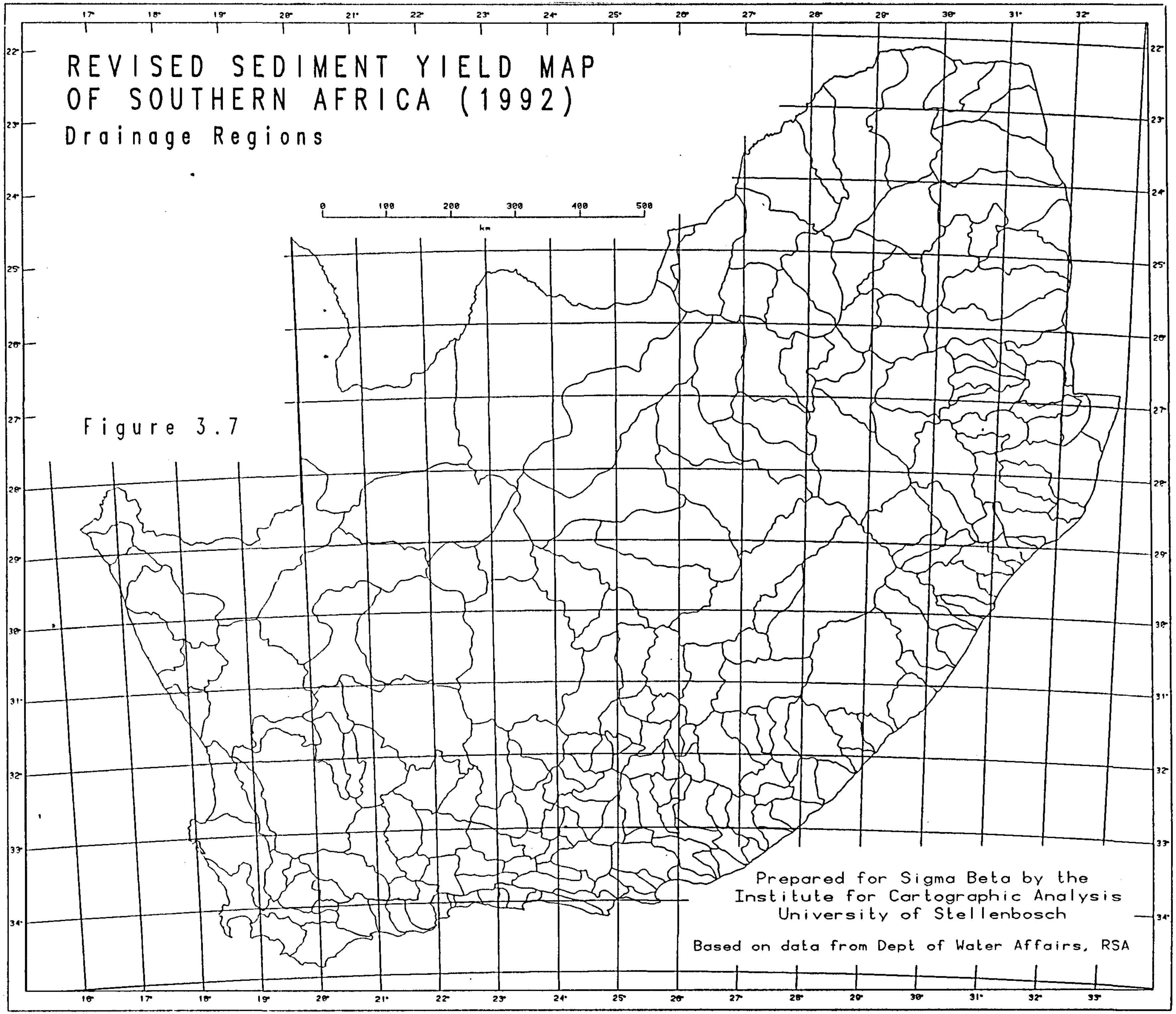
3.8.1 Rivers

Information about the rivers of southern Africa was obtained from the Department of Water Affairs in Pretoria. This dataset was in ARC/INFO EXPORT format and presented no problems of incorporation into the database. The entities were initially digitized from 1:1 500 000 Drainage Region maps of southern Africa (Republic of South Africa, 1965) drawn on a Bonne projection. The Department of Water Affairs has reprojected this information to geographical coordinates using a computer programme developed in-house. For the purpose of the sedimentation GIS, the geographical coordinates were projected to Alberts Equal Area with 18° and 35° S standard parallels and centered on the 25° E meridian using the ARC/INFO PROJECT command for the Clarke 1880 ellipsoid. Because the accuracy of the original projection of the Department of Water Affairs is unknown no assessment can be made of the final level of accuracies. It is assumed to be adequate for scales smaller than 1:1 500 000. Attributes attached to these entities are the river lengths computed by the GIS and river names. This dataset covers 3631 rivers and tributaries **(Figure 3.6)**.

3.8.2 Drainage Regions

The drainage boundaries of rivers in southern Africa were also obtained from the Department of Water Affairs in Pretoria. This dataset which resembles the rivers set, was processed in exactly the same way and therefore has similar expected levels of accuracy. The non-spatial attribute information attached to each of the catchments is its computed area and the drainage region code. The dataset contains information on 222 catchments **(Figure 3.7)**.


REVISED SEDIMENT YIELD MAP
OF SOUTHERN AFRICA (1992)
Rivers and Tributaries
0 100 200 300 400 500
km
Figure 3.6
Prepared for Sigma Beta by the
Institute for Cartographic Analysis
University of Stellenbosch
Based on data from Dept of Water Affairs, RSA


REVISED SEDIMENT YIELD MAP
OF SOUTHERN AFRICA (1992)
Drainage Regions
0 100 200 300 400 500
km
Figure 3.7
Prepared for Sigma Beta by the
Institute for Cartographic Analysis
University of Stellenbosch
Based on data from Dept of Water Affairs, RSA

3.8.3 Reservoirs

Data pertaining to reservoirs was obtained from two sources, both originating in the Department of Water Affairs. The first dataset was provided in digital format as an ARC/INFO coverage. This set contained the location of 129 large reservoirs in addition to non-spatial attributes such as dam name, drainage region code, capacity and a number of other attributes. However, these other attribute values are incomplete.

The second dataset on reservoirs represented a subset of 122 entities. These dams, for which sediment yield values were available, were selected after careful screening to ensure that they were usable for sediment yield prediction modelling. This dataset was georeferenced by tabulating longitude and latitude as published by the Directorate Survey Services of the Department of Water Affairs (Republic of South Africa, 1990). However, on merging these entities with the first dataset numerous positional inconsistencies were encountered. Eventually the location of dams as received in ARC/INFO format was given precedence. These problems presumably arose due to the differences in scale at which data had been captured initially. Non-spatial attributes linked to this dataset were river name, branch name, location code, dam name and sediment yield value.

3.8.4 Reservoir catchments

Catchments for each of the 122 reservoirs were delineated on a 1:1 500 000 scale Drainage Region map. Existing reservoir catchment boundaries were subsequently extracted from the Drainage Region coverage and updated by manually digitizing additional catchment boundaries as required. These map of Drainage Regions on a Bonne projection. As the ARC/INFO software does not make provision for the Bonne projection, the original software developed by the Department of Water Affairs was obtained and used to project to geographical coordinates. Once the additional catchment boundaries were in longitude and latitude the ARC/INFO software was used to reproject to Alberts Equal Area, whereupon the reservoir catchment coverage was updated. Non-spatial attributes attached to the reservoir catchment coverage were computed area of catchment, river name, branch name, location code, dam name and sediment yield value. With the exception of catchment area these attributes were transferred from the reservoir point coverage to the catchment polygon coverage by a spatial overlay operation.

3.8.5 Sediment gauging stations

Information on sediment yield values was also recorded at 24 sediment gauging stations in southern Africa. These data are supplementary to those on sediment yield values as derived from reservoir measurements but sufficiently different in nature to warrant the creation of a separate point coverage. Locations of sediment gauging stations were identified on the 1:1 500 000 scale Drainage Region map and manually digitized. Positions were verified by overlaying the river coverage (Section 2.1). Attributes of these sediment gauging stations were river name, branch name, location code, sediment gauging name and sediment yield value **(Figure 2.3)**.

3.8.6 Derived datasets and maps

In addition to the datasets that were captured and entered into the GIS, a number of new datasets and maps were created by combining existing information to produce specific products as required for the sediment yield prediction models. These derived products are briefly described in this section.

- **Sediment yield values**

  Based on the reservoir catchment areas and the sediment yield values measured at each reservoir, a map was produced showing the spatial variation in sediment yield values for southern Africa. This revised sediment yield map is a primary result of the study and served as basis for subsequent sediment yield estimation modelling reported elsewhere (Rooseboom, 1992).

- **Soil erodibility per catchment**

  An important input into the sediment yield estimation models is area statistics extracted from the GIS for soil erodibility classes per reservoir catchment area. These statistics were used in an attempt to correlate sediment yield values with soil erodibility properties. Similar statistics were also extracted from the GIS for correlation with sediment yield values according to suspended load measurements at sediment gauging stations. **Table 3.4** is an example of the kind of statistics provided by GIS.

TABLE 3.4: EXAMPLE OF AREA STATISTICS FOR RESERVOIR CATCHMENT AREAS

LOCATION NUMBER	DAM NAME	ERODIBILITY INDEX	AREA (km^2)
U200-01	Albert Falls	12	519.7
U200-01	Albert Falls	17	384.8
C400-02	Allemanskraal	4	50.0
C400-02	Allemanskraal	8	406.7
C400-02	Allemanskraal	10	2337.3
C400-02	Allemanskraal	14	130.5
D200-04	Armenia	5	658.2
D200-04	Armenia	7	13.8
D200-04	Armenia	9	30.6
D200-04	Armenia	10	18.1
D200-04	Armenia	12	13.5

4. CALIBRATION OF THE NEW SEDIMENT YIELD MAP FOR SOUTHERN AFRICA

4.1 MULTIPLE LINEAR REGRESSION AND THE PREDICTION OF SEDIMENT YIELDS

4.1.1 Outline of the method

Multiple linear regression is a technique which may be used to analyze the relationship between a dependent variable and a number of independent variables (Groebner and Shannon, undated).

The format of the linear regression model is:

$$Y = b_0 + b_1 X_1 + b_2 X_2 + \ldots + b_k X_k + e$$

where

b_0 = regression constant
b_1 = regression coefficient for variable X_1
b_k = regression coefficient for variable X_k
k = number of independent variables
e = residual error

The values of coefficients are determined algebraically in order to satisfy the least squares criterion (Spiegel, 1972).

Although the number of data points required to perform a regression analysis should theoretically represent at least one degree of freedom, a practical sample size is at least four times the number of independent variables (Groebner and Shannon, undated).

Any regression model that is fitted, should satisfy the following requirements:
- The overall model has to be significant;

- Individual variables have to be significant;
- The standard error of estimate should not be too large to prevent meaningful results;
- No significant degree of multicollinearity should exist i.e. the independent variables may not be correlated to one another (Groebner and Shannon).

For the assessment of regression models in terms of the abovementioned requirements a number of statistical parameters are available as aids. These parameters are included in most of the statistical computer packages which offer the facility of regression analysis.

The significance of the overall regression model is normally assessed with the aid of the multiple coefficient of determination, or R-square (R^2), which gives an indication of the amount of variation in the dependent variable explained by the regression equation (Spiegel, 1972). R-square values vary between 1, which indicates perfect explanation of variability, and 0 which indicates no explanation of variability. Another measure, the adjusted R-square value takes into account the loss of degrees of freedom with the addition of extra variables to the model. The value of the adjusted R-square, which may also vary between 1 and 0, therefore usually is lower than the value of R-square.

The problem of multicollinearity can be recognized by the following indications (Groebner and Shannon):
- Incorrect signs of coefficients;
- The significance of variables changes when additional ones are added;
- The value of variables changes significantly when additional ones are added;
- The standard error of estimate increases with the addition of variables;

- A correlation matrix gives an indication of the correlation between independent variables.

For the calibration of the sediment map, the regression model was set up in order to provide a relationship of the physical processes being modelled.

From the law of conservation of mass it can be stated that

$$T = Y_{T1} A_{T1} + Y_{T2} A_{T2} + \ldots + Y_{TN} A_{TN}$$

with

T	=	total annual catchment sediment load
$A_{T1} \ldots A_{TN}$	=	Area sizes of various subareas of which the total catchment is comprised
$Y_{T1} \ldots Y_{TN}$	=	Various annual unit sediment yields associated with the various subareas
N	=	Number of uniquely defined subareas

The delineation of uniquely defined sub-areas was based mainly on the erodibility potential of catchment sub-areas, as obtained from the map prepared by Verster **(Figure 3.1)**. For some runs with the method, the areas were defined not only in terms of erodibility potential, but also in terms of land use.

The regression analysis was performed on a regional basis. For the purpose of defining soil erodibility on a regional basis, the information on the Broad Scale soil and slope map was simplified from 20 to a maximum of five categories. This meant that a maximum of five uniquely defined area types existed within each region, implying that at least six but ideally approximately twenty data points were needed for analysis.

For the case where areas were also defined in terms of land use, the following land uses were used in conjunction with soil erodibility potential:

i) cattle farming;
ii) grain farming;
iii) fruit farming;
iv) subsistence farming;
v) other activities.

4.1.2 Results

Examples of the results obtained are given in **Tables 4.1 to 4.6** and **Figures 4.1 to 4.6**.

These examples illustrate the typical problems which were experienced in using this method.

i) The overall regression models were generally insignificant. Some models gave R-square and adjusted values close to 0, while the few models that were significant in terms of those parameters suffered from other problems, which are mentioned below.
ii) Many individual variables were insignificant in terms of the t-test parameter.
iii) Many negative coefficients were obtained which have no physical significance.
iv) There was a high measure of intercorrelation among the independent variables.
v) In conjunction with (iv), there were changing values of coefficients when new variables were added.
vi) Standard errors were generally large and did not inspire confidence in the results that were obtained.

In the light of all these indications that multiple regression is not suitable for the calibration of the sediment map, efforts in this direction were discontinued.

TABLE 4.1.1: RESULTS FOR REGION 1 - REGRESSION MODEL

INDEPENDENT VARIABLE	COEFFICIENT	t-VALUE	SIGNIFICANCE LEVEL
CONSTANT	15223	0.39	0.70
VH	-1378	-0.14	0.89
H	-75	-0.19	0.85
M	24	0.69	0.50
L	90	1.97	0.06
VL	82	2.33	0.03

R-SQUARE = 0.38

R-SQUARE (ADJ) = 0.24

STANDARD ERROR = 163 769

TABLE 4.1.2: CORRELATION MATRIX

	C	VH	H	M	L	VL
C	1.0	0.16	-0.09	-0.24	-0.39	-0.16
VH		1.0	-0.94	-0.12	-0.01	-0.04
H			1.0	-0.12	-0.03	0.05
M				1.0	-0.21	0.13
L					1.0	- 0.26
VL						1.0

TABLE 4.1.3: 95 % CONFIDENCE LIMITS FOR COEFFICIENTS

	LOWER	UPPER
C	-66000	97000
VH	-21000	18000
H	-900	+800
M	-49	+98
L	-5	+186
VL	+9	+156

VH = AREA WITH VERY HIGH EROSION POTENTIAL

H = AREA WITH HIGH EROSION POTENTIAL

M = AREA WITH MEDIUM EROSION POTENTIAL

L = AREA WITH LOW EROSION POTENTIAL

VL = AREA WITH VERY LOW EROSION POTENTIAL

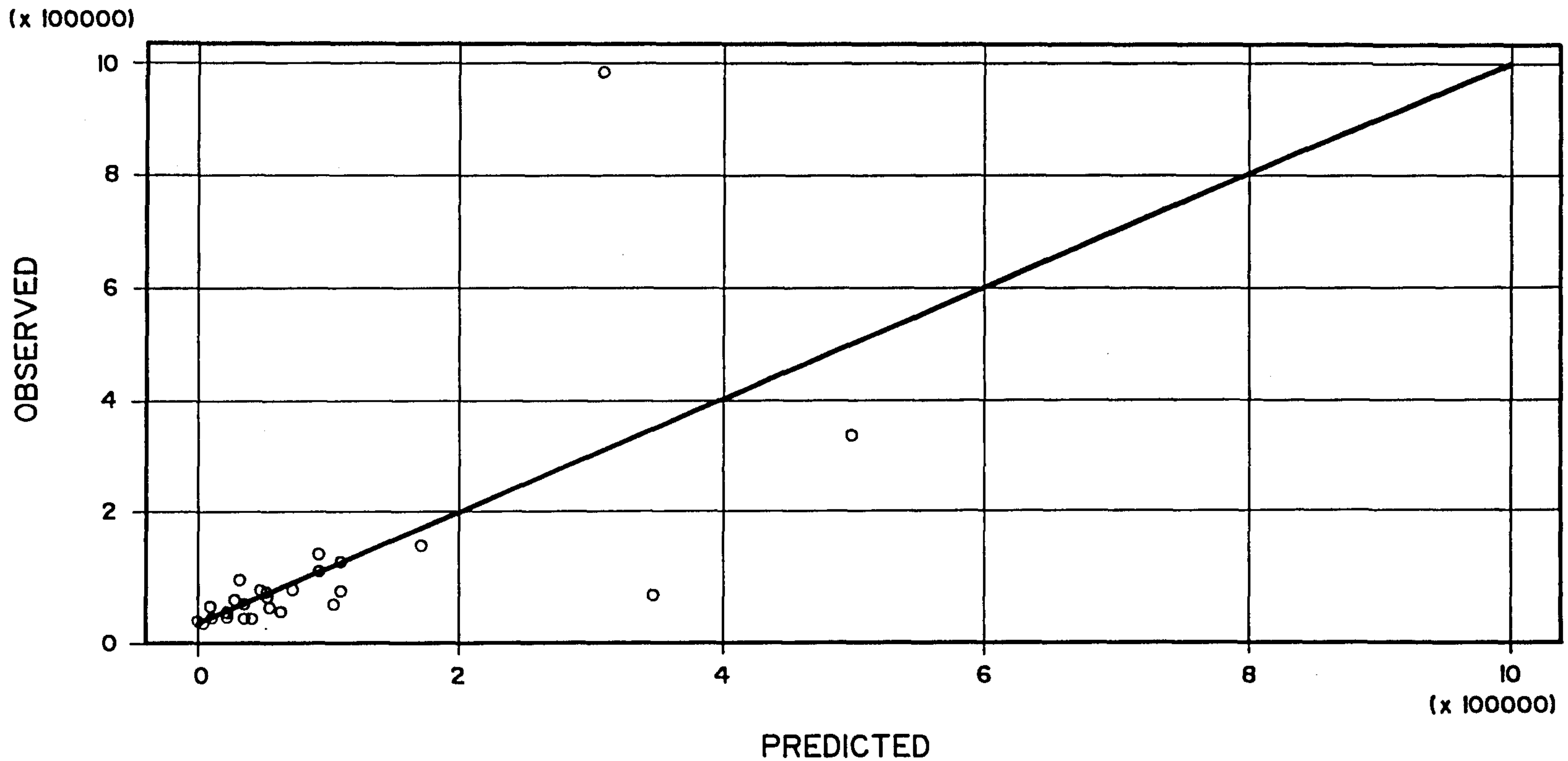


FIG. 4.1 REGION 1 :

PREDICTED AND OBSERVED VALUES
BASED ON THE REGRESSION ANALYSIS RESULTS

TABLE 4.2.1: RESULTS FOR REGION 3 - REGRESSION MODEL

INDEPENDENT VARIABLE	COEFFICIENT	t-VALUE	SIGNIFICANCE LEVEL
CONSTANT	57743	2.10	0.07
VH	27533	6.23	0.00
H	-19	-0.57	0.58
M	-179	-1.93	0.09
L	253	9.32	0.00
VL	-155	-4.89	0.00

R-SQUARE = 0.99

R-SQUARE (ADJ) = 0.97

STANDARD ERROR = 58 042

TABLE 4.2.2: CORRELATION MATRIX

	C	VH	H	M	L	VL
C	1.0	0.38	-0.45	-0.44	-0.06	-0.54
VH		1.0	-0.37	-0.96	-0.45	-0.28
H			1.0	-0.27	-0.51	0.46
M				1.0	-0.41	0.29
L					1.0	0.47
VL						1.0

