CHAPTER - IV

FUTURE TRAFFIC VOLUME IN GREATER KHARTOUM

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4.1 GENERAL

Future traffic demand is estimated on the basis of past transportation studies, social and economic data, and results of the supplementary traffic surveys, for the following purposes:

a) to forecast the required number of lanes for the New White Nile Bridge
b) to provide necessary traffic data for the intersection improvement plan related to the approach roads
c) to evaluate the economic benefits that will accrue from construction of the New White Nile Bridge

The following gives the procedure for forecasting the future traffic demand in Greater Khartoum and its results.

4.2 PROCEDURE

Future traffic demand forecasting was performed for the base year of 1989. Considering the project life and social and economic changes in the future, the estimation was made for the years 1995, 2005 and 2015. The process of traffic demand forecasting is shown in Figure 4.1.

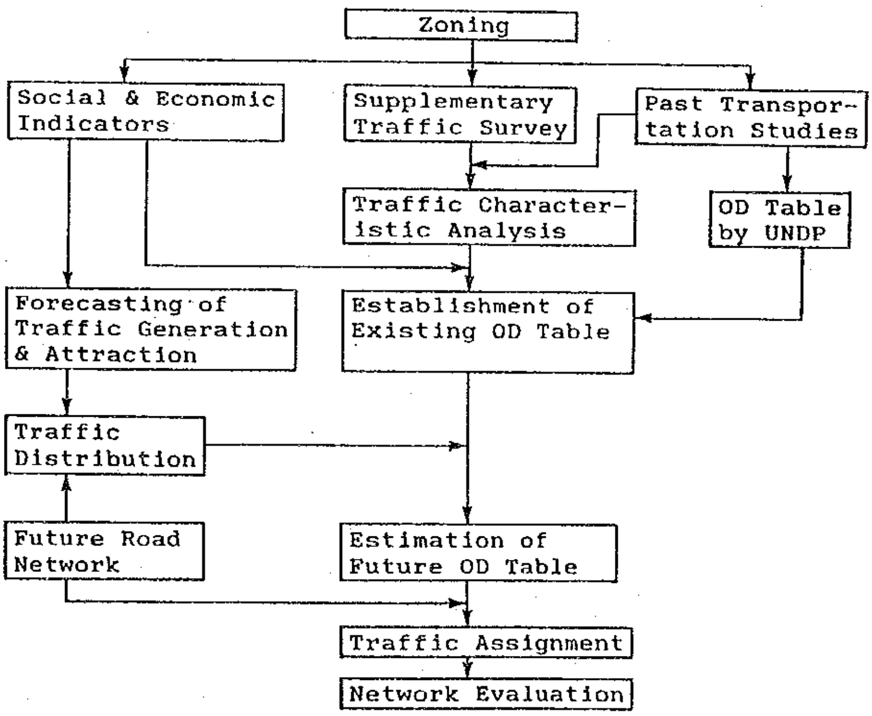


Figure 4.1 Procedures for Future Traffic Demand Forecasting

4.2.1 Analysis of Traffic Characteristics

Transportation behabiors are determined depending on various living and working activities. Therefore, traffic characteristics are deeply correlated with social and economic variables. According to data and information obtained from past studies, statistical reports, and the results of traffic surveys, traffic characteristics are examined for the purpose of precise forecasting as much as possible.

4.2.2 Establishment of the Present OD Table

The present OD table is established by supplementing the UNDP's OD table with traffic surveys conducted during the Study period. Furthermore, this OD table is adjusted in such a way that traffic volume assigned to each link matches with the corresponding actual traffic volume counts.

4.2.3 Forecasting Traffic Generation and Attraction

Future zonal traffic generation and attraction are estimated with generation/attraction models based on regression analysis. The general model of the regression is as follows:

$$T = a + b \times POP + c \times EMP + d \times CAR$$

Where,

T	:	Generation or Attraction
POP	:	Population
EMP	:	Employment
CAR	:	Car ownership
a,b,c,d	:	Parameters

4.2.4 Traffic Distribution

In order to establish the future OD table, the following gravity type model is applied for estimating inter-zonal trips newly generated or attracted in the development area:

$$Xij = k \times Gi^{a} \times Aj^{b} / Tij^{c}$$

Where,

Xij	:	Trips from i zone to j zone
Gi	:	Total trip generation of zone i
Aj	:	Total trip attraction of zone j
Tij	:	Time distance from zone i to zone j
k,a,b,c	:	Parameters

4.2.5 Establishment of Future OD Table

After the above-mentioned steps, the future OD table is established. The future target years are 1995, 2005 and 2015 as already mentioned. This future OD table reflects future population, employment, economic growth, etc.

4.2.6 Traffic Assignment

The future OD volume is then assigned to the future network to obtain future traffic volumes on road links and bridges. The conventional method of traffic assignment, the QV method, is adopted, therefore, the traffic volumes on each link are calculated by the quantity (traffic volume)/velocity ratio, which is determined by the road network inventory survey and vehicle speed survey. Figure 4.2 shows the typical QV relationship.

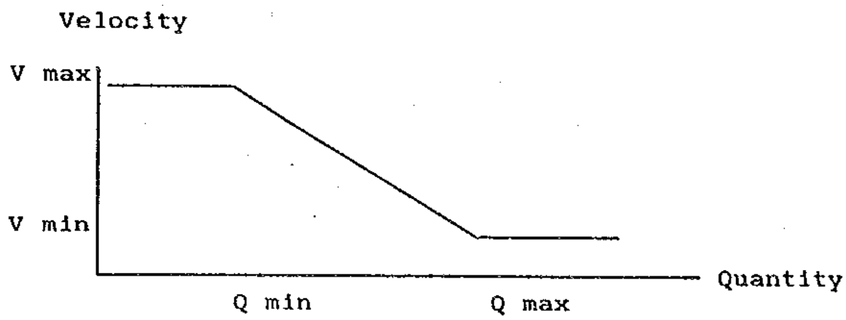


Figure 4.2 QV Relationship

4.2.7 Evaluation of Traffic Assignment

For the purpose of the evaluation, all OD tables of various vehicle types are expressed in terms of passenger car units (PCU) and then combined into a single OD table of all vehicles expressed in PCU's for each of the target years. In this step traffic volumes on the New White Nile Bridge, approach roads, and intersections near the bridge are evaluated in detail.

4.3 PROJECTION OF SOCIO-ECONOMIC INDICATORS

To forecast future traffic demand by zone, future socio-economic variables related to traffic generation or attraction had to be predetermined in each zone. The following socio-economic variables were projected for this purpose.

a) Population
b) Employment in secondary industries
c) Employment in tertiary industries
d) Number of households
e) Number of vehicles registered

4.3.1 Population

Population by zone was projected by the steps shown in Figure 4.3

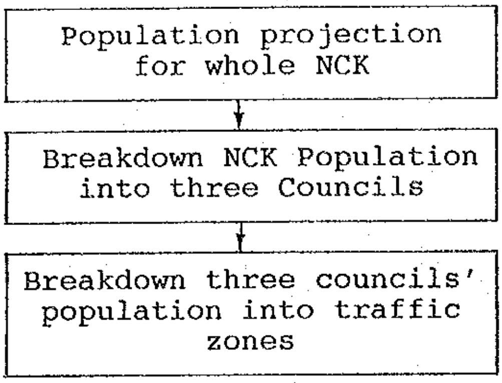


Figure 4.3 Process of Zonal Population Projection

Firstly, the total population in the whole of National Capital Khartoum (hereinafter referred as NCK) is projected, then this projected total population is broken down into three Councils' areas. Finally, the population projections of three Councils was divided into traffic zones, taking into consideration the future development pattern.

(1) Total Population in the Whole of NCK

As shown in Table 4.1, the population in NCK has grown at an average rate of 4.8% during the past 30 years and reached 1.8 million in 1983. In particular, the growth rate in the urban area is very high and increased at the rate of 7% between 1955/56 and 1983. This trend is expected to continue for the time being, taking into consideration the inflow of population not only from the rural areas but also from neighboring countries.

Table 4.1 Past Trend of Population Growth in NCK

unit : 1000 person

Year	Urban	Rural	Total
1955/56	262.6	250.0	503.6
1964/65	459.0	216.9	675.9
1973	848.8	214.5	1063.3
1983	1547.2	255.1	1802.3
Growth Rate (55/56-83)	6.8%	0%	4.8%

Source : Dept. of Statistics

The future population in NCK was forecast by applying the following log-linear curve based on the above data.

$$\text{Log } Y = -718.1464 + 95.57143 \text{ Log } x$$

Where,

Y	:	Population
X	:	Year
a,b	:	Constants

The future populations until 1995 was obtained to from the above equation, however, after that the growth rate is assumed to decrease to 2.8%, which has been the average growth rate for the whole country during the past three decades, by the year 2005. After 2005 the growth rate is assumed to be constant at 2.8%. As the growth rate of 2.8% is also a strategic policy authorized by the government, the adoption of this rate as the long-term growth rate is considered to be reasonable. Table 4.2 shows the population projection in NCK.

Table 4.2 Population projection (Low Case)

Year	Projection (thousand person)	Growth Rate (%)
1983	1,802.3	
1989	2,396.0	4.8
1995	3,197.5	4.8
2000	3,816.0	3.6
2005	4,380.9	2.8
2010	5,030.0	2.8
2015	5,774.8	2.8

Source : The Study Team

Considering the increasing migration into NCK, some reports assume a higher growth rate, however, no report has explicitly projected population in 2015. In the Study, the future population growth rate is assumed to decrease after 1995. The reasons are as follows:

a) According to "The Four Year Salvation, Recovery and Development Program (1988/89-1991/92)", balanced development and equitable distribution among regions are emphasized and the government has tried to launch the program with this purpose. It would be the best way to cause the population growth in Khartoum city to achieve this programme. Therefore, it seems reasonable for the future population growth rate in Khartoum city to approach almost the same rate as the national population growth rate of 2.8%.

b) Continuous increasing population in Khartoum city, which results in deteriorating the living environment in the city further, would make it much more difficult for the government to supply the basic infrastructure and social services such as roads, pipe water, electricity, schools, and so on. If the government implements its strategy describved in the report "The Four Year Salvation Plan" as soon as possible and the increase in job opportunities and improvement of living conditions in the rural areas are promoted strongly, the population inflow into Khartoum city from the rural areas would be considerably reduced.

c) The adverse impact on rural areas is already emphasized in terms of a shortage of labor, an increasingly heavy load on the aged population, and a reduction in the marginal productivity of the agricultural sector. However, considering the above-mentioned government strategy, the weather improvement in recent years, and the government's effort to end the civil war, some of the population already moved into Khartoum city from rural areas are expected to return to their hometowns.

d) Looking at the regional development budgetary allocation from 1980/81 to 1986/87 in Table 2.12, the budgetary allocation is steadily increasing even apart from the unusual increase in 1986/87. Therefore, NCK is forced to face the rapid population increase. However, as shown in Table 4.3, the aforementioned balanced development policy would not allow an increased allocation to NCK hereafter. From the viewpoint of financial allocation, the balanced growth of population among regions is highly desirable.

Table 4.3 Regional Development Budgetary Allocation

Unit : Million LS

Region	80/81	81/82	82/83	83/84	84/85	85/86	86/87
NCK	1.0	2.0	3.0	4.0	4.2	8.1	25.2
Northern	3.1	7.0	8.5	12.0	5.0	8.8	9.5
Central	4.0	7.0	8/0	9.3	8.0	7.3	7.6
Eastern	3.0	3.9	6.5	7.0	4.0	6.6	7.0
Kordofan	3.0	5.4	8.0	9.5	10.0	8.2	7.2
Darfur	3.0	7.0	8.5	12.0	7.0	9.9	8.5
Southern Regions	25.9	26.3	26.0	33.0	-	-	-
Equatoria	-	-	-	-	7.8	7.5	18.3
Bahr El Ghazal	-	-	-	-	7.9	7.5	8.8
Upper Nile	-	-	-	-	6.9	7.2	8.2
Total	43.0	59.4	68.5	86.8	60.8	71.1	100.3

Source : The Four Year Salvation, Recovery and Development Programme (1988/89-1991/92)

For the above reasons, it seems reasonable to assume that the future population growth rate in NCK with decrease after 1995.

In addition, considering the steady increase in population, the Study Team also examined the high projection case, which assumes that the existing population growth rate of 4.8% will continue until 2015 (hereinafter this case is referred to as the "High Case", while the former case is called the "Low Case". Table 4.4 shows the population projection for the High case. Other main results are attached in Appendices 4.1 to 4.5. Judging from the population projection by "High Case", it is obviously clear that this projection is unrealistic. Therefore, this case is considered to be none other than refernce.

Table 4.4 Population Projection (High Case)

Year	Projection (thousand persons)	Growth Rate (%)
1983	1,802.3	
1989	2,396.0	4.8
1995	3,174.3	4.8
2000	4,012.9	4.8
2005	5,073.0	4.8
2010	6,413.1	4.8
2015	8,107.3	4.8

Source : The Study Team

(2) Population of Three Councils in NCK

The projected total population in the whole of NCK was distributed among three Council districts, Khartoum, Khartoum North (including White Nile district) and Omdurman. Judging from the strikingly different growth rates between the urban and rural areas shown in Table 4.2, the population of Nile East (rural area) was pre-determined with its growth rate from 1973 to 1983. The population of the rest of Khartoum, Khartoum North (excluded Nile East) and Omdurman were estimated with the growth rate of urban areas in each district. Finally the estimated population was adjusted to be consistent with the pre-determined figure for the whole NCK population shown in Table 4.5. The projected population of each district is shown in Table 4.6.

(3) Population by Traffic Zone

In the UNDP Study the future population in developed areas such as downtown North Khartoum (traffic zone 1-5), Saggana (7), Sahafa (10), Khartoum North town (12), Shambat (15), Beit El Mal (19), Mahadia (23), Nubbawi (18) is assumed not to increase even in the future, while in suburban areas the population is assumed to be growing rapidly due to the development. At the moment development is on-going in this direction, therefore, the initial increment of population in newly developing suburban areas was firstly allocated according to the UNDP Study. Afterwards, the rest was distributed according to existing population weight. Appendix 4.1 shows the population projection by traffic zone.

Table 4.5 Future Population in Three Councils

Unit : 1000 persons

Year	Omdurman	Khartoum North	Khartoum East	Nile	Total
1973*	299.4	333.9	298.3	214.5	
1983*	526.3	476.2	341.1	255.1	
1989	838.1	686.5	589.1	282.3	
1995	1022.5	1053.1	809.6	312.3	3197.5
2000	1195.1	1308.9	972.2	339.8	3816.0
2005	1325.9	1527.1	1137.2	390.1	4380.9
2010	1488.7	1824.1	1269.4	447.9	5030.1
2015	1704.4	2171.6	1381.6	514.2	1774.8

Note * : Population of Omdurman, Khartoum and Khartoum North only includes that of urban areas.

Source : The Study Team

4.3.2 **Employment**

(1) Projection of Employment in the whole of NCK

As shown in Table 4.6, the annual growth rates of employment from 1973 to 1983 in secondary and tertiary sectors were 6.9% and 6.5% respectively, while the growth rate of employment in the agricultural sector was -3.2%. Generally the number of employment grows in line with the economic growth, so employment in the base year 1989 in secondary and tertiary sectors were estimated as the same growth rate as that of the corresponding sectorial GDP. The future employment in these two sectors is assumed to increase at the growth rate projected in "The Four Year Salvation, Recovery, and Development Program 1988/89-1991/92", that is 8.0% in the secondary sector and 4.4% in the tertiary sector. However, as far as the secondary sector is concerned, the growth rate after 2000 is assumed to be half of 8.0%, taking into consideration a possible fluctuating future economic situation. Table 4.6 shows the employment projection by sector together which actual employment in 1973 and 1983.

Table 4.6 Employment by Sector

Unit : 1000 persons

Year	Agri-culture	Secondary Industry	Tertiary industry	Total
1973	55.0	66.7	177.7	299.0
1983	40.1	130.4	328.8	499.3
1989	(40.1)	139.7	352.4	(532.2)
1995	(40.1)	221.1	456.3	(717.5)
2000	(40.1)	324.2	566.0	(930.3)
2005	(40.1)	394.0	702.0	(1136.1)
2010	(40.1)	478.9	870.7	(1389.7)
2015	(40.1)	582.0	1080.0	(1702.1)

Note : Projection of employment in agricultural sector is tentative. Actually, agricultural employment is not used in the traffic forecasting stages.

Source : The Study Team

(2) Projection of Employment in Three Councils

Projection of employment in Khartoum, Khartoum North, and Omdurman is obtained by distributing the projected employment of the whole of NCK into three Councils using the spatial distribution of employment in the UNDP Study. The results of the projection are shown in Tables 4.7 (1) to 4.7 (3).

Table 4.7 (1) Projection of Agricultural Employment by Three Councils

Unit : 1000 person

Year	Omdurman	Khartoum North	Khartoum	Total
1983	11.6	21.4	7.1	40.1
1989	11.6	21.4	7.1	40.1
1995	11.6	21.4	7.1	40.1
2000	11.6	21.4	7.1	40.1
2005	11.6	21.4	7.1	40.1
2010	11.6	21.4	7.1	40.1
2015	11.6	21.4	7.1	40.1

Note : Projection is tentative.

Source : The Study Team

Table 4.7 (2) Projection of Secondary Employment by Council

Unit : 1000 persons

Year	Omdurman	Khartoum North	Khartoum	Total
1983	46.0	40.8	43.6	130.4
1989	49.3	45.6	44.8	139.7
1995	68.1	76.5	76.5	221.1
2000	99.9	112.2	112.2	324.2
2005	121.4	136.3	136.3	394.0
2010	147.5	165.7	165.7	478.9
2015	179.2	201.4	201.4	582.0

Source : The Study Team

Table 4.7 (3) Projection of Tertiary Industry by Council

Unit : 1000 persons

Year	Omdurman	Khartoum North	Khartoum	Total
1983	73.0	54.9	200.9	328.3
1989	78.8	62.7	211.1	456.3
1995	99.0	85.8	271.5	456.3
2000	122.8	106.4	336.8	566.0
2005	152.3	132.0	417.7	702.0
2010	188.9	163.7	518.1	870.7
2015	234.4	203.0	642.6	1,090.0

Source : The Study Team

(3) Projection of Employment by Traffic Zone

Projection of employment by traffic zone was also made based on the spatial distribution in the UNDP Study. Appendix 4.2 shows employment projections by traffic zone.

4.3.3 Household

Considering the average household size shown in Table 4.8, 6 persons per household is considered to be reasonable as the average household size. Therefore, the number of households by traffic zone was obtained by dividing the zonal population by 6 persons. Appendix 4.3 shows the number of households in each zone.

