社会開発調査部報告書

No. 32

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GROUNDWATER MANAGEMENT PROJECT IN THE KATHMANDU VALLEY

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JAPAN INTERNATIONAL COOPERATION AGENCY

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HIS MAJESTY'S GOVERNMENT OF NEPAL
NEPAL WATER SUPPLY CORPORATION

GROUNDWATER MANAGEMENT PROJECT IN THE KATHMANDU VALLEY

FINAL REPORT

SUPPORTING REPORT

NOVEMBER 1990

JAPAN INTERNATIONAL COOPERATION AGENCY

GROUNDWATER MANAGEMENT PROJECT
IN
THE KATHMANDU VALLEY

FINAL REPORT

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SOCIO-ECONOMY

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1. NATIONAL SOCIO-ECONOMY

1.1 Location and Administrative Units

Nepal is located in a mountainous area in South Asia, and extends from 26° 22' to 30° 27' north latitude and from 80° 4' to 88° 12' east longitude. It is bordered by China to the north and by India to the south, east and west.

The country has an area of 147,181 km^2 and had a population of 15,022,839 in 1981. Administratively it is divided into 14 zones which zone itself consists of some districts. The districts amount to 75 units in the country as a whole and contain several small communities called town or village, which are regarded as the smallest local administrative units.

1.2 Gross Domestic Product

Gross Domestic Product (GDP) of Nepal amounted to NRs. 74,575 million in 1988/89 on the increase by about NRs. 35,000 million against that in 1983/84, at an average annual growth rate of 13.6%. Whereas the real growth rate was only 4.8% per annum. On the other hand, the per capita GDP showed NRs. 4,134 in 1988/89 at the average growth rate of 10.2% per annum at current prices, while the real annual growth rate was 2.1% (See Table A-1.1). Among industrial origins of the GDP, the agricultural sector dominated contributing to about 52% of the GDP during period 1985/86 - 1987/1987 (See Table A-1.2).

1.3 External Trade and Balance of International Payments

Exports and imports of Nepal indicated NRs. 4,115 million and NRs. 13,870 million in 1987/88, respectively (See Table A-1.3). The export was represented by three commodities; manufactured goods, food and live-animals, which accounted for 84 % of the total exports in 1987/88. Concerning the import, three commodities of machinery, transport equipment and manufactured goods accounted for 56% of the total exports in 1987/88. Of about 60 trading countries, India has held first place in the trade amount (the sum of exports and imports), for example, 35% of the total trade amount in 1987/88.

In Nepal, the imports have exceeded the exports every year, and such trade deficits have made the main cause of an imbalance of international payments. For example in 1986/87, the current account of international payments showed minus NRs. 2,858 million, and this deficit was supplemented by the capital account which included external loans and grants (see Table A-1.4).

1.4 Government Finance

In 1988/89, the Government finance of Nepal amounted to NRs. 19,520 million (equivalent to 26% of the GDP) for expenditures and NRs. 11,894 million for receipts, at the average annual rise rates of 21% and 23% respectively during the period 1983/84 - 1988/89. Of the budget expenditures, the development expenditure accounted for nearly 70% in 1988/89, or NRs. 13,368 million. On the other hand, the receipts consist of the revenue of NRs. 9,300 million and the foreign grants of NRs. 2,594 million. Budgetary statistics of the Government show that the expenditure exceeded the receipts every year, and that such financing deficits was supplemented by external and internal loans (See Table A-1.5).

The budget expenditure of drinking water supply sector in 1988/89 was NRs. 18 million (0.3% of the government budget) for the regular expenditure and NRs. 517 million (3.9%) for the development expenditure, i.e. the expenditure of drinking water supply sector was only about 4% of the total expenditure of the Government. On the other hand, budget of the Water Supply and Sewerage Corporation (WSSC) in the same year was NRs. 78 million for the expenditure and NRs. 37 million for the income. The finance of NWSC showed a deficit every year and its deficit has been supplemented by consumer deposits and bank loans (See Table A-1.6).

2. REGIONAL SOCIO-ECONOMY

2.1 Location

The Study Area (the Kathmandu valley) is located in the hilly area of Central Region and has an area of 525 km^2. Administratively, the valley consists of three districts; Kathmandu, Lalitpur and Bhaktapur. Each district has towns and villages which amount to 130 units in the valley as a whole.

2.2 Population

According to the 1981 census, the population of Nepal was 15,022,839 of which urban and rural population constituted 6.4% and 93.6%, respectively. Approximately 47% of the population lived in the hill, 44% in the plains (Terai region) and 9% in the mountains. The average annual growth rate of population showed about 2.62% for the country as a whole during the period 1971- 1981, 7.28% for the urban population and 2.37% for the rural population (See Table A-2.1). The population density was 102 persons per km_2 in 1981.

In the 1981 census, Population of the valley indicated 766,345, consisting of the urban population of 363,507 and the rural population of 402,838. During the period 1971-1981, the average annual growth rate of population was 2.14 % for the whole valley, 3.76 % for the urban area and 0.87 % for the rural area (Table A-2.1). As described above, the average growth of population in the valley showed lower rate than that for the country. Such a lower growth rate seems to be due to out-migration from the valley to other places and a relatively high effect of family planning.

In 1981, population of the Kathmandu, Lalitpur and Bhaktapur districts showed 422,237, 184,341 and 48,472, respectively, and ratio of the urban and rural population for each district was 55:54, 43:57 and 30:70. Generally the growth in urban population is conspicuous as seen in Table A-2.1, especially in the urban population of the Kathmandu district at a high growth rate of 4.47 % during the period 1971-1981. Population projections of the urban area are discussed in detail in Appendix H.

2.3 Agriculture

Nepal is a traditional agricultural country. In 1981 approximately 90% of the economically active population of the country engaged in the agricultural and agro-industrial sectors. Food production in the country depends greatly upon nature, and the Terai region is the main agricultural belt of Nepal. The hilly area has potentiality for horticultural development, and the mountainous zone is suitable for livestock farming. Paddy, maize and wheat are major food crops of Nepalese people, and potato, oil-seed, sugar-cane and jute are main cash crops. The Terai region is major production area of paddy and wheat, and main hill crops are maize and millet. On the other hand, livestock farming also is an important industry of Nepal, especially cattle farming. In 1981/82, about 9 million heads of cattle including buffaloes were being bred.

Paddy, wheat, maize and potatoes which are major agricultural crops in the Kathmandu valley showed productions of 88,090 tons, 34,750 tons and 16,700 tons in 1987/88 , respectively, but these productions were less than 5% of the total production in Nepal. Besides these major products, such crops as millet, barley and oil-seed also are produced in the valley, but the proportion of each production to the total production of the country was below 1% every year. Most of crops produced in the valley have been spent as food for the inhabitants.

Table A-2.2 shows statistics of production areas for paddy and maize in the valley, compared with those in the country. The planted areas of these crops in the valley showed 37,650 ha in 1987/88 on the decrease by about 8% against 40,990 ha in 1982/83. In Nepal as a whole despite there was a tendency for the planted areas to increase as seen in the table, such a decrease in paddy and maize fields in the valley appears to be a progress of urbanization in the valley.

2.4 Industry

2.4.1 Manufacturing industry

Major manufacturing industrial products with weight of 5 % or more of the gross output in Nepal are indicated in Table A-2.3. Production of jute goods, which have accounted for a weight of over 20 % of the gross output every year, was 17.2 thousand tons in 1987/88 showing a trend toward the decreased production since 1984/85. On the other hand, sugar, cement and cigarettes were increasing their productions for the period 1981/82-1987/88, especially the cement production in 1987/88 amounted to about 6 times of that in 1981/82.

Table A-2.4 shows statistics of establishments and employees of manufacturing industries in Nepal, and the Kathmandu valley. Establishments with 10 or more employees of manufacturing industries in Nepal amounted to 9,359 in number in 1986/87 on the increase by nearly twice as much as that in 1981/82, and number of employees indicated approximately 153,000 in 1986/87. Of the manufacturing industries in Nepal, the Kathmandu valley had about 1,500 establishments (16 %) and 53,000 employees (35 %).

Of manufacturing industries in the Kathmandu valley, the Kathmandu District possessed establishments of 820 (55 %) and employees of 30,000 (58 %) in 1986/87. On the other hand, in recent years the Lalitpur District achieved a remarkable development of the manufacturing industry, that is, establishments and employees in 1986/87 increased in number by 2.9 and 4.5 times of those in 1981/82, respectively (See Table A-2.4).

Gross output and value added of the manufacturing industry of Nepal indicated NRs. 13,500 million and NRs. 4,490 million in 1986/87, respectively. In the Kathmandu valley, those were NRs. 2,810 million (21 %) and NRs. 1,130 million (25 %) respectively in the same year, and the gross output and value added in the Kathmandu District accounted for two-third of those in the entire valley (See Table A-2.5).

2.4.2 Tourism industry

Nepal is one of the most attractive countries for tourists because of having beautiful natural resources such as snow peaks, green forest and lakes. In addition to the natural resources, historical monuments and variety of religions and cultures of ethnic groups also are the important tourism resources of Nepal. The tourism has therefore been a promising industrial sector of Nepal.

Table A-2.6 shows statistics of tourist arrivals to Nepal. Number of the tourist arrivals amounted to 248,000 in 1987 on the increase at an average rate of 6.5 % per annum since 1980, especially for the period 1986 - 1987, a high annual rate of 10 % or more. In 1987, approximately 90 % of the tourist arrivals were occupied by tourists for pleasure and trekking purposes (75 % and 15 % respectively).

According to information from the Department of Tourism, the gross foreign exchange earnings from the tourism sector amounted to US$ 60 million in 1987 at an average annual increase rate of 3.8 % for the period 1980-1987.

Of tourists to Nepal in 1987, Indian tourists accounted for 24 %, and tourists from U.S.A.(11 %), U.K.(8 %) and Japan (7 %) followed the Indian. More than 80 % of the visitors arrived by air.

The hotel industry of Nepal remained in a little growth in recent years as shown in Table A-2.7. Number of rooms and beds of hotels in Nepal was 23,194 and 45,395 in 1987 respectively, of which Approximately 80 % was located in the Kathmandu valley. In the same year, the hotel users were about 225,000 persons corresponding to 90 % of the total foreign visitors, and they stayed for 2.7 days on average at hotels. Proportion of bed occupancy in 1987 was 46 % in the Kathmandu valley and 40 % in other areas.

2.5 Water Supply

Water supply work of Nepal is presently conducted by three government agencies; Department of Water Supply and Sewerage (DWSS), Ministry of Panchayat and Local Development (MPLD) and Nepal Water Supply Corporation (NWSC). The DWSS is responsible for the water supply to communities with 1,500 population or more (except control areas by the NWSC), and for the water supply by wells for small scale communities. The MPLD keeps the control of water supply for villages (rural areas) with population of below 1,500. The NWSC is a corporation which conducts the water supply work for 13 towns (or cities) in the country, and the work is being operated by a independent profit system.

According to the national statistics on water supply, in 1985 the population served was 22% on average in the country as a whole which consists of 80% for urban areas and 18% for rural areas. In the Kathmandu District, presently the population served shows 53% for rural areas and nearly 100% for urban areas.

2.6 Health

Table A-2.8 gives statistics on cases of water-borne diseases in the Kathmandu valley. The water-borne diseases ranged from 4,000 to 7,000 a year during the period 1980-1987 and showed some 6,600 cases in 1987. Gastroenteritis amount to for 64% of the total cases of water-borne diseases in 1987, that is, 4,270 cases (about 760 cases per 100,000 population) which were a fairly high incidence even among developing countries.

It is generally said that water-borne diseases are be caused by inadequate and unsanitary conditions of four principal sources; water supply, sanitation facilities, domestic and personal cleanliness, and food hygiene. Various studies suggest that among these sources the safe and adequate drinking water supply is the most significant factor for reducing the cases of water-borne diseases. The socio-economic benefits of the present project will be mainly evaluated by two categories; one is rise in economic level due to adequate water supply, and the other is socio-economic effects of reducing the cases of water-borne diseases expected by the safe drinking water supply. This evaluation is discussed in Chapter 7 of the Main Report.