TABLE 4.2.3: 95% CONFIDENCE LIMITS FOR COEFFICIENTS

	LOWER	UPPER
C	-7284	122770
VH	17085	37980
H	-99	60
M	-397	40
L	188	317
VL	-231	-80

VH = AREA WITH VERY HIGH EROSION POTENTIAL

H = AREA WITH HIGH EROSION POTENTIAL

M = AREA WITH MEDIUM EROSION POTENTIAL

L = AREA WITH LOW EROSION POTENTIAL

VL = AREA WITH VERY LOW EROSION POTENTIAL

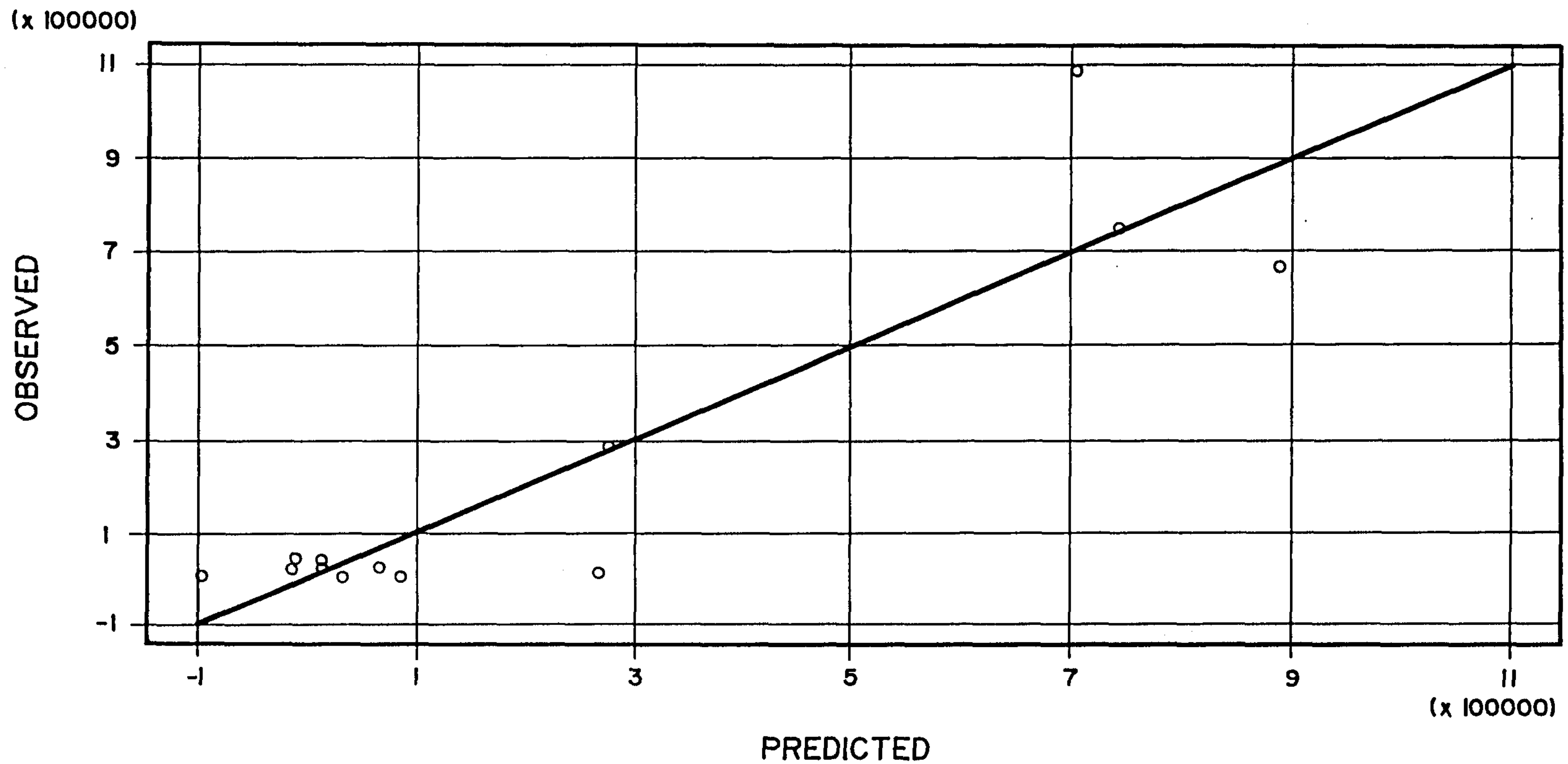


FIG. 4.2 REGION 3 :

PREDICTED AND OBSERVED VALUES
BASED ON THE REGRESSION ANALYSIS RESULTS

TABLE 4.3.1: RESULTS FOR REGION 4 - REGRESSION MODEL

INDEPENDENT VARIABLE	COEFFICIENT	t-VALUE	SIGNIFICANCE LEVEL
CONSTANT	-1.07	-3.26	0.00
VH	324	1.41	0.18
H	861	3.97	0.00
M	287	2.67	0.02
L	635	6.99	0.00
VL	98	1.55	0.14

R-SQUARE = 0.98

R-SQUARE (ADJ) = 0.98

STANDARD ERROR = 112 527

TABLE 4.3.2: CORRELATION MATRIX

	C	VH	H	M	L	VL
C	1.0	0.10	-0.24	-0.48	0.38	-0.28
VH		1.00	-0.32	-0.17	-0.15	-0.09
H			1.00	0.03	-0.33	-0.01
M				1.00	-0.75	0.08
L					1.00	-0.19
VL						1.00

TABLE 4.3.3: 95% CONFIDENCE LIMITS FOR COEFFICIENTS

	LOWER	UPPER
C	-176994	-36963
VH	-165	812
H	399	1324
M	58	515
L	441	829
VL	-37	234

VH = AREA WITH VERY HIGH EROSION POTENTIAL

H = AREA WITH HIGH EROSION POTENTIAL

M = AREA WITH MEDIUM EROSION POTENTIAL

L = AREA WITH LOW EROSION POTENTIAL

VL = AREA WITH VERY LOW EROSION POTENTIAL

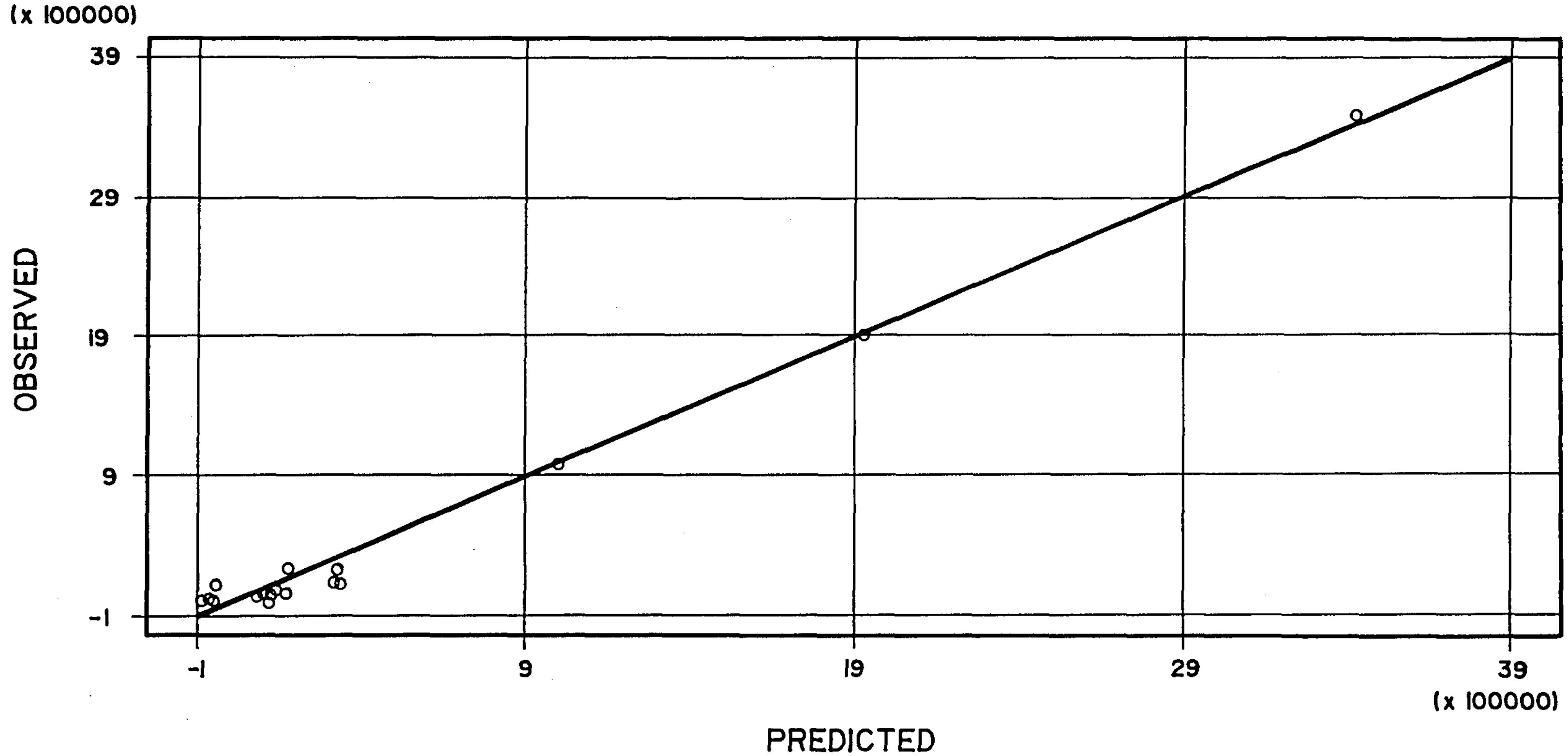


FIG. 4.3 REGION 4 :

PREDICTED AND OBSERVED VALUES
BASED ON THE REGRESSION ANALYSIS RESULTS

TABLE 4.4.1: RESULTS FOR REGION 5 - REGRESSION MODEL

INDEPENDENT VARIABLE	COEFFICIENT	t-VALUE	SIGNIFICANCE LEVEL
CONSTANT	46635	0.16	0.88
VH	-232	0.40	0.72
H	-45	-0.26	0.81
M	-47	-0.49	0.66
L	967	-0.47	0.67

R-SQUARE = 0.48

R-SQUARE (ADJ) = 0.00

STANDARD ERROR = 285 099

TABLE 4.4.2: CORRELATION MATRIX

	C	VH	H	M	L
C	1.0	-0.87	0.82	0.60	-0.85
VH		1.00	-0.87	-0.86	0.86
H			1.00	0.60	-0.99
M				1.00	-0.58
L					1.00

TABLE 4.4.3: 95% CONFIDENCE LIMITS FOR COEFFICIENTS

	LOWER	UPPER
C	-896331	989601
VH	-1628	2092
H	-604	514
M	-354	260
L	-5640	7573

VH = AREA WITH VERY HIGH EROSION POTENTIAL

H = AREA WITH HIGH EROSION POTENTIAL

M = AREA WITH MEDIUM EROSION POTENTIAL

L = AREA WITH LOW EROSION POTENTIAL

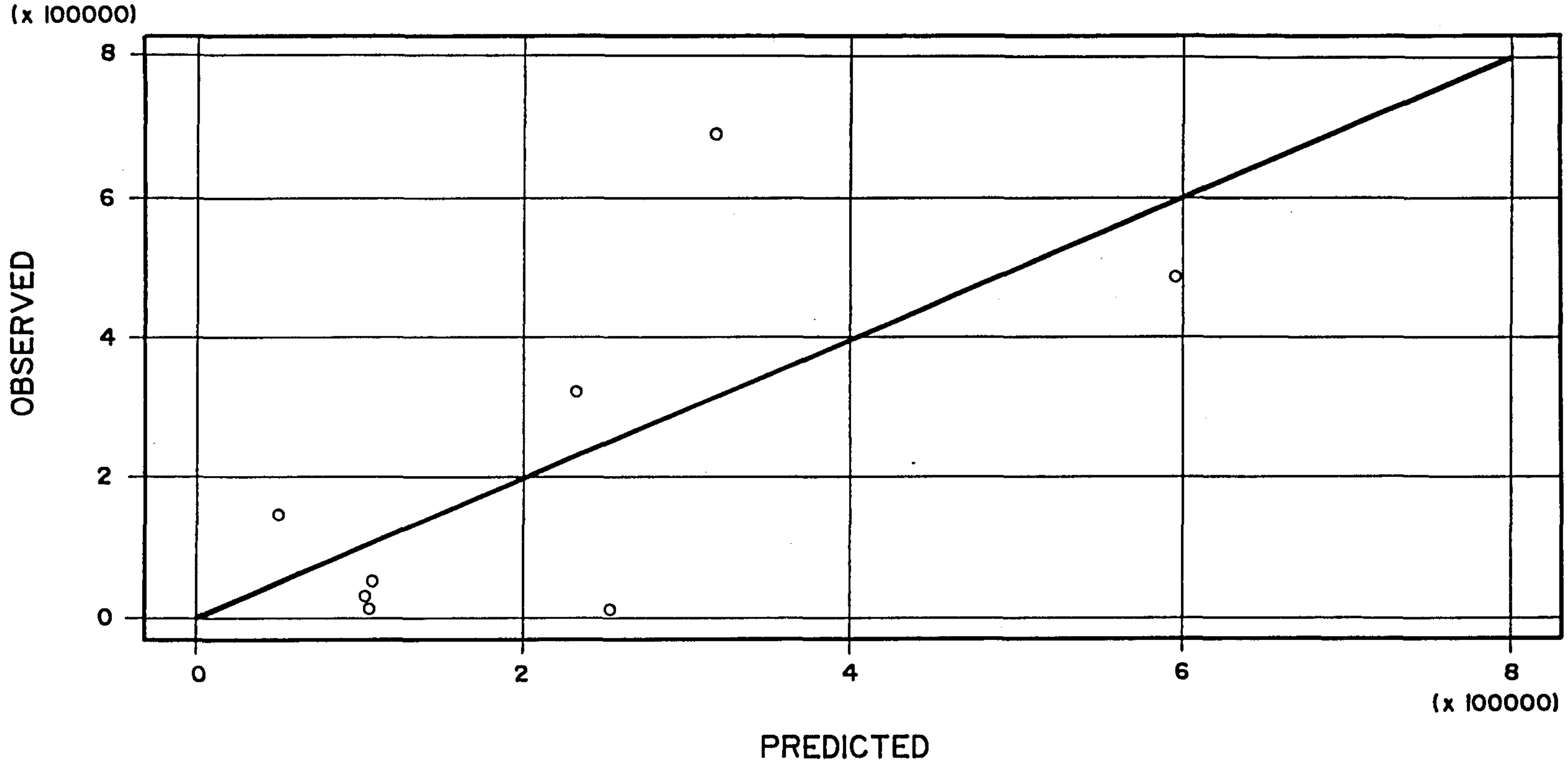


FIG. 4.4 REGION 5 :

PREDICTED AND OBSERVED VALUES
BASED ON THE REGRESSION ANALYSIS RESULTS

TABLE 4.5.1: RESULTS FOR REGION 9 - REGRESSION MODEL

INDEPENDENT VARIABLE	COEFFICIENT	t-VALUE	SIGNIFICANCE LEVEL
CONSTANT	2.3×10^5	1.11	0.29
VH	-149	-0.68	0.51
H	373	1.58	0.14
M	-145	-0.19	0.85
L	450	0.42	0.68
VL	45982	0.70	0.50

R-SQUARE = 0.76

R-SQUARE (ADJ) = 0.66

STANDARD ERROR = 528 514

TABLE 4.5.2: CORRELATION MATRIX

	C	VH	H	M	L	VL
C	1.0	-0.21	-0.11	-0.68	-0.29	0.64
VH		1.00	-0.85	0.19	-0.19	-0.05
H			1.00	-0.03	0.25	-0.18
M				1.00	0.17	-0.96
L					1.00	-0.20
VL						1.00

TABLE 4.5.3: 95% CONFIDENCE LIMITS FOR COEFFICIENTS

	LOWER	UPPER
C	-218346	669847
VH	-628	331
H	-141	888
M	-1770	1480
L	-1882	2782
VL	-96840	188804

VH = AREA WITH VERY HIGH EROSION POTENTIAL

H = AREA WITH HIGH EROSION POTENTIAL

M = AREA WITH MEDIUM EROSION POTENTIAL

L = AREA WITH LOW EROSION POTENTIAL

VL = AREA WITH VERY LOW EROSION POTENTIAL

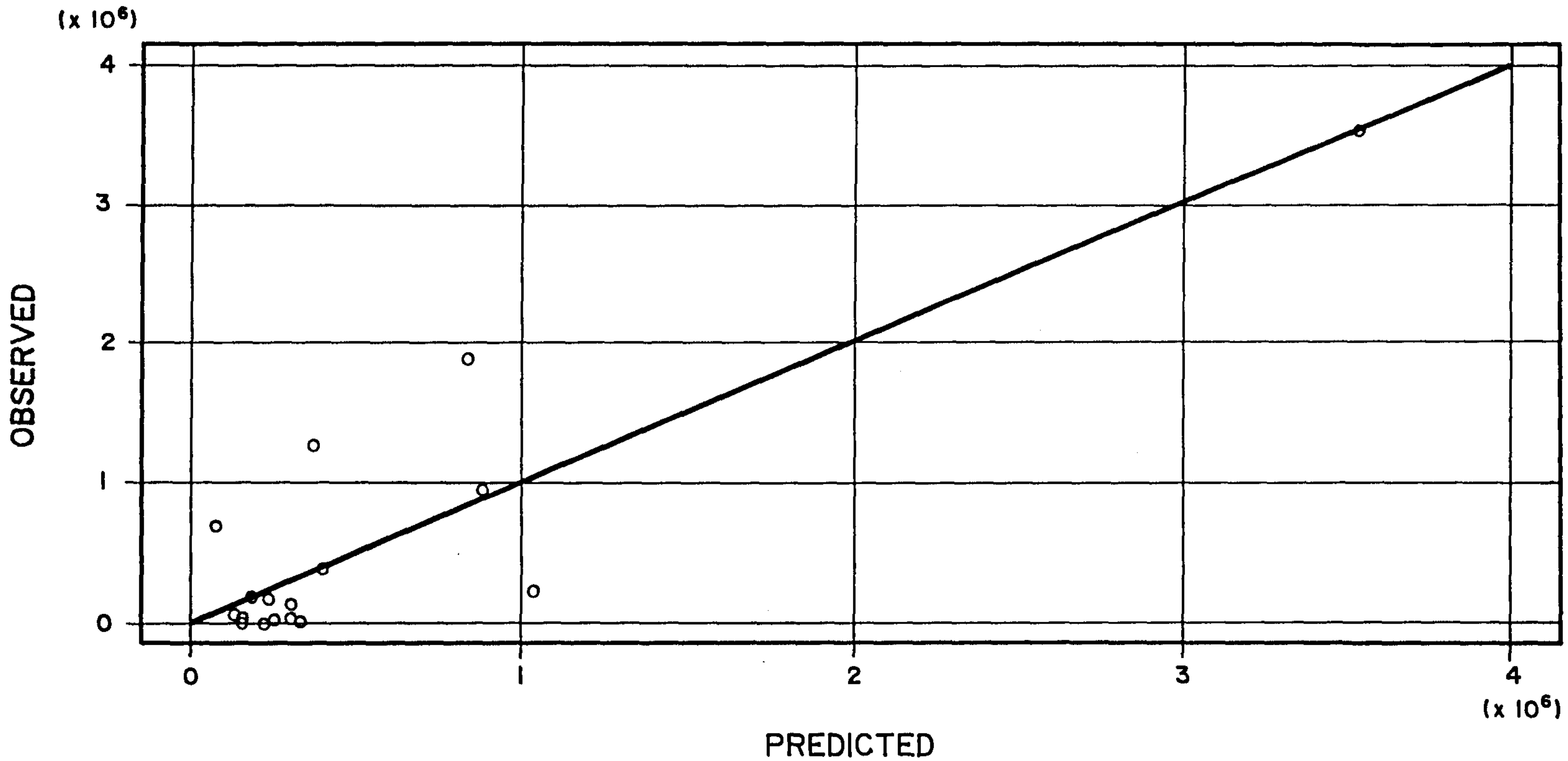


FIG. 4.5 REGION 9 :

PREDICTED AND OBSERVED VALUES
BASED ON THE REGRESSION ANALYSIS RESULTS

TABLE 4.6.1: REGRESSION FOR REGION 1 BASED ON SOIL ERODIBILITY AND LAND USE

INDEPENDENT VARIABLE	COEFFICIENT	t-VALUE	SIGNIFICANCE LEVEL
CONSTANT	299	1.43	0.18
F-H	-2	-1.03	0.33
C-VH	-11	-1.15	0.28
C-H	-1	-0.66	0.52
C-M	-2	-1.00	0.34
C-L	-3	-1.18	0.26
C-VL	-2	-1.14	0.28
G-H	-5	-0.12	0.90
G-M	-2	-0.83	0.43
G-L	-3	-1.22	0.24
E-VH	534	0.05	0.96
E-H	-28	-0.06	0.95
E-M	-3	-0.82	0.43
E-L	0	-0.0	0.99
O-M	-2	-1.04	0.32
O-L	-2	-0.72	0.49

R-SQUARE = 0.00

R-SQUARE (ADJ) = 0.00

STANDARD ERROR = 62

TABLE 4.6.2: 90% CONFIDENCE INTERVALS FOR COEFFICIENTS

	LOWER	UPPER
CONSTANT	-76	675
F-H	-6	2
C-VH	-27	6
C-H	-5	2
C-M	-6	2
C-L	-6	1
C-VL	-6	1
G-H	-80	69
G-M	-6	2
G-L	-7	1
E-VH	-19103	20170
E-H	-880	824
E-M	-10	4
E-L	-56	56
O-M	-6	2
O-L	-7	3