Table 4.8 Household and Household Size

Council	Population	Household	Household Size
Omdurman	648,700	106,719	6.1
Khartoum North	596,248	99,536	6.0
Khartoum	557,351	90,237	6.2

Source : The Study Team

4.3.4 Private Car Ownership

(1) Total Private Car Registration in the whole of NCK

As shown in Table 4.9, the growth rate in the number of private cars registered was very high during the past five years (10.3% per annum) despite the stagnant Sudanese economy. The main factor in this high growth rate was considered to be not only the concentration of population in NCK, but also perchase of cars by Sudanese working in foreing countries.

Table 4.9 Registration of Private Cars in NCK

Year	No. of Registrations	Expansion Rate
1983	58564	-
1984	65467	1.12
1985	67800	1.16
1986	69700	1.19
1987	85729	1.46
1989	95728	1.63

Source : Police Dept.

The projection of private cars registered is made by the following model:

$$CAR = EXP(a + b \times POP + c \times GDP + d \times YEAR)$$

Where,

CAR : Private Car Registered
GDP : Gross Domestic Product
YEAR : Calendar Year
POP : Population
EXP : Exponential
a,b,c, and d : constants

Estimated parameters are as follows;

	a	b	c	d	Correlation Coefficient
Parameter	1.37672	0.00085	0.00006	0.00219	0.95880
T Value	(1.3767)	(1.5309)	(0.9400)	(0.4242)	

The number of private car registrations was projected by using the above equation. The results are shown in Table 4.10.

Table 4.10 Projection of the No. of Private Car Registration

Year	Projection
1983	58,564
1989	103,309
1995	130,415
2000	158,360
2005	192,306
2010	233,570
2015	283,620

Source : The Study Team

(2) Private Car Registration by Traffic Zone

In order to obtain the future number of private cars registered by zone, firstly, the number of households by zone was divided into four income classes, Low income class, Low middle class, High middle class, and High class. Based on the car ownership rate of each income class shown in Table 4.11, which was investigated by the UNDP Study, the number of private car registrations was estimated in each traffic zone. After that, these numbers were adjusted to the aforementioned projected private car registration of the whole of NCK. The results are shown in Appendix 4.4.

Table 4.11 Car Ownership Rate by Income Class

Income Class	Number of Cars Per 1000 Inhabitants
Low	9.5
Low Middle	66.6
High Middle	129.0
High	229.0

Source : The Study Team

4.4 ESTABLISHMENT OF FUTURE OD TABLE

The future OD tables by vehicle type were established by the following procedures:

a) Projection of total trips generated and attracted in NCK

b) Projection of trip generation or attraction by zone

c) Projection of trip distribution

d) Establishment of future OD table

4.4.1 Future Total Trips Generated or Attracted

Total trips generated or attracted in the whole NCK have a strong relationship with population, employment, economic variables, etc. As the time series data related to trips are not available in Sudan, the following geometric mean is applied for determining the growth rate of trips by vehicle.

Growth rate of Passenger Car
$$= (PAS \times GDP \times COM \times POP)^{1/4}$$

Growth rate of Bus and Mini-bus
$$= (BUS \times GDP \times COM \times POP)^{1/4}$$

Growth rate of Truck and Trailer
$$= (TRU \times GDP \times COM \times EMP)^{1/4}$$

Where,

PAS	:	Growth rate of private cars registered
BUS	:	Growth rate of buses registered
TRU	:	Growth rate of trucks registered
GDP	:	Growth rate of gross domestic product
COM	:	Growth rate of consumption
POP	:	Growth rate of population
EMP	:	Growth rate of Secondary and Tertiary Employment.

The future growth rates of vehicles are shown in Table 4.12. In the table, Low case means population growth rate will decrease after 1995, while High case means existing population growth rate continues until the target year of 2015.

With the growth rates listed in Table 4.12, total trips generated or attracted in NCK were forecast for each vehicle type. Table 4.13 shows the projection of future trips by vehicle type.

Table 4.12 Growth Rate of Trips by Vehicle Type Generated and Attracted

	1989-1995	1995-2000	2000-2005	2005-2010	2010-2015
Passenger Car	2.600 2.600	2.417 2.597	2.206 2.597	2.206 2.597	2.206 2.597
Mini-bus & Bus	3.732 3.732	3.472 3.732	3.170 3.732	3.170 3.732	3.170 3.732
Truck & Trailer	3.831 3.831	3.881 4.060	3.621 4.103	3.621 4.150	3.621 4.060

Note : Upper line -- Low Case
Lower Line -- High Case

Source : The Study Team

Table 4.13 Future Total Trips by Vehicle Type Generated or Attracted

		1989	1995	2000	2005	2010	1015
Passenger Car	Low Case	225185	297673	335478	374094	417218	465313
	High Case		299670	338383	384664	474282	539150
Mini-bus	Low Case	37952	47284	56083	65554	76624	89564
	High Case		47284	56791	68209	81923	98394
Bus	Low Case	13839	117242	20450	23903	27940	32659
	High Case		17242	20709	24873	29874	35880
Truck	Low Case	34089	42715	51673	61731	73747	88101
	High Case		42715	53486	65397	80141	97809
Trailer	Low Case	4795	6008	7268	8683	10373	12392
	High Case		6008	7523	9198	11272	13757

Source : The Study Team

4.4.2 Future Total Trips Generated or Attracted by Zone

Zonal generated and attracted trips were projected by the following two steps;

a) First step : First projection of zonal trips with regression model

b) Second step : To expand or reduce the first zonal trip projection to equal its summation with the total trips listed in Table 4.13.

(1) Regression Analysis

To obtain the relationship between zonal generated or attracted trips and socio-economic indicators, regression analysis was applied by the following models;

$$TE_{ij} = F_j(POP_i, SEMP_i, Temp_i, VEH_i, HLD_i)$$

TE : Trip Generation or Trip Attraction

POP : Population

SEMP: Secondary Employment

TEMP: Tertiary Employment

VEH : Number of Vehicles Registered

HLD : Household

i : Type of Vehicle

j : Zone

As a result of trial and error, the following models and parameters were adopted for projecting zonal generated or attracted trips. Table 4.14 shows a summary of these results; models and parameters are common for the Low Case and High Case. Trailers are included with their trucks due to data insufficiency.

Table 4.14 Model and Parameter per Zonal Trip Projection

		Cons-tant	Popula-tion	Secondary Employ.	Tertiary Employ.	Sec.& Tert. Employ.	Correlation Coeff.
Pass Car	G	2344.72 (2.06)	0.02799 (2.83)	0.21567 (1.45)	0.26269 (5.21)	--	0.8353
	A	1860.19 (1.96)	0.17482 (2.12)	0.31874 (2.58)	0.43389 (8.18)	--	0.9271
Mini-bus	G	-109.21 (-0.47)	0.00710 (3.55)	0.04647 (1.55)	0.05582 (5.47)	--	0.8511
	A	-100.08 (0.42)	0.00611 (2.94)	0.05806 (1.86)	0.05699 (5.39)	--	0.8544
Bus	G	82.89 (0.33)	0.00270 (0.14)	--	--	0.04681 (9.94)	0.9268
	A	-2293.39 (-1.40)	0.00150 (0.91)	--	--	0.04938 (10.83)	0.9250
Truck	G	14.66 (-0.11)	0.01254 (10.58)	0.06769 (3.81)	0.00246 (0.41)	--	0.8990
	A	1041.53 (5.13)	--	0.02770 (0.61)	0.00903 (0.59)	--	0.9351

Note : - ( ) means T-value

- G: Generation A: Attraction

Source : The Study Team

(2) Determination of Future Zonal Generated or Attracted Trips

The summation of zonal generated or attracted trips projected to the regression model are not guaranteed to be equal with the total generated or attracted trips, and these projected zonal generated or attracted trips were expanded or reduced to meet the aforementioned total trips. The results are shown in Appendix 4.5.

(3) Projection of Trip Distribution

With the improvement or development of the road network (including the construction of a new bridge), the future trip pattern is considered to be changed in order for drivers and passengers to select the shortest route to arrive at their destinations. Considering such a kind of indigenous trip nature, the following gravity model is applied for projecting the future trip distribution.

$$Tij = a \times (Ti^b \times Tj^c) / D^d$$

Where,

Tij : Inter-zonal trips from i zone to j zone
Ti : Trip generation in i zone
Tj : Trip attraction in j zone
D : Distance from i zone to j zone
a, b, c, d : constants

The of the gravity model are estimated with the regression analysis. Table 4.15 shows the estimated of the gravity model.

Table 4.15 Parameters of Gravity Model

Type of Vehicle	a	b	c	d	Correlation Coefficient
Passenger Car	-10,75211 (13.26)	0.84299 (13.83)	0.93149 (15.68)	0.05100 (10.19)	0.58083
Mini-bus	-5.62335 (10.24)	0.68060 (12.85)	0.63628 (11.45)	0.13258 (2.57)	0.60040
Bus	-5.62335 (16.00)	0.47024 (4.92)	0.50494 (5.50	0.13217 (0.62)	0.63470
Truck	-7.59053 (11.62)	0.74468 (11.19)	0.81506 (11.42)	0.39918 (6.72)	0.61930

Note : ( ) means T-Value
Source : The Study Team

After the inter-zonal trips are estimated by the above gravity model, the summation of estimated inter-zonal trips generated or attracted in zone i are not necessarily guaranteed to be equal with the zonal generated or attracted trips obtained above. The Fratar method was applied for equalizing the former with the latter. The fratar method is formulated as follows:

$$T_{ij} = t_{ij} \times F_i \times F_j \times (L_i+L_j) / 2$$

Where,

$$F_i = G_i/g_i$$
$$F_j = A_j/a_j$$
$$L_i = \sum_j X_{ij} / \sum_j (X_{ij}F_j)$$
$$L_j = \sum_i X_{ij} / \sum_i (X_{ij}F_i)$$
$$g_i = \sum_j T_{ij}$$
$$a_j = \sum_i T_{ij}$$

T_{ij} : Inter-zonal trips after correction from zone i to zone j
t_{ij} : Inter-zonal trips before correction from zone i to zone j
G_i : Zonal trip generation in zone i
A_j : Zonal trip attraction in zone j

4.4.3 Establishment of Future OD Table

After applying the Fratar method, the future OD tables by vehicle type were established for the years 1995, 2005 and 2015. Established future OD tables of all vehicle types for those three years are attached in Appendix 4.6, while the future OD table for these three years by macro zone are shown in Tables 4.16 (1) to (3). As a reference, the relation between traffic zones and macro zones is summarized in a table attached in Appendix 4.7.

From above tables, it can be noticed that the total traffic demand in the Study Area for the year 2015 will exceed 1 million trips, while about a half of them will still be related to the central part of Khartoum, followed by the western part of Khartoum North and the central part of Omdurman. The total traffic demand between Khartoum and Omdurman in the year 2015 is calculated as approximately 130,000 trips per day.

4.4.4 Desire Line of Future Traffic Demand

Figure 4.4 illustrates the desire line of the future traffic demand between Khartoum and Omdurman in the year 2015.

Traffic demand between the central areas of both Khartoum and Omdurman is very high at about 47,000 PCU, which is about 36% of the total traffic demand between Khartoum and Omdurman.

Table 4.16 (1) Future Macro Zone OD Table in 1995

FUTURE OD TABLE : YEAR 1995

VEHICLE TYPE : ALL VEHICLES BY PCU

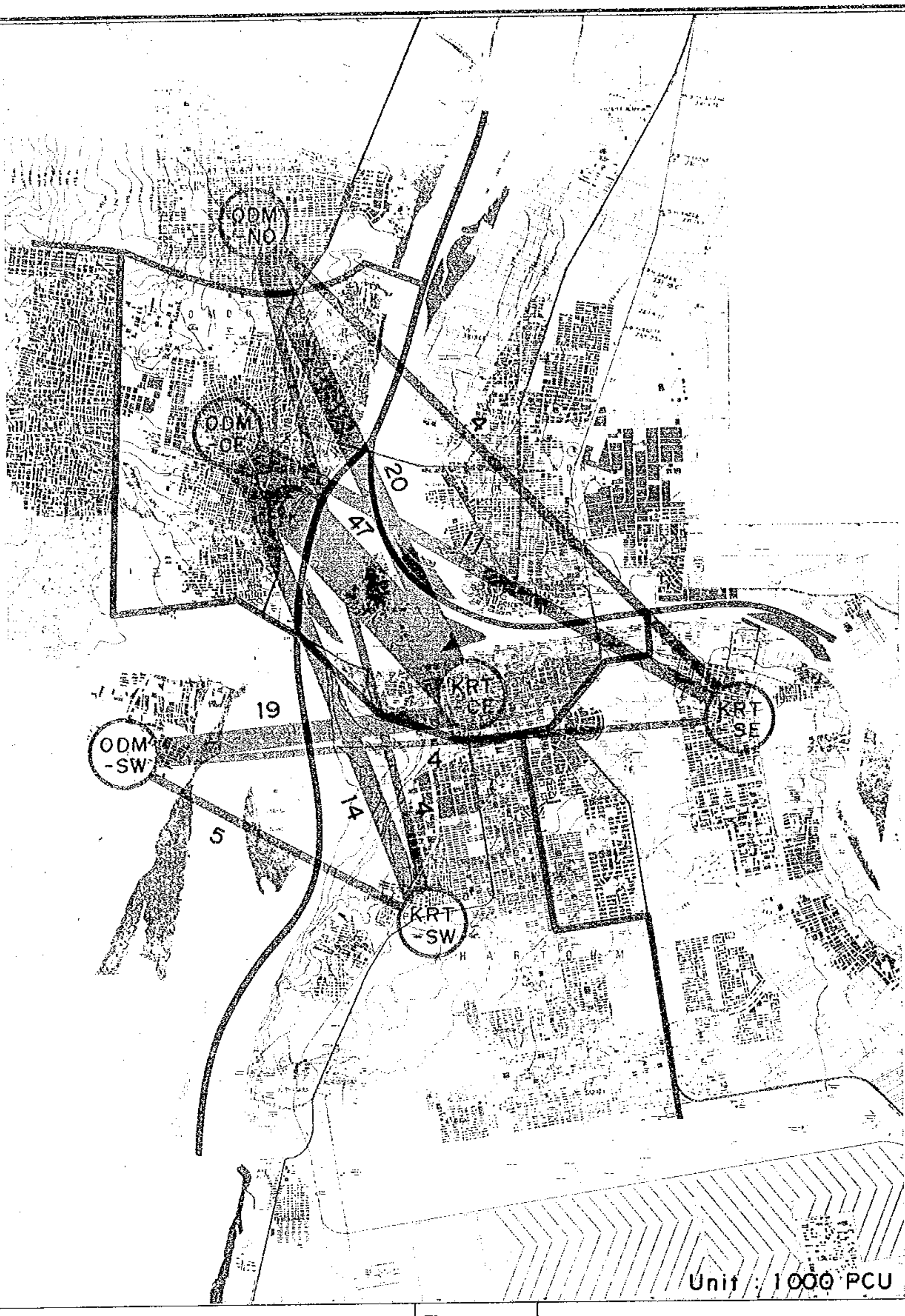
ORI/DES	KRT-CE	KRT-SW	KRT-SE	KRTN-W	KRTN-E	ODM-CE	ODM-SW	ODM-NO	TOTAL
KRT-CE	15803 2.9%	27022 5.0%	19538 3.6%	12238 2.3%	8127 1.5%	14876 2.8%	3674 0.7%	3413 0.6%	104691 19.4%
KRT-SW	35127 6.5%	17671 3.3%	6358 1.2%	3076 0.6%	4643 0.9%	4994 0.9%	1266 0.2%	930 0.2%	74065 13.7%
KRT-SE	26446 4.9%	6473 1.2%	13301 2.5%	3554 0.7%	5234 1.0%	4151 0.8%	834 0.2%	1208 0.2%	61201 11.3%
KRTN-W	16232 3.0%	3404 0.6%	4330 0.8%	32541 6.0%	13589 2.5%	10311 1.9%	1275 0.2%	1740 0.3%	83422 15.5%
KRTN-E	9293 1.7%	2923 0.5%	3601 0.7%	14426 2.7%	20037 3.7%	2699 0.5%	1126 0.2%	899 0.2%	55004 10.2%
ODM-CE	14829 2.7%	5947 1.1%	3492 0.6%	9441 1.8%	3512 0.7%	18401 3.4%	8927 1.7%	8740 1.6%	73289 13.6%
ODM-SW	4340 0.8%	1952 0.4%	1042 0.2%	1227 0.2%	927 0.2%	11498 2.1%	13443 2.5%	8126 1.5%	42555 7.9%
ODM-NO	5595 1.0%	1331 0.2%	1231 0.2%	1798 0.3%	1838 0.3%	11139 2.1%	8059 1.5%	14112 2.6%	45103 8.4%
TOTAL	127665 23.7%	66723 12.4%	52893 9.8%	78301 14.5%	57907 10.7%	78069 14.5%	38604 7.2%	39168 7.3%	539330 100.0%

Table 4.16 (2) Future Macro Zone OD Table in 2005

ORI/DES	KRT-CE	KRT-SW	KRT-SE	KRTN-W	KRTN-E	ODM-CE	ODM-SW	ODM-NO	TOTAL
KRT-CE	35642 4.6%	30782 4.0%	22825 3.0%	15550 2.0%	10839 1.4%	18342 2.4%	5427 0.7%	5270 0.7%	144677 18.8%
KRT-SW	40766 5.3%	36196 4.7%	7025 0.9%	4043 0.5%	5449 0.7%	5770 0.8%	1632 0.2%	1317 0.2%	102198 13.3%
KRT-SE	31696 4.1%	7180 0.9%	31028 4.0%	4663 0.6%	6157 0.8%	4972 0.6%	1210 0.2%	1608 0.2%	88514 11.5%
KRTN-W	21692 2.8%	4406 0.6%	5451 0.7%	57285 7.5%	15389 2.0%	11486 1.5%	1836 0.2%	2335 0.3%	119880 15.6%
KRTN-E	135419 1.8%	3685 0.5%	16054 0.6%	39930 2.1%	3662 5.2%	1573 0.5%	1369 0.2%	84262 0.2%	39251 11.0%
ODM-CE	19186 2.5%	6575 0.9%	4097 0.5%	10318 1.3%	4281 0.6%	39823 5.2%	9787 1.3%	9646 1.3%	103713 13.5%
ODM-SW	7380 1.0%	2362 0.3%	1443 0.2%	1822 0.2%	1450 0.2%	12629 1.6%	25798 3.4%	8720 1.1%	61604 8.0%
ODM-NO	8444 1.1%	1719 0.2%	1606 0.2%	2344 0.3%	2307 0.3%	12201 1.6%	8584 1.1%	26202 3.4%	63407 8.3%
TOTAL	178347 23.2%	92905 12.1%	77923 10.1%	112079 14.6%	85802 11.2%	108885 14.2%	55847 7.3%	56467 7.4%	768255 100.0%

Table 4.16 (3) Future Macro Zone OD Table in 2015

ORI/DES	KRT-CE	KRT-SW	KRT-SE	KRTN-W	KRTN-E	ODM-CE	ODM-SW	ODM-NO	TOTAL
KRT-CE	61224 5.8%	35332 3.3%	27361 2.6%	19887 1.9%	14186 1.3%	22546 2.1%	7700 0.7%	7957 0.8%	196193 18.5%
KRT-SW	47607 4.5%	58556 5.5%	7882 0.7%	5156 0.5%	6352 0.6%	6643 0.6%	2053 0.2%	1832 0.2%	136081 12.8%
KRT-SE	39138 3.7%	8137 0.8%	56192 5.3%	6361 0.6%	7503 0.7%	6079 0.6%	1762 0.2%	2266 0.2%	127438 12.0%
KRTN-W	28499 2.7%	5568 0.5%	7077 0.7%	88667 8.4%	17492 1.6%	12847 1.2%	2552 0.2%	3155 0.3%	165857 15.6%
KRTN-E	18587 1.8%	4549 0.4%	5634 0.5%	18004 1.7%	63823 6.0%	4715 0.4%	2100 0.2%	1989 0.2%	119401 11.3%
ODM-CE	24557 2.3%	7294 0.7%	4929 0.5%	11404 1.1%	5174 0.5%	65531 6.2%	10853 1.0%	10862 1.0%	140604 13.3%
ODM-SW	11304 1.1%	2861 0.3%	2014 0.2%	2581 0.2%	2080 0.2%	13998 1.3%	41709 3.9%	9562 0.9%	86109 8.1%
ODM-NO	12396 1.2%	2224 0.2%	2187 0.2%	3103 0.3%	2927 0.3%	13576 1.3%	9323 0.9%	43119 4.1%	88855 8.4%
TOTAL	243312 22.9%	124521 11.7%	113276 10.7%	155163 14.6%	119537 11.3%	145935 13.8%	78052 7.4%	80742 7.6%	1060538 100.0%



THE FEASIBILITY STUDY ON THE CONSTRUCTION OF THE NEW WHITE NILE BRIDGE	Fig. 4.4	DESIRE LINE OF FUTURE TRAFFIC DEMAND IN 2015
	JAPAN INTERNATIONAL COOPERATION AGENCY	

CHAPTER - V

BRIDGE LOCATION AND ROUTE STUDY

CHAPTER-V BRIDGE LOCATION AND ROUTE STUDY

5.1 GENERAL

During the first three (3) months (Phase-I Study), the Study Team has concentrated on the selection of bridge location along with its route. This chapter describes what route alternatives were considered and how the most favorable route was selected.