2.7 Prices

Urban consumer prices in the Kathmandu District as well as the country as a whole rose to over four times (an average annual rise rate of about 10 %) for the period 1972/73-1987/88 (Table A-2.9). Prices of food and beverages indicated somewhat high rise rates, compared with those of non-food and services for the same period, in particular the rise rates of over five times for vegetables, spices, meat, fish, eggs, edible oil and butter. While sugar, clothes, footwear, cigarettes and transport & communications showed the relatively stable prices.

TABLES

Table A-1.1 GROSS DOMESTIC PRODUCT (GDP)

Items	1983/84	1984/85	1985/86	1986/87	1987/88	1988/89	Average Annual Growth Rate(%)*1 (1983/84-1988/89)
1. GDP (Million NRs.)							
(1) at current prices	39,390	44,417	50,428	57,828	67,835	74,575	13.62
(2) at 1974/75 prices	22,262	23,630	24,645	25,299	27,765	28,189	4.84
2. Per capita GDP*2 (NRs.)							
(1) at current prices	2,489	2,734	3,024	3,379	3,862	4,136	10.16
(2) at 1974/75 prices	1,407	1,455	1,478	1,478	1,581	1,563	2.10

Source : Statistical Year Book of Nepal 1989, Central Bureau of Statistics.

Note : *1: Based on Geometric series.
*2: Population is estimated based on an annual grawth rate of 2,61 % *3 and the 1981 census population.
*3 Plausible rate in "Population Projection of Nepal 1981-2001", Central Bureau of Statistics, 1986.

Table A-1.2 PERCENTAGE DISTRIBUTION OF GROSS DOMESTIC PRODUST AT CURRENT PRICES (1982/83-1987/88)

Unit :Percent

Industrial Origin	1982/83	1983/84	1984/85	1985/86	1985/86	1986/88
Agriculture	56.52	57.30	53.87	52.66	52.35	52.06
Mining & Quarrying	0.25	0.28	0.32	0.24	0.23	0.17
Manufacturing	4.32	4.61	4.50	5.20	6.15	5.98
(a) Modern	3.02	3.41	3.37	4.02	5.01	4.97
(b) Cottage	1.30	1.20	1.13	1.18	1.14	1.01
Electricity, Gas & Water	0.38	0.40	8.44	0.68	0.65	0.58
Construction	7.04	6.54	0.07	7.91	8.14	8.72
Trade, Restaurant & Hotal	3.55	3.86	4.14	4.38	4.43	4.49
(a) Trade	3.17	3.46	3.75	3.92	3.98	4.05
(b) Hotal & Restaurant	0.39	0.40	0.39	0.45	0.45	0.44
Transport, Communication & Storage	6.30	6.27	6.22	6.19	5.77	5.49
Financial & Real Estate	7.68	7.46	7.70	7.82	7.72	7.33
Community & Social Services	7.67	7.23	8.31	8.26	8.28	8.05
GDP at factor Cost	93.73	93.94	93.56	93.33	93.74	92.87
Indirect Taxes	6.27	6.06	6.44	6.67	6.26	7.13
GDP at Market Prices	100.00	100.00	100.00	100.00	100.00	100.00

Source: Statistical Year Book of Nepal 1989, Central Bureau of Statistics.

Table A-1.3 FOREIGN TRADE

Unit:Million NRs.

Items	1982/83	1982/83	1984/85	1985/86	1986/87	1987/88
1. Exports (f.o.b.)	1,132	1,704	2,741	3,078	2,991	4,115
(a) India	843	1,161	1,602	1,241	1,302	1,568
(b) Other countries	289	543	1,139	1,837	1,689	2,547
2. Imports(c.i.f.)	6,314	6,514	7.742	9,341	10,905	13,870
(a) India	2,500	3,058	3,896	3,971	4,262	4,596
(b) Other countries	3,814	3,456	3,846	5,370	6,643	9,274
3. Trade Balance	-5,182	-4,810	-5,001	-6,263	-7,914	-9,755
(a) India	-1,656	-1,897	-2,294	-2,730	-2,960	-3,028
(b) Other countries	-3,526	-2,913	-2,707	-3,533	-4,954	-6,727

Source: Statistical Year Book of Nepal 1989, Central Bureau of Statistics.

Table A-1.4 BALANCE OF INTERNATIONAL PAYMENTS

Unit: Million NRs.

Items	1981/82	1982/83	1983/84	1984/85	1985/86	1986/87
A. Trade Balance	-3,452	-5,197	-4,823	-5,022	-6,286	-7,914
B. Service account	1,378	1,635	1,407	1,079	1,555	2,367
C. Unrequited Transfers	1,682	1,891	2,073	2,094	2,167	2,689
D. Current account	-392	-1,671	-1,343	-1,849	-2,564	-2,858
E. Capital account	774	924	1,203	1,270	1,811	2,281
F. Miscellaneous	120	72	14	-287	1,314	789
G. Change in Reserves	502	-675	-126	-866	-561	-212

Source: Statistical Year Bok of Nepal 1989, Central Bureau of Statistics.

Table A-1.5 BUDGETARY POSITION OF GOVERNMENT

Unit: Million NRs.

Item	1983/84	1984/85	1985/86	1986/87	1987/88	1988/89
1. Expenditures	7,437	8,395	9,797	11,513	13,678	19,520
.Regular	2,273	2,906	3,584	4,135	4,789	6,152
.Development	5,164	5,489	6,213	7,378	8,889	13,368
2. Receipts	4,286	4,840	5,817	7,260	9,399	11,894
.Revenue	3,409	3,917	4,644	5,975	7,320	9,300
.Foreign Grants	977	923	1,173	1,285	2,079	2,594
3. Surplus(+) or Deficit(-)	-3,151	-3,555	03,980	-4,253	-4,279	-7,626
4. Source of Financing Deficit						
.Foreign Loan & Reimbursement	1,671	1,755	2,501	2,706	3,191	6,296
.Internal Loan	1,577	1,800	1,404	1,645	1,088	1,330
5. Cash Balance	- 97	0	75	- 98	0	0

Source: Statistical Year Book of Nepal 1989, Central Bureau of Statistics.

Table A-1.6 INCOME AND EXPENDITURE OF WATER SUPPLY AND SEWERAGE CORPORATION (WSSC)

Unit: Thousand NRs.

Item	1984/85	1985/86	1986/87	1987/88	1988/89
1. Income	20,766	23,654	27,553	33,320	37,160
Operation Income	17,615	18,617	20,300	24,289	26,716
Others	3,151	5,037	7,253	9,031	10,444
2. Expenditure	45,663	48,784	42,615	55,400	77,852
Production	8,756	9,465	15,072	15,389	18,296
Distribution	4,397	3,680	4,885	6,438	9,206
Consumer's account	2,085	2,135	2,865	2,520	4,383
Administration	4,225	5,074	5,535	11,040	15,332
Quality Control	-	-	-	-	3,404
Electro-Mechanics	2,013	-	-	-	6,177
Sewerage	-	-	-	742	1,954
Depreciation	8,923	11,061	11,021	10,585	15,000
Others	15,264	17,369	3,720	8,686	4,100
3. Balance	-24,897	-25,130	-15,062	-22,080	-40,692

Source: Information from WSSC.

Table A-2.1 POPULATION AND POPULATION GROWTH RATE BY URBAN AND RURAL AREAS IN NEPAL AND KATHMANDU VALLEY

Location	Population				Average Annual Growth Rate(%) *1		
	1952/1954	1961	1971	1981	1952/54-1961	1961-1971	1971-1981
Nepal	8,256,625	9,412,996	11,555,883	15,022,839	1.64	2.05	2.62
urban	235,892	336,222	461,938	956,721	4.43	3.18	7.28
rural	8,020,733	9,076,774	11,094,045	14,066,118	1.55	2.01	2.37
Kathmandu Valley	410,995	459,990	618,911	766,345	1.41	2.97	2.14
urban	178,699	202,609	249,563	363,507	1.57	2.08	3.76
rural	232,296	257,381	369,348	402,838	1.28	3.61	0.87
Kathmandu District	193,782	224,867	353,756	422,237	1.86	4.53	1.77
urban	105,247	121,019	150,402	235,160	1.75	2.17	4.47
rural	88,535	103,848	203,354	187,077	1.99	6.72	-0.83
Lalitpur District	133,753	145,301	154,998	184,341	1.03	0.65	1.73
urban	41,334	47,713	59,049	79,875	1.79	2.13	3.02
rural	92,419	97,588	95,949	104,466	0.68	-0.17	0.85
Bhaktapur District	83,460	89,822	110,157	159,767	0.92	2.04	3.72
urban	32,118	33,877	40,112	48,472	0.67	1.69	2.10
rural	51,342	55,945	70,045	111,295	1.07	2.25	4.63

Source: Population Monograph of Nepal, Central Bureau of Statistics, 1987
Note: Urban area is defined as comunity with 5,000 population or more.
*1: Exponential model

Table A-2.2 PLANTED AREA OF PADDY AND MAIZE IN NEPAL AND THE STUDY AREA

Unit: Hectare

	1982/83	1983/84	1984/85	1985/86	1986/87	1987/88
Nepal						
Paddy	1,264,840	1,334,200	1,376,860	1,391,040	1,333,360	1,423,290
Maize	510,770	503,770	578,720	614,680	626,710	673,810
Total	1,775,610	1,837,970	1,955,580	2,005,720	1,960,070	2,097,100
Kathmandu Valley						
Paddy	20,730	21,120	22,020	20,790	20,580	20,240
Maize	20,260	19,370	18,850	18,700	18,400	17,410
Total	40,990	40,490	40,870	39,490	38,980	37,650
Kathmandu District						
Paddy	11,550	11,000	11,240	11,200	11,100	10,460
Maize	10,210	10,210	9,600	9,500	9,200	8,890
Total	21,760	21,210	20,840	20,700	20,300	19,350
Lalitpur District						
Paddy	3,950	5,290	5,560	4,700	4,680	4,590
Maize	7,620	6,730	6,950	7,000	7,000	6,240
Total	11,570	12,020	12,510	11,700	11,680	10,830
Bhaktapur District						
Paddy	5,230	4,830	5,220	4,890	4,800	5,190
Maize	2,430	2,430	2,300	2,200	2,200	2,280
Total	7,660	7,260	7,520	7,090	7,000	7,470

Source: Statistical Year Book of Nepal 1989, Central Bureau of Statistics.

Table A - 2.3 PRODUCTION OF PRINCIPAL INDUSTRIES

Products	Unit	1981/ 1982	1982/ 1983	1983/ 1984	1984/ 1985	1985/ 1986	1986/ 1987	1987/ 1988
Jute Goods	Metric ton	15,502	19,619	21,323	20,026	16,389	18,289	17,198
Sugar	Metric ton	20,764	22,357	17,496	11,039	15,190	24,565	30,040
Cigarettes	In lakh sticks	28,345	32,090	37,407	42,520	47,410	56,000	60,460
Leather	1,000 pieces	1,637	2,800	2,770	2,247	2,001	2,877	1,509
Bricks & Tiles	1,000 pieces	20,884	30,689	29,760	25,254	28,451	33,876	34,629
Cotton Textiles	1,000 metres	6,862	7,966	10,240	10,533	14,118	17,822	9,914
Cement	Metric ton	30,378	36,959	39,225	31,479	96,043	151,631	215,010

Source: Statistical Year Book of Nepal 1989, Central Bureau of Statistics.

Table A - 2.4 NUMBER OF MANUFACTURING INDUSTRIAL ESTABLISHMENTS AND EMPLOYEES IN NEPAL AND KATHMANDU VALLEY

Region	No. of Industrial Establishments *1		No. of Persons Engaged	
	1981/82	1986/87	1981/82	1986/87
Nepal	4,903	9,359	81,050	152,579
Kathmandu Valley	798	1,504	16,315	52,863
Kathmandu District	521	819	10,582	30,746
Lalitpur District	148	423	3,476	15,673
Bhaktapur District	129	262	2,257	6,444

Source: Statistical Year Book of Nepal 1989, Central Bureau of Statistics.