F-H = FRUIT FARMING - HIGH EROSION POTENTIAL
C-VH = CATTLE FARMING - VERY HIGH EROSION POTENTIAL
C-H = CATTLE FARMING - HIGH EROSION POTENTIAL
C-M = CATTLE FARMING - MEDIUM EROSION POTENTIAL
C-L = CATTLE FARMING - LOW EROSION POTENTIAL
C-VL = CATTLE FARMING - VERY LOW EROSION POTENTIAL
G-H = GRAIN FARMING - HIGH EROSION POTENTIAL
G-M = GRAIN FARMING - MEDIUM EROSION POTENTIAL
G-L = GRAIN FARMING - LOW EROSION POTENTIAL
E-VH = SUBSISTENCE FARMING- VERY HIGH EROSION POTENTIAL
E-H = SUBSISTENCE FARMING- HIGH EROSION POTENTIAL
E-M = SUBSISTENCE FARMING- MEDIUM EROSION POTENTIAL
E-L = SUBSISTENCE FARMING- LOW EROSION POTENTIAL
O-M = OTHER FARMING - MEDIUM EROSION POTENTIAL
O-L = OTHER FARMING - LOW EROSION POTENTIAL

TABLE 4.6.3: CORRELATION MATRIX

	C	F-H	C-VH	C-H	C-M	C-L	C-VL	G-H	G-M	G-L	E-VH	E-H	E-M	E-L	O-M	O-L
C	1.00	-0.96	-0.23	-0.96	-0.98	-0.97	-0.97	-0.05	-0.9	-0.94	0.00	0.00	-0.57	-0.07	-0.97	-0.98
F-H		1.00	0.22	0.92	0.94	0.94	0.93	0.05	0.86	0.90	0.00	0.00	0.55	0.06	0.93	0.94
C-VH			1.00	0.15	0.26	0.14	0.23	0.01	0.21	0.21	0.00	0.00	0.13	0.02	0.22	0.22
C-H				1.00	0.94	0.94	0.93	0.05	0.86	0.90	0.00	0.00	0.55	0.06	0.93	0.94
C-M					1.00	0.94	0.96	0.05	0.88	0.92	0.00	0.00	0.56	0.07	0.95	0.96
C-L						1.00	0.95	0.05	0.88	0.92	0.00	0.00	0.56	0.07	0.95	0.96
C-VL							1.00	0.05	0.88	0.92	0.00	0.00	0.55	0.06	0.94	0.96
G-H								1.00	0.21	-0.22	0.00	0.00	0.03	0.00	0.05	0.05
G-M									1.00	0.77	0.00	0.00	0.51	0.06	0.87	0.89
G-L										1.00	0.00	0.00	0.53	0.06	0.91	0.92
E-VH											1.00	0.00	-0.81	0.99	0.00	0.00
E-H												1.00	0.81	0.99	0.00	0.00
E-M													1.00	-0.99	0.55	0.56
E-L														1.00	0.06	0.07
O-M															1.00	0.94
O-L																1.00

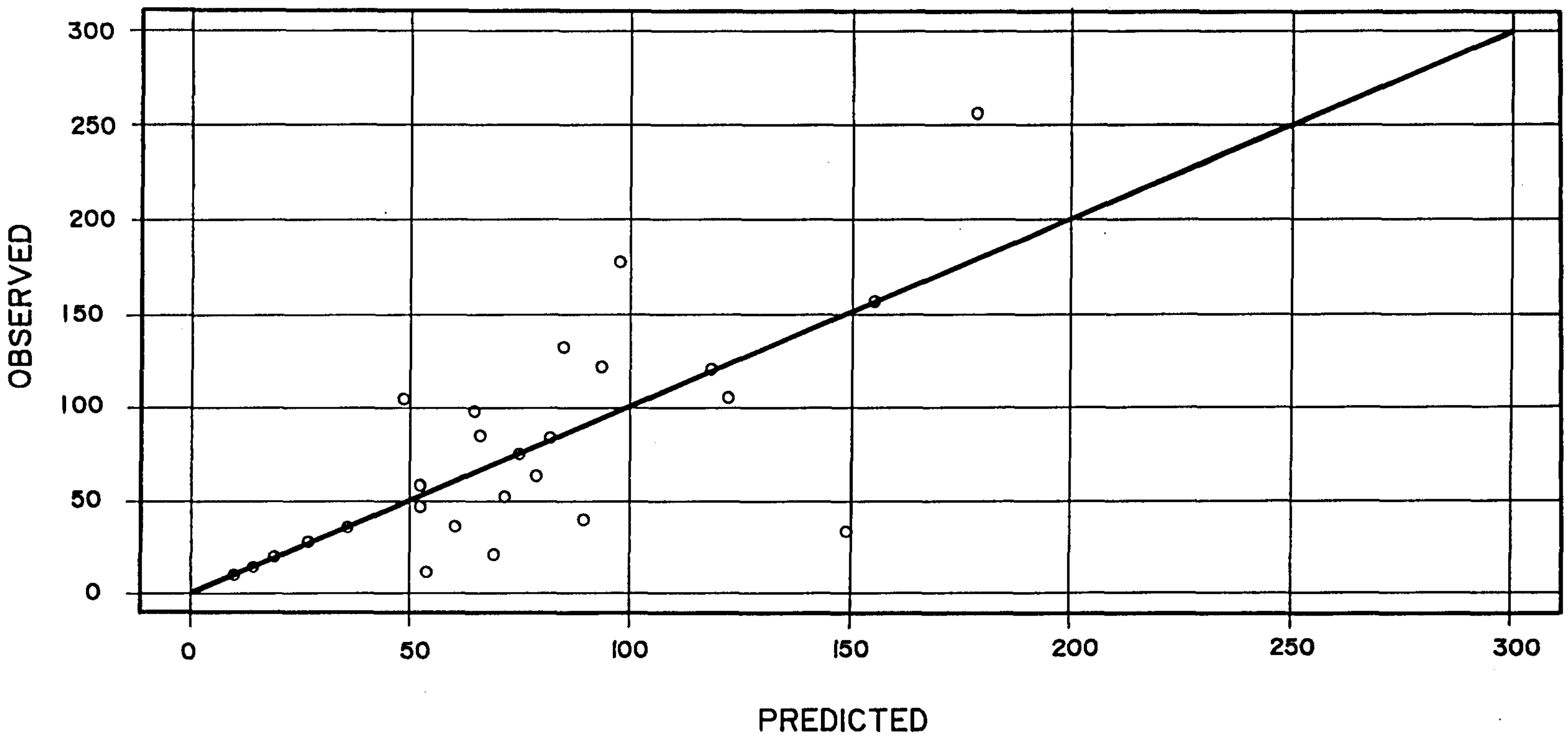


FIG. 4.6 REGION I :

PREDICTED AND OBSERVED VALUES BASED ON REGRESSION ANALYSIS WITH AREAS DEFINED IN TERMS OF BOTH EROSION POTENTIAL AND LAND USE

4.2 A MATHEMATICAL MODEL FOR THE HYDRAULIC TRANSPORT OF SEDIMENT FROM CATCHMENTS

4.2.1 Format of the Model

Rooseboom (1992) has derived equations which describe the sediment transport carrying capacity of run-off in catchments. These equations are based on a consideration of fundamental principles of open channel hydraulics in terms of applied stream power.

The formulas read:

$$q_S = A_S^{\frac{4z}{3}} \, q^{\left(\frac{z}{3}+1\right)}$$
$$z = B\,(q_S)^{-\frac{1}{3}}$$
$$q = Ci$$

with

- **q_S = sediment discharge per unit width**
- **S = catchment slope**
- **Z = measure of sediment transport capacity**
- **q = unit run-off**
- **i = rainfall intensity**
- **A = coefficient related to sediment availability**
- **B = coefficient related to sediment carrying capacity**
- **C = run-off coefficient**

In view of the limitations posed by the available data and the scale of the data, the following assumptions have to be made when this method is used:

i) Uniform flow conditions exist for overland flow.

ii) Sediment particle dimensions, hydraulic roughness and average catchment conditions are approximately homogeneous for a sediment yield region.

The main issue in the calibration process, is to estimate values for the coefficients. By using a mean annual run-off map published by the Water Research Commission (Midgley, Pitman and Middleton, 1983) a value for unit run-off (q) could be found directly, eliminating the need for the estimation of C. A bigger problem is posed by the estimation of Z, which is unknown and could assume a large range of values. The method followed in this case consisted of estimating a minimum value for Z, from which the equation could be calibrated and then incrementally increasing the value until the best solution for a particular region was found.

4.2.2 Results

The mathematical model does not adequately describe the large variability in sediment yields for especially small catchments. This is attributed to the fact that the hydraulic transporting capacity is generally sufficient to carry the predominantly very fine sediments as entrainment takes place. The determining factor is therefore the availability of particulate sediment rather than transporting capacity.

Calculated and measured values are compared in **Figure 4.7 - 4.13** for the various regions.

The results indicated that it is not possible to obtain meaningful relationships between yields and sediment carrying capacities, even though the formulae do contain a coefficient which is representative of sediment availability (Rooseboom, 1992).