5.2 ALTERNATIVE ROUTES

5.2.1 Existing Road Conditions and Constraints

Existing arterial roads, with which the New White Nile Bridge can be connected, are shown in Figures 5.1.A and 5.1.B.

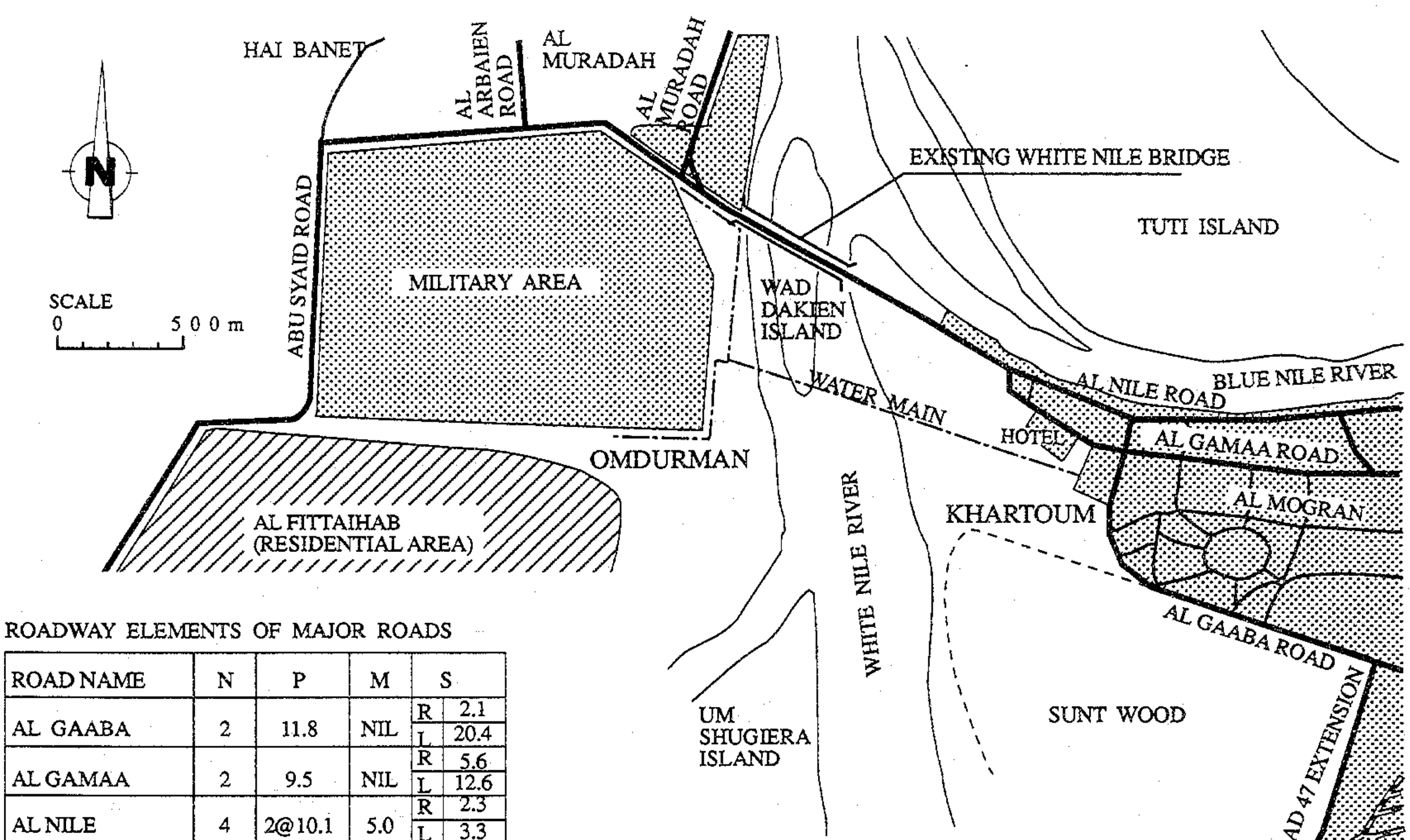
The Military Area lies in Omdurman City, just beyond the west bank of the White Nile. This area covers about 1.3 sq.km surrounded by Abu Syaid Road, the White Nile and natural drainage.

Though Al Arbaien Road and its continuation in this military area would be a convenient access road to the New White Nile Bridge, this military area is a restricted one which cannot be used for civilian purposes. Consequently, access roads which pass through this area should be discarded for the route study.

Al Fittaihab Town and residential areas in Omdurman City have been expanding towards the south. It seems probable that land acquisition and compensation for buildings in these areas would be difficult for future implementation. Therefore, any routes which would pass through these areas must be planned to minimize land acquisition and compensation for buildings.

As for Khartoum City, Al Mogran has many significant places and buildings whose acquisition and compensation would be very difficult. Therefore, routes which pass through these areas will be discarded.

Figures 5.1(A) and 5.1(B) show these constraints along with the existing road elements.



ROADWAY ELEMENTS OF MAJOR ROADS

ROAD NAME	N	P	M	S	
AL GAABA	2	11.8	NIL	R	2.1
				L	20.4
AL GAMAA	2	9.5	NIL	R	5.6
				L	12.6
AL NILE	4	2@10.1	5.0	R	2.3
				L	3.3
EXIST.WHITE NILE BR.	4	4.1+8.4+4.0	NIL	R	-
				L	-
AL MURADAH	4	2@9.2	1.7	R	4.5
				L	5.0
AL ARBAIEN	2	2@9.1	1.9	R	6.2
				L	9.9
ABU SYAID	2	9.1	NIL	R	6.0
				L	5.2

NOTATION;

N=No. OF LANES
P=PAVEMENT WIDTH (m)
M=MEDIAN WIDTH(m)
S=SIDEWALK OR SHOULDER WIDTH(m)
R=RIGHT } TOWARDS NORTH OR EAST
L=LEFT }

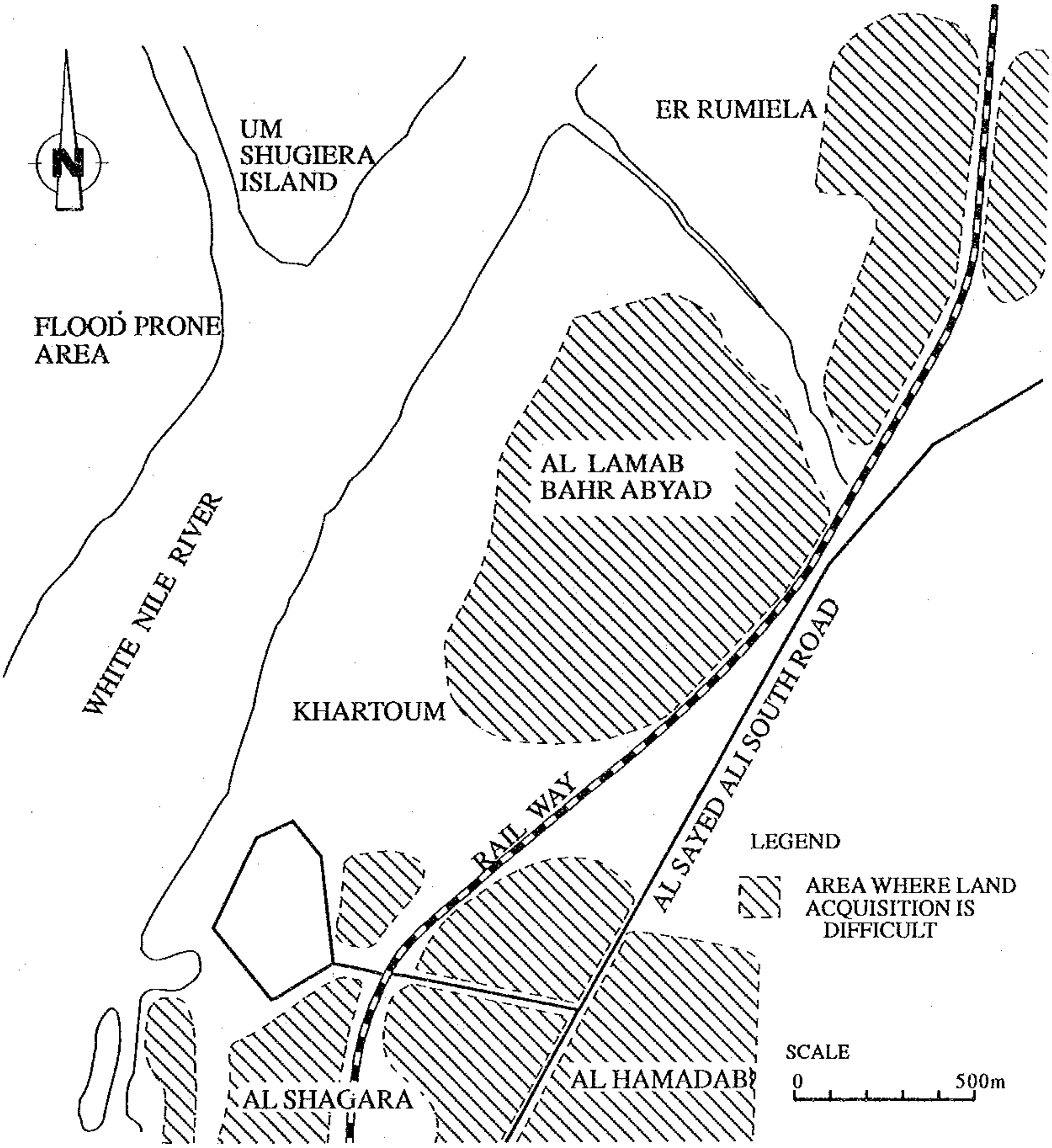
LEGEND

-AREA WHERE LAND ACQUISITION IS IMPOSSIBLE OR VERY DIFFICULT (dotted)
-AREA WHERE LAND ACQUISITION IS DIFFICULT (hatched)

THE FEASIBILITY STUDY ON THE CONSTRUCTION OF THE NEW WHITE NILE BRIDGE

Fig. 5.1 (A) EXISTING ROADS IN THE SURROUNDING AREA

JAPAN INTERNATIONAL COOPERATION AGENCY



ROADWAY ELEMENTS OF MAJOR ROADS

ROAD NAME	N	P	M	S	
AL SAYED ALI SOUTH	4	2@8.1	1.3	R	3.5
				L	2.3

NOTATION;
N= No. OF LANES
P= PAVEMENT WIDTH (m)
M= MEDIAN WIDTH (m)
S= SIDEWALK OR SHOULDER WIDTH (m)
R= RIGHT } TOWARDS NORTH OR EAST
L= LEFT

THE FEASIBILITY STUDY ON THE CONSTRUCTION OF THE NEW WHITE NILE BRIDGE	Fig. 5.1 (B)	EXISTING ROADS IN THE SURROUNDING AREA
	JAPAN INTERNATIONAL COOPERATION AGENCY	

5.2.2 Functional Classification

As far as routes are concerned, conceivable alternatives were made taking into consideration previous studies such as the "Khartoum traffic management and public transport study" conducted by BCEOM in 1983 (so-called UNDP Study) and so on, along with other possible routes newly considered by the Study Team. Alternative routes identified in this study are basically in the following three (3) classifications:

(1) Classification-A : Enlargement of Existing Arterial Road over the White Nile

This route would enlarge the traffic capacity of the existing White Nile Bridge and serve as a 1st-class arterial road, along with the existing route,between Khartoum and Omdurman cities.

(2) Classification-B : By-pass Route with Potentiality of Beltway Connector

The functions of this route would be twofold:

a) to diversify present traffic movement passing on the existing White Nile Bridge to a by-pass movement pattern and to serve as a 1st-class new arterial road connecting Khartoum and Omdurman cities.

b) to have the potentiality of integration with a future Beltway as identified in the UNDP study as mentioned above to form a circumferential expressway round Greater Khartoum, in the future.

(3) Classification-C : Beltway Connector

This route would actually form part of the future Beltway (expressway) to serve long trip vehicles in a circumferential pattern round Greater Khartoum.

5.2.3 **Identification of Alternative Routes**

On the basis of the preceding subsections, 5.2.1 and 5.2.2, together with the following requirements, several route/bridge locations were examined.

a) Although the existing White Nile Bridge lost mechanical function of its swing span bridge, the River Transport Corporation (RTC) intends to operate steamers on the White Nile. Therefore, all the alternative routes should satisfy the navigational clearance discussed in Chapter-VII.

b) The existing White Nile Bridge would be utilized in future by means of appropriate rehabilitation and maintenance by NCK.

c) In the interests of economy and reliable design, alternative alignments should cross the White Nile as nearly as possible at right angles.

d) In the case of Classification-A, the design speed and geometric requirements are tentatively determined as:

Design Speed = 60km/h

Radius of Horizontal Curve $\geq$ 150m

Longitudinal Grade $\leq$ 5%

e) In the case of Classifications- B and C, the design speed and geometric requirements are tentatively determined as:

Design Speed = 80km/h

Radius of Horizontal Curve $\geq$ 280m

Longitudinal Grade $\leq$ 4%

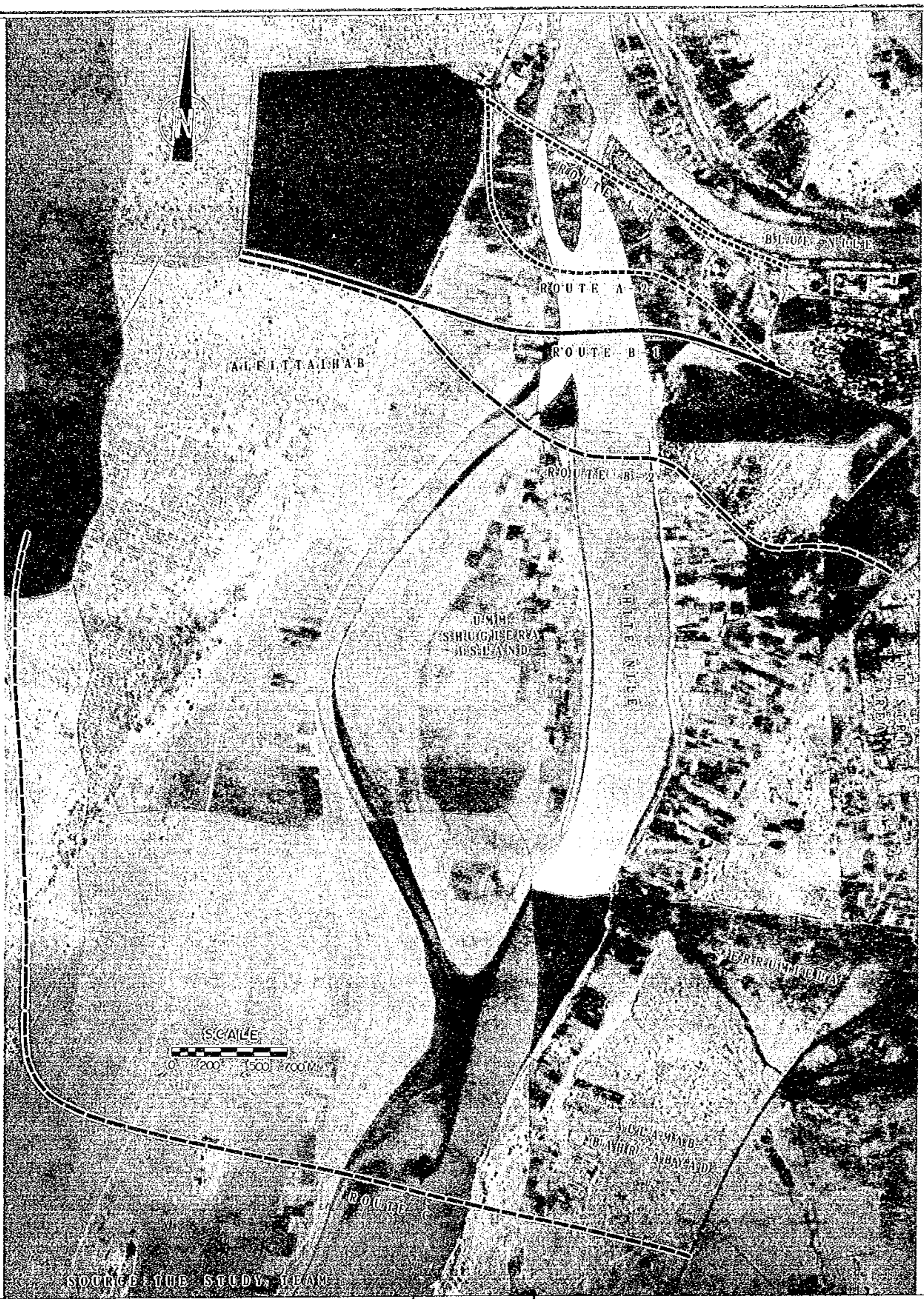
As a result, the following five(5) alternatives (A-1, A-2, B-1, B-2 and C) were identified for comparative study. Conceptual route locations are shown in Figure 5.2.