Note : *1 Establishment with ten or more employees.

Table A - 2.5 GROSS OUTPUT, GROSS INPUT AND VALUE ADDED OF MANUFACTURING INDUSTRIES IN NEPAL AND KATHMANDU VALLEY

Unit: Million Nrs.

Region	Gross Output		Gross Input		Value Added	
	1981/82	1986/87	1981/82	1986/87	1981/82	1986/87
Nepal	7,098.2	13,537.6	4,736.9	9,048.1	2,361.3	4,489.5
Kathmandu Valley	1,148.1	2,809.6	753.6	1,674.6	394.5	1,135.0
Kathmandu District	724.3	1,911.7	466.1	1,146.7	258.2	765.0
Lalitpur District	142.0	692.8	88.8	395.7	53.2	297.1
Bhaktapur District	281.8	205.1	198.7	132.2	83.1	72.9

Source: Statistical Year Book of Nepal 1989, Central Bereau of Statistics.

Table A - 2.6 STATISTICS OF TOURIST ARRIVALS

Item	1981	1982	1983	1984	1985	1986	1987
Total Number	161,669	175,448	179,405	176,634	180,989	223,331	248,080
Growth Rate (%)	-0.8	8.5	2.3	-1.5	2.5	23.4	11.1
Number by Purpose							
Pleasure	127,709	136,693	132,350	140,592	128,217	163,958	184,979
Trekking	21,668	23,507	24,198	15,010	28,707	33,609	36,164
Business	6,379	7,374	9,801	8,137	10,416	10,863	11,781
Official	5,674	7,166	8,479	9,399	9,230	8,825	8,882
Others	239	708	4,577	3,496	4,419	6,076	6,274
Gross Foreign Exchange Earnings (US$1,000)	44,935	33,441	35,667	41,273	39,185	50,841	60,229
Growth Rate (%)	-13.0	-25.6	6.7	15.7	-5.1	29.7	18.5

Source: Statistical Year Book of Nepal 1989, Central Bureau of Statistics.

Table A - 2.7 STATISTICS OF HOTEL INDUSTRY

Item	1981	1982	1983	1984	1985	1986	1987
Number of Rooms	24,675	26,038	25,033	22,361	21,862	23,784	23,194
Kathmandu Valley	20,512	22,038	20,695	19,092	18,356	19,778	19,097
Other Areas	4,163	4,000	4,338	3,269	3,508	4,006	4,097
Number of Beds	49,047	50,534	48,607	43,728	42,724	47,266	45,385
Kathmandu Valley	40,343	42,432	40,031	37,288	35,453	38,960	37,221
Other Areas	8,704	8,102	8,576	6,440	7,271	8,306	8,164
Arrivals	202,268	193,788	179,638	175,044	175,652	231,152	224,835
Guest Nights	527,206	528,773	475,314	516,719	452,166	571,769	623,282
Average Guest Nights per arrivel	2.6	2.7	2.6	3.0	2.6	2.5	2.7
Percentage of Bed Occupancy							
Kathmandu Valley	35.8	35.5	32.9	40.2	35.9	41.8	46.2
Others	31.8	29.3	28.9	31.3	28.9	29.4	40.5

Source: Statistical Year Book of Nepal 1989, Central Bureau of Statistics.

Table A-2.8 CASES OF WATER-BORNE DISEASES IN KATHMANDU VALLEY

Diseases	1980		1981		1982		1983		1984		1985		1986		1987	
	No.	%	No.	%	No.	%	No.	%	No.	%	No.	%	No.	%	No.	%
Gastro-Enteritis	2954	69.5	3011	69.2	2646	57.3	3497	50.6	3371	48.4	2430	38.1	2260	37.4	4274	64.3
Cholera	24	0.6	116	2.7	-	-	115	1.7	4	0.1	-	-	-	-	10	0.1
Enteric Fever	76	1.8	98	2.3	152	3.3	343	5.0	410	5.9	489	7.7	476	7.9	322	4.8
Diphtheria	2	0.0	9	0.2	10	0.2	-	-	-	-	-	-	-	-	-	-
Measles	261	6.2	225	5.2	157	3.4	322	4.7	196	2.8	74	1.2	249	4.1	45	0.7
Hepatitis	81	1.9	283	6.5	645	13.9	343	5.0	478	6.9	701	11.0	486	8.1	511	7.7
Dysentry	261	6.2	199	4.6	275	5.9	321	4.7	491	7.0	474	7.5	368	6.1	246	3.7
Tetanus	40	0.9	38	0.9	39	0.8	61	0.9	51	0.7	38	0.6	37	0.6	20	0.3
Meningitis	14	0.3	8	0.2	68	1.5	493	7.2	236	3.4	139	2.2	273	4.5	103	1.6
Others	534	12.6	358	8.2	633	13.7	1392	20.1	1729	24.8	2014	31.7	1886	31.3	1113	16.8
Total	4243	100	4345	100	4625	100	6892	100	6966	100	6359	100	6035	100	6644	100

Source: Statistical Year Book of Nepal 1989, Central Bureau of Statistics.

Table A - 2.9 URBAN CONSUMER PRICE INDEX IN KATHMANDU
(BASE YEAR: 1973/73 = 100)

Categories	1982/ 1983	1983/ 1984	1984/ 1985	1985/ 1986	1986/ 1987	1987/ 1988
Food and Beverages	266	278	280	337	392	434
Restaurant Meals	306	304	327	384	436	459
Grains and Cereal Products	256	253	239	294	344	372
Pulses	267	291	330	371	386	449
Vegetables	301	346	349	460	523	570
Spices	347	330	359	394	512	657
Meat, Fish and Eggs	306	346	364	415	499	527
Milk and its products	201	205	243	290	316	367
Oil and Clarified Butter	275	335	350	353	455	582
Sugar	204	196	206	280	274	274
Beverages	221	244	247	276	302	322
Non-Food and Services	244	261	284	317	350	377
Cloths, clothing and Sewing Services	221	234	245	271	295	313
Footwear	232	246	248	286	308	321
Housing	291	319	356	401	442	490
Transport and Communications	242	244	272	281	297	316
Medical and Personal Care	199	213	238	277	307	330
Education, Reading Materials and Recreation	261	273	292	338	384	394
Cigarettes	168	171	186	189	207	225
Overall Index	258	271	282	330	376	412

Source: Statistical Year Book of Nepal 1989, Central Bereau of Statistics.

APPENDIX B
TOPOGRAPHY AND GEOLOGY

APPENDIX B
TOPOGRAPHY AND GEOLOGY

LIST OF FIGURES

1. DATA COLLECTION AND FIELD RECONNAISSANCE

The purpose of geological and topographic survey is to obtain general topographic and geological conditions of the Kathmandu valley. Examination on potentiality of the groundwater recharge and selection of potential damsites for reserving surface water were made basing on the obtained information regarding topography and geology. The study of topographic and geological surveys has been made in the period between the beginning of February and the end of March, 1989.

The study has been made from collected and reviewing of the existing geologic data and aerial photographs, which were taken in 1978 and 1979. Field reconnaissance has been made widely in the study area for collection of topographic and geological data in natural condition. The field reconnaissance has been carried out also for confirming the results of interpretation of the aerial photographs.

In the initial stage of this study, core drilling was programmed, with total depth of 150 meters for ten (10) holes to obtain the general information on permeability of materials in the main riverbeds for assuming the potentially of groundwater recharge. The scope of study has been slightly modified with the progress of the study because it is cleared that the quantity of the groundwater is limited. For obtained general geological information, core drilling for 60 m (4 holes) has been allocated from the total scheduled drilling amount to the selected potential damsite on the way of study accordingly.

The location of ten bore holes are shown geological map (Fig. B-1.1). The drilling results of these bore holes are shown in Data Book B (B-1 Drill Log). The perforated PVC (polyvinyl chloride) pipes were installed after completed of drilling to observe of groundwater level for each hole respectively.

2. LANDFORM CLASSIFICATION BY AERIAL PHOTOGRAPHS

2.1 Interpretation of Aerial Photographs

Landform classification has been carried out by interpretation of aerial photographs for obtaining topographic features of the Kathmandu Valley. The aerial photographs interpreted are 38 sheets (6 courses) in total on the approximate scale of 1:60,000 at and around Greater Kathmandu. The landform classification map has been prepared with connecting interpreted sheets of stereo pairs as an uncontrolled mosaic.

The Kathmandu Valley has the shape of a indented an circular basin occupying about 525 km^2. Greater Kathmandu is situated in the western central part of the basin. The central part of the Kathmandu Valley consists of very gentle and flat lands at elevations of 1,300 m to 1,400 m, and the flat land is surrounded by high mountain ranges of more than 2,000 m in elevation. Phulcoki in the southern watershed of the valley has the maximum elevation of 2,762 m. Sheopur has secondary high elevation of 2,726 m in the northern watershed.

The Bagmati river is the only river, and drains all the water collected into the valley basin to the south. The Bagmati river dissects the mountains of Mahabharat range to the southwest of the valley. The major tributaries of the Bagmati river are the Bisnumati, the Bagmanti and Manohara, which rises in the northern and northeastern watersheds, and they flow to the south to the southwest and join near Greater Kathmandu.

The Hanumante river, which flows to the west, and the Balkhu kh, which flows to the east, are the main tributaries in the central part of the valley. The tributaries which rise in the southern water shed are the Godawari kh., the Khodu kh. and the Nakhu kh. They flow from the south to the north to join with the Bagmati river near Greater Kathmandu.

The Kathmandu Valley is represented by contrasting two types of land forms; very gentle lands and high relief areas. The landform of the Kathmandu Valley is mainly classified into three categories of flat lands, high relief areas and gently inclined slopes by interpretation of aerial photographs. The landform classification map indicates hazard areas such as intensively weathered areas and landslide areas also. The landform classification map is shown in Fig. B-2.1.

2.2 Landform Units Classification

The landform units classified and their characteristics are mentioned below.

(1) Alluvial low plains: low flatland developed along the river channel

(2) Terraces: flat facets along the major rivers with some height differences above the alluvial low plains

(3) Higher gentle plain I: areas with highest elevation of about 1,600 m in the southern area of the valley bottom; the area is composed of subrounded to rounded gravel predominantly.

(4) High gentle plain II: areas with elevation of about 1,550 m, overlying the following high flat plains in the valley bottom; these areas are overlain by the high gentle plain I; these are composed of subrounded to rounded gravel with intercalating thin silty clay layer.

(5) High flat plains: flat plains composed of lacustrine deposits in

the bottom portions of the valley; the plains are bounded by steep cliffs with big gaps from alluvial plains.

(6) Talus and alluvial fan: moderately inclined slopes at skirts of the surrounding mountains and at outlets of rivers from steep mountains to flat plains of the valley bottom.

(7) High relief area and mountains: mountains surrounding flat plains of the valley bottom; these mountains are composed of bedrocks of Precambrian and Devonian age.

(8) Intensively eroded badlands: rugged lands by intensive erosion; irregular narrow lands are only remained.

(9) Landslides: landslides occurred in the middle reaches of the Nakhu kh.

(10) Steep cliffs and slopes surrounding flat and gentle plains: steep cliffs surrounding high flat and gentle plains composed of lacustrine deposits and gravel deposits

(11) Gentle slopes below high flat plains: gentle plains developed between steep cliff and alluvial low plains; these plains are probably produced by erosion of the steep cliffs.

(12) Low hills: gentle low hills in the flat plains of the valley bottom; these hills are composed of the same bedrocks as the surrounding high mountains.