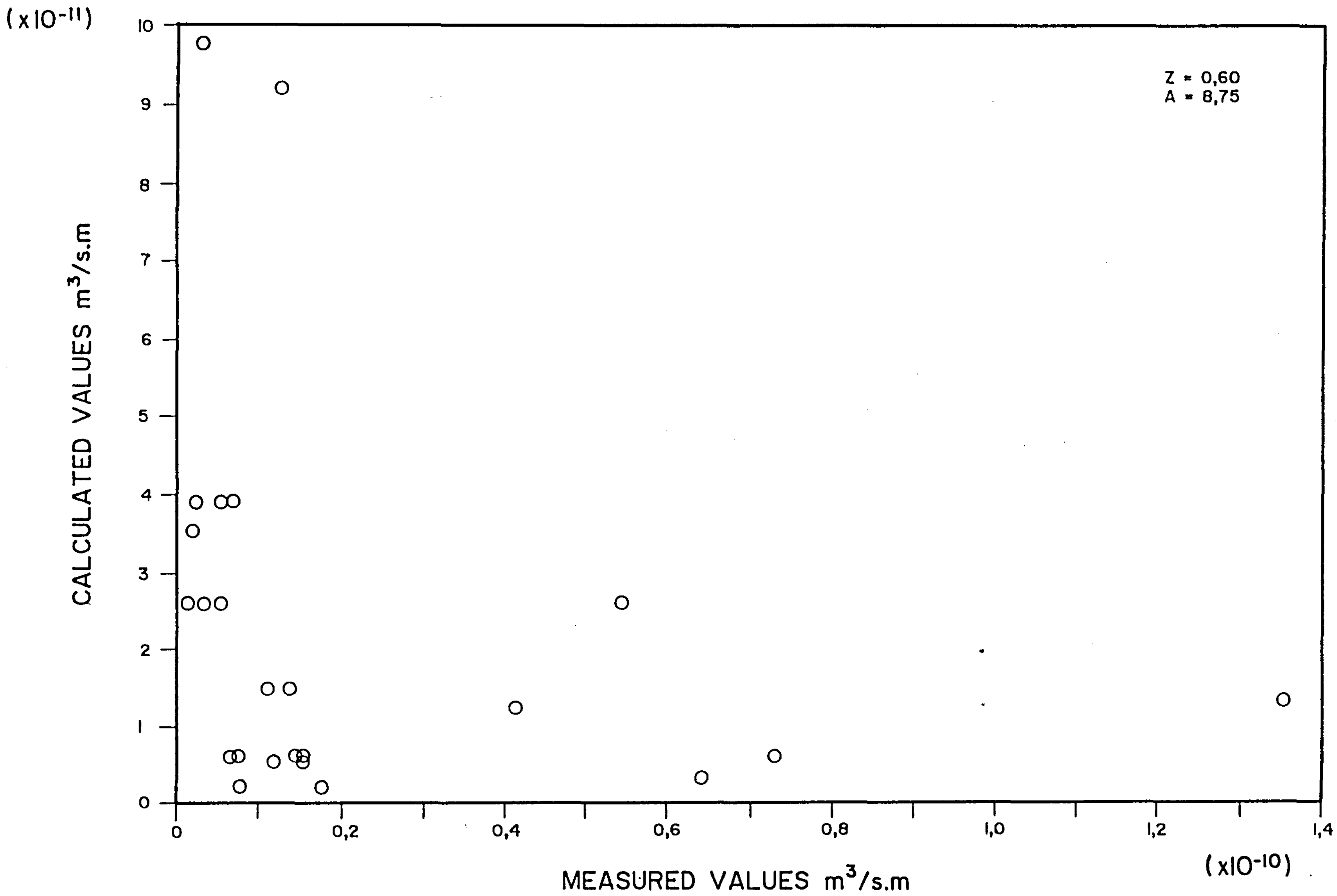


FIG. 4.7 REGION I :
MEASURED AND CALCULATED VALUES FOR SEDIMENT DISCHARGE BASED ON CARRYING CAPACITY OF RUNOFF

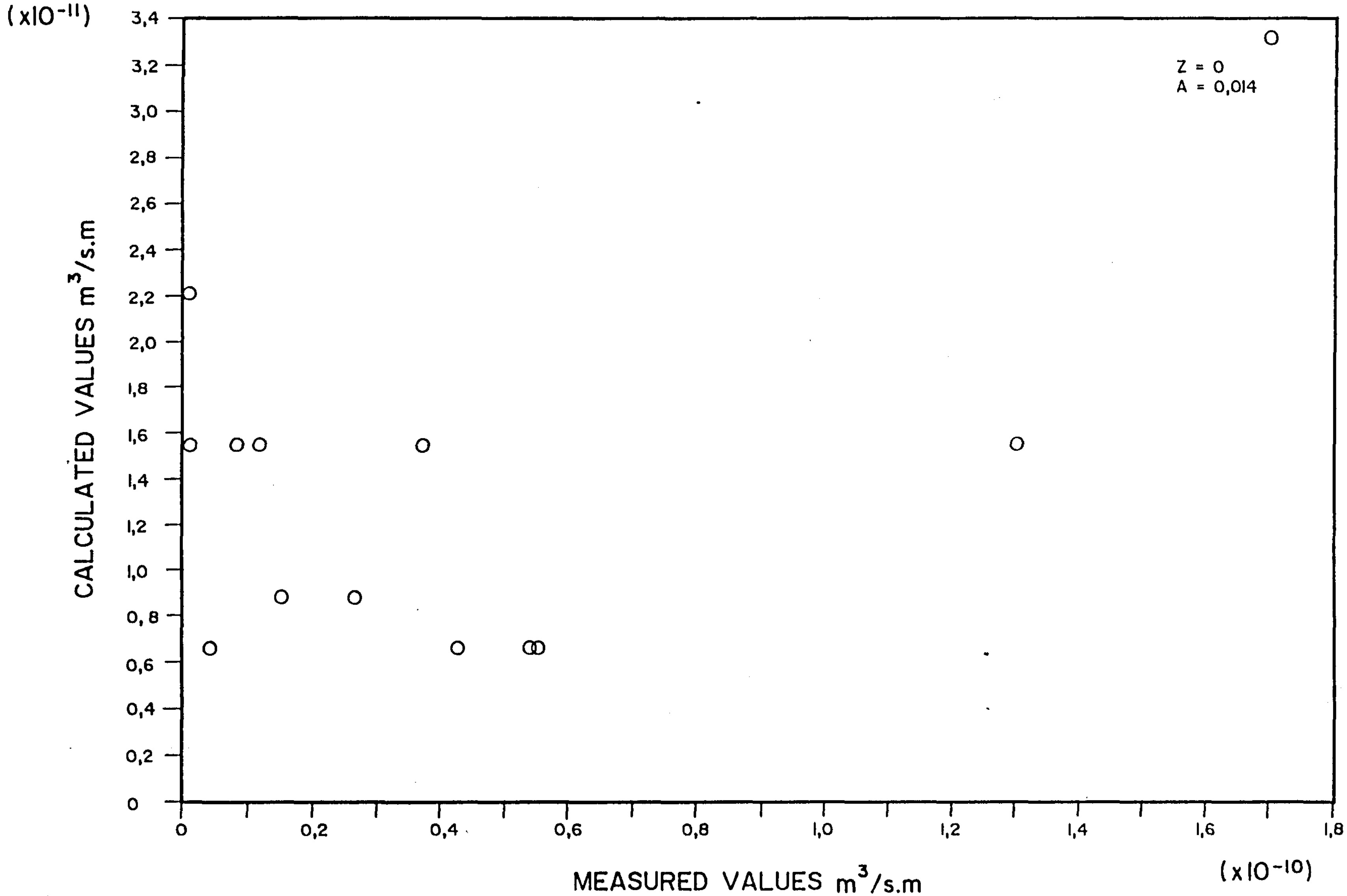


FIG. 4.8 REGION 3 :
MEASURED AND CALCULATED VALUES FOR SEDIMENT DISCHARGE BASED ON CARRYING CAPACITY OF RUNOFF

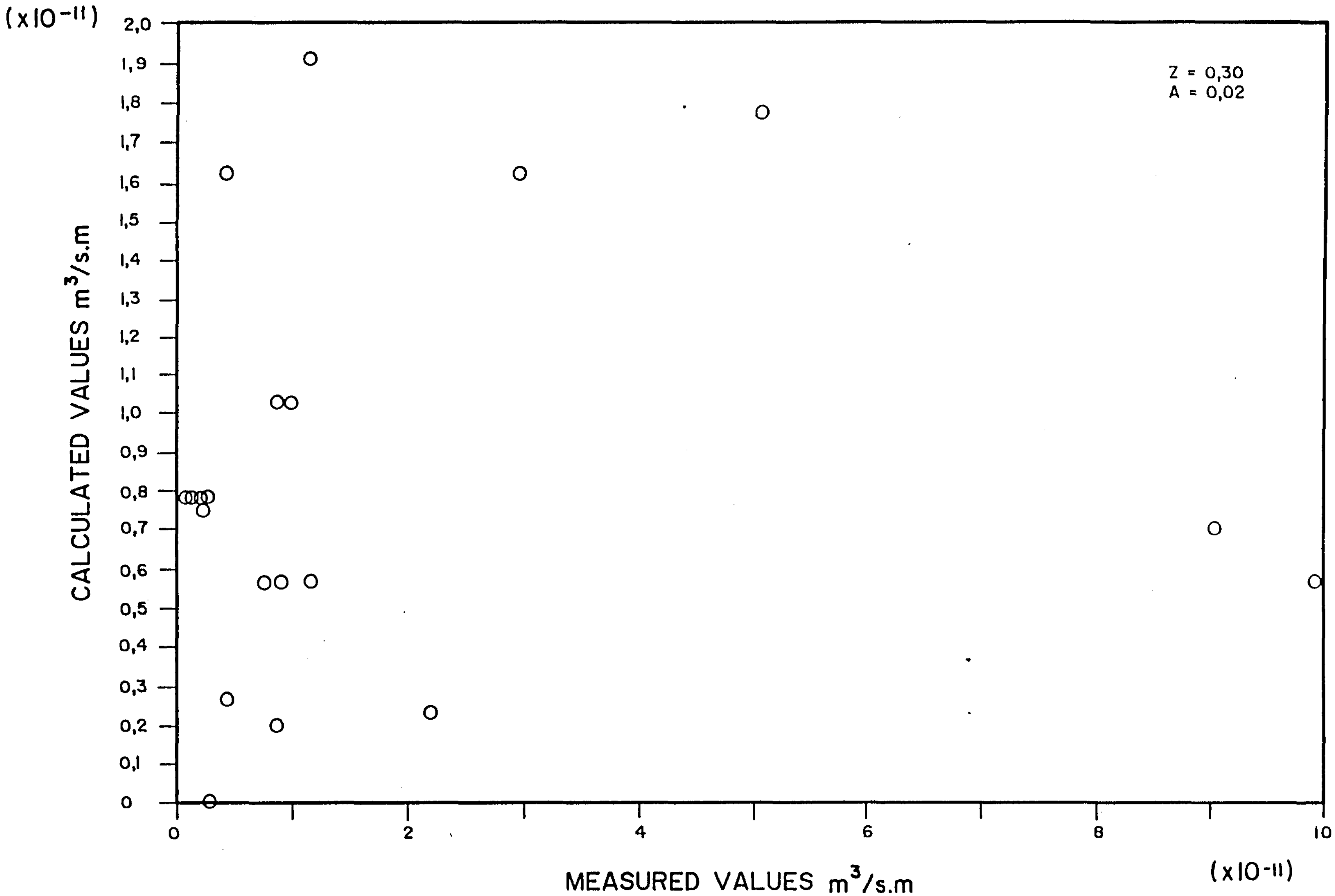


FIG. 4.9 REGION 4 :
MEASURED AND CALCULATED VALUES FOR SEDIMENT DISCHARGE BASED ON CARRYING CAPACITY OF RUNOFF

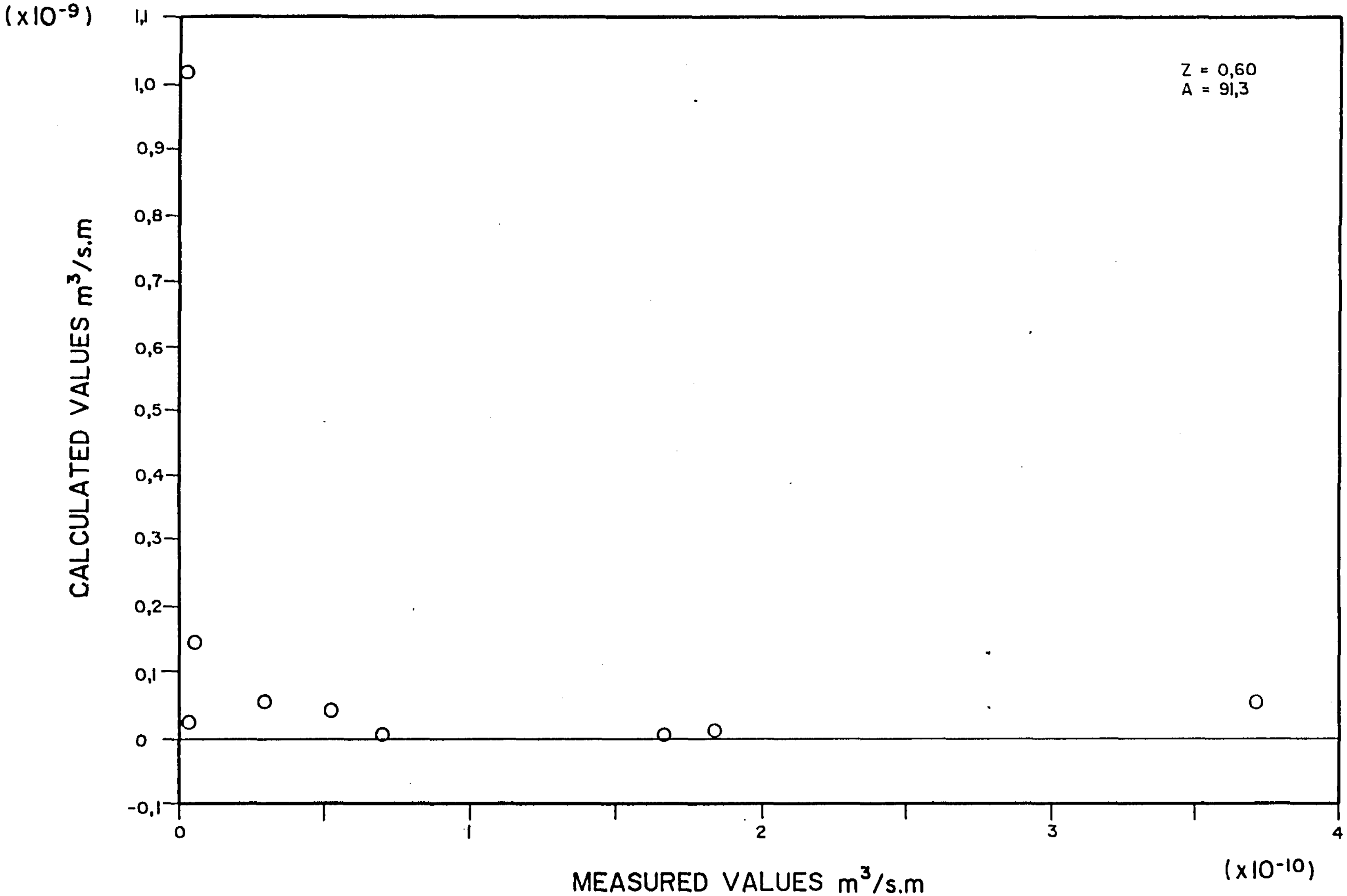


FIG. 4.10 REGION 5 :
MEASURED AND CALCULATED VALUES FOR SEDIMENT DISCHARGE BASED ON CARRYING CAPACITY OF RUNOFF

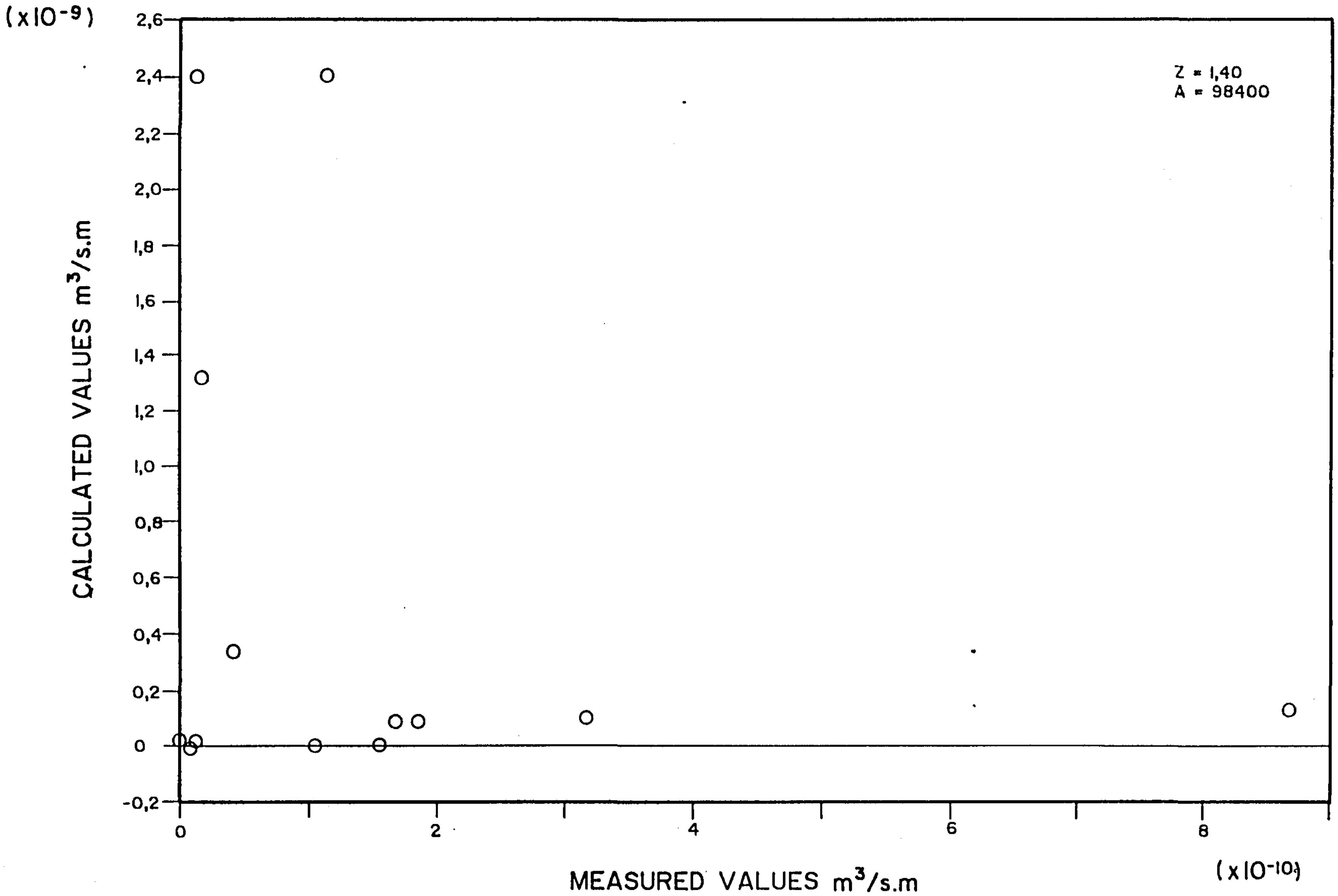


FIG. 4.11 REGION 6 :
MEASURED AND CALCULATED VALUES FOR SEDIMENT DISCHARGE BASED ON CARRYING CAPACITY OF RUNOFF

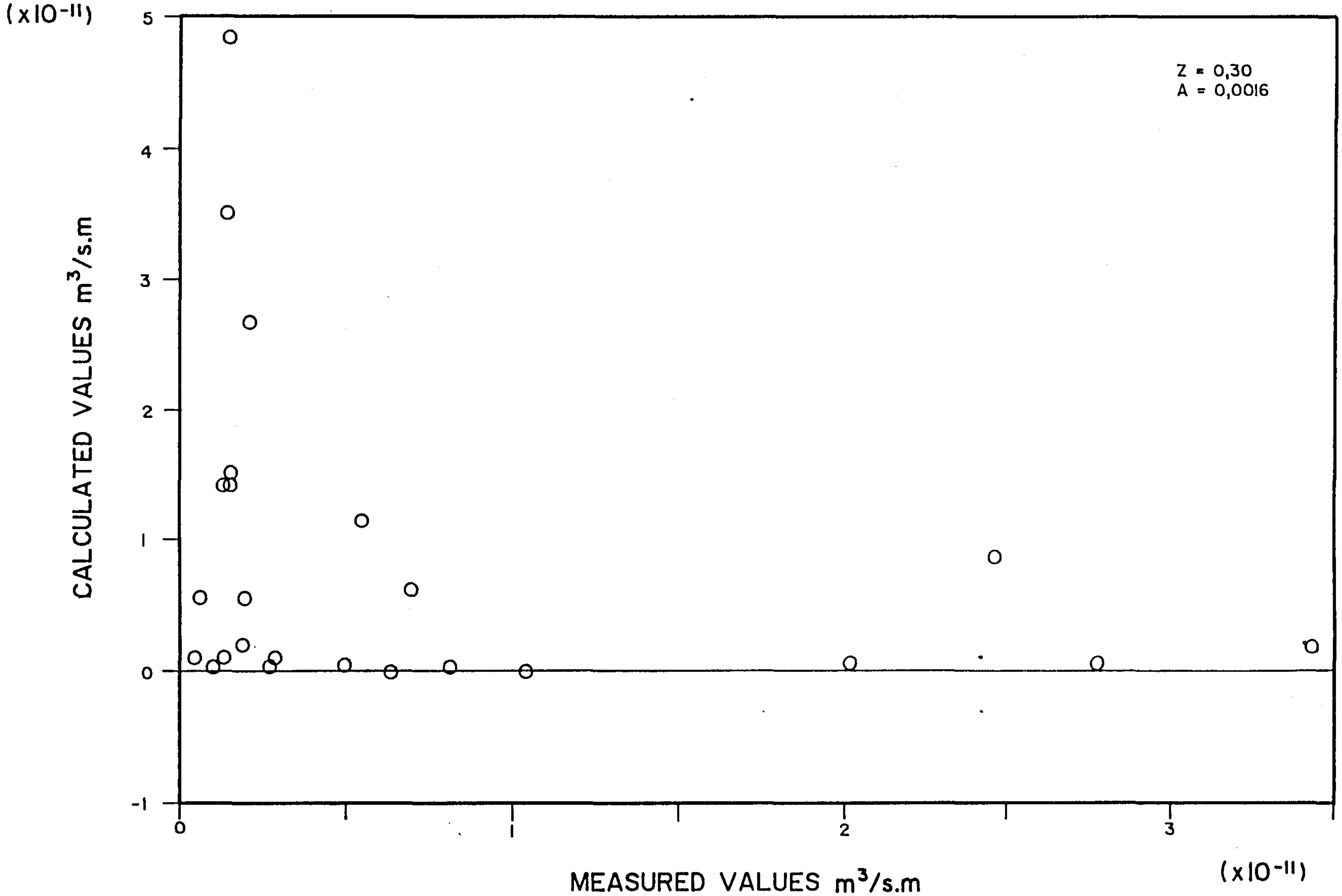


FIG. 4.12 REGION 8 :
MEASURED AND CALCULATED VALUES FOR SEDIMENT DISCHARGE BASED ON CARRYING CAPACITY OF RUNOFF

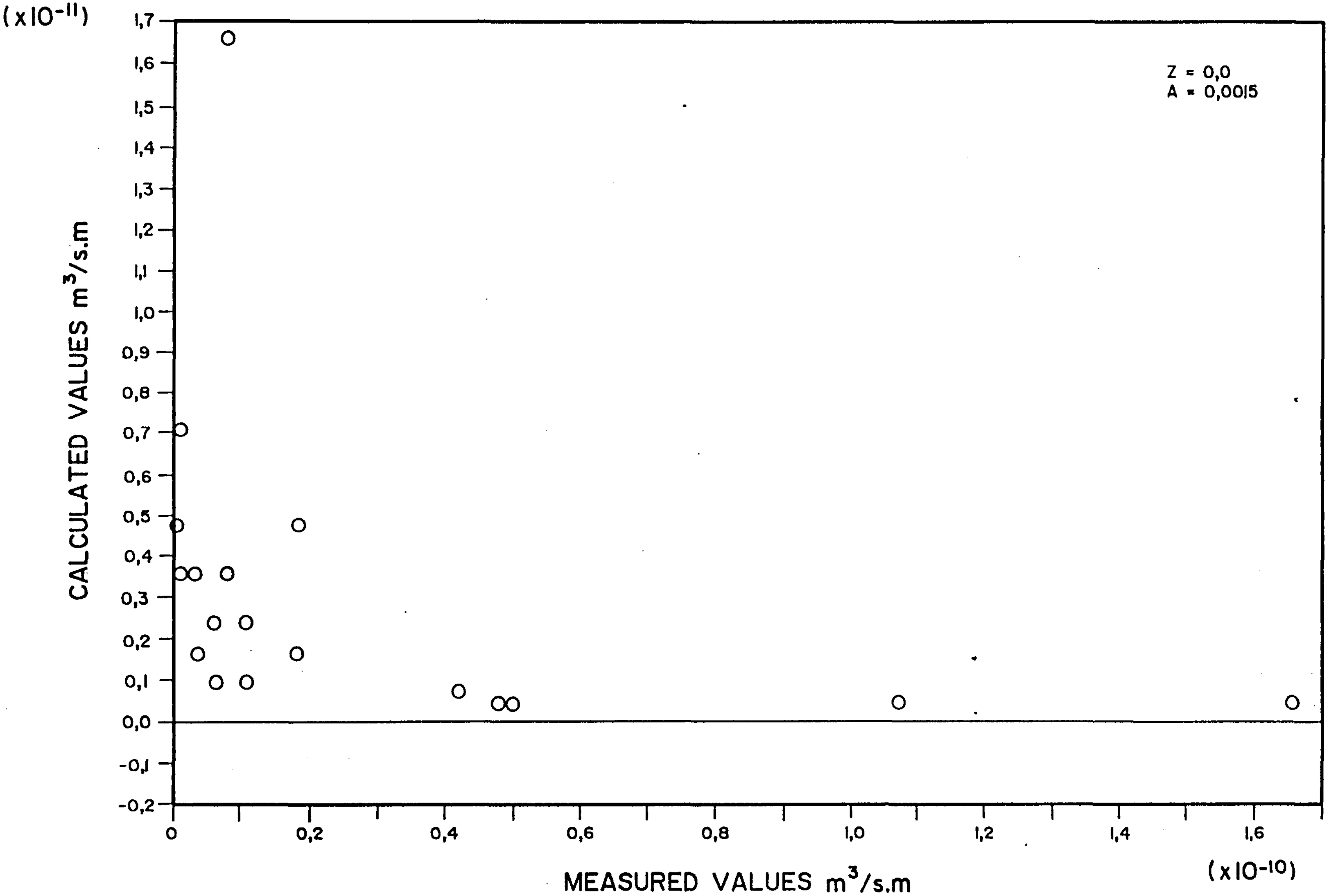


FIG. 4.13 REGION 9 :
MEASURED AND CALCULATED VALUES FOR SEDIMENT DISCHARGE BASED ON CARRYING CAPACITY OF RUNOFF

4.3 STATISTICAL ANALYSIS OF SEDIMENT YIELDS BASED ON THE AVAILABILITY OF SEDIMENT IN CATCHMENTS

4.3.1 Sediment availability related to different yield zones

Statistical analysis was performed on a regional basis in order to quantify the variability observed in sediment yields.

The method is based on the fundamental assumption that sediment availability is the determining factor in the sediment transport processes of southern Africa.

The main input for the method consists of the map, prepared by Verster **(Figure 3.1)** on soil erodibility potential. From the information on this map, soil types in each region were divided into three categories:

i) Soils with high erosion potential.
ii) Soils with moderate erosion potential.
iii) Soils with low erosion potential.

In order to standardize regional yield values for the purpose of statistical analysis, the assumption was made that within each sediment yield region, the ratio between yield values from the different categories is constant.

In order to quantify these ratios, yield values obtained for each region were classified according to the dominant soil erodibility category in each catchment. The ratios of the median values for each soil erodibility category were then taken as representative of the ratios between yield values in the various erodibility categories and these ratios were used to standardize all yield values in a region. These ratios are shown in **Table 5.2** (next chapter).

4.3.2 Statistical distribution of standardized regional yield values

Sediment transport is essentially a hydrological process and therefore is a function of the same parameters that influence all hydrological processes, e.g. rainfall and catchment conditions.

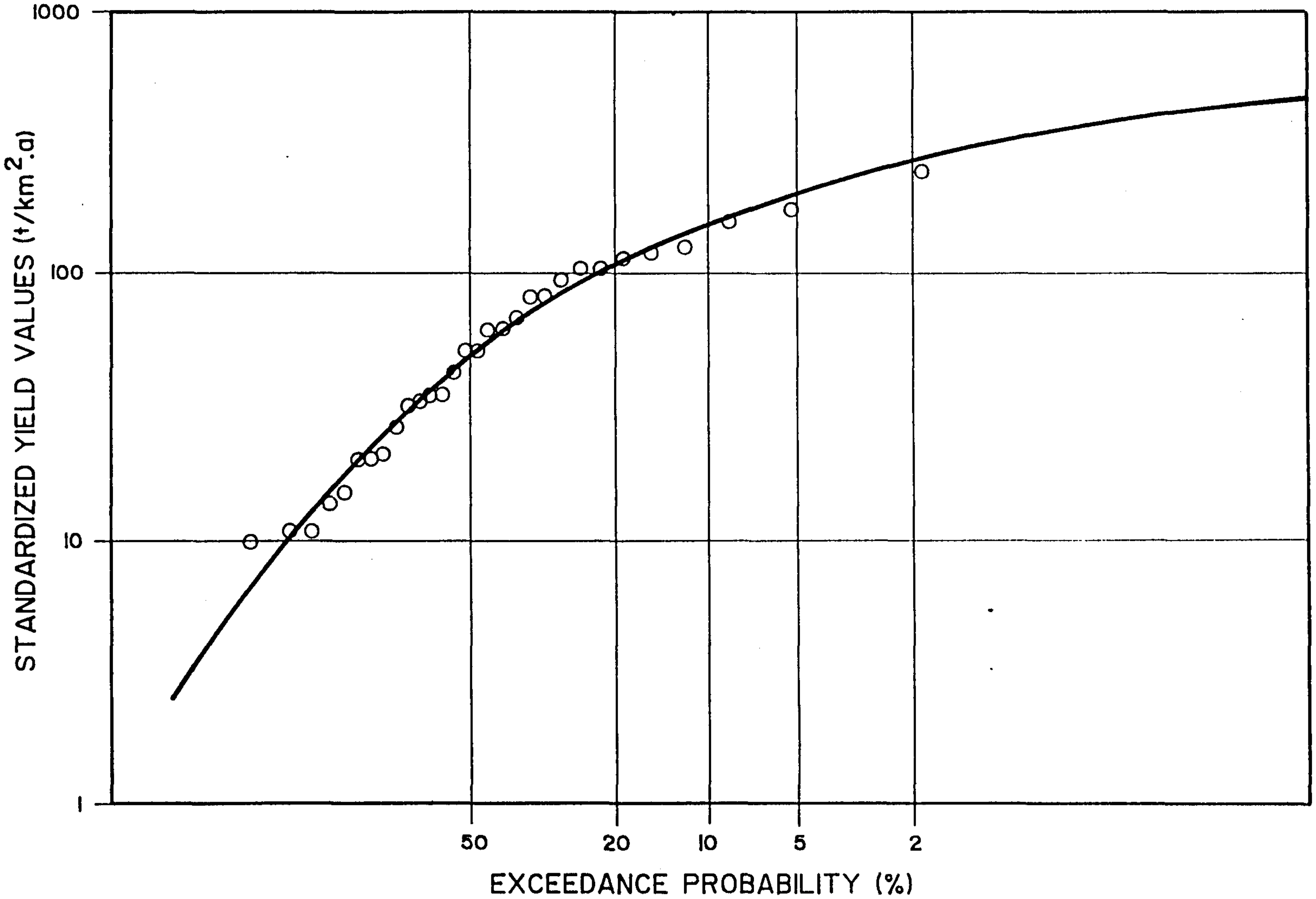
In the description of flood hydrology, certain statistical distributions, which describe the product of a large number of independent variables, have been found to describe southern African conditions reasonably well (Alexander, 1990). Log normal and log Pearson type 3 distributions as well as log Gumbel, and log generalised extreme value distributions have been found to be best suited. These distributions give reasonable descriptions of flood-frequency relationships even though a certain degree of interdependence is present in flood producing variables.

Although a certain degree of interdependency also exists between the various factors involved in sediment transport processes, these distributions were fitted to the sediment yield data.

The log normal and log general extreme value distributions were found to give good results, with the log general extreme value distribution giving the most consistent results.