(1) Alternative Route A-1

This route was considered for Classification-A for the case of a movable bridge.

a) Alignment

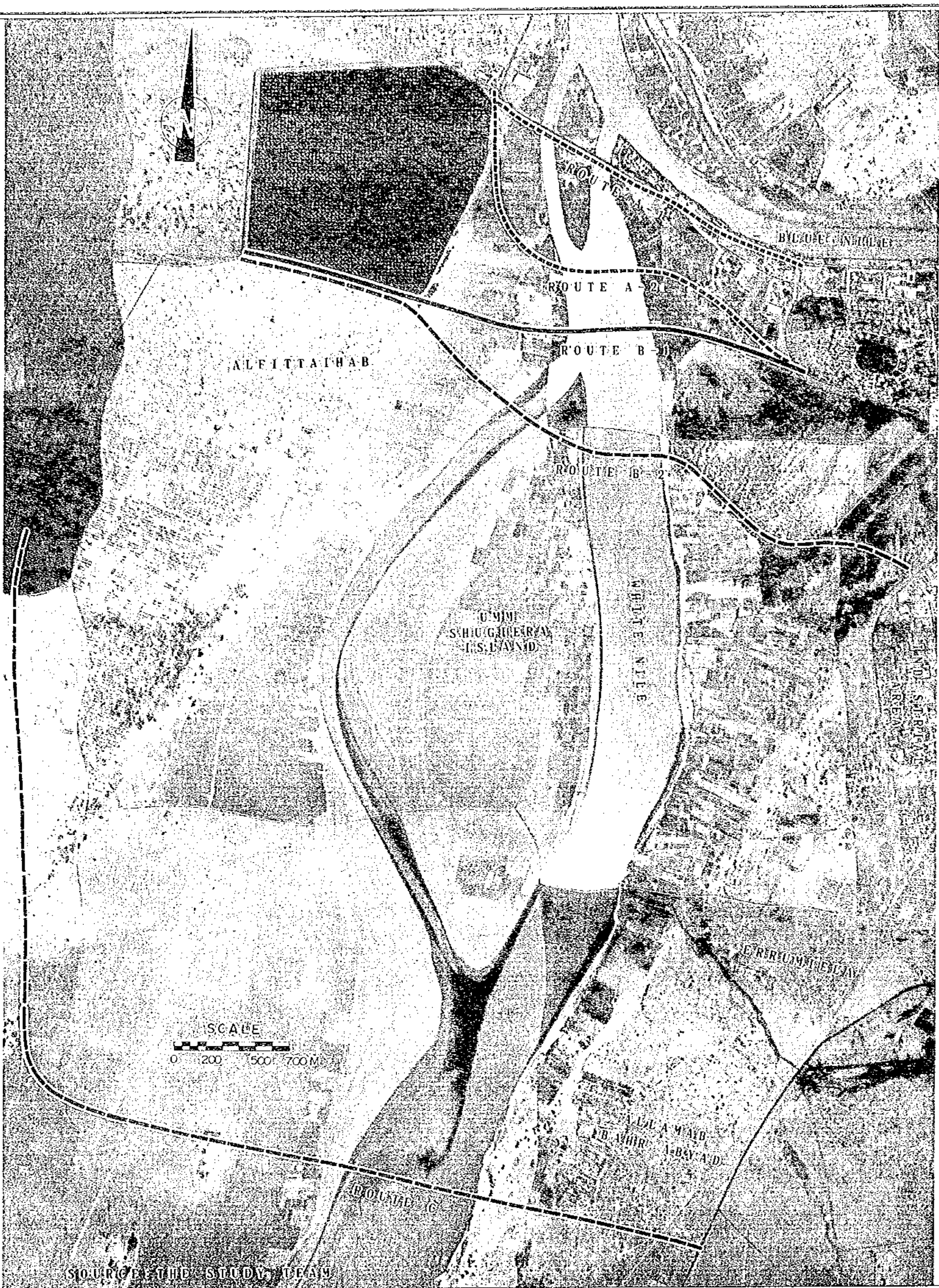
This route would begin on the Omdurman side at the intersection of Abu Syaid Road and Al Muradah Road as a widening of Abu Syaid Road; pass upstream of the existing bridge and parallel to it; cross the intersection of Al Niel Road and Al Gamaa Road near the Hilton Hotel; and end at the intersection of Al Niel Road and Al Gaaba Road in Khartoum City.



THE FEASIBILITY STUDY ON THE CONSTRUCTION OF THE NEW WHITE NILE BRIDGE

Fig. 5.2 ALTERNATIVE ROUTES

JAPAN INTERNATIONAL COOPERATION AGENCY



THE FEASIBILITY STUDY ON THE CONSTRUCTION OF THE NEW WHITE NILE BRIDGE	Fig. 5.2	ALTERNATIVE ROUTES
	JAPAN INTERNATIONAL COOPERATION AGENCY	

The length of this route would be about 2,100m in total.

b) Bridge

The new bridge would have to be built about 60m upstream of the existing one to satisfy the geometric requirements for the horizontal alignment.

As the approach road distance from the Omdurman side intersection to the bridge abutment is only about 300m, a movable steel bridge, similar to the existing bridge which has a swing span of 91m, would be the only way to facilitate river navigation by steamers.

The clear distance limitation of 60m between the two bridges as discussed above would necessitate use of a bascule or lift bridge.

The bridge would be approximately 620m to 700m long.

c) Intersections

It seems probable that the terminal intersections would be planned as grade-separated intersections. However, the intersection near the Hilton Hotel might be planned as a compound at-grade intersection with a U-turn ramp at its west side minor intersection.

The anticipated intersections are:

Omdurman side	:	1 no. -	grade-separated
Khartoum side	:	1 no. -	at-grade
		1 no. -	grade-separated
Total	:	3 no.	

(2) Alternative Route A-2

This route was considered for Classification-A and for the case of a fixed bridge.

a) Alignment

This route would begin at the same place as Route-A1 in Omdurman City. Alignment of this route is thought of as a continuation of Al Muradah Road to the south, then turning eastwards to cross over the White Nile River about 200m south from Wad Dakien Island, afterwards turning to south-east in Khartoum District, and ending at a connection point with Al Gaaba Road.

The length of this route would be about 2,900m in total.

b) Bridge

The new bridge would be located 200 m or more to the south of the Wad Dakien Island in order to provide the navigational clearance at the center span of the new bridge (fixed bridge).

Both concrete and steel type bridges would be applicable to this route.

The bridge would be approximately 700m to 800m long.

c) Intersections

The anticipated intersections are:

Omdurman side:	1 No. -	grade-separated intersection
Khartoum side:	1 No. -	at-grade intersection
Total :	2 No.	

(3) Alternative Route B-1

This route was considered for Classification-B and for the case of connection with Al Gaaba Road in Khartoum City.

a) Alignment

This route would begin at the turning point of Abu Syaid Road at Al Fittaib Town, then running southeastwards along the military boundary wall, crossing over the White Nile almost at right angles and passing the northern edge of Sunt Wood, and end at the connection point with Al Gaaba Road.

The anticipated length of this route would be about 4,400 m in total.

b) Bridge

The location of the new bridge would be about 1,000m to 1,200m to the south of the existing bridge.

According to the survey by the Study Team in February 1989, the river width was measured at 540m (from bank to bank in the dry season) and the water depth was 2.2m at the deepest point.

Navigational clearance will be maintained at the main span of the new bridge (fixed bridge).

Both concrete and steel type bridges are applicable to this route.

The bridge would be approximately 700m to 800m long.

c) Intersections

The anticipated intersections are:

Omdurman side	: 1 no. -	at-grade intersection
Khartoum side	: 1 no. -	at-grade intersection
Total	: 2 no.	

(4) Alternative Route B-2

This route was considered for Classification-B and for connection with Road No.47, where asphaltic concrete pavement is now under construction by USAID, located in Khartoum-3.

a) Alignment

This route would begin at the same point as Route-B1 in Omdurman City and follow a similar alignment to Route-B1, then turn southeastwards to cross over the northern tip of Um Shugiera Island, pass through the southern part of the Sunt Wood, and end at the connection point with Road No.47 in Khartoum-3.

The anticipated length of this route would be about 5,200m in total.

b) Bridge

The location of the new bridge would be about 1,700m to the south of the existing bridge. According to the survey by the Study Team in February 1989, the river widths were measured at 460m and 160m in the right and left river courses respectively. The maximum water depth at that time was 2.0m.

The navigational clearance will be maintained at the center of the right side river course during the dry season.

Both concrete and steel type bridges will be applicable to this route.

The bridge would be approximately 1,100m to 1,300m long.

c) Intersections

The anticipated intersections are:

Omdurman side	: 1 no. -	at-grade intersection
Khartoum side	: 1 no. -	at-grade intersection
Total	: 2 no.	

(5) Alternative Route C

This route was considered for Classification-C.

a) Alignment

This is a continuation of Abu Syaid Road and would begin at the end of the existing asphaltic pavement, at the southern part of Al Fittaihab Town. It would run south and then turn to the east, crossing over the White Nile about 2,000m to the south of Um Shugiera Island, and passing through the southern part of Al Lamab Bahr Abyad Town, crossing over the railway line, and end at the connection with Al Sayed Ali South Road.

The anticipated length of this route would be about 7,400m in total.

b) Bridge

The location of the new bridge would be about 6,200m to the south of the existing bridge. The navigational clearance will be maintained at the center span of the new bridge.

Both concrete and steel type bridges will be applicable to this route.

The bridge would be approximately 1,000m to 1,300m long.

c) Intersections

The anticipated intersections are:

Omdurman side	: Nil	
Khartoum side	: 1 no. -	railway fly-over
	1 no. -	at-grade intersection
Total	: 2 no.	

5.3 FUTURE TRAFFIC VOLUME ON ALTERNATIVE ROUTES

5.3.1 Methodology of Traffic Assignment

In order to estimate the traffic volume on the road network, including the proposed bridge, the following traffic assignment procedure is adopted:

Step 1: Before assigning the traffic to each link of the road network, the relationship between traffic volume and travel time was predetermined. In this relationship, which is referred to as the Q-V formula, the travel time on each link is assumed to increase with the increase in the traffic volume on the same link.

Step 2: The vehicular OD traffic is divided into three parts. At first 50% of the total volume is assigned to the road network and the resultant travel time is computed for each link. The next step is to assign a further 30% of the traffic volume to the network and a new set of resultant travel times is computed for all links. Finally the remaining 20% of the traffic is assigned and the final time is computed.

In this procedure as the volume of traffic on a link increases, so the travel time on that link increases, too. Therefore, the travel speed on that link decreases just as the traffic congestion causes the vehicle speed to lower in the real situation.

5.3.2 Road Network for Traffic Assignment

The following are the basic conditions of the future road network used for traffic assignment.

(1) Alternative Routes

Five (5) cases of road networks, namely "A-1", "A-2", "B-1", "B-2", and "C", were considered to be the alternative road networks for the traffic assignment. Details of these alternatives are described in Section 7.3.

(2) Existing White Nile Bridge

The Existing White Nile Bridge was considered to be functioning at the present in the year 2015 under proper maintenance/rehabilitation.

(3) Road network in 1995

- Al Gaaba Extension Road (between Al Gaaba Rd. and Al Shagra Rd.) and the road along the railway line in Khartoum North were considered to be 2-lane paved roads.

- Other roads were considered to be in the same condition as the present.

(4) Road network in 2005

- Al Gaaba Road and a part of Abu Syaid Road were considered as 4-lane roads.

- A part of the Beltway in Khartoum and Omdurman were considered to be completed as 4-lane roads. In addition, Beltways in Khartoum and Omdurman were considered to be connected to a new bridge, in the cases of alternatives "B-1", "B-2" and "C".

(5) Road network in 2015

- A part of the Beltways in Khartoum and Omdurman were considered to be widened to 6-lanes.

5.3.3 Future Traffic Volume

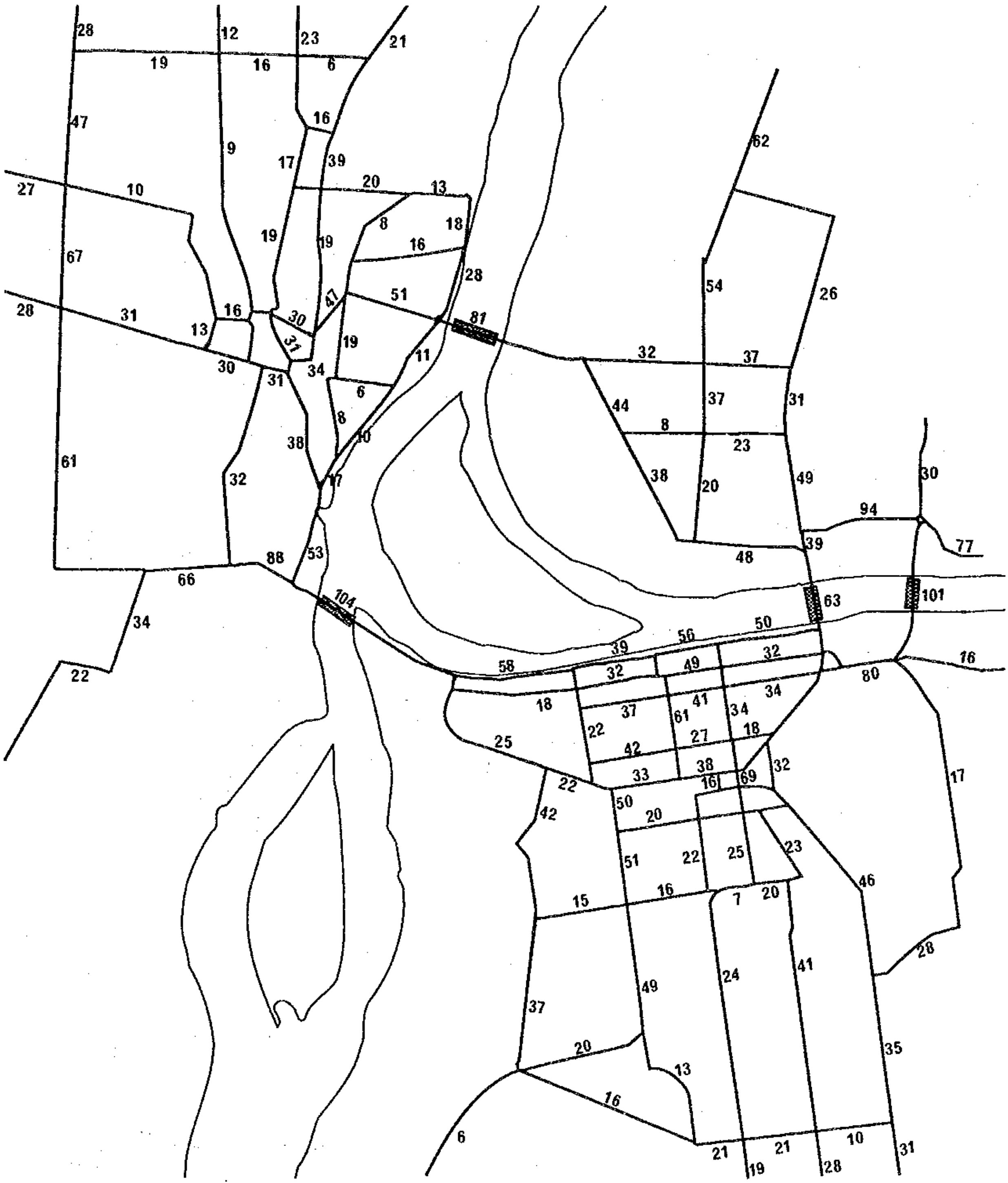
As explained in section 4.1, the QV method was applied for obtaining traffic volumes on each link in the future road network.

In the Study, the capacity of the road and the velocity of vehicles on ordinary road sections are two indicators to determine the least travel time routes between each OD pair. Hence, if certain road sections are over saturated, additional traffic would divert to another route with the next least travel time, even though those routes have longer travel distances.

After establishment of the future OD table, the projected inter-zonal trips were assigned on the future road network including proposed alternative routes of the New White Nile Bridge.

Figures 5.2 (A) to 5.2 (F) illustrate the results of traffic assignment on the future road network in 2015 for the "Base Case (without case or do-nothing case)", "A-1", "A-2", "B-1", "B-2" and "C", respectively.