2.3 Hazard Prone Areas

Based on the landform classification map, hazard prone areas are selected. The hazard areas are represented by the landslide areas and the badlands where erosion develops intensively and gullies develop frequently. The intensively eroded areas and gully developed areas are observed in the northern parts of the valley bottom. On the contrary, landslides are concentrated into the middle reaches of the Nakhu kh. The direct causes of landslides seem to depend on the river erosion at foot parts of the flat plains.

In the hazard prone area, civil works in a large scale are not recommended to execute without proper remedy measures because reliable foundations for the structures will not be found easily, and maintenance and repair of the structures will be required endlessly.

2.4 Groundwater Recharge Potential Areas

Potential areas for groundwater recharge are confined in the high flat plains and alluvial low plains because exploitation of groundwater in the surrounding high mountains would be difficult. No potential damsites are to be found on the flat plains except where the low hills are not composed of bedrocks because dam foundation rocks are not to be expected in the flat plains within a reasonable depth. Hazard prone areas have also to be eliminated from the potential damsites.

3. GENERAL GEOLOGY OF THE STUDY AREA

3.1 Introduction

The Kathmandu Valley is composed of two series of geological successions; one is Quaternary, which overlie the lower portions of the valley; the other is Precambrian to Devonian, which surrounds the Kathmandu Valley. The geological map prepared in this study is mainly based on interpretation of aerial photographs at an approximate scale of 1:60,000 with supplemental field point checking. The geological map is shown in Fig.B-1.1

The boundaries of the Kathmandu group, which consists bedrocks of the Kathmandu Valley, are approximately followed by Geological Map of Central Nepal on the scale of 2,500,000. The previous reports such as Natural Gas Resources in Kathmandu Valley (JICA, 1980) and Kathmandu Water Supply and Sewerage Scheme (WHO,1973) are referred for the compilation of the geological map.

Geological units in the study area are summarized as follows:

QUATERNARY	River deposits
	Talus and fan deposits
	Terrace deposits
	Predominant gravel deposits
	Gravel and clay deposits
	Arenaceous deposits (lacustrine deposits)
	Intermediate type of arenaceous and argillaceous deposits (lacustrine deposits)
	Argillaceous deposits (lacustrine deposits)
PRECAMBRIAN to DEVONIAN (Kathmandu formation)	Crystalline limestones, quarzites (Chandragiri formation)
	Phyllites, sandstones, sandy limestones (Tistung formation)
	Augen gneiss, banded gneiss

3.2 Geological Units

Materials of geological units classified are summarized below.

3.2.1 Quaternary

(1) River deposits: sand and clayey materials which are eroded from the lacustrine deposits with small gravels supplied from the surrounding high mountains occasionally.

(2)Talus and alluvial fan: angular to sub-angular gravel with clayey soil, which was removed fallen from the steep slopes by gravity and washed out from valleys.

(3)Terrace deposits: flat plain facets underlain by rounded gravel with sandy and clayey soil; these facets have some height differences from the flat plains composed of river deposits

(4)Predominant gravel deposits: poorly sorted thick layers of sub-rounded to rounded gravel deposits in the southwestern part of the Kathmandu valley bottom; this gravel layer is in semi-consolidated condition generally; this gravel layer has the maximum thickness of 50 m to 70 m approximately.

(5)Gravel and clay deposits: thick layers composed of sub-rounded to rounded gravel and clayey layers overlain by the predominant gravel deposits; this layer overlies the lacustrine deposits directly in the southwestern part of the valley bottom; the maximum thickness of this deposits is 50 m to 70 m approximately; this deposit and to predominant gravel deposits are in sub-horizontal or dip about 5 deg. to the north.

(6)Arenaceous deposits (lacustrine deposits): whitish sandy materials supposed to be supplied mainly from erosion of the gneissose rocks which occupy the northern mountain ranges.

(7)Intermediate type of arenaceous and argillaceous deposits (lacustrine deposits): intercalation of clayey and sandy layers occupying the central part of valley bottom from the northwest to the southeast; this layer includes silty clay or silty sand layers also; the materials of this layer seem to be supplied from limestones of Chandragiri formation and phyllites and sandstones of Tistung formation mainly.

(8)Argillaceous deposits (lacustrine deposits): dark grayish thick clay layer in the western and central southern parts of the valley bottom; the clayey materials of this layer is considered to be supplied from the erosion of the limestones of Chandragiri formation, which underlies mountain ranges in the southern marginal parts of the valley.

3.2.2 Precambrian to devonian

(1)Chandragiri formation: very hard crystalline limestones and quarzites are main component rocks of this formation. The crystalline limestones have sandstone like textures in general.

(2)Tistung formation: this formation is mainly composed of phyllites, sandstones and sandy limestones; weathering on phyllites are generally developed intensively and they are weak; this formation seems to be the source for silty materials of the lacustrine deposits.

(3)Augen gneiss and banded gneiss: these rocks dominate the northern and northeastern mountain ranges of the valley; arenaceous deposits of the lacustrine deposits were definitely supplied from these gneissose rocks.

3.3 Gravel Deposits in the Kathmandu Valley

Predominant gravel deposits and intercalation of gravel and clay deposits are confirmed in the southern parts of the valley bottom. These deposits are classified into two types. The upper zone is mainly composed of sub-rounded to rounded gravel of 10 cm to 20 cm on an average in size. These gravel layers are in semi-consolidated condition with poor sorting. The lower zone is the intercalations of gravel layers and silty clay layers of 1 m to 2 m in thickness. The lower gravel and silty clay layers overlie the lacustrine deposits directly.

These gravel layers are only found in the southern bottom part of the Kathmandu valley. The gravel layers are mainly composed of the calcareous schistose sandstones, and dip gently to the north in general, though the lacustrine deposits are in sub-horizontal or dip to the south gently.

Judging from the facts observed, these gravel layers seem to be supplied mainly from the basins of the Nakhu kh. and Lele kh. These gravel deposits and gravel and clay deposits seem to be washed out from these southern river basins in the final course of dissection of the southern outlet of the Kathmandu valley by the Bagmati river.

3.4 Lacustrine and Fluvial Deposits in the Kathmandu Valley

The lacustrine deposits are classified into three types, arenaceous sediments, argillaceous sediments and intermediate type of these sediments. This classification is made basing on the field observation, the results of electrical prospecting and logs of the existing wells.

Arenaceous deposits, which are composed of coarse to medium grain sand with small rock fragments, are surely believed to have been supplied from the northern mountainous areas underlain by gneissose rocks. Argillaceous deposits composed of clayey materials are considered to have been supplied from erosion of the limestones, which underlie the southern mountainous areas.

Intermediate type of the above-mentioned two kinds of deposits distribute in the central part of the valley between the areas composed of arenaceous deposits and argillaceous deposits. The materials seem to be supplied alternately from erosion of limestones and phyllites which underlie the western and southern mountainous areas.

Arenaceous materials are in loose condition and apt to be easily eroded by river flows, being formed as steep cliffs beside river channels. Gullies are developed in flat plains composed of arenaceous materials especially in the northern parts of the valley bottom. The areas where gullies are frequently developed are recognized as badlands.

River flanks of the areas underlain by argillaceous materials appear to be very gentle in contrast to the areas underlain by arenaceous deposits. Since percolation of surface water seems to be relatively small in argillaceous deposits, cultivation of lands in the area underlain by argillaceous materials is considered to be more advanced than in the area underlain by arenaceous deposits in the northern parts.

Landslides are concentrically occurred in the area underlain by argillaceous materials especially in the middle reaches of the Nakhu kh. The reason why the biasedly occurred landslides in the area is mainly due to side erosion of river flows and remaining of higher pore pressure in the argillaceous materials because of fine grain size of the materials.

Intermediate type of deposits occupies the central part of the valley bottom from the west to the east. The materials of this type is composed of silty clay or clayey silt and intercalations of sandy layers and clayey layers. In the shallow zones of the materials, a small amount of water seepages are occasionally observed on the top of clayey layers along the boundaries between clayey layer and sandy layers, indicating impermeability of clayey layers. Percolation of the precipitation seem to be obstructed by the clayey layers in this area accordingly.

3.5 Basement Rock of the Kathmandu Valley

Several low hills are confirmed in the southwestern part of the valley bottom. These hills are on the line connecting Naikap, Kirtipur, Cobhar, Thanagau and Magargau from the northwest to the southeast. In the southeastern extent of this line, there is low hills near Baregau. The lower slopes of these hills near buried by the lacustrine deposits. The low hills are mainly composed of calcareous schistose sandstones.

Many mountain ridges extend to the valley bottom from the surrounding mountains, implying there are many buried ridges. The depth to Precambrian bedrocks from the ground surface is confirmed to range from more than 500 m to several ten meters by electrical prospecting and existing well logs. The ground surfaces of the Kathmandu Valley bottom is flat but the buried bedrock surface is estimated to be abound in irregular shapes and high reliefs.

4.POTENTIALITY OF GROUNDWATER RECHARGE

4.1 Introduction

Potentiality of groundwater recharge is to be outlined hereunder basing on the confirmed geological condition of the Kathmandu Valley, the results of electrical prospecting, and the collected data concerning the existing wells so far.

4.2 Lithofacies and Permeability

Regarding the groundwater recharge, potential rechargeable geological units are confined to the lacustrine deposits especially in the area underlain by arenaceous deposits because of the material and topographic condition. Mountain ranges surrounding the valley has no high possibility for groundwater recharge because of high relief topographic condition though several water springs are observed in the mountain ridges composed of sandy schistose limestones.

The central and southern parts of the valley bottom are underlain by argillaceous materials and intercalation of the argillaceous and arenaceous sediments. High potentiality of groundwater recharge will not be expected in these areas because of the presence of impervious materials. The arenaceous sediments are limited to the northern margin areas of the bottom parts of the Kathmandu valley. According to field survey, grayish clayey layers of 0.5 m to 1.5 m in thickness are observed intercalating with medium to coarse sandy materials in river flanks in the northern parts of the valley bottom.

As for the result of electrical prospecting, lower resistivities of several tens ohm-m are predominantly measured in the valley bottom. Relatively higher resistivities of more than 100 ohm-m to several hundreds ohm-m are measured in the northern marginal area where arenaceous materials are confirmed in river flanks along upstream tributaries of the Bagmati river. The high resistivity areas coincide fairly well with the areas underlain by arenaceous deposits.

In this study core drillings with field tests in boreholes were performed for measuring permeabilities of the materials surrounding the boreholes, and confirming general density of the materials along the river channels of the Dhobi kh., the Bisnumati and Bagmati rivers in the middle reaches of these rivers. The measured permeability coefficients in boreholes range from the order of $x10^{-2}$ cm/s to $x10^{-4}$ cm/s with the average value of $2x10^{-3}$ cm/s in the zones shallower than 20 m in depth.

4.3 Geological Formations as Percolation Conditions

According to drill logs of the existing wells, argillaceous materials intercalates with arenaceous deposits in the deeper extents even in the area where arenaceous deposits are present predominantly.

SPT, standard penetration test, was carried out in the boreholes for clarifying general density of the materials. The obtained N-values by SPT range more than 30 in the sections deeper than 10 m in depth, though the N-values ranges 10 to 20 even less than 10 in the shallow zones less than 10 m. The boreholes are located in the areas underlain by the arenaceous materials or the intermediate type materials. Increasing of N-values indicates of decreasing of the void ratio of the materials. That is, percolation ratio will be implied to decrease.

4.4 Recharge Area

Taking the above mentioned whole condition into consideration, the potentiality of groundwater recharge seem to be limited in the shallow zones of about 10 m to 15 m below the riverbeds in the area of the northern valley bottom in which arenaceous materials sediment dominantly in shallow zones. Remarkable drawdowns of the groundwater levels are observed in operating wells in the northern part of the valley. This is believed to indicate that the groundwater has been over exploited, and groundwater recharge has not been attained sufficiently in natural condition.

5. ENGINEERING GEOLOGY OF POTENTIAL DAMSITE

5.1 Introduction

Since further groundwater exploitation is assumed to be difficult because of poor water quality and drastically decreased groundwater table in the operating wells, the scope of study has been slightly modified to add the study on potential reservoirs to store surface water effectively in the Kathmandu Valley.