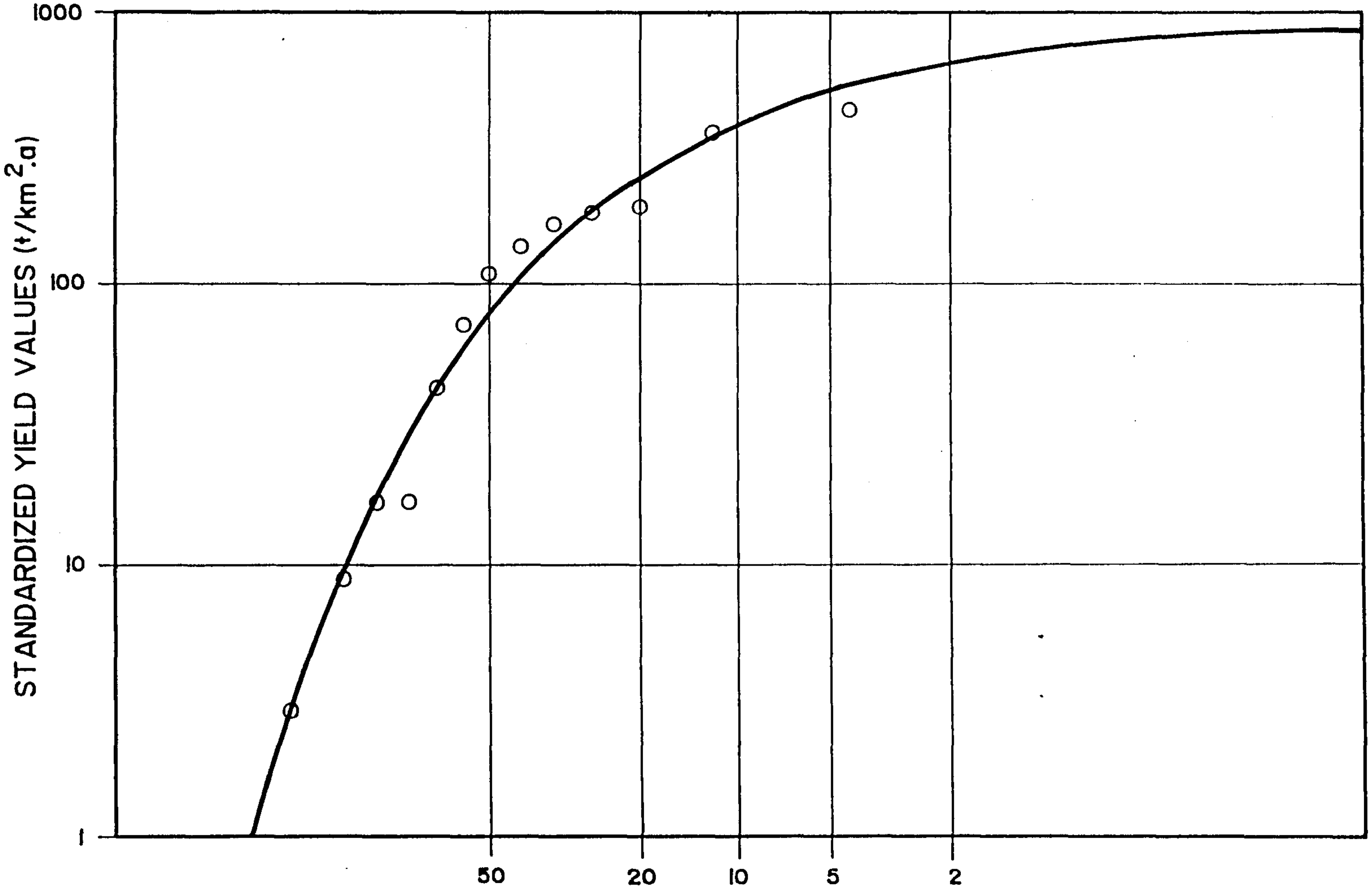
The results obtained with the log general extreme value distribution (log GEV) was therefore used as a basis for further development of methodology for estimating sediment yields in catchments.

The fitting of the log GEV distribution to the data of the various regions is shown in **Figures 4.14 - 4.21.**