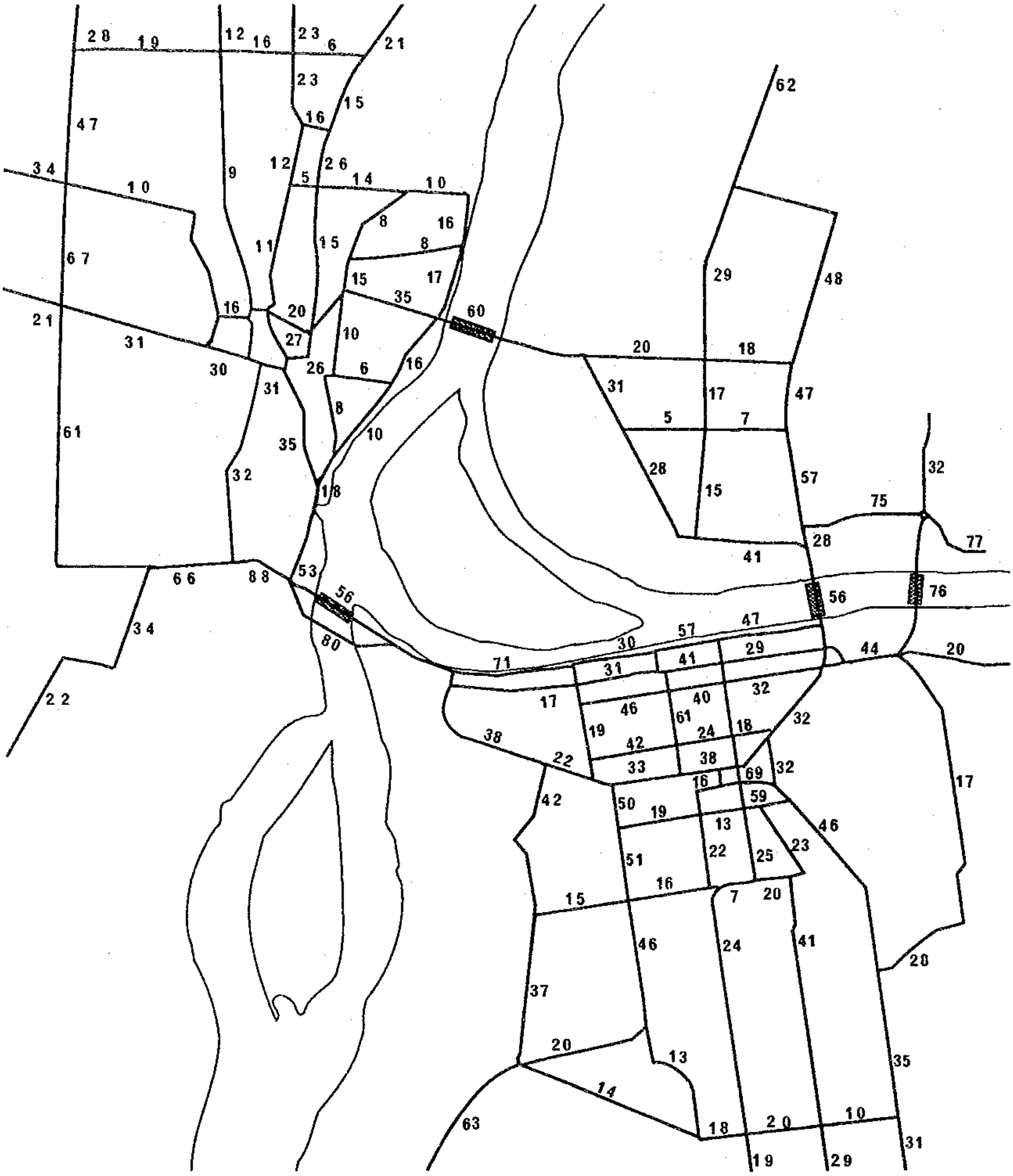
BASE CASE 2015



UNIT: 1000pcu/day

THE FEASIBILITY STUDY ON THE CONSTRUCTION OF THE NEW WHITE NILE BRIDGE	Fig. 5.3 (A)	RESULT OF TRAFFIC ASSIGNMENT IN 2015 (BASE CASE)
	JAPAN INTERNATIONAL COOPERATION AGENCY	

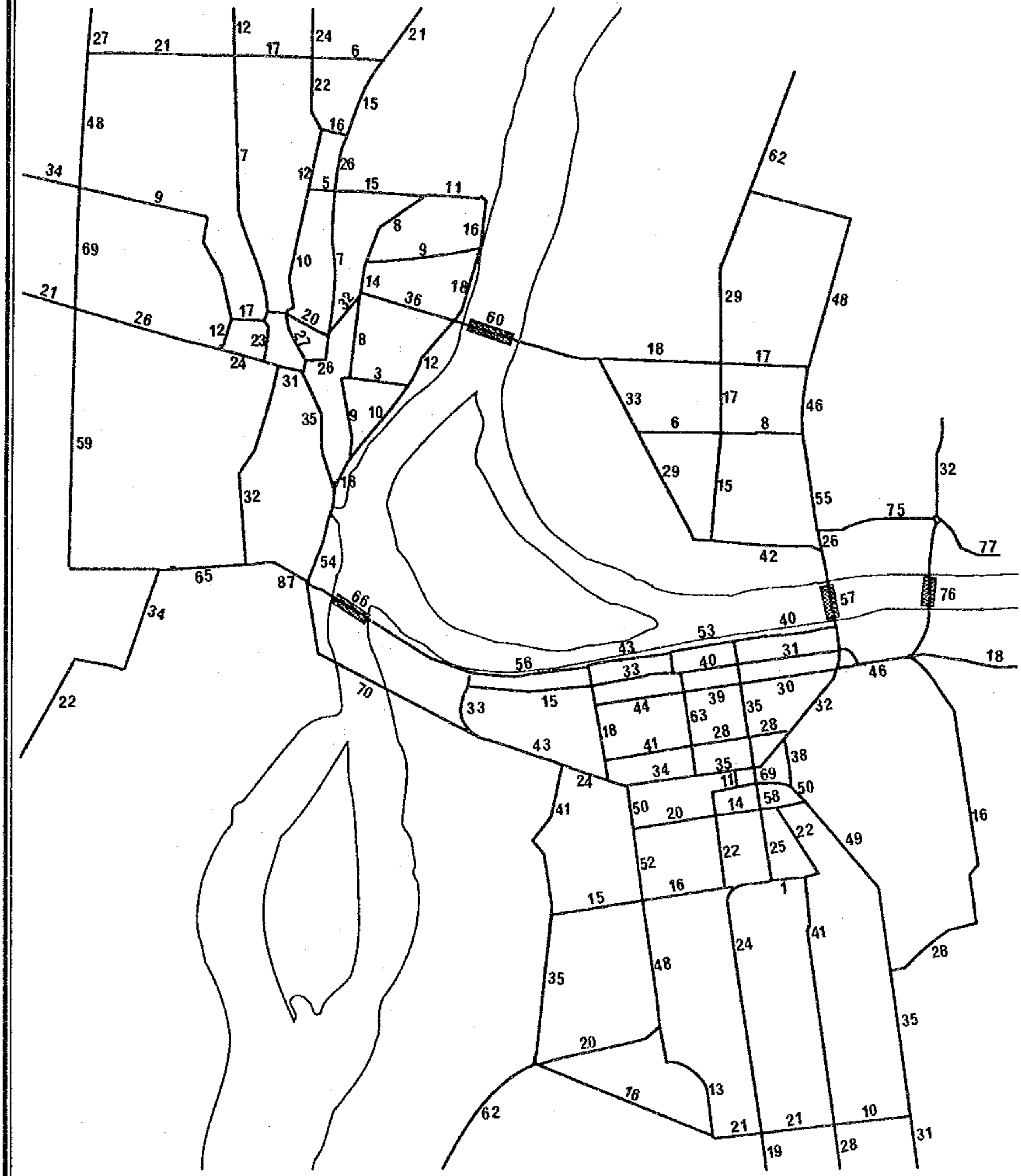
CASE A-1 2015



UNIT: 1000pcu/day

THE FEASIBILITY STUDY ON THE CONSTRUCTION OF THE NEW WHITE NILE BRIDGE	**Fig.** 5.3 (B)	RESULT OF TRAFFIC ASSIGNMENT IN 2015 (CASE A-1)
	JAPAN INTERNATIONAL COOPERATION AGENCY	

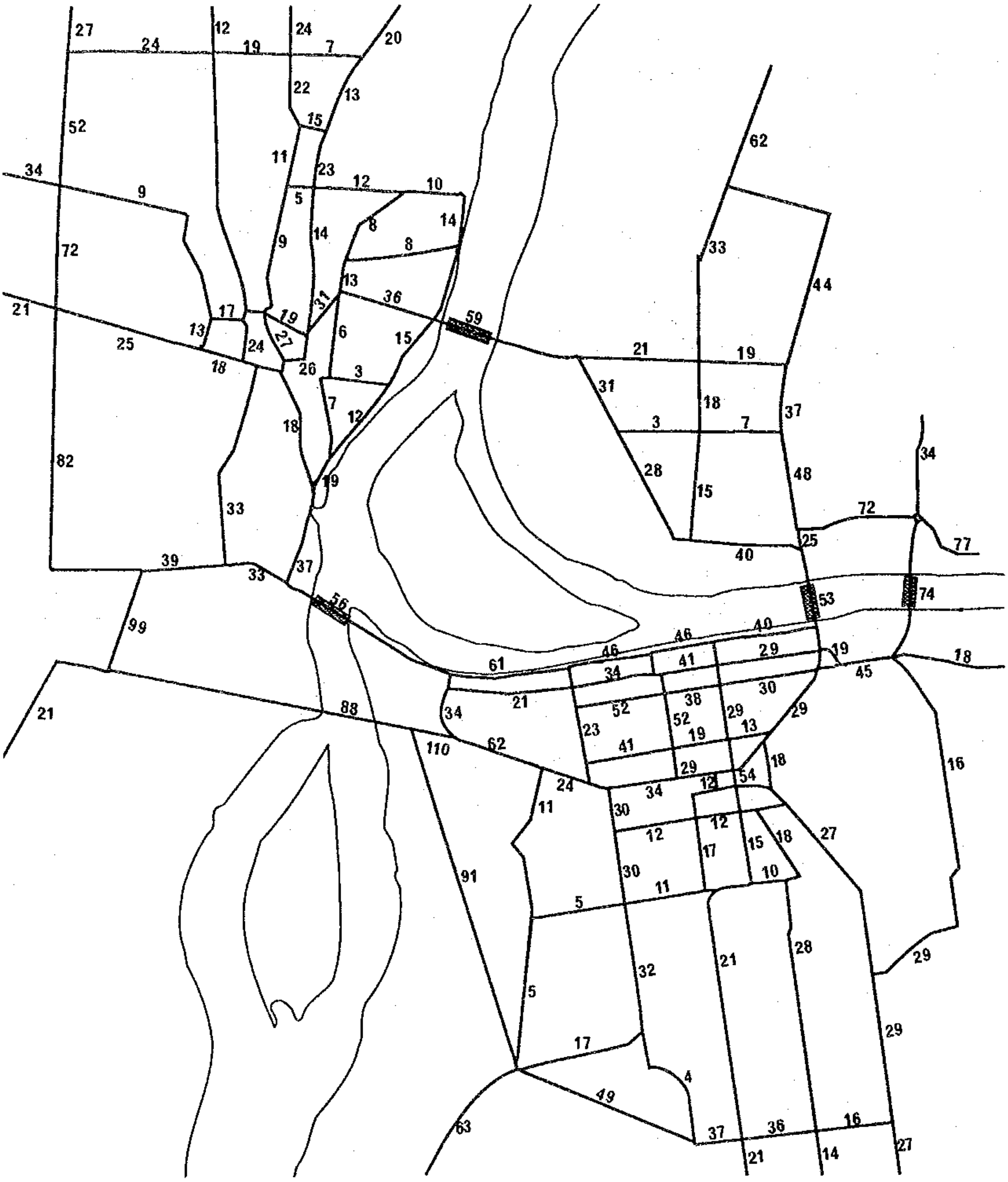
CASE A-2 2015



UNIT: 1000pcu/day

THE FEASIBILITY STUDY ON THE CONSTRUCTION OF THE NEW WHITE NILE BRIDGE	Fig. 5.3 (C)	RESULT OF TRAFFIC ASSIGNMENT IN 2015 (CASE A-2)
	JAPAN INTERNATIONAL COOPERATION AGENCY	

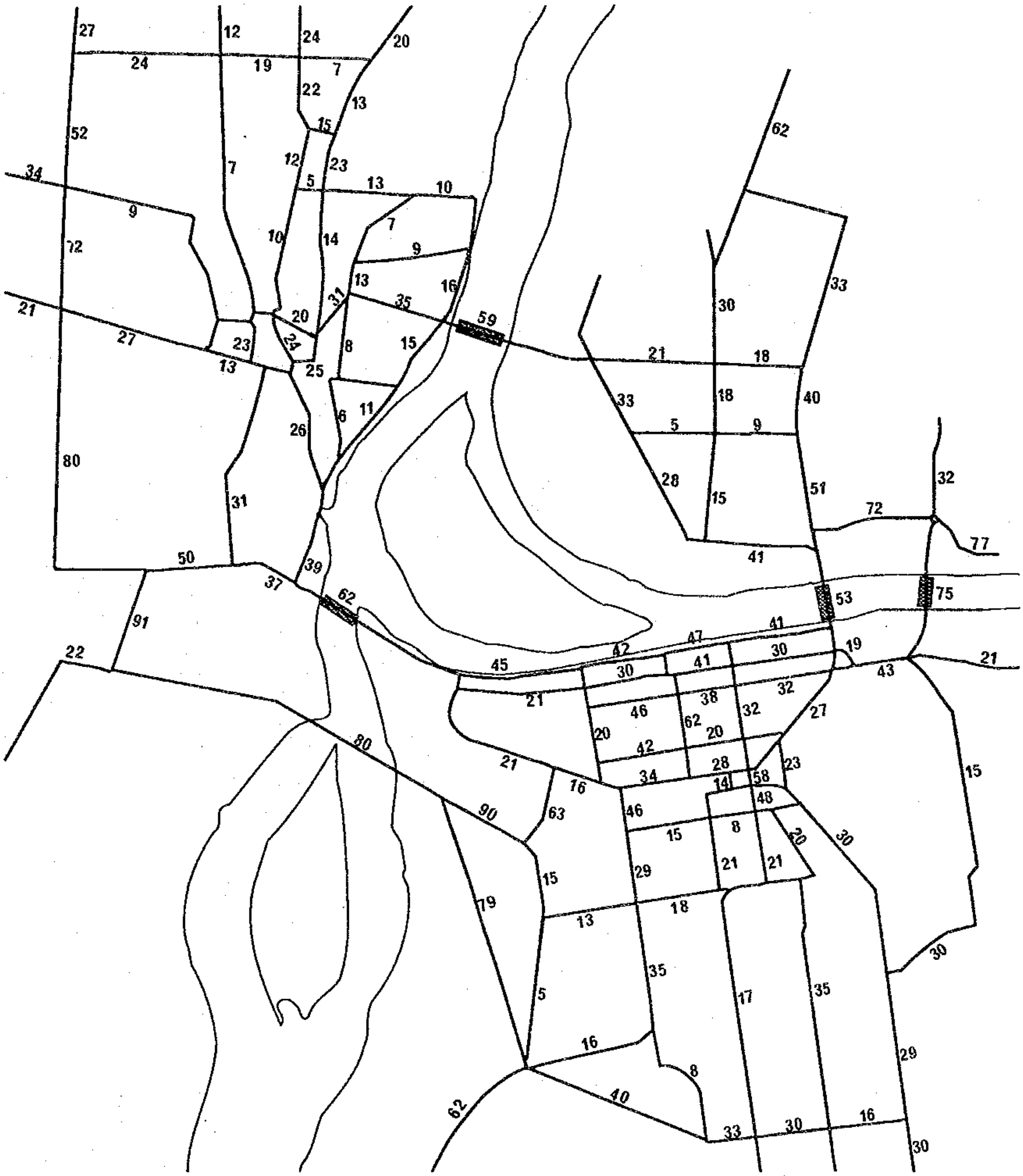
CASE B-1   2015



UNIT: 1000pcu/day

THE FEASIBILITY STUDY ON THE CONSTRUCTION OF THE NEW WHITE NILE BRIDGE	Fig. 5.3 (D)	RESULT OF TRAFFIC ASSIGNMENT IN 2015 (CASE B-1)
	JAPAN INTERNATIONAL COOPERATION AGENCY	

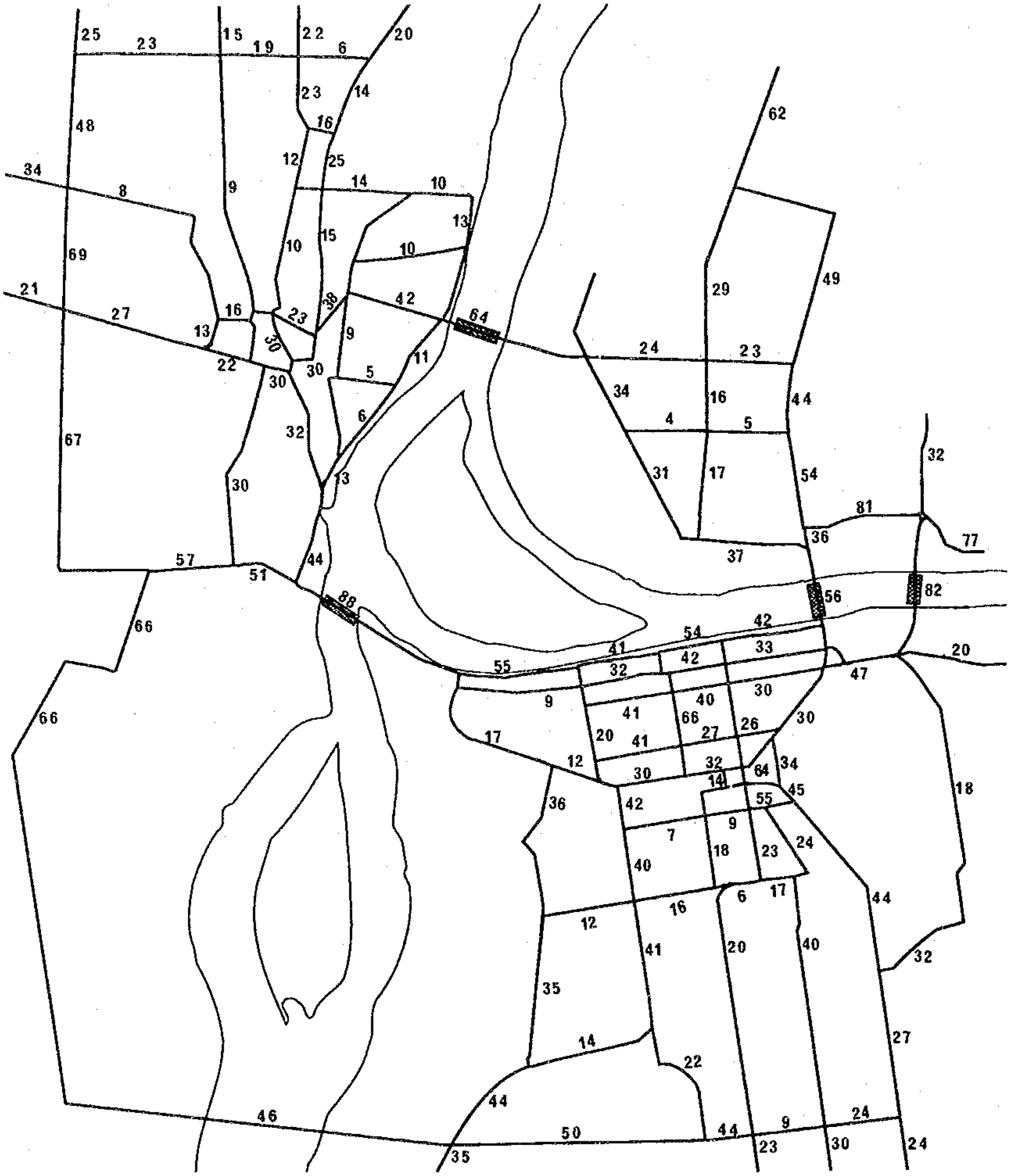
CASE B-2 2015



UNIT: 1000pcu/day

THE FEASIBILITY STUDY ON THE CONSTRUCTION OF THE NEW WHITE NILE BRIDGE	Fig. 5.3 (E)	RESULT OF TRAFFIC ASSIGNMENT IN 2015 (CASE B-2)
	JAPAN INTERNATIONAL COOPERATION AGENCY	

CASE C 2015



UNIT: 1000pcu/day

THE FEASIBILITY STUDY ON THE CONSTRUCTION OF THE NEW WHITE NILE BRIDGE	Fig. 5.3 (F)	RESULT OF TRAFFIC ASSIGNMENT IN 2015 (CASE C)
	JAPAN INTERNATIONAL COOPERATION AGENCY	

5.3.4 Evaluation of the Most Favorable Route

(1) Criteria for the Evaluation

Based on the traffic assignment of future traffic demand on several alternative road networks, evaluation of these alternative road networks is conducted. In this case the following points are considered to be criteria for the evaluation:

a) Traffic volume on each alternative route

b) Reduction of congestion degree on the existing White Nile Bridge

c) Reduction of congestion degree on access roads of the White Nile Bridge both at Khartoum and Omdurman sides since these road sections are supposed to be over saturated for some alternative cases.
(Al Nile Road, Al Gama'a Road and Al Gaama Road in Khartoum; and Al Murradah Road and Abu Syaid Road in Omdurman)

d) Reduction of congestion degree on Blue Nile and Burri Bridges

e) Reduction of congestion degree on Shambat Bridge

(2) Evaluation of Future Road Network

According to the criteria mentioned above, comparison of traffic congestions are made by traffic demand of the Low case for the year 2015. The following table shows the results of the comparison. In this case, every comparison is made with a case without construction of the New White Nile Bridge (Base Case).