5.2 Screening of Damsite

Field reconnaissance has been carried out on about 40 candidate damsites for the selection of potential damsites. The screening of damsite selection has been made from geological and topographic approaches. The first priority for the potential damsite is given to the damsites at which foundation rocks are confirmed. The damsites which have wider dam crest and lower dam abutment slopes are rejected from the potential damsites from topographic view points.

The selected potential damsites are Nakhu dam, Lele dam, Balkhu dam, kodku dam and Sundarijal dam, situating on the middle to upper reaches of the Nakhu kh., the Lele kh., the Balkhu kh., the Kodku kh., and the Bagmati river.

Though the quantity is insufficient, total 60 m (4 holes) of core drillings were allotted to three damsites, Nakhu dam, Lele dam and Kodku dam, from the scheduled drilling quantities in the riverbeds of the northern and central parts of the valley. The core drillings were made near the damsite for confirming general foundation rock condition of the selected damsites.

5.3 Geological Condition of the Potential Damsites

Geological condition of the damsites will be summarized as follows basing on the field observation and drilling results.

5.3.1 Nakhu dam

Hard silicious schistose sandy limestones are the foundation rocks of this site. Cracks and slightly opened spaces are developed along schistosities. The schistosities of foundation rocks cross the assumed dam axis with the angle of about 30 deg., and they dip about 40 deg. to the downstream side. One borehole for 16.5 m was drilled at this site with recovering short cylindric and fragmental cores. Obtained permeability coefficients range in the order of $x10^{-3}$ cm/s.

Artesian water is confirmed at about 13 m in depth with the head of 1.4 m above the riverbed. Judging from the recovered core samples and the obtained relatively high permeability coefficients of the foundation rocks, weathering on the foundation rocks seem to be developed deeper at and around the damsite.

Predominant gravel deposits overlie the area behind the left abutment, being observed along valleys near the damsite. The gravel deposits are in semi-consolidated condition, and permeability of the materials will not be very high, probably in the order of $x10^{-4}$ cm/s. The detail properties, however, have to be confirmed in the future stage. The permeability of the gravel deposits will be closely related to the matters of water leakage from the reservoir.

The foundation rocks of silicious schistose sandy limestones crop out in the left abutment slope. However, the gravel deposits overlie the schistose limestones behind the left dam abutment. The confirmation will be also required on the extent of gravel deposits in the left abutment because this will affect the dam stability and construction cost. Whole drill logs of the recovered core samples from boreholes are referred to the data book.

5.3.2 Lele dam

Almost the same foundation rocks as at the Nakhu damsite are observed at this site. One borehole for 13.5 m was drilled near the damsite with recovering weathered schistose sandy limestones. Cracks are developed along schistosities, and they seem to cause recovery of short cores and fragmental samples by mechanical vibration during drilling. Bedrocks crop out continuously in the riverbed generally, and river deposits are almost not found at the damsite. The measured permeability coefficients in the borehole in the silicious schistose sandy limestones range in the order of $x10^{-4}$ cm/s.

A small saddle composed of the predominant gravel deposits are confirmed behind the left abutment. This saddle is so narrow that water leakage will be expected through this part after impounding water in this reservoir. Special treatment will be required for this saddle portion for preventing the water leakage. Since the gravel deposits are also found partly along a long ridge continued to the left abutment, the permeability of the gravel deposits and the detail extent of the zones underlain by the gravel deposits will be required to clarify in relation to the assumed high water level of the reservoir in the future stage.

5.3.3 Balkhu dam

Calcareous schistose sandstones were recovered from two boreholes, one for 18 m and the other for 12 m, were drilled at this site. Cracks are developed along schistosities, and weathering observed along the cracks. Poor core recovery and recovery of fragmental samples from this borehole seem to depend on these cracks and weathering with mechanical vibration.

This damsite has a steep v-shape topography and hard rocks crop out continuously along the riverbed. Lacustrine deposits seem to overlie the flat plains on the left abutment. Permeability coefficients measured in the boreholes in the foundation rocks range in the order of $x10^{-4}$ cm/s. Springs of artesian water were confirmed at the depth of 11 m and 18 m with the pressure of about 0.7 kg/cm^2.

5.3.4 Kodku dam

Almost the same type of rocks at Balkhu dam underlies this damsite. Vertical cracks are frequently developed in the foundation rocks at interval of 20 cm to 30 cm. The schistosity of foundation rocks dips to the downstream side with the angle of about 60 deg. The dam abutment slope form a steep v-shape to almost vertical topography.

Permeability coefficients of the foundation rocks are empirically estimated to be the same orders as measured at Balkhu damsite. Permeability of the lacustrine deposits has to be confirmed in the future stage along the ridge bounding the reservoir from the basin of the Godawari kh.

5.3.5 Sundarijal dam

The foundation rocks of the damsite are augen gneisses. Continuous outcrops of hard gneissose rocks are observed along the riverbed. Rocks crop out in the left bank of the river; however, outcrops of the rocks are not observed in the upper slopes of the right bank. Weathering accordingly seems to be developed more on the right abutment than the left abutment. Weathering on gneissose rocks develops irregularly in the upstream reaches of the Bagmati river. Therefore, detail development of weathering of the damsite has to be confirmed in the future stage.

Generally, extraordinarily higher permeability is not expected on the same type of rocks observed at the damsite after removing weathered zones of the foundation rocks. Only thin river deposits are observed at and around the damsite.

5.4 Type of Dam

Though total 60 m (4 holes) of core drillings were performed at three potential damsites, the work quantity is insufficient for clarifying the properties of the foundation rocks. Generally rock fill dams seem to be recommendable for all selected potential damsites according to the confirmed geological condition so far.

However, topographic conditions of the most damsites seem to be suitable for concrete gravity dams. Since rocks, which crop out at the damsites, will be expected to be firmer and less pervious with increasing of depth in general, the foundation rocks have to be confirmed on their properties by deeper drillings with physical and mechanical tests in the future stages. Based on the result of the further investigation, the preferable types for the dams have to be selected.

5.5 Proposed Borrow Areas

Borrow sites for construction materials for a rock-fill type dam are tentatively proposed as follows for each potential damsite.

5.5.1 Nakhu dam

Impervious core materials will be obtainable from weathered calcareous sandstones or limestones of mountain slopes of Bhaga Ban which is the mountain range continued to the right abutment of the damsite. Rock materials will be expected from the deeper fresh rocks of calcareous sandstones and limestones of Bhaga Ban.

5.5.2 Lele dam

The same sources as the Nakhu dam will be considered to be preferable.

5.5.3 Balkhu dam

Weathered soil of limestone for core materials will be collected from Cobhar and lower ridges of southern mountains of Kisipiri. Rock materials will be supplied from the quarry site at Thankot or southern mountains of Kisipiri.

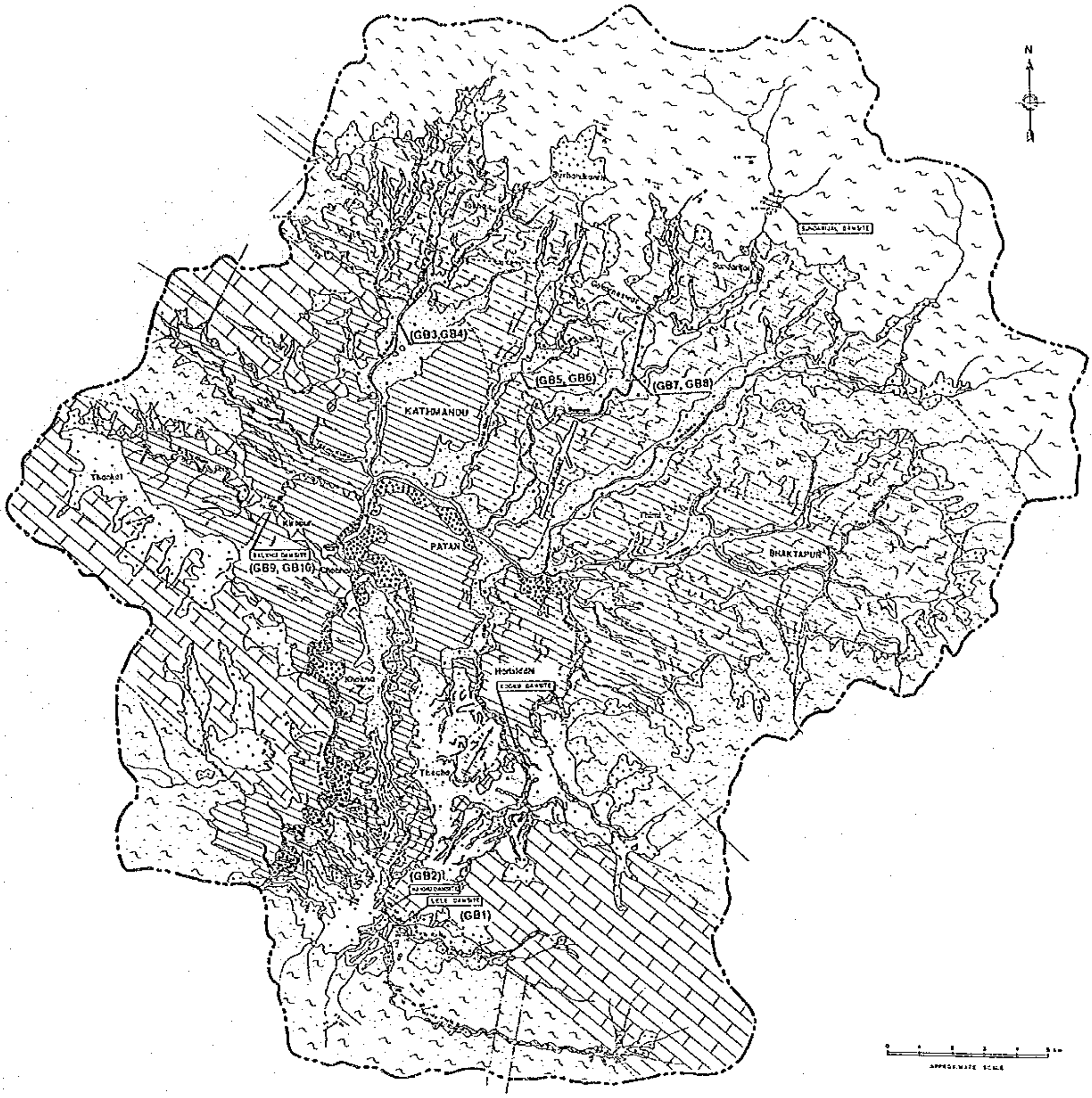
5.5.4 Kodku dam

Favorable core materials seem to be collectible from the weathered limestones in the western neighboring low hills. Crystalline limestones at Godawari quarry site or eastern mountains of Baregau will be promising for rock materials.

5.5.5 Sundarijal dam

The surrounding area of the damsite is very steep, and weathering on bedrocks are developed in general. Therefore, careless excavation will cause heavy sedimentation into the conceivable reservoir. For avoiding such situation impervious core materials and rock materials have to be expected in the upstream reaches of the Bagmati river or upper parts of Manicur Dar.