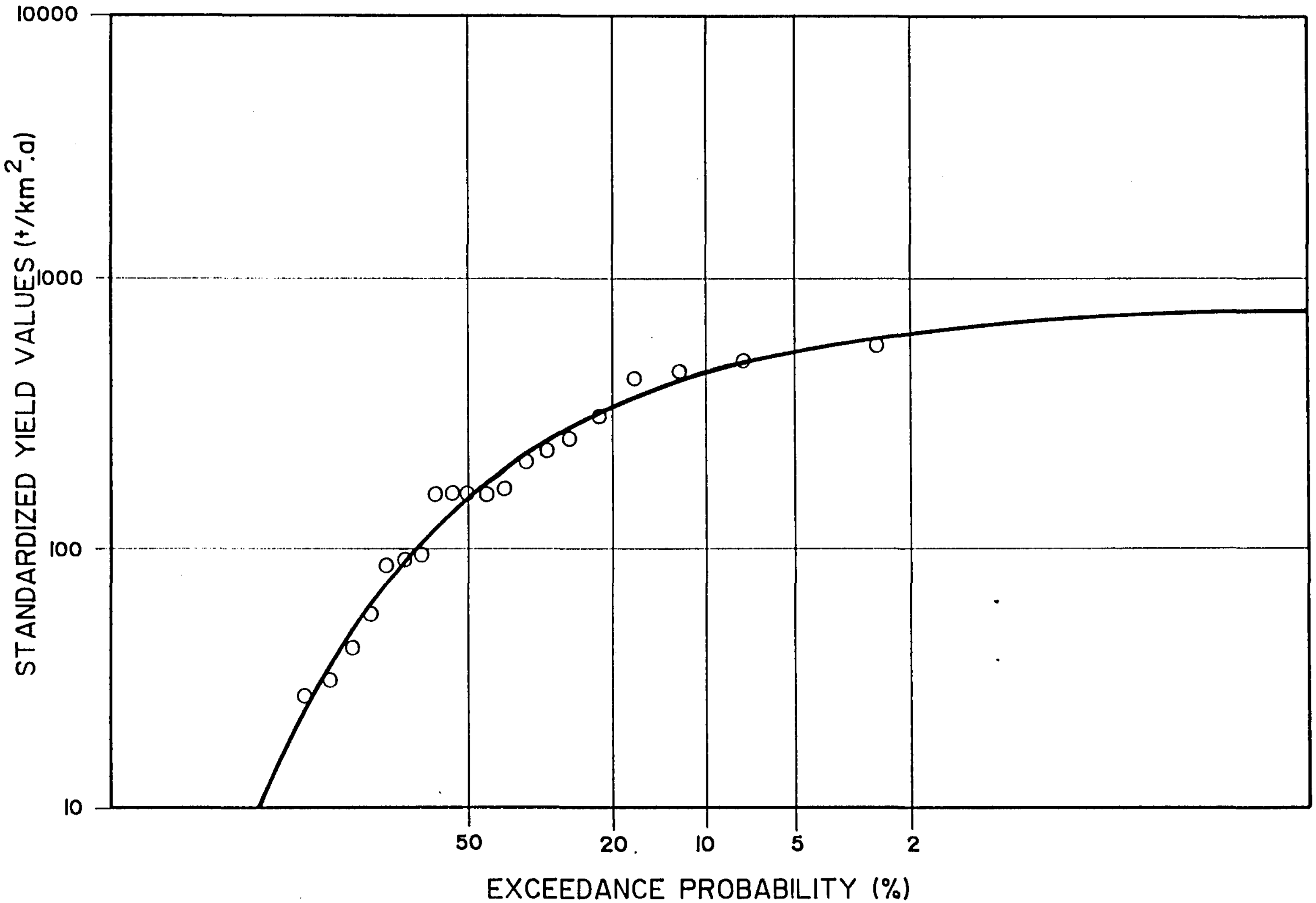
LOG EXTREME VALUE PROBABILITY SCALES AND GRINGORTEN PLOTTING POSITION

FIG 4.14 REGION I : LOG GEV DISTRIBUTION



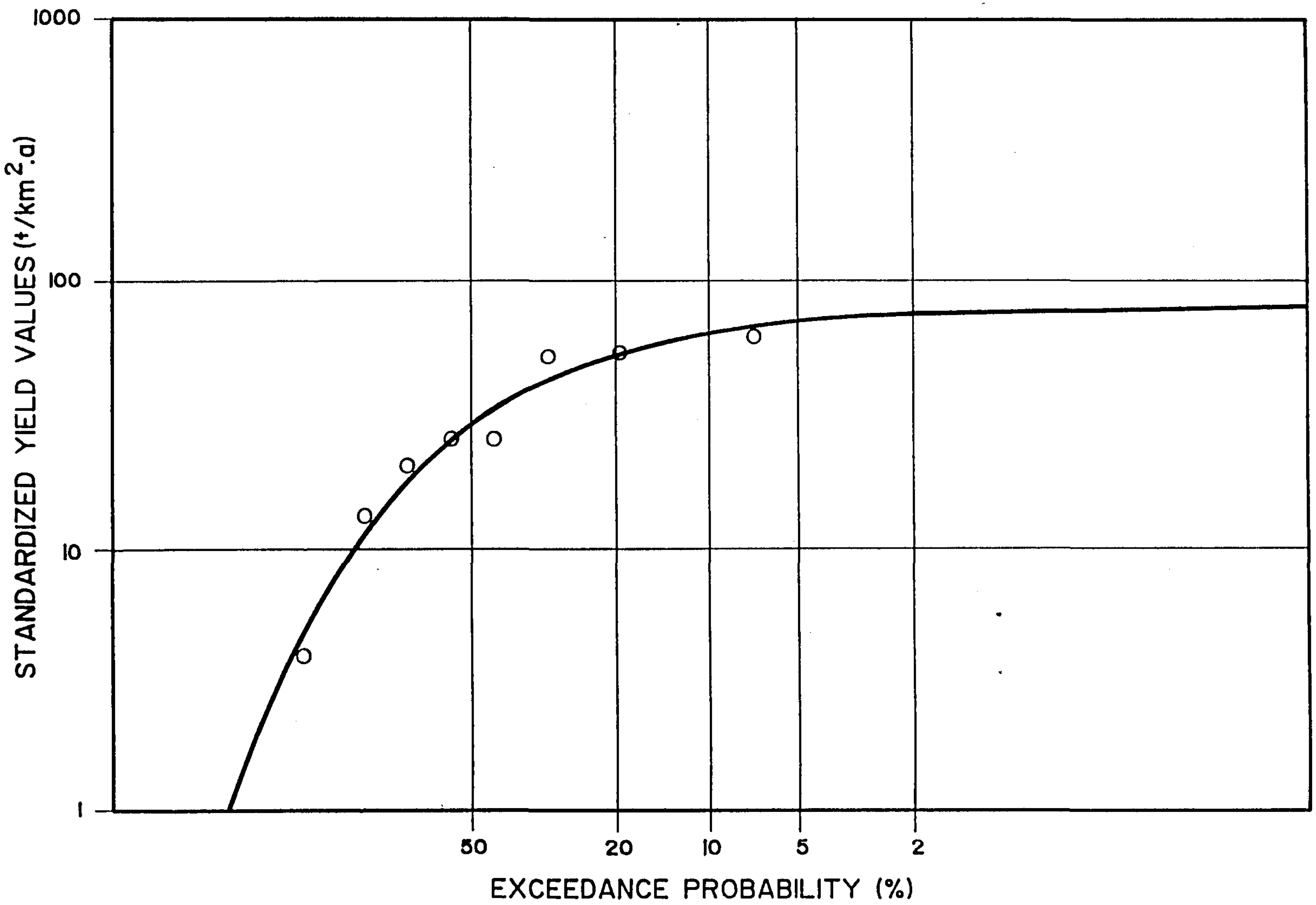
LOG EXTREME VALUE PROBABILITY SCALES AND GRINGORTEN PLOTTING POSITION

FIG 4.15 REGION 3 : LOG GEV DISTRIBUTION



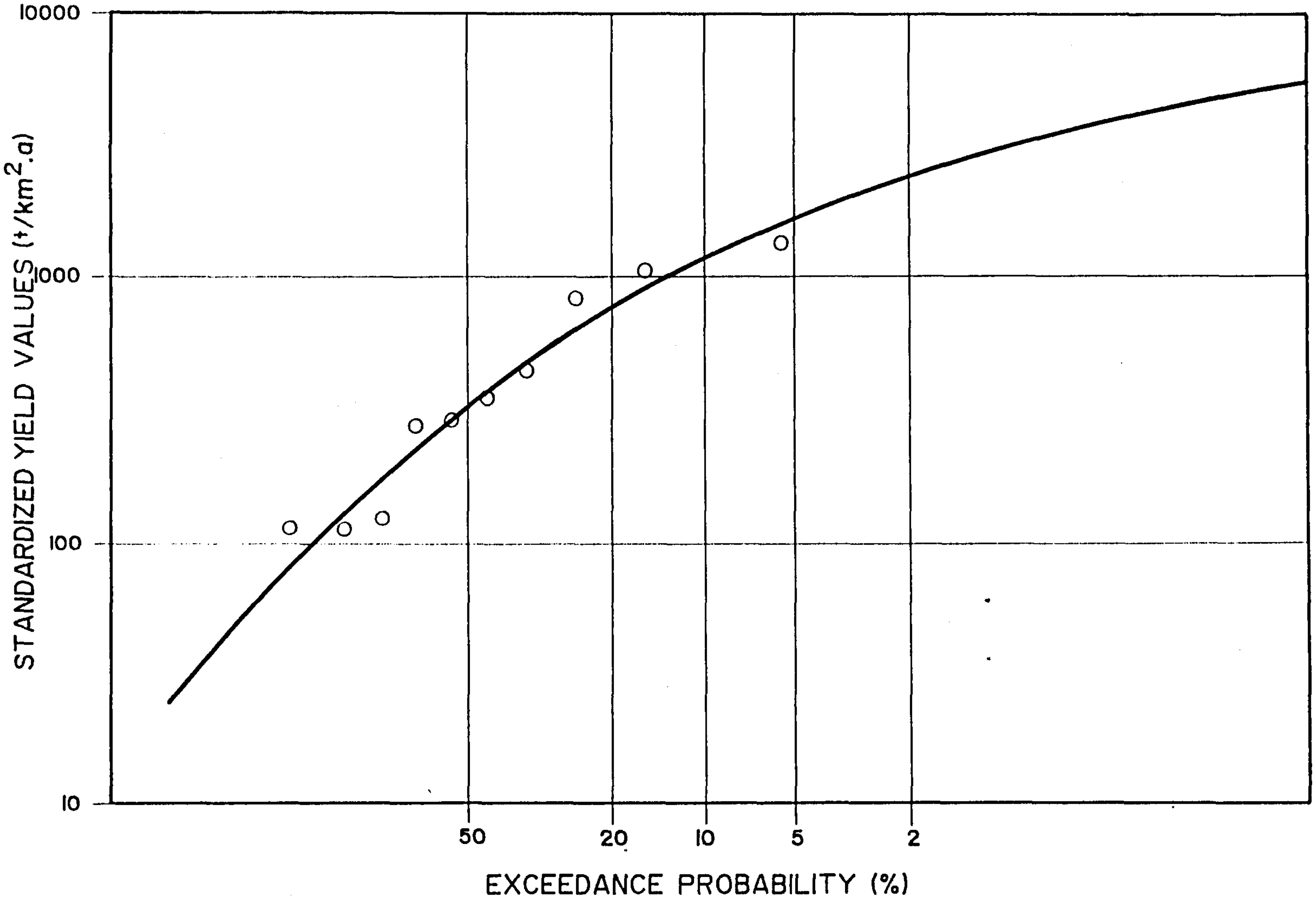
LOG EXTREME VALUE PROBABILITY SCALES AND GRINGORTEN PLOTTING POSITION

FIG 4.16 REGION 4 : LOG GEV DISTRIBUTION



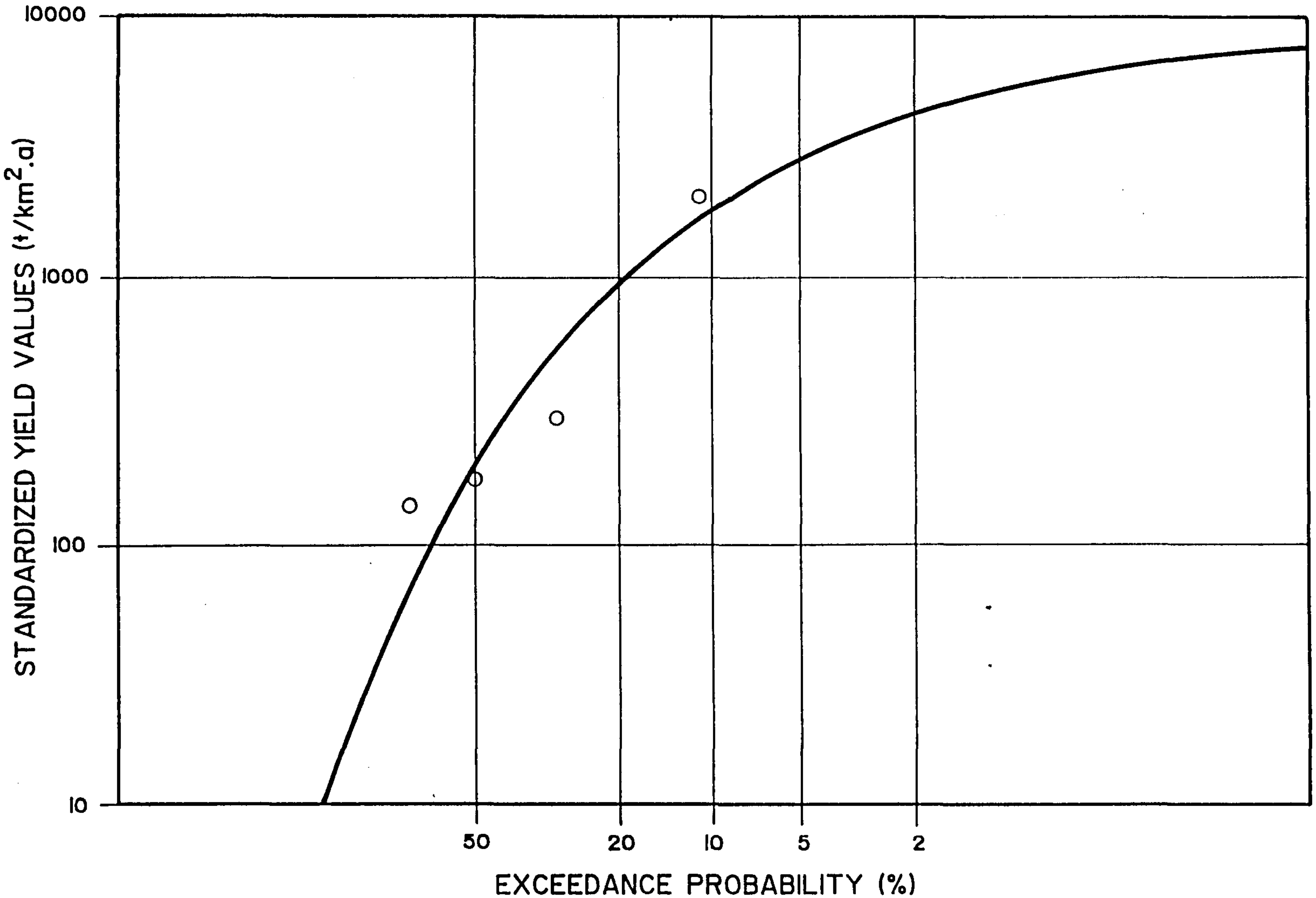
LOG EXTREME VALUE PROBABILITY SCALES AND GRINGORTEN PLOTTING POSITION

FIG 4.17 REGION 5 : LOG GEV DISTRIBUTION



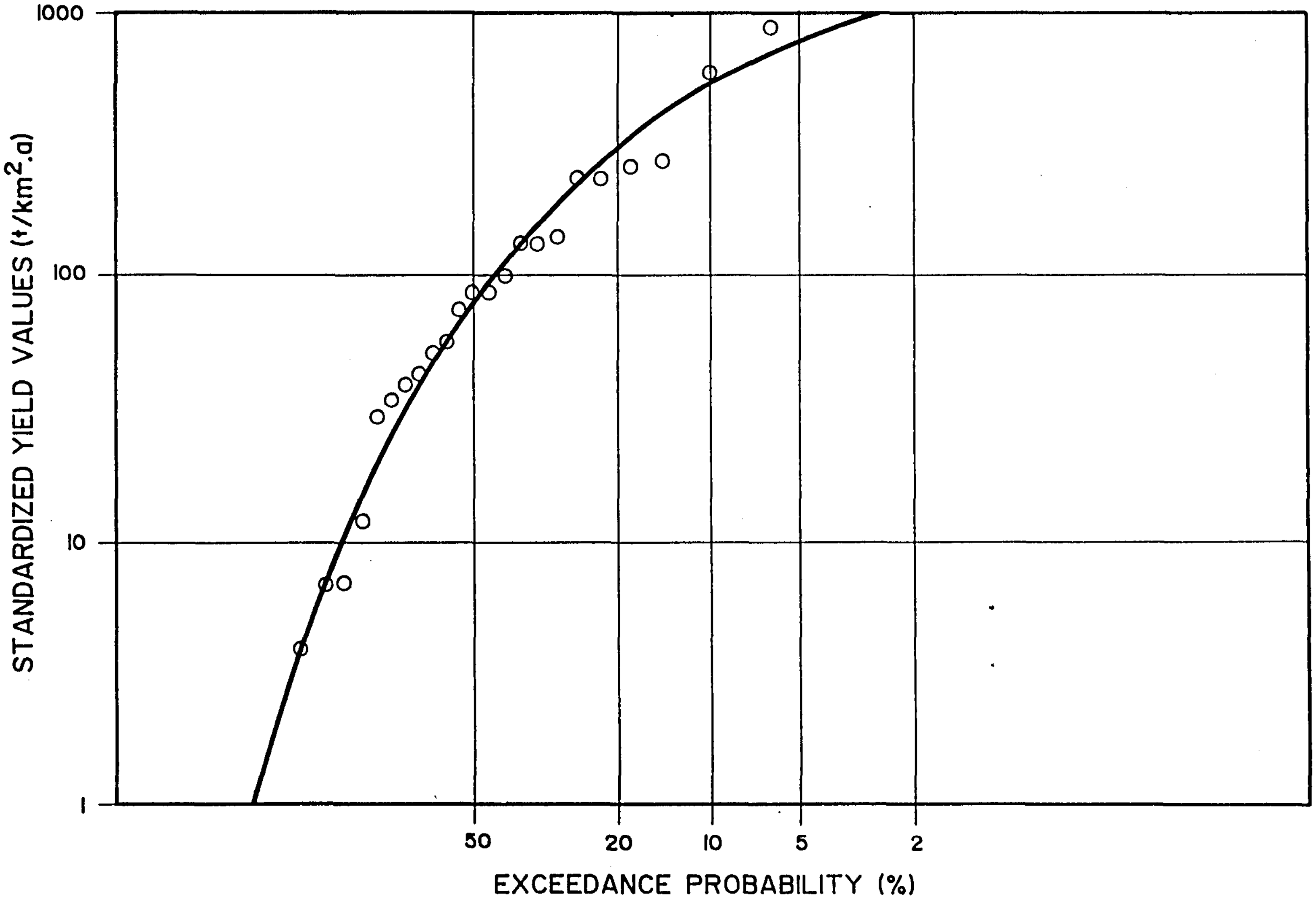
LOG EXTREME VALUE PROBABILITY SCALES AND GRINGORTEN PLOTTING POSITION

FIG 4.18 REGION 6 : LOG GEV DISTRIBUTION



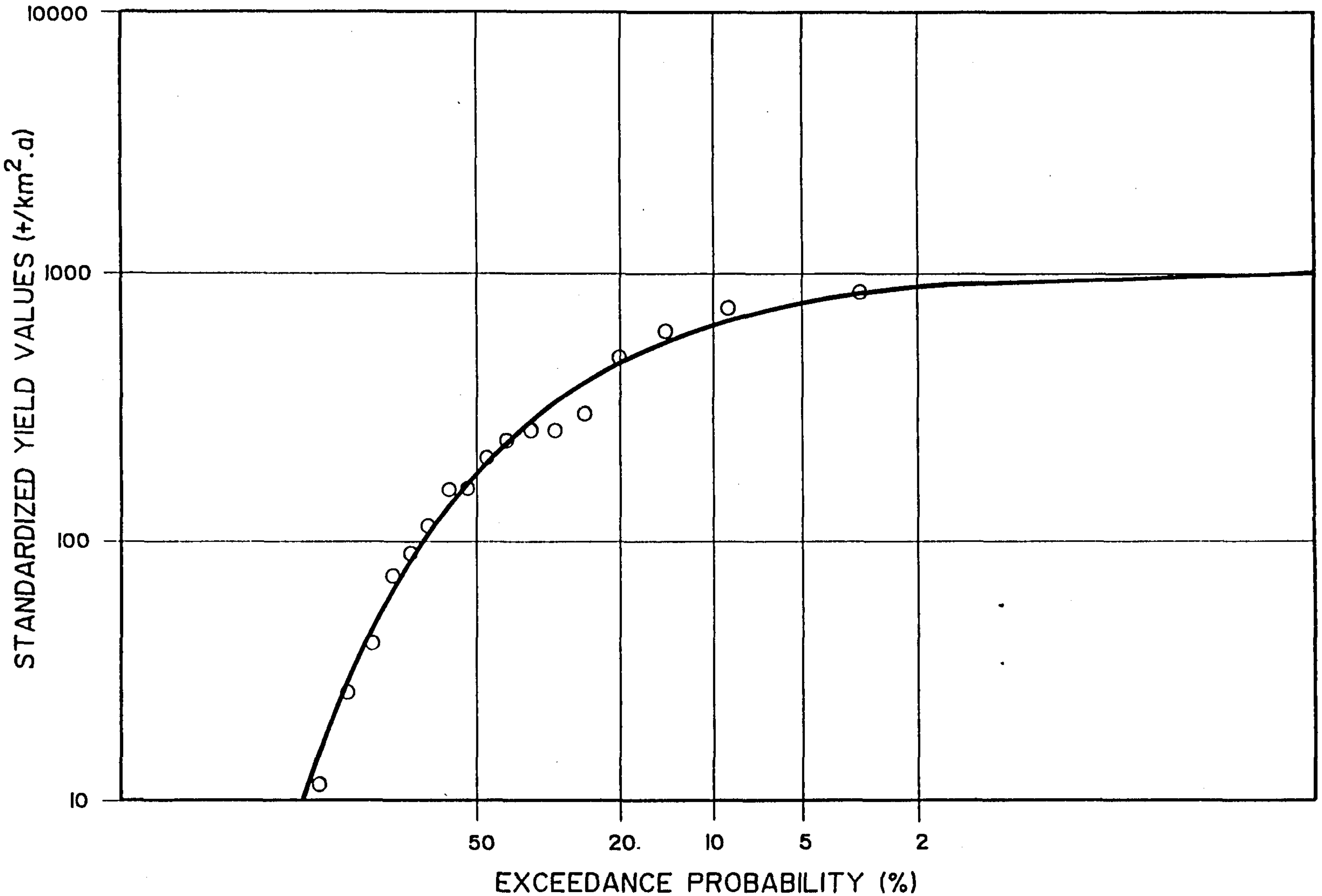
LOG EXTREME VALUE PROBABILITY SCALES AND GRINGORTEN PLOTTING POSITION

FIG 4.19 REGION 7 : LOG GEV DISTRIBUTION



LOG EXTREME VALUE PROBABILITY SCALES AND GRINGORTEN PLOTTING POSITION

FIG 4.20 REGION 8 : LOG GEV DISTRIBUTION



LOG EXTREME VALUE PROBABILITY SCALES AND GRINGORTEN PLOTTING POSITION

FIG 4.21 REGION 9 : LOG GEV DISTRIBUTION

4.3.3 The influence of catchment size on sediment yields

As a much higher variability in sediment yield values must be expected in the case of small catchments than for very large catchments, it was decided to examine the relationship between yield and catchment size. As the regional data was described well by the log general extreme value distribution, it was assumed that any subset of the data would also be log GEV distributed.

The sediment data for each region was then arranged according to catchment size and the log GEV distribution was fitted to the data on a ten point moving basis. Mean values and confidence bands were thus obtained. As may be expected, these values showed a strong tendency to converge to a regional mean value with increase in catchment size. The plotted moving averages as well as the mean values are shown in **Figures 5.2 to 5.9** in Chapter 5 in which the full methodology is described. For those regions with limited data, a single factor only is given for each confidence band for all catchment sizes.

5. <u>RECOMMENDED METHODOLOGY FOR ESTIMATING SEDIMENT YIELDS FROM UNGAUGED CATCHMENTS</u>

5.1 METHODOLOGY

The recommended methodology for estimating sediment yields from ungauged catchments is based on the statistical analysis of the available data, as described in the previous chapter.

For the determination of sediment yield values, the following aids are included:

i) A map of southern Africa **Figure 5.1** on which the nine main sediment yield regions are indicated. The three categories of sediment yield potential for soils (higher, medium and lower) are also indicated.

ii) A table containing mean standardized sediment yield values for each of the nine sediment regions **(Table 5.1)**.

iii) Graphs showing, for each region, recommended multiplication factors which may be selected to account for variability in sediment yield values, linked to catchment size **(Figure 5.2 - 5.9)**.

iv) A table with factors for each region, by means of which the standardized sediment yield values can be converted to weighed average yield values for any given catchment **(Table 5.1)**.

The purpose of this method is firstly to determine the regional standardized sediment yield value, which is applicable to a catchment with a specific size and location, then to convert this value into an actual yield value,

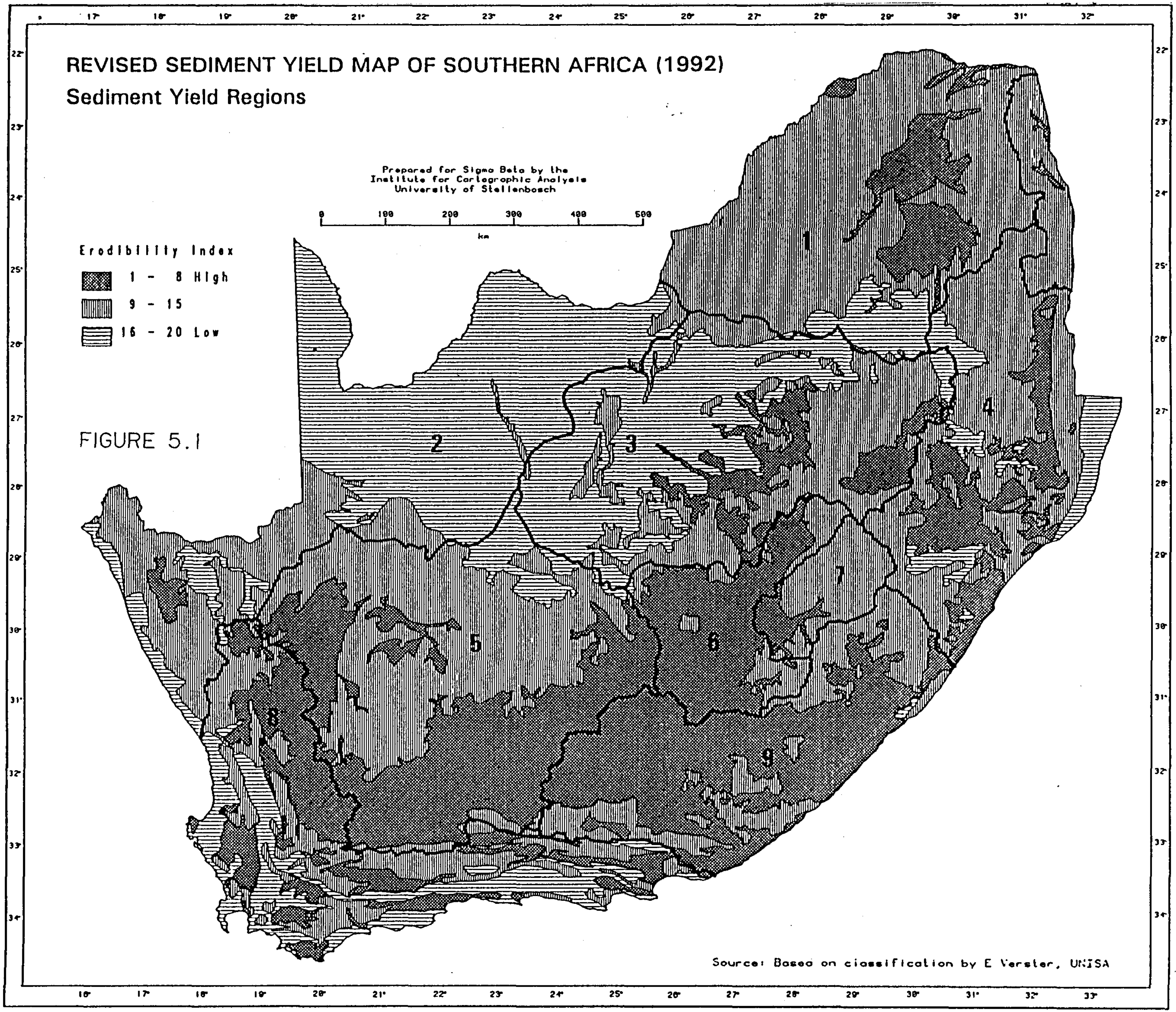

REVISED SEDIMENT YIELD MAP OF SOUTHERN AFRICA (1992)
Sediment Yield Regions
Prepared for Sigma Beta by the
Institute for Cartographic Analysis
University of Stellenbosch
0 100 200 300 400 500
km
Erodibility Index
1 - 8 High
9 - 15
16 - 20 Low
1
2
3
4
5
6
7
8
9
Source: Based on classification by E Verster, UNISA

FIGURE 5.1

taking into account the actual yield potential of the different soils in the catchment.

The method consists of the following steps:

i) Determine the location and the size of the catchment for which the estimated sediment yield is to be determined.

ii) Obtain from the sediment yield region map **(Figure 5.1)**, the yield region for the catchment, as well as the sizes of sub-areas within the catchment, which consists of soil categories with different yield potential (higher, medium and lower yield potential).

iii) For the given region obtain the regional standardized mean yield given in **Table 5.1.**

iv) From the graph for the region, select the sediment yield multiplication factor, applicable to the size of the catchment under consideration **Figure 5.2 - 5.9).** Note that the multiplication factors are envelope values and are expressed as multiples of the regional mean standardized sediment yield. Multiply the regional mean standardized sediment yield value with the multiplication factor to obtain a standardized yield value.

v) Convert the standardized sediment yield values to site specific yield values by means of the formula:

$$Y_C = Y_S \left[F_H \frac{A_H}{A_T} + F_M \frac{A_M}{A_T} + F_L \frac{A_L}{A_T} \right]$$

with $\mathbf{Y_C}$ = estimated catchment sediment yield value ($t/km^2.a$)

$\mathbf{Y_S}$ = standardized sediment yield value ($t/km^2.a$)