As a result, alternative road network "B-1" is judged to be the best alternative network from the traffic point of view. However, alternative "B-2" is judged to be the second best alternative with a very close rating.

By contrast, alternatives "A-1" and "A-2" could not get high scores,since these alternatives would worsen the traffic congestion on access roads, especially in Omdurman.

In addition, it should be noted that it will definitely be necessary to have another bridge link not only between Khartoum and Omdurman, but also between Khartoum and Khartoum North by the year 2015.

Table 5.1 Evaluation of Future Road Network

Criterion	Alternative					
	Do-nothing	A1	A2	B1	B2	C
Traffic on New Bridge	-	79,880 (2)	69,847 (2)	88,213 (3)	80,079 (3)	45,713 (1)
Congestion on White Nile Bridge	2.1	1.16 (3)	1.37 (2)	1.16 (3)	1.29 (2)	1.83 (1)
Congestion on KRT Access Road	1.44	1.88 (0)	1.15 (2)	1.27 (2)	1.03 (3)	1.22 (2)
Congestion on ODM Access Road	2.18	2.44 (0)	2.43 (0)	1.22 (3)	1.33 (2)	1.65 (1)
Congestion on Blue Nile & Burri Bridges	2.28	1.85 (2)	1.85 (2)	1.77 (3)	1.78 (3)	1.92 (1)
Congestion on Shambat Bridge	1.69	1.25 (3)	1.25 (3)	1.19 (3)	1.22 (3)	1.34 (2)
TOTAL POINTS		10	11	17	16	8

Note: Numbers in ( ) are points for the alternative. These points reflect the relative benefits of each alternative.

5.4 SELECTION OF THE MOST FAVORABLE ROUTE

5.4.1 Initial Economic Evaluation Of Routes

Internal Rate of Return (IRR) was adopted as an economic indicator for the evaluation. The following are the assumptions to obtain the IRR:

(1) Indicative Cost

All the costs in this section were approximately estimated in order to compare and comprehend the order of construction cost for the various alternatives. Costs estimated below cover construction costs and exclude other costs such as tax, land acquisition and engineering costs.

A) Base Price

All the costs were estimated approximately based on prevailing prices in February 1989 in Sudanese Pounds.

B) Assumed Quantities

Quantities required for the respective alternatives were assumed taking into consideration similar projects experienced in the past. As for bridge types, steel bascule was tentatively considered as a bridge type for Route A-1 while prestressed concrete bridges were considered for Routes A-2 to C

C) Unit Price by Work Item

a) Bridge Works

In regard to long-span bridges, bid prices for the New White Nile Bridge at Kosti (Kosti Bridge) in 1975 are the latest ones which can be applicable to this initial cost estimation.

In this study, bid prices of Kosti Bridge were increased in the ratio of present (year 1989) to the past (year 1975) consumers' price indices which are shown in Appendix 5.3.

b) Approach Road and Intersection Works

Recent bid prices for earthworks and pavements were adopted from on-going projects in Greater Khartoum, namely "The Greater Khartoum Roads Construction" and so on. Prices of other items were derived in a similar manner to the above-mentioned bridge works.

c) Land Reclamation for Construction Yard

This price was estimated tentatively on the assumption that the hauling distance of fill materials is 5 km or less to use the materials of Borrow-1 shown in Figure 6.7 (A).

d) Slope Protection Work of Riverbank

As for the protection works, the prices for Kosti Bridge were increased taking into consideration the past consumers' price indices in Sudan.

D) Physical Contingency

Physical contingency was tentatively considered as 10 % of construction cost.

E) Indicative Cost by Routes

As a result, approximate direct construction costs were obtained as shown in Table 5.2.

Table 5.2 Indicative Costs

Unit : LS million

Cost Item	Alternative Route				
	A-1	A-2	B-1	B-2	C
Bridge	734	445	496	803	534
Approach Roads	104	143	154	177	217
Intersections	69	41	-	-	-
Railway Flyover	-	-	-	-	24
Construction Yard	70	70	70	70	70
Others	118	70	36	53	42
Sub Total	1,095	769	756	1,103	887
Physical Contingency	110	77	76	110	89
Total	1,205	846	832	1,213	976
(Order of Cost)	(4)	(2)	(1)	(5)	(3)

Note : These costs were estimated based on parallel rate of US$1.0=LS12.1 in March 1989, just for comparison purposes of route selection.

(2) Economic Cost

As the construction and operating cost for the proposed new bridge is the financial cost, it should be converted into the economic cost. In this initial economic evaluation, the financial cost was converted with the standard conversion factor (SCF) which was obtained by the following equation:

SCF = (E+I) / (E+I+Itax-Etax)

Where,

E : Export
I : Import
Itax : Import tax
Etax : Export tax

SCF is estimated at 0.53 from the following data ; 1) Exports LS.578 million; 2) Imports LS.1,185 million; 3) Import tax LS.1,600 million; and Export tax LS.60 million in 1987/1988.

Applying this factor to the domestic portion of the construction cost (assumed at 35 % of the total cost), the economic cost for each alternative was estimated as shown in Table 5.3.

Table 5.3 Economic Construction Cost

Cost Item	Alternatives (LS.million)				
	A-1	A-2	B-1	B-2	C
Construction cost	1,195	708	696	1,015	817
Maintenance cost per year	1.4	0	0	0	0
Operation cost per year	1.3	0	0	0	0

(3) Benefit

The benefit to be accrued from the construction of the New White Nile Bridge comprises total vehicle operation cost saving benefits, total travel time saving benefits, and savings in the maintenance cost of the existing White Nile Bridge.

A) Total Vehicle Operation Cost Saving Benefits

Total vehicle operation cost saving was calculated by the following equation:

Total Vehicle Operation Cost Saving

$$CT = \sum_{i}\sum_{j}\sum_{k} C^k \cdot \triangle C^k_{ij} \cdot T^k_{ij}$$

CT = Total vehicle operation cost saving

C^k Unit cost of vehicle operation

$\triangle C^k_{ij}$ Saving of vehicle operation cost between i zone and j zone

T_{ij} Traffic volume

k Type of vehicle

In the above equation, Tij was obtained from the traffic assignment. C^k was set for each vehicle type based on "Sudan Feeder Roads Master Plan Updating General Report, August 1986" and is shown in Table 5.4.

Table 5.4 Vehicle Operating Cost

Unit:LS./vehicle:km

Type of vehicle	1984 price	Price escalation coeff.	1989 price
Passenger Car	0.353	3.16	1.115
Mini Bus	0.498	3.16	1.574
Bus	1.286	3.16	4.064
Truck	1.238	3.16	3.912
Trailer	2.593	3.16	8.194

Note:

- Considering the road surface in Khartoum, Vehicle operating cost (VOC) is calculated as follows:

VOC=(VOC on Bituminous road + VOC on Gravel road)/2

- Price escalation coefficient is calculated by the Study Team based on "The Four Year Salvation, Recovery and Development Programme".

Total vehicle operation cost saving was calculated and is shown in Table 5.5.

Table 5.5 Total Vehicle Operating Cost Saving

Year	Alternatives (LS1,000) A-1	A-2	B-1	B-2	C
1995	15,935	12,515	11,805	7,965	-850
2005	29,005	24,070	4,945	6,090	-10,455
2015	49,435	38,800	3,370	210	-33,765

(4) Total Travel Time Saving Benefit

Total travel time saving benefit was calculated by the following equation:

Total Travel Time Saving

$$BT = \sum_i \sum_j \sum_k V^k \cdot \Delta t_{ij} \cdot T^k_{ij}$$

BT Total travel time saving

V^k Time value

Δt_{ij} Saving of time value between zone i and zone j

T_{ij} Traffic volume between zone i and zone j

k Type of vehicle

Time value for each vehicle was estimated by the following procedure:

A) Income estimation of bus and car users

Based on the income distribution in Khartoum studied by UNDP, the percentage share of income level of car and bus users was estimated as shown in Table 5.6.

Table 5.6 Percentage Share of Car and Non-Car Owners by Income Level

Income level	0-300	301-600	601-900	901+
Price escalation coefficient	5.77	5.77	5.77	5.77
Income class	0-1730	1731-3462	3463-5193	5194+
Income (medium)	850	2500	4500	11000
Share				
Income class (%)	33.8	32.6	15.6	18.0
Car owner (%)	5.8	39.9	77.2	100.0
Non-car owner(%)	94.2	60.1	22.8	0.0

Note : Price escalation coefficient is estimated by the Study Team based on "The Four year Salvation, Recovery and Development Program".

B) Estimation of Time Value

Time values of car and bus users were estimated on the assumption that car owners use cars and non-car owners use buses.

The share of car owners in each income class was calculated as shown in Table 5.7.

Table 5.7 Percentage Share of Car Owners by Income Level

Income class	Weight	Share (%)
0-1730	33.8x0.058= 2.0	4.4
1731-3462	32.6x0.399=13.0	28.9
3463-5193	15.6x0.772=12.0	26.7
5194+	18.0x1.000=18.0	40.0

From the above share, the time value of a car owner is worked out below:

Time value of car owner

= 850 x 0.044 + 2500 x 0.289 + 4500 x 0.267
+ 11000 x 0.400

= 6361.4 (LS./month)

= 30.3 (LS./hour)
(1 month=30 days, 1 day=7 working hours)

On the other hand, the share of bus users in each income class as shown in Table 5.8 is calculated by the method:

Table 5.8 Percentage Share of Bus Users by Income Level

Income class	Weight	Share (%)
0-1730	33.8x0.942=31.8	57.8
1731-3462	32.6x0.601=19.6	35.6
3463-5193	15.6x0.228= 3.6	6.6
5194+	18.0x0.000= 0.0	0.0

From the above share, the time value of a non-car owner is worked out below.

Time value of non-car owner

= 850 x 0.578 + 2500 x 0.356 + 4500 x 0.066 + 11000 x 0.000

= 1678.3 (LS./month)

= 8.0 (LS./hour)
(1 month=30 days, 1 day=7 working hours)

C) Estimation of Time Value of Vehicle

With the time value of car and bus users, vehicle time value was estimated based on the trip purpose and occupancy rate obtained by the traffic survey which is shown in Table 5.9. The time saving benefit was calculated for trips related to business activities including commuting trips.

Table 5.9 Trip Purpose by Type of Vehicle

	Occupancy rate (person)	Business trip	Non-business trip
Passenger car including taxi and pick-up	2 /1	3343 (66.5%)	1684 (33.5%)
Mini bus	15.3	587 (87.1%)	87 (12.9%)
Bus	42.8	166 (87.8%)	23 (12.2%)

Note : /1 not to include persons who are not related to business trip

- Time value of passenger car
  30.3 x 2 x 0.665 = 40.3 (LS./hour)

- Time value of mini bus
  8.0 x 15.3 x 0.871 = 106.6 (LS./hour)

- Time value of bus
  8.0 x 42.8 x 0.878 = 300.6 (LS./hour)

Total travel time saving benefit is summarized in Table 5.10.

Table 5.10 Total Time Saving Benefit

(Unit : LS. 1,000)

Year	Alternatives				
	A-1	A-2	B-1	B-2	C
1995	18,180	41,160	68,341	36,360	77,430
2005	77,430	77,430	241,380	223,200	154,860
2015	500,160	854,670	1,245,480	1,209,120	1,072,440

(3) Savings in the Maintenance Cost of the White Nile Bridge

After completion of the New White Nile Bridge, a large part of its traffic will divert to the New White Nile Bridge. Therefore, some maintenance cost will become unnecessary after commencement of the service of the New

White Nile Bridge. This cost saving can also be included in the benefits accrued from the construction of the proposed bridge. The maintenance cost saving is estimated as follows:

- Repair cost savings LS.30 million in 1995
- Maintenance cost savings LS.1.4 million in each year
- Operation cost savings LS.0.3 million in each tear

(4) Economic Evaluation

Table 5.11 summarizes IRR of alternative routes with consideration of economic construction cost and projected benefit aforementioned:

Table 5.11 Internal Rate of Return For Alternative Routes

Alternative Route	IRR (%)
A-1	9.7
A-2	15.6
B-1	21.3
B-2	16.0
C	16.6

Judging from the IRR, the alternative B-1 shows the highest value of IRR of 21.3 %. Therefore, in the initial economic evaluation, the B-1 route is recommended as the most viable route from the economic aspect.

This economic evaluation was performed even for the constant population growth rate case. As for the IRR for this case, the IRR shows a lower value than that of the afore-mentioned case. The reason is that the heavy traffic volume as forecasted in the latter case forces drivers to make a detour as long as the road situation remains as it is, which leads to a negative vehicle operating cost saving. To cope with this situation, the NCK is requested to develop or improve roads within Greater Khartoum City, or to introduce car restrictions as the UNDP study suggested.

5.4.2 Initial Engineering Evaluation

(1) Road and Bridge Engineering

A) Alignment

An alignment with a large curvature is not desirable, especially for the bridge, because of increasing difficulties in design and construction. In this regard, Routes B-1 and C are better than the rest.

B) Type of bridge

The type of bridge for Route A-1 would be bascule made only of steel. Routes A-2 to C, however, could employ a more ideal bridge type, either concrete or steel type bridge. Such flexibility is very significant in examining not only structural types but also construction materials and methods in order to grasp the most preferable solution. According to this criterion, Route A-1 is inferior to the others.

C) Skew Angle of Bridge

The most desirable alignment of bridge center-line is to cross over the river at right angles (90 degrees) from the viewpoint of construction cost, reliable design, construction safety and appearance. In this regard, Route B-1 is better than the others.

(2) River Hydrological Engineering

The number and size of the piers to be newly constructed is very significant for river hydrology. The main bridge for each route has almost the same bridge length and span. So, the criterion for this evaluation depends on the size of pier because the size of the pier is closely related to the obstruction caused to the river and scouring of the riverbed. In this regard, Route A-1 is judged inferior to others.

(3) Navigation Safety

The White Nile becomes narrow near the existing White Nile Bridge and the velocity of the river current is faster than upstream of Wad Dakien Island.

Thus in terms of navigational safety, the New White Nile Bridge should be situated as far upstream as possible. Also Route A-1 would require a bascule while the existing White Nile Bridge is a swing bridge. From this point of view, it is clear that Route A-1 is the worst alternative.

(4) Degree of Relief to Traffic Congestion

The present traffic congestion at the existing White Nile Bridge and its access roads will be relieved when the New White Nile Bridge is constructed.

Relief degree is estimated by the following formula and summarized in Table 5.12.

$$R.D = (1 - C.D_i / C.D_0) \times 100$$

where,

R.D : Relief degree of traffic congestion (%)
C.Di : Congestion with the New White Nile Bridge in 2015
C.D0 : Congestion without the New White Nile Bridge in 2015
(Refer to Table 5.1 for C.D)

Table 5.12 Relief Degree by Route Alternatives

Specific Road	A-1	A-2	B-1	B-2	C
Exist.White Nile Bridge	47%	37%	50%	41%	16%
Omdurman side access Rd.	-12%	-11%	44%	40%	24%
Khartoum side access Rd.	-31%	20%	10%	28%	15%

As a result, the following is revealed:

- Route A-1 will relieve traffic congestion on the existing White Nile Bridge. However, it might cause more traffic congestion on both the access roads on the Khartoum and Omdurman sides.

- Route A-2 will relieve the traffic congestion on the existing White Nile Bridge and access roads on the Khartoum side. But it might cause more traffic congestion on the access roads on the Omdurman side.

- Routes B-1, B-2 and C will relieve the traffic congestion on the existing White Nile Bridge and on both the access roads on the Khartoum and Omdurman sides.

(5) Geological Engineering

It seems probable that there is no significant difference in geological condition such as bearing layer between the site of Route A-1 and Route C.

(6) Future Maintenance

The alternative route A-1 would have a bascule mechanism requiring much more maintenance than others in future.

(7) Land Acquisition and Compensation

Before the start of the bridge construction, some compensation will have to be paid, namely:

- Land acquisition
- Existing building and structure demolition e.g., houses, electric cables and poles, and water main crossing over the White Nile

According to the present situation for the above items, it seems probable that land acquisition and compensation for existing buildings and structures are relatively easy in case of Routes A-1, A-2, B-1 and B-2. However, Route C has some difficulties because of its alignment which passes the residences at Al Fitaihab Town on the Omdurman side.

5.4.3 The Selected Route

Figure 5.4 summarizes the results obtained from the preceding subsections 5.4.1 and 5.4.2.

Accordingly, Route B-1 is judged as the most favorable route for the reasons that it excels in all the evaluation items as well as IRR and it is concluded that the subsequent work of the Study be made based on **Route B-1**.