FIGURES



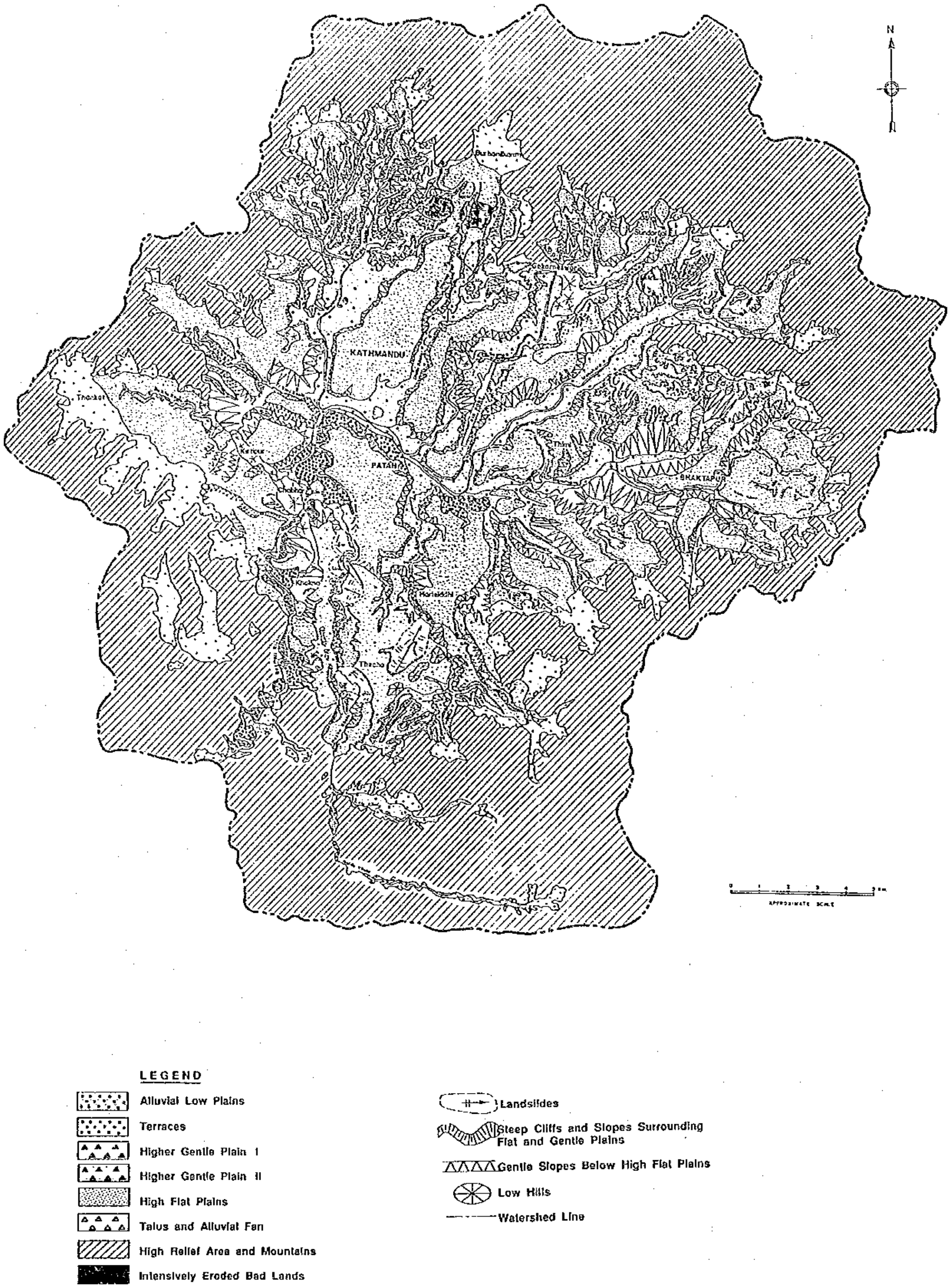
LEGEND

Quaternary
- River Deposits
- Talus Deposits and Fan Deposits
- Terrace Deposits
- Predominant Gravel Deposits
- Gravel and Clay Deposits
- Arenaceous Deposits (Lacustrine Deposits)
- Intermediate Type of Arenaceous and Argillaceous Deposits (Lacustrine Deposits)
- Argillaceous Deposits (Lacustrine Deposits)

Kathmandu Group (Precambriam -Devonian)
- Chandragiri Formation: Crystalline Limestone, Quartzites
- Tistung Formation: Phyllites, Sandstone, Sandy Limestones
- Augen Gneisses, Banded Gneisses

- Landslides
- Steep Cliffs
- Gentle Cliffs
- Watershed Line
- Dip and strike of Bedding Planes and Schistosity
- Water Spring
- Lineaments
- (GB1) Boreholes in this Study

HIS MAJESTY'S GOVERNMENT OF NEPAL GROUND WATER MANAGEMENT PROJECT IN THE KATHMANDU VALLEY JAPAN INTERNATIONAL COOPERATION AGENCY	Fig. B-1.1	GEOLOGICAL MAP OF THE KATHMANDU VALLEY



HIS MAJESTY'S GOVERNMENT OF NEPAL GROUND WATER MANAGEMENT PROJECT IN THE KATHMANDU VALLEY JAPAN INTERNATIONAL COOPERATION AGENCY	Fig. B-2.1	LANDFORM CLASSIFICATION MAP OF THE KATHMANDU VALLEY

APPENDIX C
METEOROLOGY AND HYDROLOGY

APPENDIX C
METEOROLOGY AND HYDROLOGY

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1. GENERAL

1.1 Introduction

This Appendix describes the results of meteorological and surface water hydrological study carried out during the periods from January 1989 to February 1990. Field investigations are made in the Kathmandu valley during two periods from January to March and from August to October 1989. Data and information are collected at sites and from authorities concerned. The collected data and information obtained are used for studies in Japan.

Investigation and studies are carried out to clarify the natural conditions in the study area in order to assess the potentiality of surface water resources. The results are incorporated in the water balance simulation study described in Appendix-F to formulate the overall development plan for municipal water supply. The objective of the study covers the following items.

(1) to collect and study the meteorological and surface water hydrological data in the Kathmandu valley

(2) to estimate 5-day runoff discharge for continuous 46 years period from 1941 through 1986 at each control point for the water demand and supply balance study.

(3) to grasp the present condition of the land use and existing irrigation systems and to estimate the present water use for irrigation

(4) to estimate peak discharge of probable flood for promising dam design

(5) to estimate sediment load to the reservoir of promising damsites

1.2 Study Area

Kathmandu valley is located at the upstream of the Bagmati river, which has its origin in the northern part oh the Kathmandu valley and flows to the Ganga through the mid-land mountain range and the Terai plain, at the latitude of 27°32'N to 27°49'N and the longitude of 85°12'E to 85°32'E geographically. The study area lies in the administrative district of Kathmandu, Lalitpur and Bhaktapur in Bagmati Zone.

The study area, shaped like a square with an area of 656 km^2 at valley outlet (585 km^2 at Cobhar), consists of very gentle and flat lands of which elevation is 1,300 m to 1,400 m, and the flat land is surrounded by high mountain ranges more than 2,000 m in elevation.

The Bagmati river is the only one river which drains whole water collected in the valley basin to the south. The Bagmati and its tributaries flow along eroding the fluviolacustrine deposits filled in the valley bottom. The major tributaries are nine (9) in total. They are Mai Khola, Nakhu Khola, Balkhu Khola, Bisnumati Khola, Dhobi Khola, Manohara Khola, Khodu Khola, Godawari Khola, Hanumante Khola in the order counting from the mouth. The Bagmati river dissects the mountains of Mahabharat range at the southwest of the valley.

2. AVAILABLE DATA

2.1 Meteorological Data

2.1.1 Rainfall data

There are 23 meteorological service stations in and around the study area currently being operated under the management of the Department of Hydrology and Meteorology (DHM), Ministry of Water Resources. All stations are equipped with standard rain gauge and/or automatic recording rain gauge. Their inventory are shown on Table C-2.1. The key station in the valley is located at Kathmandu airport. This station is well equipped with automatic recording instruments, whereas data processing does not follow last ten years.

A rainfall observation network was established in early 1970s with standard rain gauges. The stations were relatively concentrated in the lowland. A recording rain gauge was first introduced to the Kathmandu airport station in 1968. Since the mid 1980s, DHM has been constructing its network with recording rain gauges in the valley.

Daily rainfall records of eleven stations including the Kakani station located near the study area are collected from DHM. Their inventory and location are shown on Table C-2.1 and Fig.C-3.3, respectively. Duration of the collected data varies station to station and are shown on Fig.C-2.1.

For the purpose of supplementing the precipitation data in the mountainous zone of the study area, four automatic rain gauges have been installed with the standard rain gauges by the study team during the field investigation periods. The location of the station is included on the Fig.C-3.3 and obtained data is compiled in DATA BOOK.

2.1.2 Evaporation

The monthly value of evaporation of class A pan at Kathmandu airport stations are obtained from "Climatological Record of Nepal" (Ref. 3). This data are given in daily averages instead of monthly totals because of the relatively high percentage of missing data. The duration of the records are from 1976 to 1972.

2.1.3 Other meteorological data

(a) Air temperatures

Air temperature records at five stations; that is, the Kathmandu airport, Indian embassy, Khumaltar, Godawari and Nagarkot stations are collected. They are daily maximum, daily minimum, dry-bulb and wet-bulb temperatures. Frequency of observation varies from station to station: every three hours at the airport to once a day at Godawari. At every station, missing data is found in the records of almost every year.

(b) Relative humidity

Daily relative humidity at four station; that is, airport, Nagarkot, Khumaltar and Godawari are collected. The average of relative humidity observed at 8:40 and 17:40 are adopted to the daily relative humidity.

(c) Sunshine hour

The airport station had a Campbell sunshine recorder. The record of daily sunshine hour is dated back to 1968. However, missing data is there in the every year record. The Campbell sunshine recorder at the Khumaltar station was removed in 1978.

(d) Wind speed

There are only four stations which observe the daily wind speed; that is, Kathmandu airport, Nagarkot, Khumaltar and Shivapuri. The record of the Kathmandu airport between 1976 and 1984 is missing. Moreover, the record is not complete every year. The Shivapuri station has been newly established and the record is not published yet.

(e) Air pressure

There is only one station at Kathmandu airport which does observation of air pressure in the valley. Though the air pressure are observed at some times everyday, the average of the record at 8:40 and 17:40 are adopted to the daily air pressure. This parameter has been recorded since 1968.

2.2 Runoff Record

There are three gauging stations within the valley where water levels are regularly observed. They are Sundarijal, Gauri Ghat and Budhanilkantha stations. There were seven regular stations in the 1960s including these stations. However, observation at those stations near Sundarijal, Mahankal and Shyamdado was terminated in the early 1970s. Observation at Cobhar and Tika Bhairab stations were also terminated in the 1980s. The Cobhar station was one of the best equipped stations in the country, but closed. The Tika Bhairab station was closed because the location was not suitable for gauging station. Their inventory and locations are shown on Table C-2.2 and Fig.C-2.2, respectively.

Daily discharge at five stations; that is, Sundarijal Reservoir, Tika Bhairab, Cobhar, Gauri Ghat and Mahankal are collected during the field survey. The duration of collected records are shown on Fig.C-2.1. However, the attention should be paid into that only the data at Sundarijal are considered the natural runoff with long recording period. Because there exist a number of irrigation systems abstracting a certain amount of river water in their catchment. Therefore, the runoff data at Sundarijal are utilized for estimation of natural runoff at ungauged sub-basins. The daily discharge at Cobhar which is situated at almost outlet of the valley, having the catchment area of 585 km^2, are used for the calibration of the water demand and supply balance simulation study.

With the aim of obtaining hydrological information about stream runoff characteristics at upstream and downstream points along the tributaries and potential damsites, twelve stream gauging stations have been installed and discharge measurement are carried out during the field investigation periods. Their locations are shown on Fig.C-3.3.The results of discharge measurement are shown in Table C-2.3 and obtained data at new gauging station are compiled in DATA BOOK.

The data of direct discharge measurement are also collected from DHM to examine the rating tables for conversion from water level to the discharge and to calibrate the water balance study.

The peak discharge record of annual maximum flood in the study area at each station is obtained from DHM and peak discharge of maximum recorded flood in Nepal is obtained from "Surface Water Record of Nepal" (Ref. 4).

2.3 Sediment Data

Sampling of suspended sediment was done at the Cobhar station during the period between August, 1966 and July, 1978. The completeness of the daily record is varied from 54% in February to 99% in July in the period from

January, 1973 to December, 1977. The relation between sediment flux and discharge at time of sampling are developed from the data.