$\mathbf{F_H}$ = high yield potential factor **(Table 5.1)**

$\mathbf{F_M}$ = medium yield potential factor

$\mathbf{F_L}$ = low yield potential factor

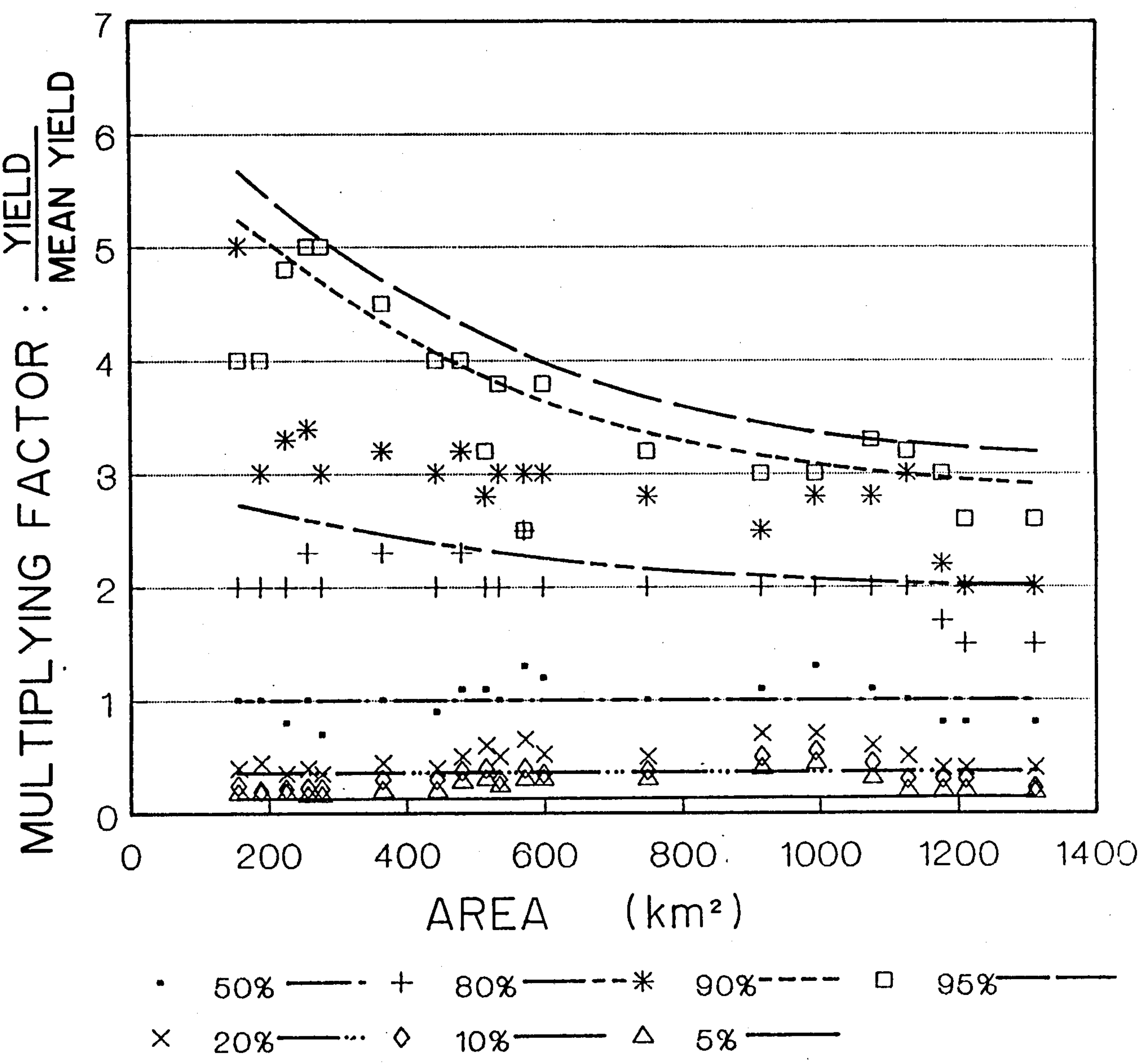


FIG 5.2 REGION I
SEDIMENT YIELD CONFIDENCE BANDS

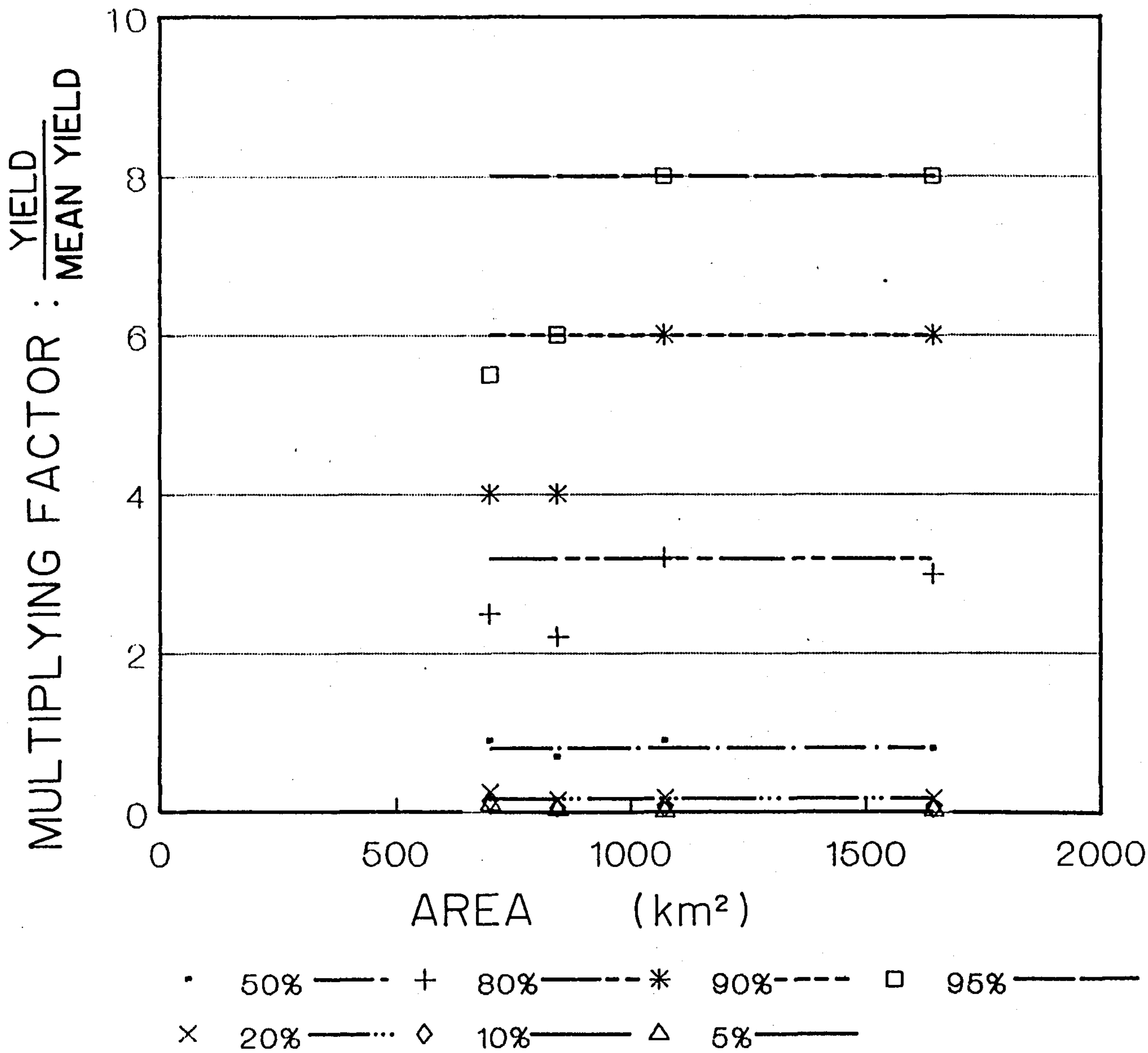


FIG 5.3 REGION 3

SEDIMENT YIELD CONFIDENCE BANDS

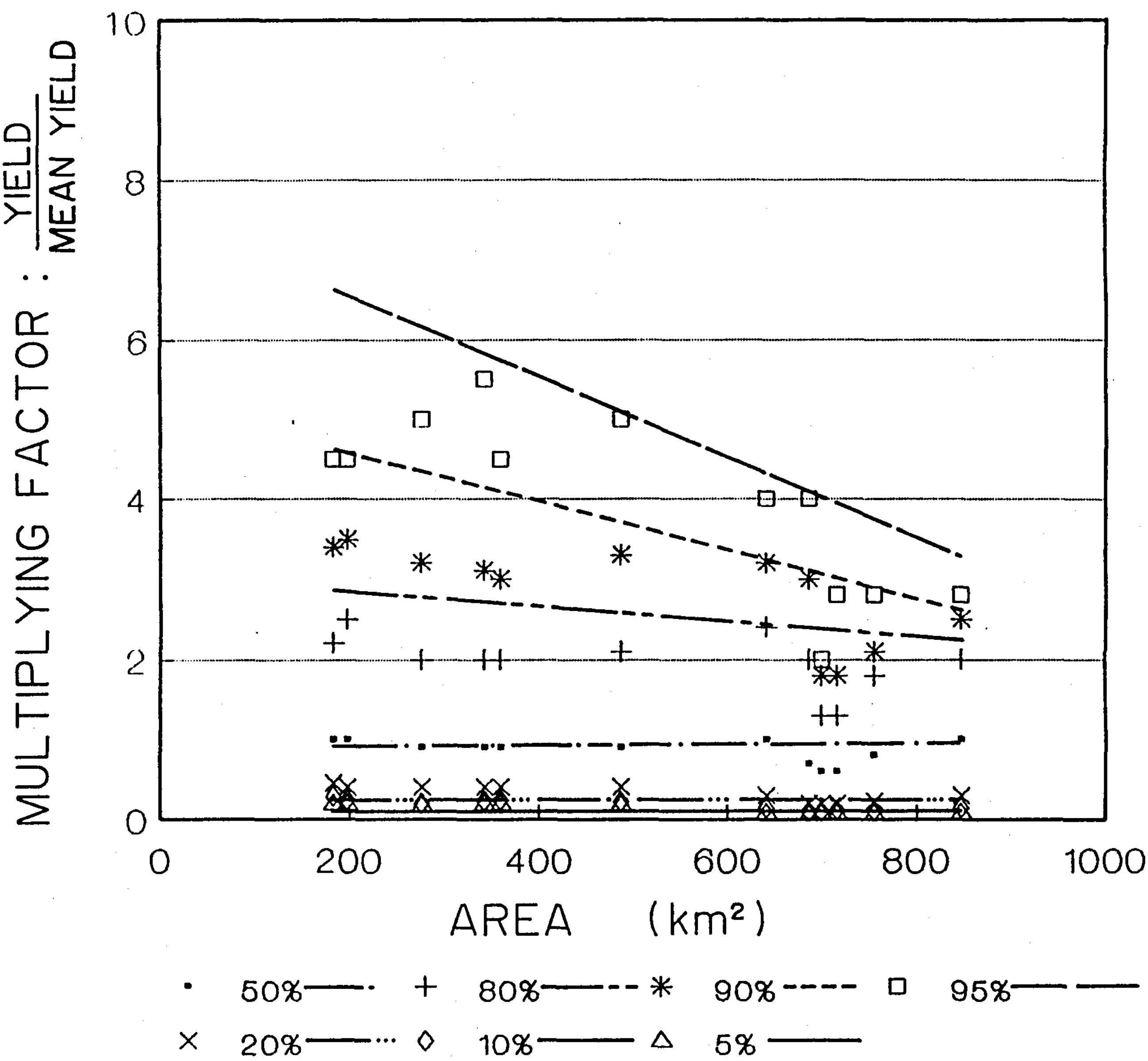


FIG 5.4 REGION 4

SEDIMENT YIELD CONFIDENCE BANDS

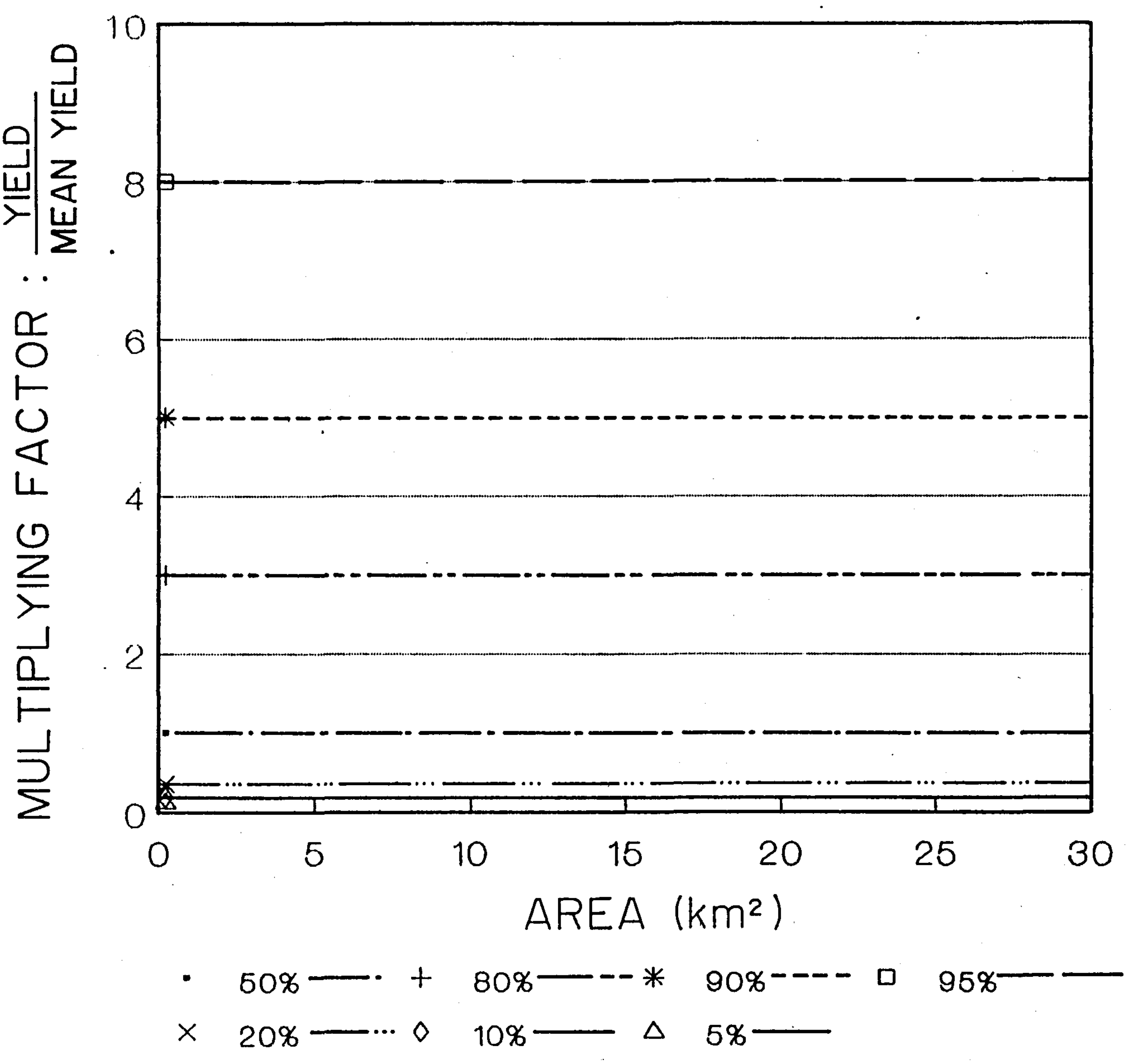


FIG 5.5 REGION 5

SEDIMENT YIELD CONFIDENCE BANDS

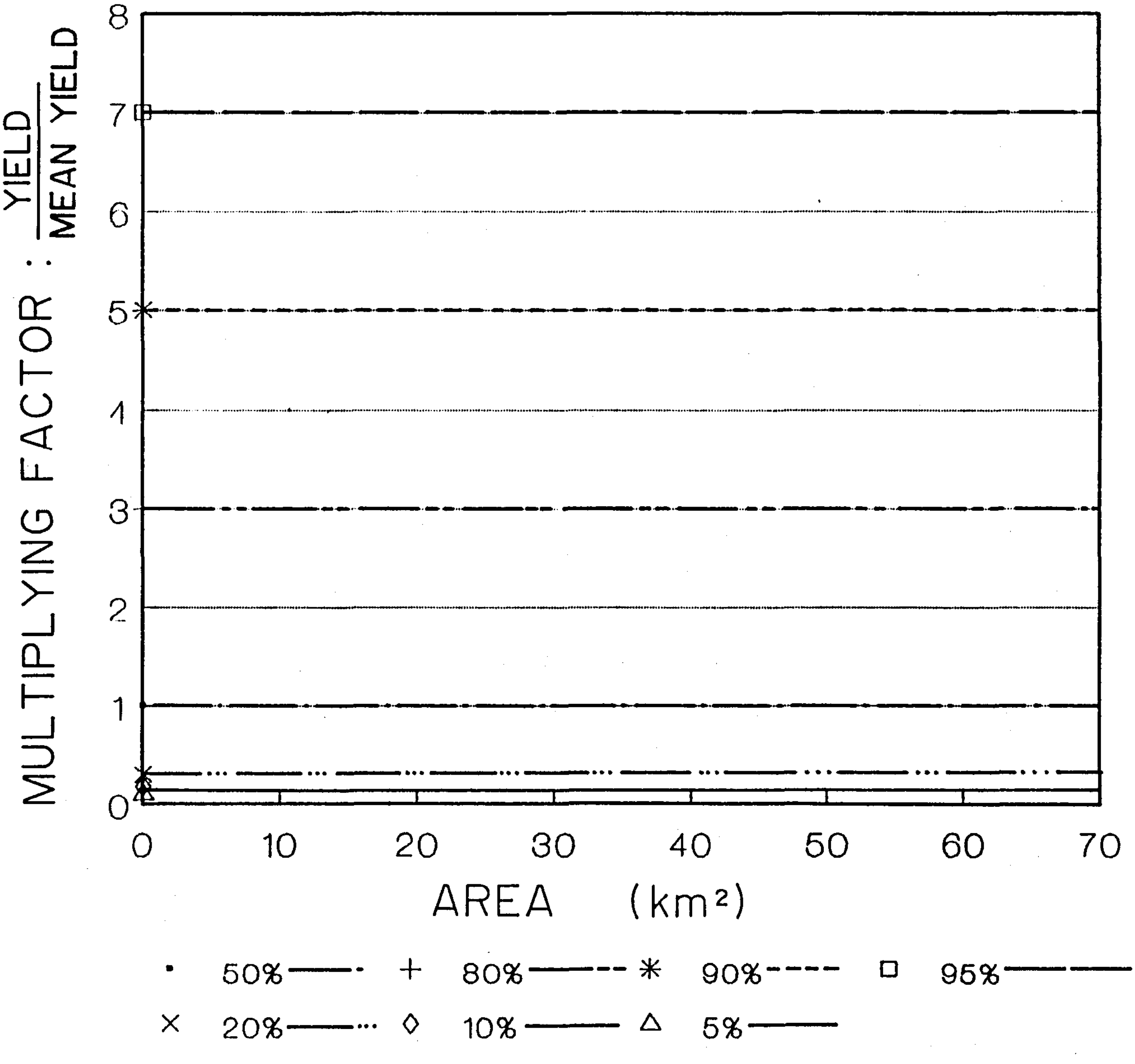


FIG 5.6 REGION 6
SEDIMENT YIELD CONFIDENCE BANDS

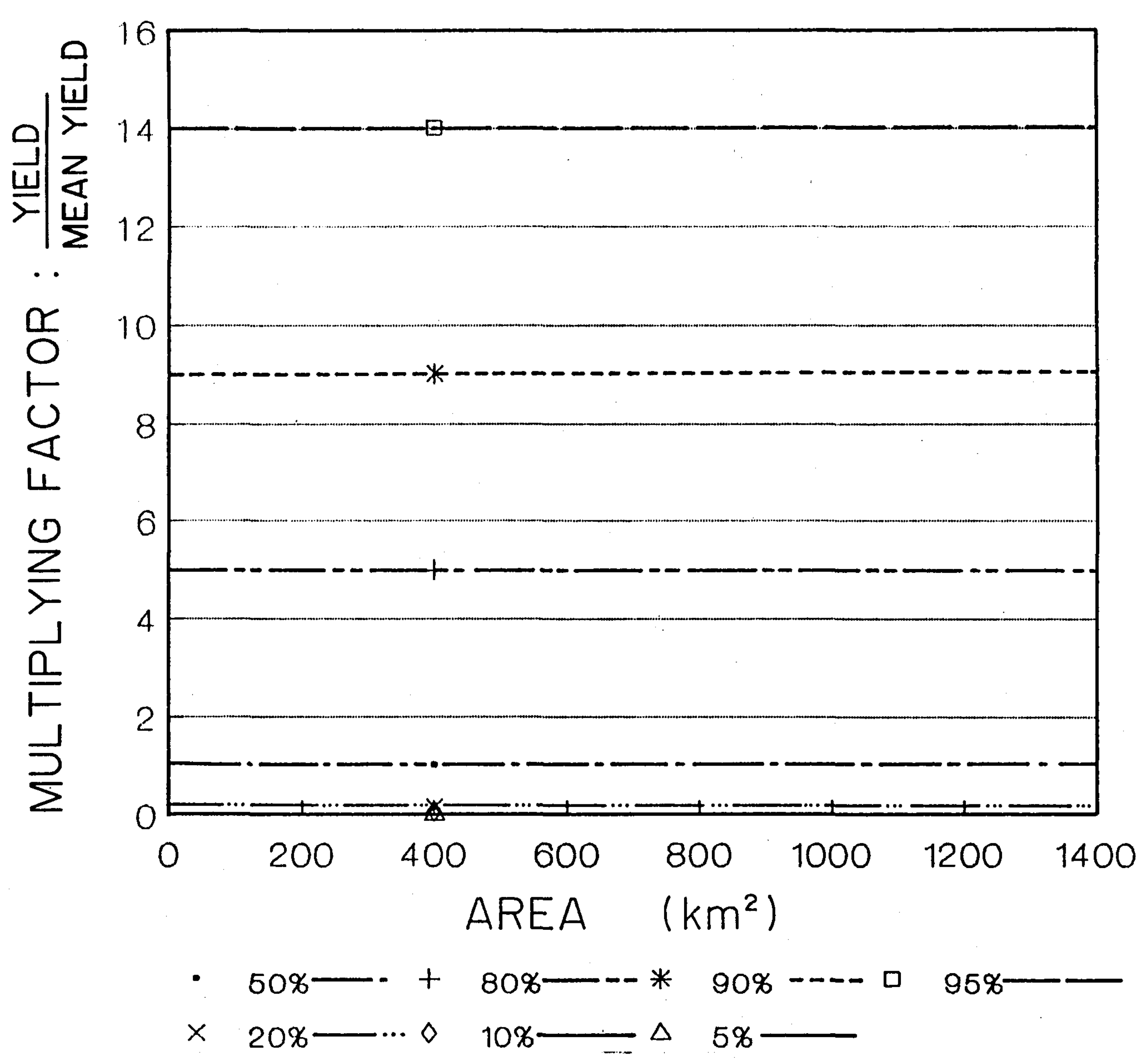


FIG 5.7 REGION 7

SEDIMENT YIELD CONFIDENCE BANDS

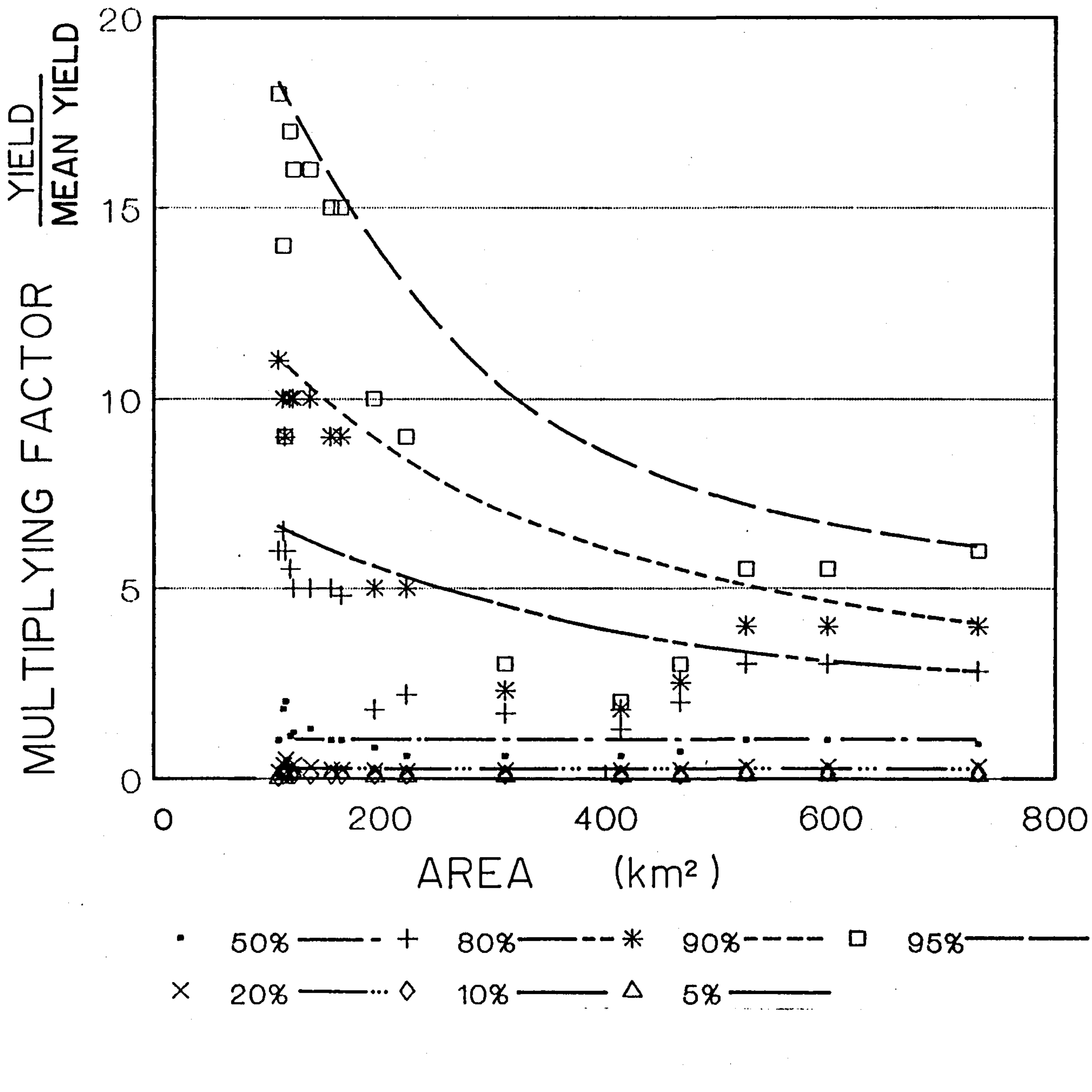


FIG 5.8 REGION 8

SEDIMENT YIELD CONFIDENCE BANDS

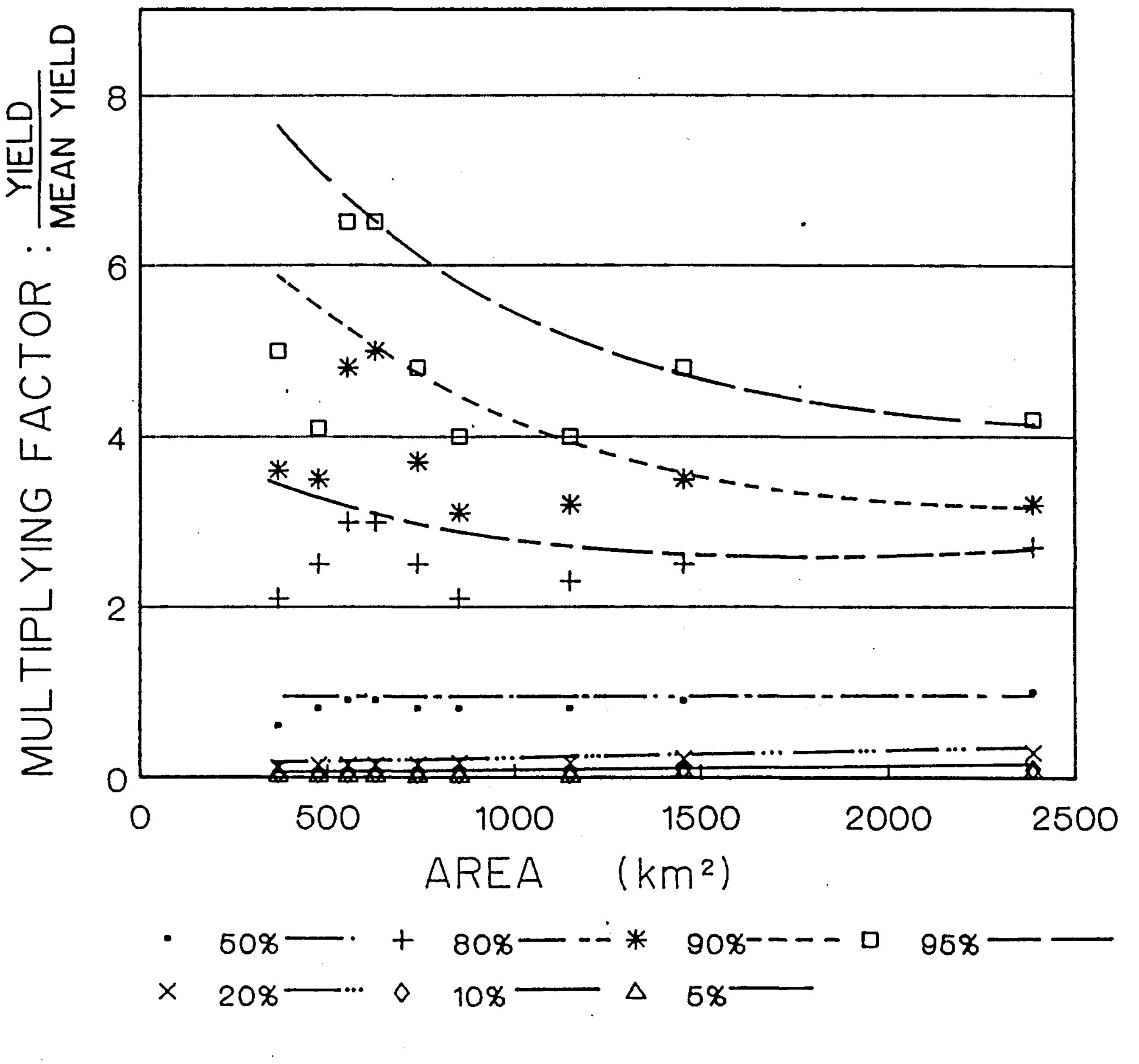


FIG 5.9 REGION 9

SEDIMENT YIELD CONFIDENCE BANDS

A_H = size of area consisting of soils with higher sediment yield potential (km^2)

A_M = size of area consisting of soils with medium sediment yield potential (km^2)

A_L = size of area consisting of soils with low sediment yield potential (km^2)

A_T = total catchment area (km^2)

TABLE 5.1: FACTORS FOR CONVERTING STANDARDIZED YIELD VALUES TO SITE SPECIFIC YIELD VALUES

		SEDIMENT POTENTIAL FACTORS		
REGION	**STANDARDIZED AVERAGE YIELD ($t/a.km^2$)**	F_H	F_M	F_L
1	49	2.23	1.00	0.92
2	N/A	N/A	N/A	N/A
3	82	1.87	1.00	0.35
4	155	1.44	1.00	0.18
5	30	2.69	1.00	N/A
6	335	1.00	1.00	N/A
7	203	N/A	N/A	1.00
8	35	1.00	1.00	0.23
9	185	1.00	1.00	N/A

* **Where insufficient data was available, no distinction was possible, indicated by N/A.**

When it was not possible to draw clear distinctions, factors of 1 were adopted for F_H and F_L.

vi) In selecting the appropriate factor(s), it will always be necessary to consider actual conditions within the catchment when estimates are prepared and also to compare the value obtained to recorded yields for comparable catchments.

5.2 SOME RELEVANT ASPECTS TO BE CONSIDERED WHEN ESTIMATING SEDIMENT YIELDS FOR THE VARIOUS REGIONS

Developing, highly urbanized and industrialized areas in Region 1 have to be carefully considered as these areas produce above average yields. An example is the Hartebeespoort Dam, which has a large catchment containing parts of Johannesburg, and other large urbanized areas.

Region 2 has very little information on which to base sediment yield values. Because of very dry conditions, it is unlikely that many reservoirs will be constructed in this area. Sediment yields in the region are relatively low.

In Region 3 the sediment yield values do not converge towards a regional mean value with increase in catchment size. This could be attributed to the fact that most of the smaller catchments for which data is available, are situated in the upper reaches of the Vaal catchment, where sediment yield values tend to be low. As the sizes of catchments increase, some areas with higher sediment yield potential are added. This means that small catchments situated in the lower areas of the Vaal River catchment have to be treated with care, as their sediment yield potential may be higher than is reflected in the data.

Reservoirs in Region 4 for which information is available, are not homogeneously distributed through the region. Most of the reservoirs are situated in the area between Durban and Lesotho, in the catchments of the Mgeni and Tugela Rivers. Little data is available in the vicinity of Swaziland, where reservoirs with significant sediment trapping potential have only recently been constructed.

Sugar cane production areas are not well presented in the available data. As these areas have high sediment yield potential, care has to be taken when evaluating sediment yields for areas in which sugar cane production is significant. Yields in excess of 1000 $t/km^2.a$ are possible from such catchments.

In Region 5, because of limited data, a single value for each multiplication factor was calculated for all catchment sizes. The same procedure was followed in Region 6.

Generally, high sediment yield values should be expected in Region 6, as some of the highest sediment yield areas in the country are situated within this region, mainly in the Caledon river catchment.