		Route Alternatives				
		A-1	A-2	B-1	B-2	C
Outline of Each Route	Functional Classification	Enlargement of Existing Arterial Road over the White Nile		By-pass with Potentiality of Beltway Connector		Beltway Connector
	Project Length	2,100 m	2,900 m	4,400 m	5,200 m	7,400 m
	Bridge Length	620 - 700 m	700 - 800 m	700 - 800 m	1,100 - 1,300 m	1,000 - 1,300 m
	Bridge Type	Movable Bridge	Fixed Bridge	Fixed Bridge	Fixed Bridge	Fixed Bridge
Evaluation	Economic Internal Rate of Return (EIRR)	8.9 %	15.6 %	21.3 %	16.0 %	16.6 %
	Road and Bridge Engineering Aspect	△	○	◉	○	○
	River Hydrological Aspect	△	◉	◉	◉	◉
	Navigational Safety	×	◉	◉	◉	◉
	Relief Degree of Traffic Congestion	△	△	◉	◉	○
	Future Maintenance	△	○	○	○	○
	Land Acquisition and Compensation	◉	○	○	○	△
OVERALL EVALUATION		△	○	◉	○	○

Recommended (B-1)

LEGEND:

- ◉ Very Good
- ○ Good
- △ Fair
- × Bad

THE FEASIBILITY STUDY ON THE CONSTRUCTION OF THE NEW WHITE NILE BRIDGE	Fig. 5.4	EVALUATION TABLE BY ALTERNATIVES
	JAPAN INTERNATIONAL COOPERATION AGENCY	

CHAPTER - VI

ENGINEERING INVESTIGATION AND SITE ASSESSMENT

CHAPTER-VI ENGINEERING INVESTIGATION AND SITE ASSESSMENT

6.1 GENERAL

Site investigations and assessments had largely to be conducted, i.e. data collection, topographic surveys, subsoil and material investigations and desk studies, as a part of the engineering feasibility study. These investigations and assessments were carried out as parallel activities, although most inter-relate with each other.

The site discussed in this chapter is mainly defined as the areas where the route B-1 selected in Chapter-V passes or areas where construction materials such as soil for embankments or rock for concrete aggregates can be obtained.

6.2 TOPOGRAPHIC SURVEY

6.2.1 Methodology

The survey was carried out around the White Nile and limited to the area from 15° 3′ to 15° 32′ North latitude and from 32° 20′ to 32° 31′ East longitude. The area is divided into two administrative districts; Omdurman and Khartoum cities. The area consists of gently undulating ground occupied by mud houses and a military area on the Omdurman side, and the White Nile, and vegetable fields and existing roads on both sides.

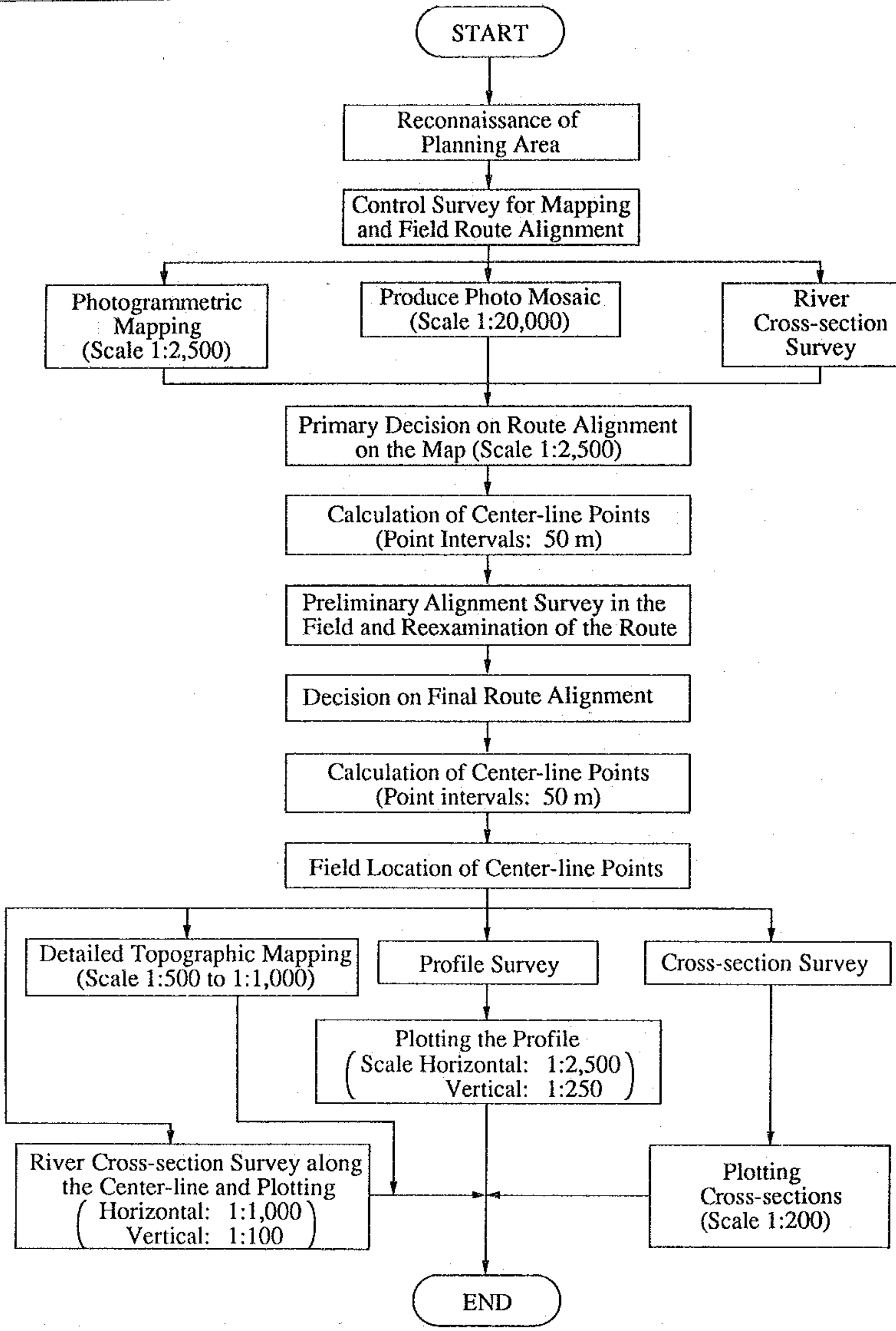
The survey procedure conducted in this topographic survey is shown in Figure 6.1. Details are shown in Appendix 6.1.

6.2.2 Controls Employed

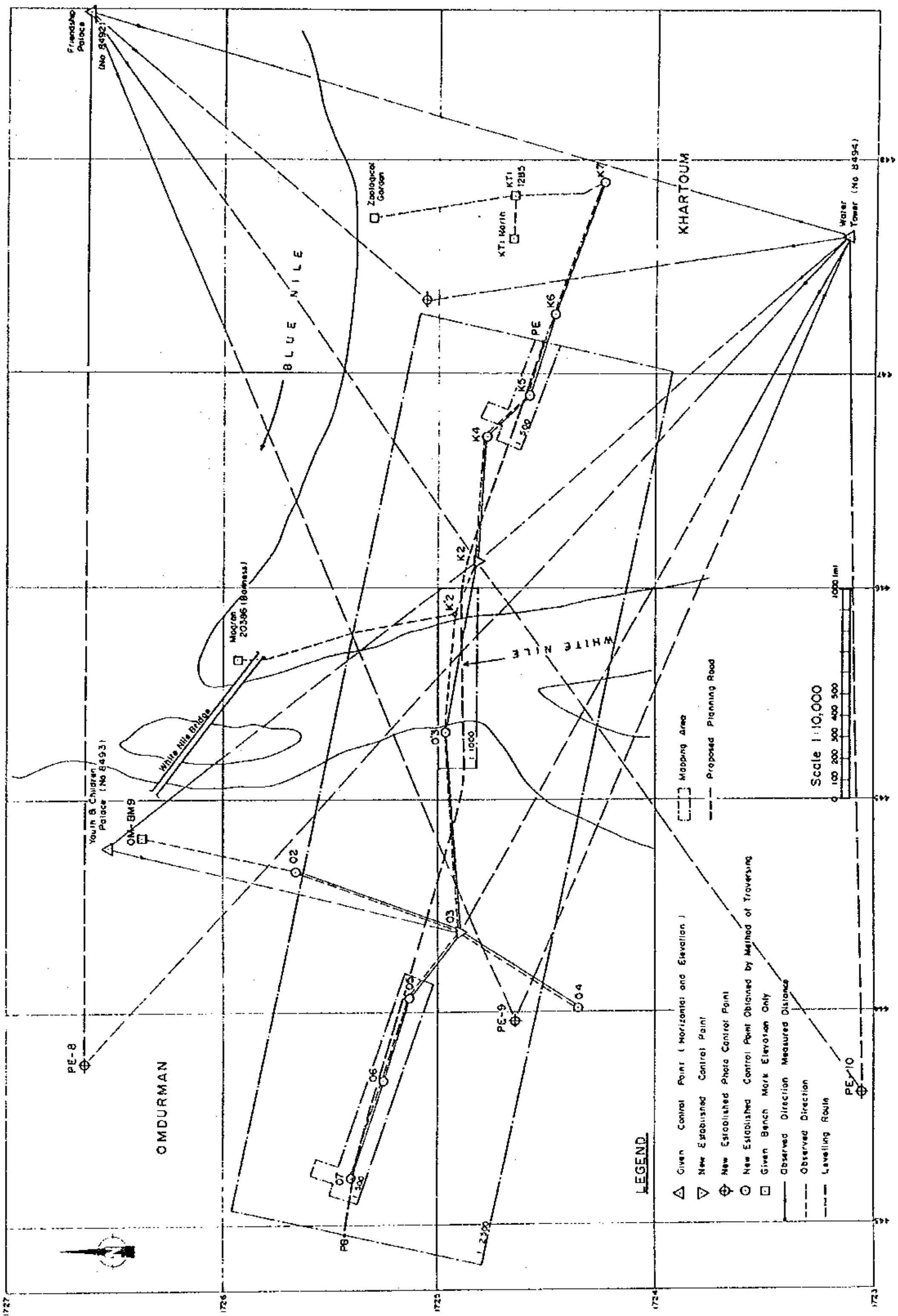
Existing bench marks and newly establised controls are shown in Table 6.1 and Figure 6.2. All the topographic survey results in this report are based on them. Elevations shown in this report are based on reduced levels above mean sea level at Alexandria in Egypt and expressed as RL plus meters.

6.2.3 Schematic Plan For Center-line Survey

A center-line survey was conducted based on a schematic plan shown in Figure 6.3. Stakes were temporarily placed into the ground in this survey, at 50 meter intervals, and profile and cross-section surveys were executed.



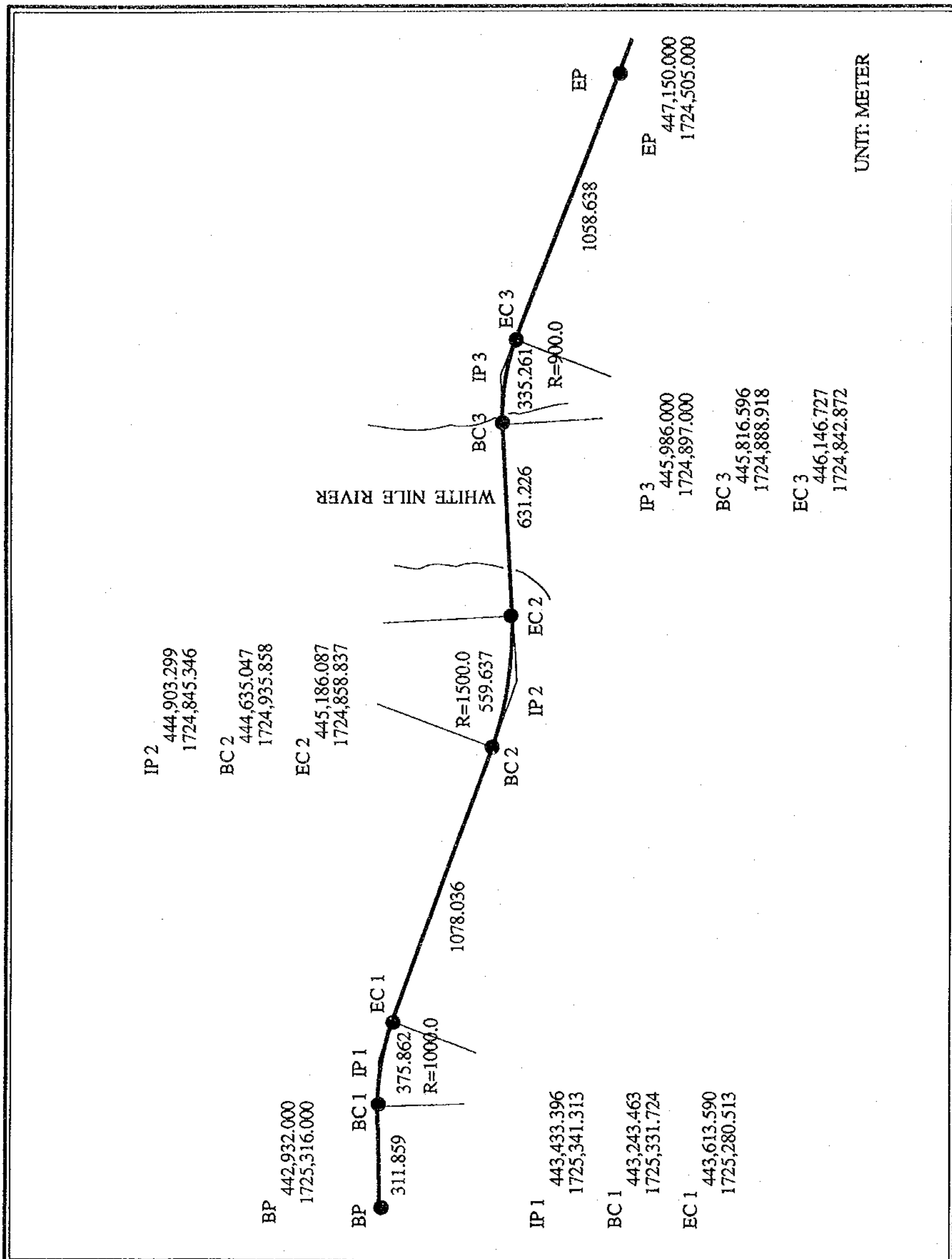
THE FEASIBILITY STUDY ON THE CONSTRUCTION OF THE NEW WHITE NILE BRIDGE	Fig. 6.1	SURVEYING PROCEDURE AT PHASE-1 AND 2 STUDIES
	JAPAN INTERNATIONAL COOPERATION AGENCY	



THE FEASIBILITY STUDY ON THE CONSTRUCTION OF THE NEW WHITE NILE BRIDGE

Fig. 6.2 LOCATION MAP OF CONTROLS

JAPAN INTERNATIONAL COOPERATION AGENCY



THE FEASIBILITY STUDY ON THE CONSTRUCTION OF THE NEW WHITE NILE BRIDGE	Fig. 6.3	HORIZONTAL ALIGNMENT
	JAPAN INTERNATIONAL COOPERATION AGENCY	

Table 6.1 Control Points and Bench Marks

Point Name or Number	Coordinate N (m)	E (m)	Elevation RL+(m)	Remarks
(C o n t r o l s)				
Youth & Childr. P	1,726,520.630	444,776.228	413.555	Sudan Control No.8439
Water Tower	1,723,120.720	447,649.155	421.220	Sudan Control No.8494
Friendship Hotel	1,726,630.736	448,680.724	433.940	Sudan Control No.8492
K2	1,724,769.883	446,113.917	376.843	JICA Team Control
K4	1,724,770.457	446,706.678	380.812	ditto
K5	1,724,577.985	446,894.096	379.673	ditto
K6	1,724,460.172	447,267.683	379.109	ditto
K7	1,724,254.667	447,898.818	380.621	ditto
O2	1,725,648.628	444,667.862	377.362	ditto
O3	1,724,882.867	444,384.110	376.681	ditto
O3'	1,724,968.747	445,311.831	375.724	ditto
O4	1,724,243.628	444,030.217	376.796	ditto
O5	1,725,120.536	444,070.991	380.642	ditto
O6	1,725,249.527	443,681.424	383.648	ditto
O7	1,725,328.437	443,213.898	385.264	ditto
(L e v e l C o n t r o l s)				
Zoological Garden			381.305	Sudan Control
KTI (12852)			379.678	Sudan Control
OM-BM9			384.714	Sudan Control
Mogran (20386)				Sudan Control (bad)

6.3 GEOLOGY AND SUBSOIL INVESTIGATION

6.3.1 Geological Background

The Nile River, the great river of Africa has been flowing serenely in the vast continent from ancient times to the present, approximately 10 billion years in geological time.

As shown in Figure 6.4, the geological basement in the region of the Nile rivers principally consists of Pre-Cambrian complex (over 2 billion years in age, granite, gneiss etc. in rock type). On the other hand, Cretaceous formation (1 billion years in age, sandstone, etc. in rock type) is distributed in the northern regions to a certain extent. Younger geological layers, Tertiary to Quaternary formations, are also found. Especially in the area along the Nile River, Quaternary formations (soil layer) are widely spread.

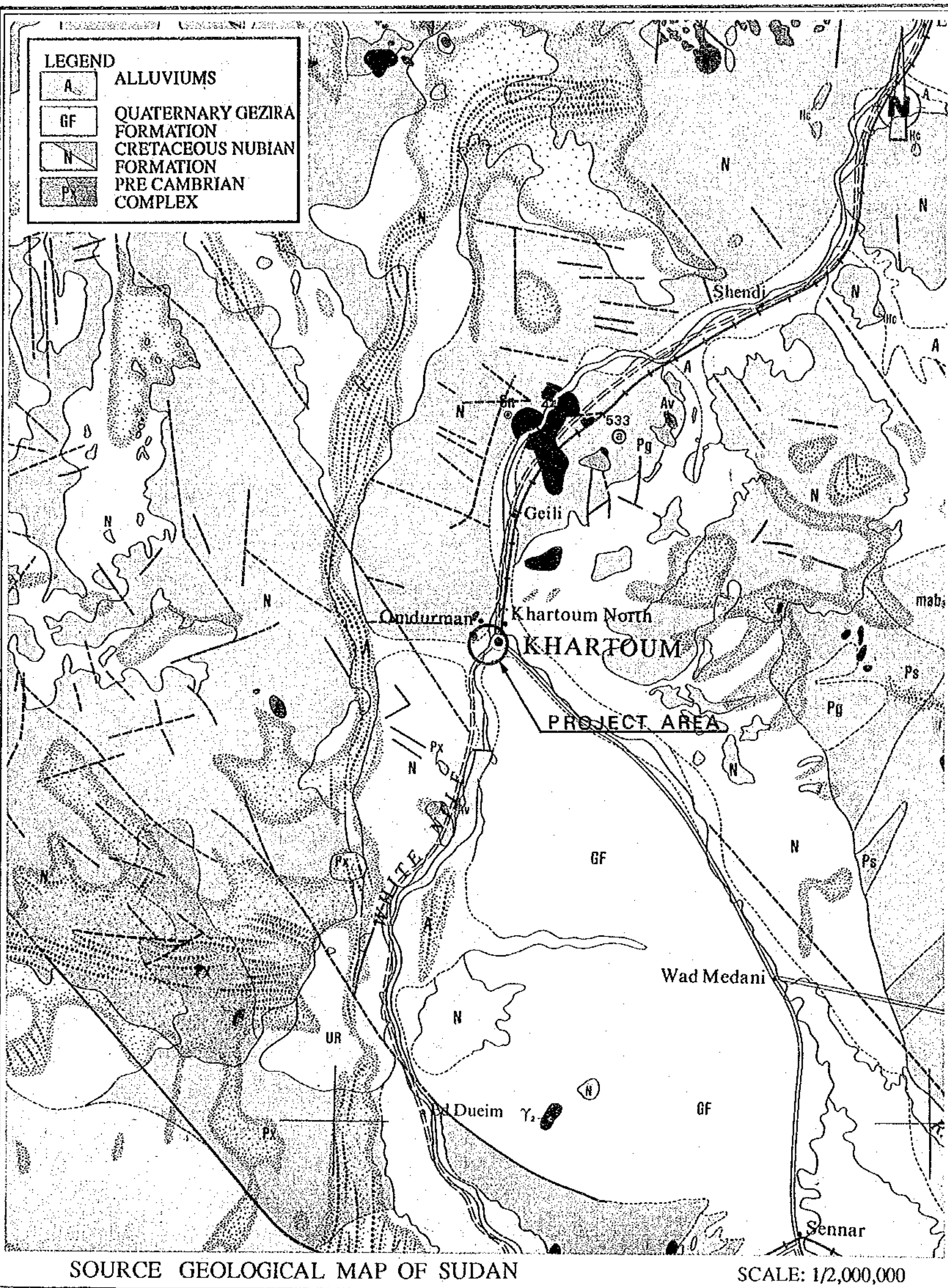
From the viewpoint of structural morphology flat land (Platform) is widely spread in this region, while a mountainous zone (Orogenic belt) is formed in the eastern region of the River Nile. Platform shows a typical flat topography which has been formed as a result of the leveling action of the arid weathering over a long period.