3. METEOROLOGY

3.1 Climate

The Kathmandu valley in the semi-tropics is characterized by a warm and temperate climate with the monsoon period from June to September, caused by the winds from the Bay of Bengal. Most rainfall occur during the monsoon season from June to September. The spring months from March May are characterized by showery and windy weather, higher humidity and pre-monsoon thunderstorms with occasional humidity and pre-monsoon thunderstorms with occasional hail. From September February, the skies are mostly cloudless with calm and windless night.

In winter months from December to February, rainfall is brought by the trade wind from the northwest. Occasional winter and early spring showers deposit show on the mountains around the edge of the valley. Dense fog frequently occurs in early mornings.

3.2 Rainfall

3.2.1 Reliability and correlation

The reliability and consistency of the collected records are examined by means of the double mass curve method as shown on Fig.C-3.1. The results shows good consistency of the data with some exceptions at Tokha before 1975, Sankhu and Nagarkot from 1978 to 1982.

As aforementioned, the duration of the observed record varies station to station. The lacking data are filled in using regression coefficient of each station in order to complete the data from 1940 through 1986 as a material for the water balance study. The regression equation applied in this estimate are expressed as follows.

$$R_a = a \times R_b$$

where, R_a : dependent variable
R_b : independent variable
a : regression coefficient

In this process, Kathmandu airport and Sundarijal are selected as the key stations taking into consideration the distribution of the stations, duration of the record, reliability and correlation to the other stations, etc. In case that Kathmandu airport has the lack of data, the data are filled in based on the data of Sundarijal and Indian Embassy, and the case of Sundarijal, the data estimated from Indian embassy and Sankhu are used to complete.

The regression coefficient "a" and correlation coefficient "r" for each station are presented in Tables C-3.1 and C-3.2 respectively. This table shows good correlations among the stations near each other which "r" are more than 0.9.

3.2.2 Rainfall characteristics

Daily rainfalls are completed to filled in using the regression coefficient and the daily rainfalls are processed to the monthly data.

Average value of the calculated monthly rainfall at respective stations and annual rainfall are shown in Tables C-3.3 and C-3.4, and completed 47 year monthly rainfall record at respective stations are shown in Table C-3.5 and their distributions are illustrated on Fig.C-3.2. The rainfall varies substantially according to the altitude. Average annual rainfall varies from 1,245 mm at Khumaltar in the valley bottom to 2,984 mm at Kakani in the mountain area, and monthly variation indicates that about 80% of the annual rainfall occurs during the rainy season from June September and that July or August is generally wettest month.

3.2.3 Annual isohyet and basin rainfall

For the purpose of the estimate of basin rainfall, Thiessen Polygons are established based on the data at the base nine stations. The weighted factors of respective stations are estimated as follows and the annual basin rainfall are calculated at 1,780 mm.

Station	Thiessen Coef.	Station	Thiessen Coef.
Tokha	0.129	Thankot	0.086
Sundarijal	0.123	Bhaktapur	0.130
Indian Embassy	0.099	Khumaltar	0.091
Sankhu	0.104	Godawari	0.155
KTM Airport	0.083	Total	1.000

However, since the almost existing rainfall stations are situated in the low area, these stations do not represent high mountain ranges. Taking into consideration the relation between annual rainfall and elevation derived based on the annual rainfall data, an isohyetal map is developed as shown on Fig.C-3.3. Based on this map, annual basin rainfall in the study area is estimated 1,912 mm, which is 1.07 of the estimate by the Thiessen Polygon

Method.

The estimated basin rainfall using this ratio 1.07 are summarized as follows.

Unit:mm

Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Total
19	21	32	71	125	309	509	491	252	68	7	8	1,912

3.3 Evaporation

The evaporation usually varies from day by day under the influence of air temperature, relative humidity and rainfall, etc. The evaporation rate for the period from March to October is high due to air temperature, while that in the period from November to February is relatively low due to low temperature.

Following table shows the monthly pan-evaporation at Kathmandu airport.

Unit:mm/day

Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Mean
2.4	3.0	4.1	5.0	5.0	4.7	4.5	4.6	3.7	3.3	2.6	1.9	3.7

3.4 Other Meteorological Condition

(a) Air temperature

The air temperature in the study area is much influenced by the southeast and the northwest monsoons prevailing in the wet and in the dry season, respectively. The monthly mean, monthly mean maximum and monthly mean minimum air temperature observed at five stations as mentioned in 2.1.3 are summarized in Tables C-3.6 and illustrated on Fig.C-3.4 for the airport. At the airport station, where the sub-tropical climate is predominant, the mean air temperature is 18°C. From December February, the weather is cool with a mean temperature about 11°C. From March November is warm season, having a mean temperature about 23°C. The highest temperature peak at the airport occurs in June, occasionally rises up to about 30°C. the coldest time is in the period from December to January and temperature rarely falls under 0°C.

(b) Relative humidity

Monthly relative humidity at stations are summarized in Table C-3.6, and illustrated on Fig.C-3.4 for the airport station. The average relative humidity at airport is about 77 % and varies from 63 % in the dry season to 84 % in the wet season as shown in Fig.C-3.4. The lowest relative humidity occurs in April, while the highest in July to December. The relative humidity in the project area is also subject to the influence of the said two monsoons and its seasonal variation is almost conformable to rainfall pattern of the study area.

(c) Sunshine hours

The monthly sunshine hours at two station as shown in Table C-3.5. The annual mean daily sunshine hours at the airport is 6.8 hours. The sunshine hours varies from 4.4 hours in July to 7.9 hours in March.

(d) Wind speed

The monthly wind speed at three station is compiled in Table C-3.6. The mean wind speed at Khumaltar is 4.7 km/hr (1.3 m/sec), varying from 3.6 km/hr (1.0 m/sec) to 5.8 km/hr (1.6 m/sec). Usually the highest occurs in April or May and the lowest is in November or in December.

(e) Air Pressure

The monthly air pressure at the airport is compiled in Table C-3.6. As seen in the table, annual mean air pressure is 864 mb.

4. RUNOFF STUDY

4.1 River System and Spring

4.1.1 River system

The study area is located in the catchment area of the Bagmati river and the surface water resources for the study area are the Bagmati river and its tributaries. The Bagmati river has its origin in Sivpuri Lekh situated at the northern border of the Kathmandu valley. All tributaries are originating from hilly region and drop into the Bagmati river. The schematic diagram and river profile are shown on Fig.C-4.1 and summarized bellow.

River	Drainage Area(km^2)
Bisnumati kh.	103.4
Dhobi kh.	28.9
Bagmati kh.	74.2
Manohara kh.	73.1
Hanumante kh.	91.2
Godawari kh.	45.1
Khodu kh.	34.6
Nakhu kh.	57.2
Balkhu kh.	43.0

4.1.2 Spring

The major springs exist in the Phulchauki - Chardragiri range, and springs in the Nagarjun - Naichal range are minor. They are situated at the feet of mountain range and utilized for municipal water supply and/or irrigation. In the field investigation, discharge measurement are carried out at some springs of which locations are shown on Fig.C-2.2 and the results are summarized below.

Unit: l/sec

	Feb./Mar.	Aug./Sep.
Baikhumuhul	3.4	4.0
Muldole	32.0	32.6
Godavari Kund	21.5	32.8
Hatatirtha	16.6	21.8
Sat Mul	198.0	-
Sesh Warayan	66.5	127.0
Kotoli Mul	58.5	-

4.2 Evaluation of Runoff Data

As aforementioned, Sundarijal is key station in order to estimate the natural runoff at ungauged sub-basins. The daily runoff record are reviewed, particularly in low water stage by checking of the discharge rating curve referring to the previous discharge measurement. As the result, the daily runoff record from 1967 to 1972 are considered to be reliable for low water analysis.

The annual runoff at Cobhar station which is situated at almost outlet of the valley having the catchment area of 585 km^2 is estimated at 500 MCM, and runoff coefficient is estimated at 45 %. The monthly runoff at Cobhar is shown in Table C-4.1 and summarized below.

Unit: m^3/sec

Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Mean
2.48	1.89	1.44	1.73	2.49	15.50	47.30	53.87	35.39	16.73	7.00	3.88	15.81

4.3 Estimate of Natural Runoff

4.3.1 Tank model

In the absence of long term runoff record required for the water balance simulation study, tank model analysis is executed to generate the stream flow at Sundarijal from rainfall records.

Prior to the tank model analysis, the rainfall data are examined as mentioned in the previous section, and prepared with modification using the ratio the relation between rainfall and elevation in the period from 1941 to 1986. Streamflow data are also examined and 6 years daily records are selected as the observed data from 1967 to 1972 to compare the calculated and observed data.

The tank model used in this study are composed of four tanks combined vertically and runoff outlet at each tank. The top tank represent the ground surface and top soil, and its output correspond to flood runoff. The second tank represent the sub-surface runoff and evaporation. The third tank and fourth tank correspond to base flow from the groundwater. In the course of the simulation, daily rainfall depth is put into the top tank and the depth of water released from a hole is calculated by the following equation.

$$I = a \times H$$

where,
- I : Depth of water released (mm/day)
- a : Coefficient of hole (1/day)
- H : Water depth above the hole.

The water from the bottom hole is put into the second tank and the same process is repeated up to the fourth tank. The depth of stream runoff is given as the sum of the water released from side holes.

Simulation calculations are conducted by computer until obtaining adequate accuracy between the observed streamflow records and calculated runoff. The results of calculations and determined models are shown on Fig.C-4.2. The calculated daily runoff data is processed into 5-day discharge for the water balance study as shown in Table C-4.4. The synthesized runoff and monthly variation at Sundarijal are presented on Tables C-4.2, C-4.3, and Fig.C-4.3, respectively and summarized below.

Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Mean
Runoff (m^3/sec)												
0.23	0.20	0.19	0.21	0.31	0.90	2.30	3.09	2.17	0.95	0.44	0.29	0.94
Specific Discharge (m^3/sec/100km^2)												
1.4	1.3	1.2	1.3	1.9	5.6	14.4	19.3	13.6	5.9	2.8	1.8	5.9

4.3.2 Estimate of natural runoff at ungauged sub-basin

The natural runoff at ungauged sub-basin required for water balance simulation study are estimated based on the synthesized runoff at the Sundarijal station using following equation.

$$Q_i = Q_s \times (R_i \times A_i)/(R_s \times A_s)$$

where,
- Q : natural runoff (m^3/sec)
- R : annual basin rainfall (mm)
- A : drainage area (km^2)
- i : for ungauged basin
- s : for Sundarijal stream gauge basin

In this process, the annual basin rainfalls are estimated at each sub-basin based on the isohyetal map shown on Fig.C-3.3, and the results are described in the water balance study in Appendix-F.

5. FLOOD STUDY

5.1 Procedure of Flood Study

Flood study is required for deciding design flood of promising damsite. However no flood record are observed at respective damsites. For the estimation of probable flood at ungauged damsites, it is generally conceivable to make use of the relationship between the probable flood runoff and drainage area, which is expressed by Creager's Equation.

Creager's Equation is introduced in some previous studies near the study area (Ref. 12 and 13) and expressed as follows:

$$Q = 46 \cdot C \cdot A^n$$
$$n = 0.89 \cdot A^{-0.048}$$

where,
- Q : Flood peak runoff (ft^3/sec)
- A : Drainage area (sq.mile)
- C : Coefficient depending upon the characteristic of the drainage basin

5.2 Frequency Analysis

Flood records are available at Cobhar, Sundarijal, Tika Bhairab, Gauri Ghat, Mahankal, Shyamdado and Burhanikantha stations in the study area. Their annual recorded peak discharge are shown in Table C-5.1. As seen in this table, it is noted that they mostly occurred for the period from the beginning of July to the end of August in the rainy season. For the frequency study, Cobhar, Sundarijal and Tika Bhairab stations are analyzed in terms of the recorded length. The annual peak discharge records are plotted on log-normal paper for each station as given on Fig.C-5.1.