Region 7 generally should have lower sediment yields, due to the basaltic regions in the area. Some very high sediment yields occur in cases where the same soils that are present along the upper regions of the Caledon River, are included in certain catchments. This is the cause of the wide confidence limits for the region.

The sediment yield values in Region 8 converge very clearly to a regional mean value. Some smaller catchments have exceptionally high values relative to the mean value. At least some of these high values, notably for Wemmershoek Dam, can be ascribed partially to the influence of bush fires. Fires increase the resistance of the soils to water penetration and change the soil texture, resulting in increased surface run-off, higher flow velocities and increased sediment yields.

Region 9 displays the tendency of convergence of sediment yield values to a regional mean value, with increase in catchment size.

6. CONCLUSIONS AND RECOMMENDATIONS

1) Whilst it was possible to calibrate the new sediment yield map in terms of regions which are theoretically homogeneous in terms of their basic sediment yield potential, it was not possible to quantify the impact of specific variables such as land-use, rainfall intensity, slopes and vegetation in a meaningful way. A special programme of sediment monitoring would be required to provide meaningful answers regarding the impacts of land-use on sediment yields.

2) In order to obtain meaningful results it proved necessary to sub-divide the southern African region into 9 relatively homogeneous sub-regions and the data for each sub-region had to be analyzed separately. It was also necessary to reduce the number of differing yield zones for each sub-region to three (high, medium and low).

3) It proved that the availability of sediment for transport plays the dominant role in determining sediment loads in rivers. Local sediment loads consist mainly of very fine particles and winds can play important intermediary roles in the processes whereby sediment is eventually delivered to rivers. No meaningful relationships could be found between sediment yields and run-off transporting capacity for different catchments.

4) As was expected, the variability in recorded yield values around the mean decreases with increasing catchment size. It is believed that the diagrams which represent the variability around the mean for different catchment zones will form useful statistical tools together with the appropriate base maps in estimating yields from ungauged catchments. Subjective assessment of catchment conditions will still be required to evaluate the actual current sediment yield potential of a catchment, but it will now be

possible to affix probabilities to the values which are adopted.

5) GIS (Geographic Information System) proved to be a most useful tool in the manipulation of spatial data.

6) More sediment yield information is required in certain areas such as the far northern Transvaal, central OFS, Swaziland, parts of Natal, and the north-western Cape.

Future reservoir re-surveying should be concentrated on these areas. Where necessary and practicable, stream sediment sampling should be considered for limited periods, especially where the total load for a catchment is known, but information is required regarding the relative contributions of sub-catchments. Much more detailed information on yields for specific catchments would be required to determine the impacts of different land-use activities on yields.

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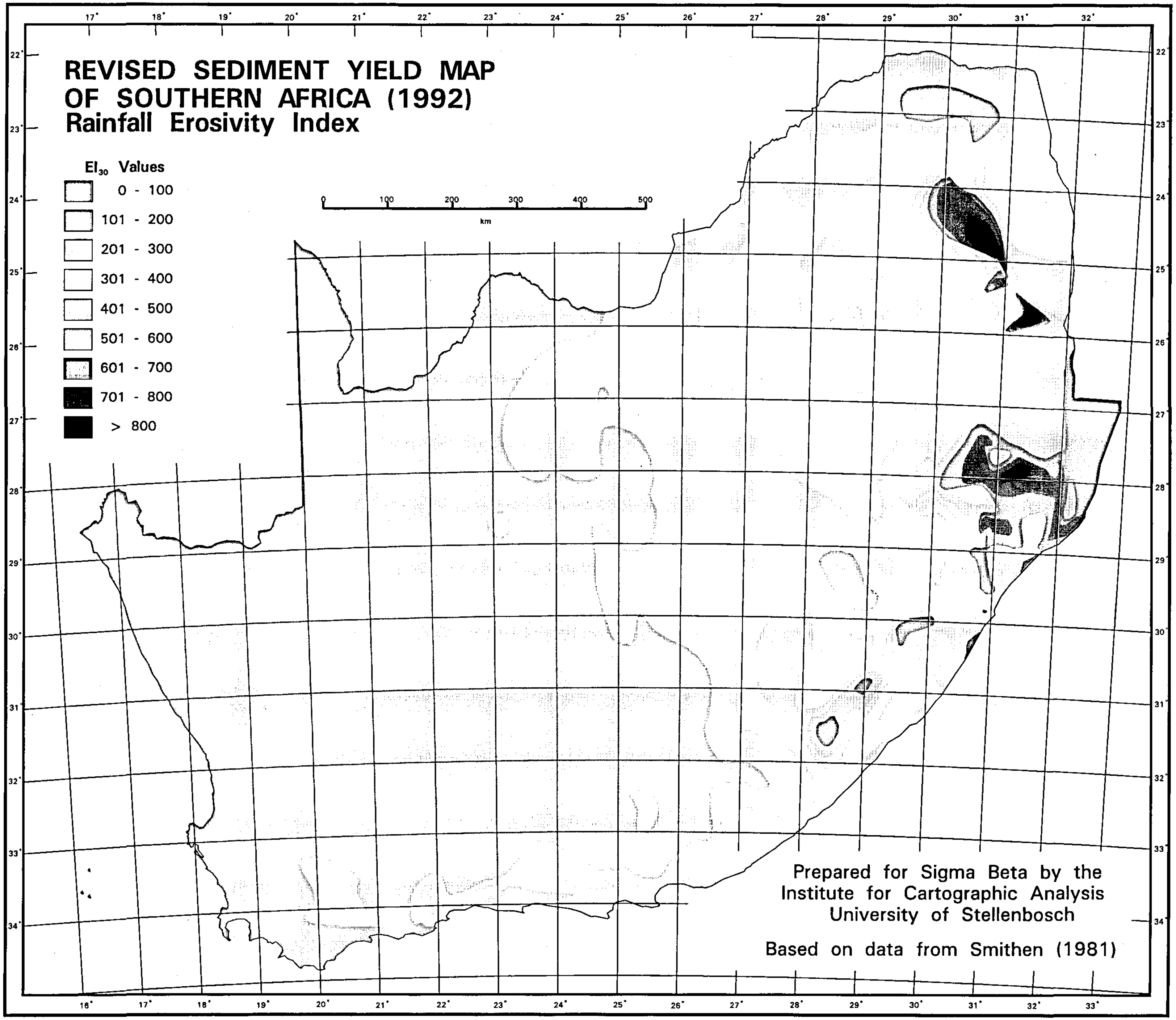

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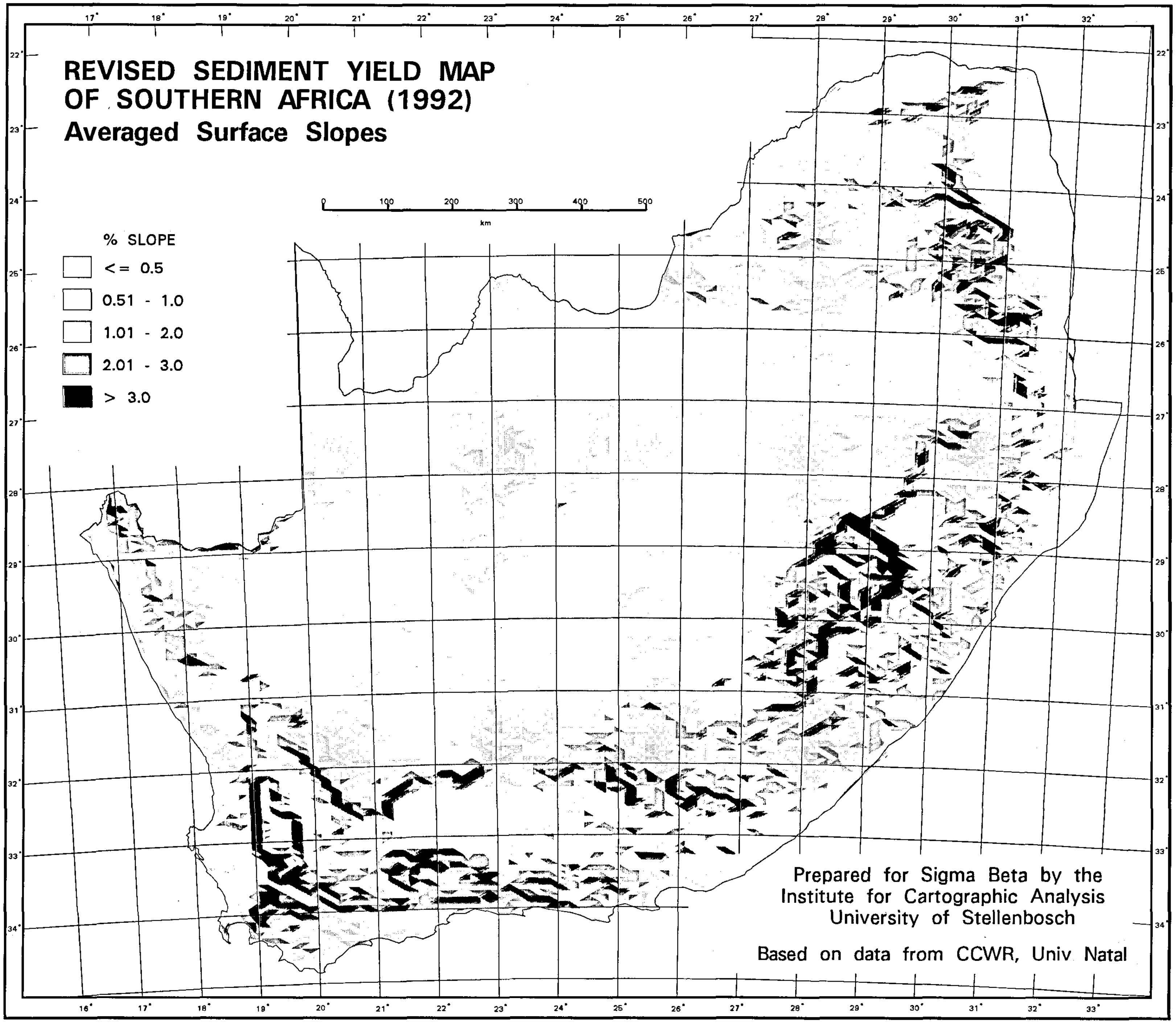
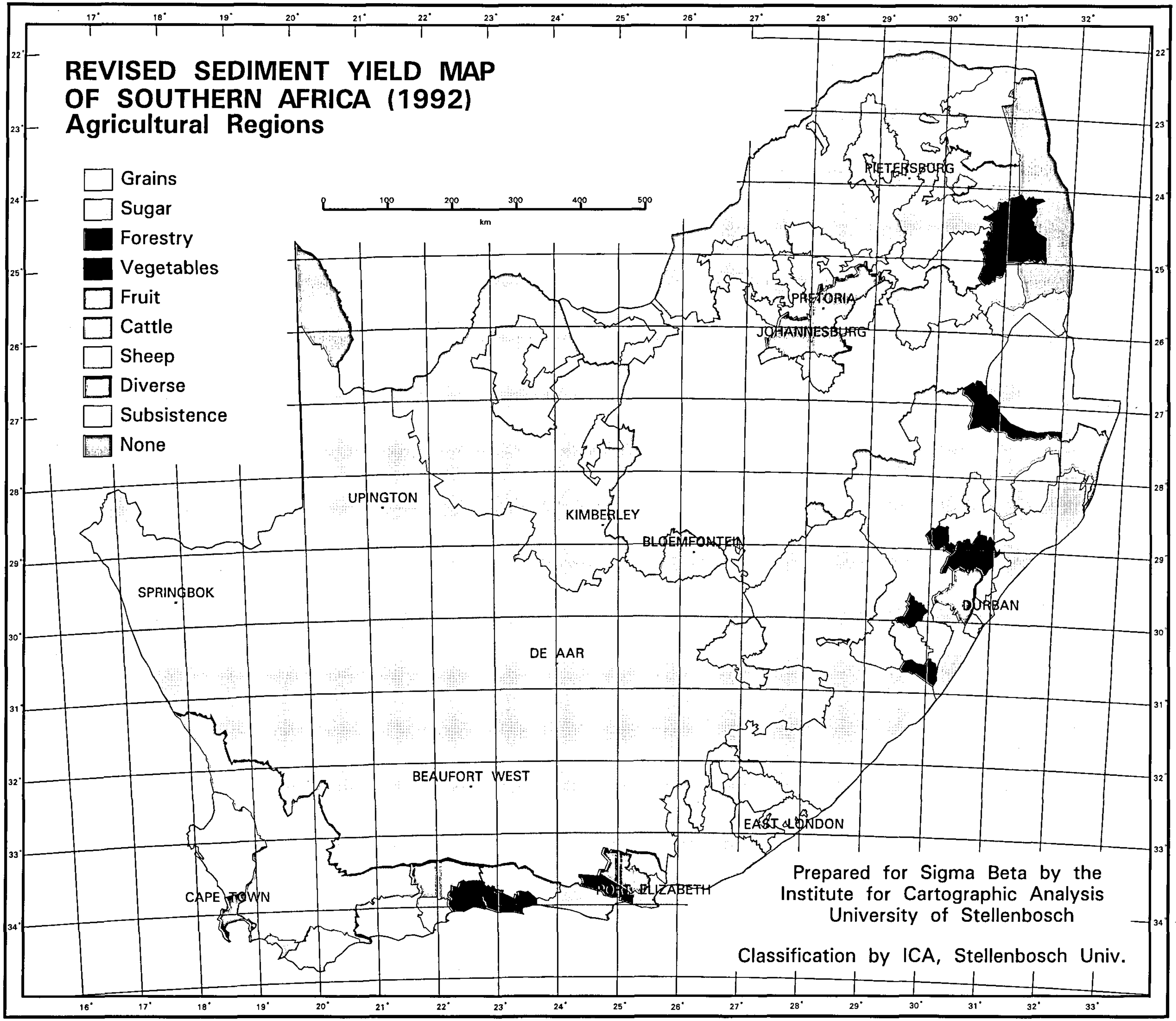


REVISED SEDIMENT YIELD MAP
OF SOUTHERN AFRICA (1992)
Averaged Surface Slopes
% SLOPE
<= 0.5
0.51 - 1.0
1.01 - 2.0
2.01 - 3.0
> 3.0
0 100 200 300 400 500
km
Prepared for Sigma Beta by the
Institute for Cartographic Analysis
University of Stellenbosch
Based on data from CCWR, Univ Natal



REVISED SEDIMENT YIELD MAP
OF SOUTHERN AFRICA (1992)
Agricultural Regions
Grains
Sugar
Forestry
Vegetables
Fruit
Cattle
Sheep
Diverse
Subsistence
None
0 100 200 300 400 500
km
PIETERSBURG
PRETORIA
JOHANNESBURG
UPINGTON
KIMBERLEY
BLOEMFONTEIN
SPRINGBOK
DURBAN
DE AAR
BEAUFORT WEST
EAST LONDON
CAPE TOWN
PORT ELIZABETH
Prepared for Sigma Beta by the
Institute for Cartographic Analysis
University of Stellenbosch
Classification by ICA, Stellenbosch Univ.