The orogenic belt is a mountainous district which extends from south to north 1,000km long, 200km wide in parallel with the Red Sea (great tectonic line joined to the African Rift).

Lithologically, the Pre-Cambrian complex is mainly composed of granite and gneiss, associated with sedimentary rocks in minority. The cretaceous formation, another main basal layer, is composed of sandstone with interlaid mudstone. Local intrusive basalt, in addition, is found in some places. Major geological faces in the quaternary layer along the River Nile are composed of fine soil.

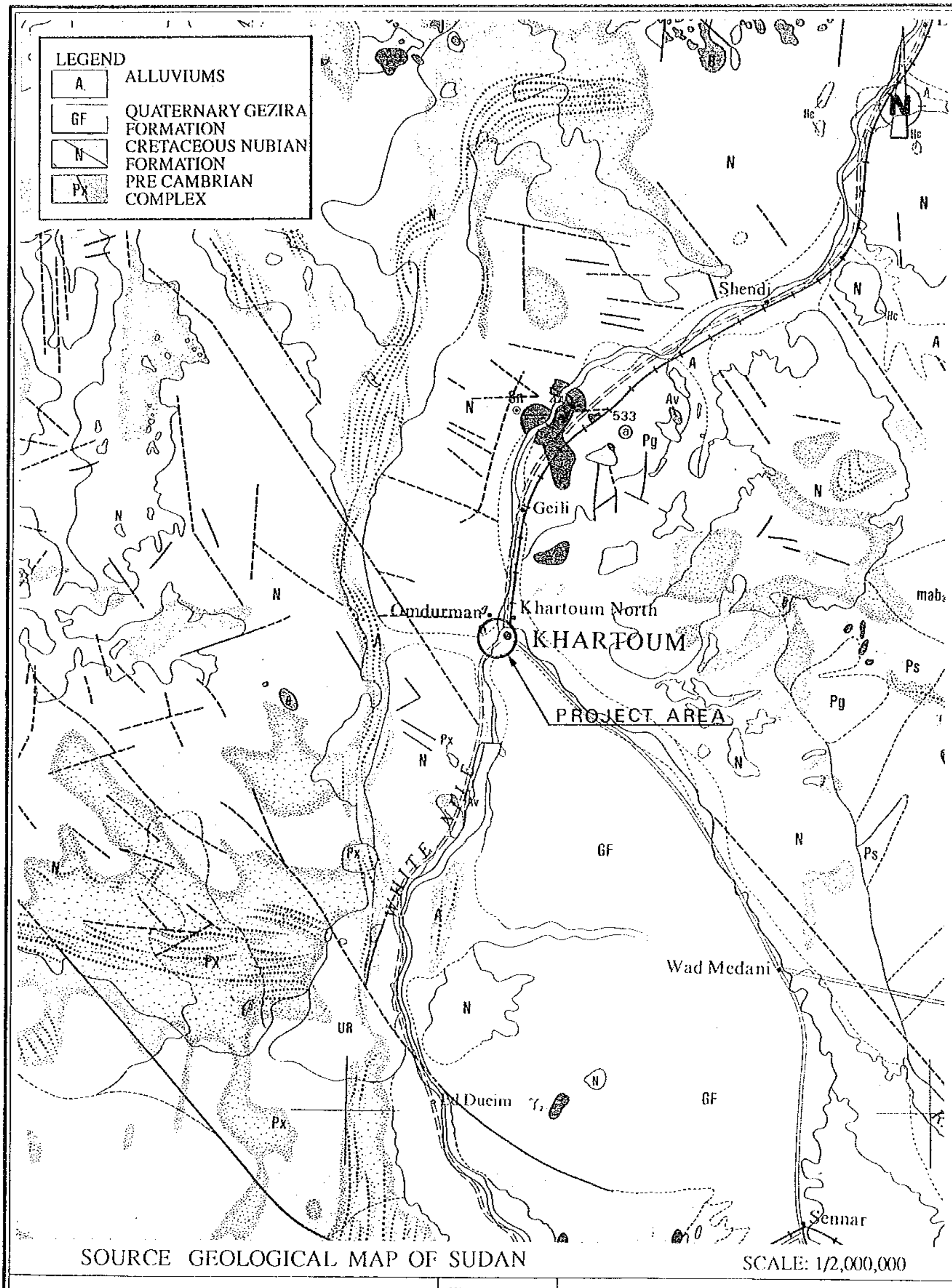
The project area as shown on the frontispiece is located on the upstream side of the confluence of the White Nile and Blue Nile. In this area the slope of the riverbed is very gentle, 1 to 10,000 in grade. The average widths of the rivers are 700 m and 400 m, for the White Nile and Blue Nile respectively. Especially in the White Nile, flooding to the extent of several hundred meters on both banks takes place during the rainy season. As a consequence, the river is expanded to 2,500m in width. Small islands (Cay) of a crescent or flat shape are formed. These cays remain in the river with a height of 5 to 10 meters above the water level during the dry season.

The basal layer is the Cretaceous formation which is called the Nubian Sandstone Formation. This layer is mainly composed of sandstone partially alternated with mudstone and associated with a thin conglomerate layer.

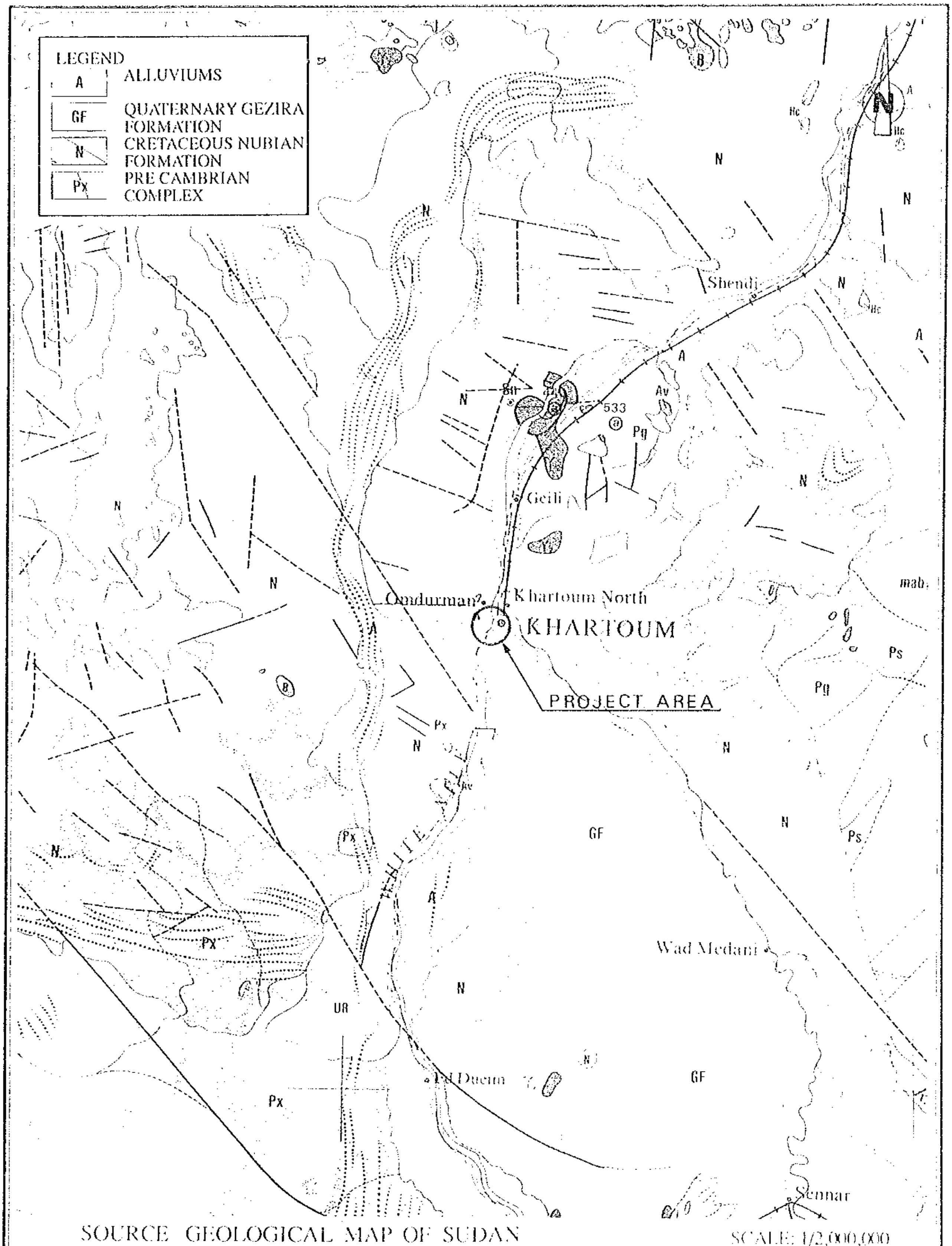


SOURCE GEOLOGICAL MAP OF SUDAN SCALE: 1/2,000,000

THE FEASIBILITY STUDY ON THE CONSTRUCTION OF THE NEW WHITE NILE BRIDGE	Fig. 6.4	GEOLOGICAL MAP
	JAPAN INTERNATIONAL COOPERATION AGENCY	



THE FEASIBILITY STUDY ON THE CONSTRUCTION OF THE NEW WHITE NILE BRIDGE	Fig. 6.4	GEOLOGICAL MAP
	JAPAN INTERNATIONAL COOPERATION AGENCY	



THE FEASIBILITY STUDY ON THE CONSTRUCTION OF THE NEW WHITE NILE BRIDGE	Fig. 6.4	GEOLOGICAL MAP
	JAPAN INTERNATIONAL COOPERATION AGENCY	

Outcrops of this layer occur sporadically in the vicinity of the White Nile, 200 to 500 meters away from the river bank.

The principal geological face in this area is the soil layer of Quaternary. This is mainly composed of clayey soil which is distributed widely along the river bank. A relatively minor sand layer is deposited in the river bed and water side downstream of the confluence. On the other hand intrusive basalt layers as in the rock quarry occur locally.

6.3.2 Geological Composition

The geological composition has been investigated by test boring. Boring locations and profile are shown in Figure 6.5.

The main strata at the project site consist of Alluvial layers and the basal rock layer (so-called Nubian Formation).

The alluvial layers can be classified into three clay layers and a sand layer, according to the boring logs (refer to Appendix-6.2). The Nubian formation is composed of sandstone alternating with mudstone.

The characteristics of these layers are summarized below and are shown in Figure 6.5.

(1) Clay ACL1

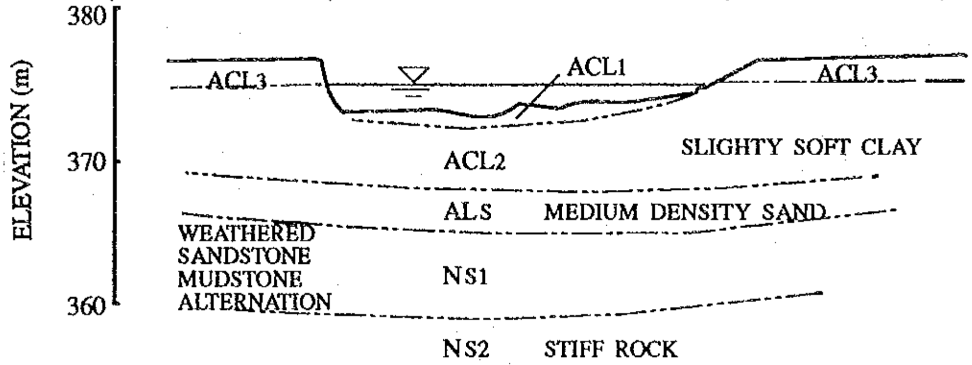
Current river deposit
It lies on the surface of the river-bed with a few meters thickness. N-value of SPT (standard penetration test) is 1, very loose and soft clay.

(2) Clay ACL2

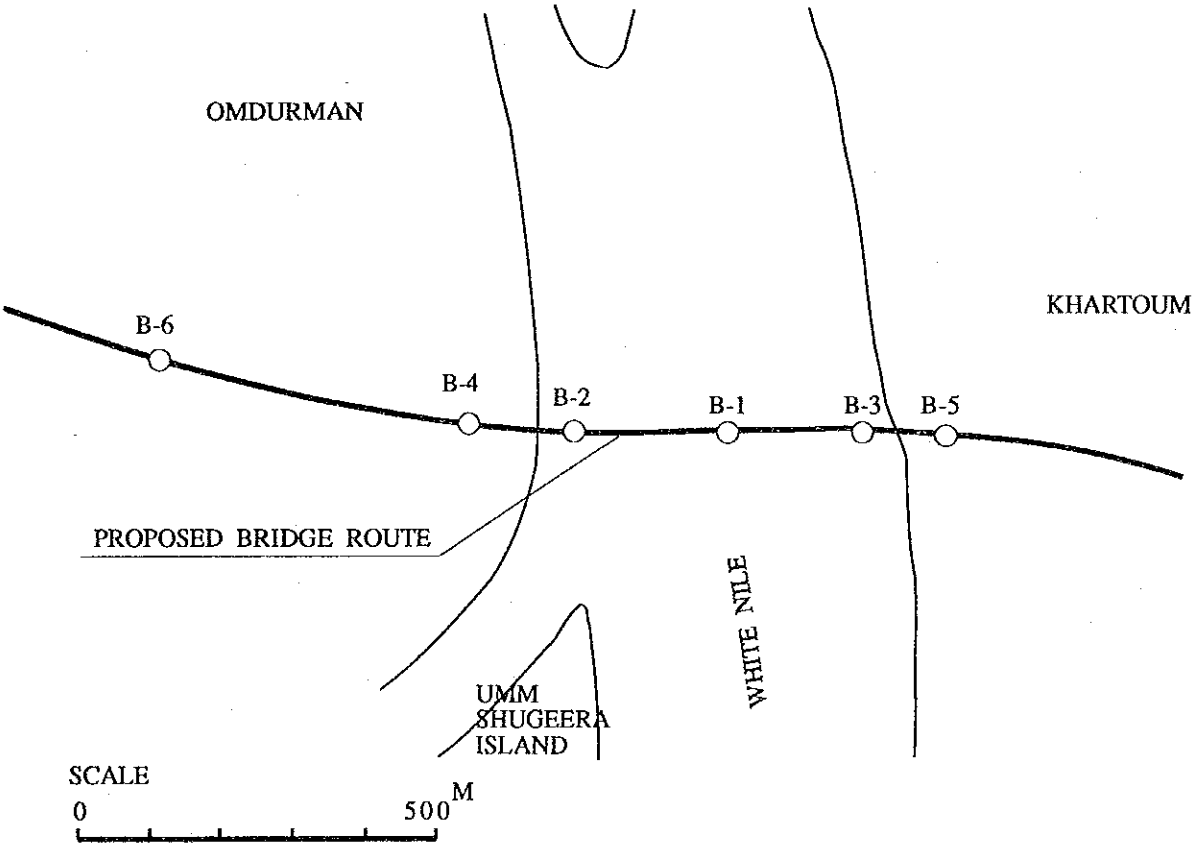
Homogeneous clay
It contains a small quantity of silt. N-value averages 5, which shows a moderate consistency.

(3) Clay ACL3

This layer is distributed on both banks in the shape of a river terrace. Soil type is a silty clay which contains about 15 % silt fraction. Its very hard condition, similar to cemented clay, is due to desiccation and dry weathering which prevail except during an abnormal flood season. N-values 6 to 11.



GEOLOGICAL PROFILE



PLAN

THE FEASIBILITY STUDY ON THE CONSTRUCTION OF THE NEW WHITE NILE BRIDGE	Fig. 6.5	BORING LOCATION AND GEOLOGICAL PROFILE
	JAPAN INTERNATIONAL COOPERATION AGENCY	

(4) Sand As

This stratum underlies the clay layer ACL2 with a thickness of 4 to 5 m. It consists of homogeneous fine sand (poor grain size distribution). N-values 20 to 40 so a comparatively dense layer.

(5) Nubian Formation Nb

This stratum is a rock layer which consists of sandstone alternating with mud-stone; for the most part influenced by iron oxidation with ferro-substance concentrates in some places; moderately well solidified, however, with upper part of the layer decomposed through weathering action.

Design values of the stratum, namely the values of C, Ø, r, Eo are determined by N-values and soil tests, where, C is cohesive strength; Ø is angle of internal friction, r is unit density and Eo is deformation modulus. The values are shown in Table 6.2.

Table 6.2 Design Values of Basic Engineering Properties

Stratum		N	C tf/m2	Ø deg.	r tf/m3	Eo kgf/m3
ACL1	Clay	1	1	0	1.4	14
ACL2	Clay	6	3	0	1.6	35
ACL3	Clay	5	3	0	1.6	40
As	Sand	20	0	30	1.8	135
Ns	Sandstone Mudstone	>50	50	35	2.3	1,250

From the N-values obtained in the field, C and Ø is assumed as follows:

In clay layer : C = 0.6 x N (tf/m2)

In sand layer : Ø = 12 N + 15 (deg.)

Judging from the condition of rock in the boring core sampled in the Nubian rock layer, the properties are empirically given as C = 50 tf/sq.m, Ø = 35° and r = 2.3 tf/cu.m.

As to the cohesive strength of the clay layer, the values in the saturated condition are given taking into consideration the conditions in the flood season.