Table C-5.2 shows the results of the frequency analysis by means of Iwai, Hazen, Gunbel and Pearson methods. The result of Pearson method, considered to be best fit as shown on Fig.C-5.1 are summarized as follows.

Unit:m^3/sec

Return Period	Sundarijal (505) (CA = 16 km^2)	Tika Bhairab (540) (CA = 42.5 km^2)	Cobhar (505) (CA = 585 km^2)
2	13.2	37.5	403.5
5	25.9	67.6	571.0
10	36.8	92.8	687.6
20	48.9	120.4	800.7
50	68.3	163.9	959.5
100	85.0	201.2	1,051.6
200	103.8	243.3	1,208.6
1,000	156.6	367.0	1,535.5

5.3 Creager's Envelop of the Recorded Flood

To evaluate the design flood at the damsites the recorded maximum floods in Nepal obtained from "Surface Water Records of Nepal" (Ref. 4) are plotted against the drainage area as shown on Fig.C-5.2. This figure includes Creager's Envelop Curve having the C-value of 42 corresponding to the recorded maximum floods. On this figure, number of flood records is not sufficient and especially for small drainage due to the lack of stream gauging stations in small drainage and the relatively short length of the stream gauging records.

Since data on flood record is insufficient to estimate each C-value, probable flood estimated in the existing and on-going project near the study area, which are Kulekhani, Kulekhani II, Marsyangdi, and Water Supply for Kathmandu-Lalitpur from outside the valley (Ref. 7, 8, 9 and 12) , are plotted on this figure.

5.4 Probable Flood at Damsites

The probable flood with recurrence internal of 2 - 1,000 year and probable maximum flood (PMF) at the damsites are estimated using each C-value derived from Fig.C-5.2. The results are shown on Table C-5.3 with reference of C-value and summarized as follows:

Unit: mm^3/sec

Return Period	C-value	Balkhu kh. (CA=37km^2)	Sundarijal (CA=30km^2)	Khodu kh. (CA=16km^2)	Lele kh. (CA=15km^2)	Nakhu kh. (CA=43km^2)
2	10	105	90	58	55	116
5	18	188	163	104	99	208
10	24	251	217	138	132	278
20	30	314	271	173	164	347
50	39	408	353	224	214	452
100	46	481	416	265	252	533
200	55	575	498	316	301	637
1000	77	805	697	443	422	891
PMF	107	1119	968	615	586	1239

6. SEDIMENT STUDY

6.1 Suspended Load

Sediment study is carried out to estimate the sediment yield in the study area and the result are used for the design of reservoir.

The rivers in the study area generally transport high sediment load due to the deforested land, steep slope in the mountain range and high rainfall intensity in the rainy season. Water of the Bagmati river and tributaries seems to be clear in the dry season, while it becomes muddy in the rainy season due to a large quantity of sediment transports from the upstream basin.

The Bagmati river and tributaries tend to frequent change the river course by every flood. Some portions at the existing weir sites are severely eroded and scoured by flood.

The transportation of the suspended load is depend on the flood occurring in the rainy season. The suspended load are plotted against the runoff discharge as shown on Fig.C-6.1. As seen on this figure, the relation between suspended load and water discharge is represented by following formula.

$$Q_s = 0.00398 \cdot Q^{2.003}$$

where, Q_s : Suspended sediment load (ton/day)
Q : Discharge (m^3/sec)

6.2 Sediment Load at Promising Damsites

Applying daily discharge of the Bagmati river at Cobhar during a period from 1965 through 1980, annual total sediment load at Cobhar having the catchment area of 585 km^2 is computed by above mentioned formula. The average suspended sediment load for 16 years is 0.69 million tones per year. The design sediment load is estimated at 1350 tones /km^2/year, allowing 15 % for unmeasured bed load. For soil bulk density of 1.2 g/cm, this is equivalent to an annual depth of 1.2 mm/year over the catchment area.

7. WATER USE FOR IRRIGATION

Generally, water use is related to the activities like irrigation, drinking water supply, industrial, livestock and other domestic purpose. While the municipal water supply are studied in Appendix-G and the other water use out of irrigation can be considered to be small, water use on irrigation is described in this chapter.

7.1 Land Use and Cropping Pattern

7.1.1 Present land use

Figure C-7.1 shows present land use in the study area. Major part of the study area is occupied by the cultivated land. In order to grasp the extent of the cultivated land, land utilization map is collected from Survey department. The detailed information and data is obtained from the Land Utilization Report on the Land Resources Mapping Project (Ref. 16).

Most of the land within the valley rim is used for agriculture. The hilly land is forested or left as shrub, but party terraced for cultivation near the villages.

The agricultural land are classified into lowland area (Khet) and upland area (Pakho). Further, lowland area is classified into rainfed area and irrigated area by means of water availability for additional irrigation. The present land use in the project area in each categories is shown in Table C-7.1 and summarized below.

Agricultural Land	421.8 km²	64.3%
Lowland in Net	(222.6 km²)	(33.9%)
Upland in Net	(92.0 km²)	(13.9%)
Forest	134.3 km²	20.5%
Shrub	68.9 km²	10.5%
Sand, Gravel, Boulders	4.6 km²	0.7%
Urban	26.4 km²	4.0%
Total	656.0 km²	100.0%

7.1.2 Present cropping pattern

The data and information on cropping pattern are obtained from the authority concerned, and the percentage of the cultivation area for each cropping are obtained from district profile (Ref. 20).

Figure C-7.2 shows the typical cropping pattern in each district. As seen on this figure, the main crop of lowland cultivation are paddy in monsoon season and wheat and followed by potato and vegetables in winter season. In upland cultivation, the main crop is maize and followed by millet, barley, oil seed, vegetable, etc.

7.2 Irrigation System

In the Kathmandu valley, there exist a number of irrigation systems abstracting a certain amount of water from the river to the field. The existing irrigation systems in the study area are classified into two systems. One is a government aided irrigation system and the other is a locally developed farmers' system. Since their inventory including small/temporary systems is yet prepared to cover the study area, the data and information are obtained from the authorities concerned, previous reports (Ref. 14, 15 and 17) and field investigation. They are listed up in Table C-7.2 and their locations are shown on Fig.C-7.3. Their net commanding area is estimated at about 7,600 ha in total.

Since 1950, the government has set up the irrigation development in the Kathmandu valley under the government policy. Table C-7.3 shows the feature of the existing Government aided irrigation schemes in the study area. They are composed of permanent intake weir and main or main and secondary canal. Intake gates are operated by gate operator according to the request of the farmers. Regarding the farmers' build irrigation systems, generally, they consist of small-scaled temporary diversion weirs made by simple stone piling and small supply ditches without lining and permanent structures. When the weirs are washed away by flood, it is reconstructed by farmers themselves.

Irrigation efficiency on the systems are considered still low owing to poor water management facilities. Further, it is hardly possible to operate the regulating facilities quickly responding to unforeseeable rainfall especially in the rainy season. On the other side, irrigable area in the dry season is limited due to the lack of river water.

7.3 Irrigation Water Abstraction

7.3.1 Estimate of irrigation water requirement

Since there are scarcely the actual operation record in the irrigation system, irrigation water requirement for each system as a material for the water balance study is estimated. The requirement to be diverted at intake site is calculated on monthly basis during the period from 1940 through 1986, using standard procedure recommended by FAO (Ref 22). Calculation formula for estimating the requirement are outlined below:

$$IR = (CU + LP + PL - ER) \cdot Ef$$

$$CU = Kc \times ETo$$

Where,
- IR : Irrigation water requirement (mm)
- CU : Consumptive use (mm)
- LP : Land preparation requirement (mm)
- PL : Percolation rate (mm)
- ER : Effective rainfall (mm)
- Ef : Irrigation efficiency
- Kc : Crop coefficient at given stage
- ETo : Potential evapotranspiration (mm)

Irrigation systems in the study area are divided into following six groups according to the cropping pattern and rainfall station represented to the system.

River basin	Crop. pattern	Rainfall Station
Bisnumati and Dhobi kh.	Kathmandu	Indian Embassy
Bagmati kh.	Kathmandu	Airport
Manohara kh.	Kathmandu	Sankhu
Hanumante kh.	Bhaktapur	Bhaktapur
Godavari and Nakhu kh.	Lalitpur	Khumaltar
Balkhu kh.	Kathmandu	Khumaltar

The Parameter adopted in this study are described below.

Consumptive Use

Consumptive use is estimated as a product of the crop growth stage coefficient and the potential evapotranspiration which is calculated by means of the Modified Penman Method.

Monthly value of the potential evapotranspiration (ETo) calculated by applying the average climatic data obtained at Kathmandu airport represented for the study area are as follows.

Unit : mm

Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual
56	82	128	152	170	154	133	134	117	103	71	52	1352

Crop coefficients (Kc) for each crop are determined according to the standard literature recommended by Department of Irrigation (Ref. 19) as follows.

Crop	Crop coefficient (half monthly basis)											
Paddy	1.10	1.10	1.10	1.10	1.05	1.05	0.95					
Wheat	0.43	0.65	1.05	1.05	1.15	1.15	1.15	1.15	0.90	0.40		
Potato	0.42	0.55	0.79	1.01	1.13	1.08	0.86					
Vegetable	0.34	0.54	0.93	0.93	1.05	1.05	1.05	1.05	1.05	1.05	1.04	0.91

Percolation Rate and Land Preparation

The percolation rate varies depending on the soil characteristics, hydropedological condition, groundwater table condition, topographic condition, etc. Since the actual measurement of percolation does not cover whole study area, average percolation rate 3 mm per day is assumed referring to recommended figure by Department of Irrigation (Ref. 19)

Land preparation requirements depend on soil type, moisture content, groundwater table, etc., and vary from season to season. In this study, land preparation requirement for paddy and pre irrigation for upland crops are assumed to be 300 mm and 75 mm respectively.

Effective Rainfall

Effective rainfall is defined as the portion of total rainfall which meets with part of land preparation and crop water requirements. It is compositely influenced by several factors such as rainfall intensity and distribution, permeability and water holding capacity of soils, amount of irrigation water supplied, irrigation management practices, form of field plot and topography of lands. Generally little rainfall is not effective.

The effective rainfall for paddy is calculated applying followings.

ER = 0.67 x (MR-25)
ER = 225 when EF>225
ER = 0 when ER<25

Where, ER : Effective Rainfall (mm)
MR : Monthly Rainfall (mm)

The effective rainfall for upland crops is assumed by using the S.C.S. Method adopted by U.S.D.A. (United States, Department of Agriculture's Soil Conservation Service Method) as follows (Ref. 23)

ER = MR x Ratio

where, ER : Monthly effective rainfall
MR : Monthly rainfall

Irrigation Efficiency

Overall irrigation efficiency is attribute to farm application, conveyance and operation losses and varies depending on soil conditions, type of canal regulating structures, water management practices, etc.

Generally, the irrigation efficiency in rainy season can be considered lower than in dry season, because it is hardly possible to operate the regulating facilities quickly responding to unforeseeable rainfall. However, due to the difficulties to evaluate the difference in rainy and dry season in every irrigation system, irrigation efficiency of 50 % is uniformly applied throughout the year in this study.

Return Flow

Irrigation water requirement includes various kinds of unavoidable losses such as conveyance, distribution, application, percolation and operation losses. A certain amount of the above irrigation losses is expected to return to the river through drainage networks or underground permeable layer. For the water balance study, the amount of return flow should be considered as an usable water source. Since there in no actual measurement and evaluation for the return flow, it is assumed that 20 % of diverted water for irrigation system locating upstream of the water balance study point may return to the downstream of the river.

The schematic diagram of return flow included in the water balance study is mentioned in Appendix-F.

7.3.2 Irrigation abstraction

Irrigation water requirement is calculated during the period from 1940 through 1986 based on the calculation methodology aforementioned and the cropping patterns presented on Fig.C-7.2.

Though calculated water requirement does not meet the actual water abstraction, it is difficult to estimate the amount of water exactly abstracted during various seasons at every intakes due to the lack of actual operation record in the irrigation systems. The irrigation water requirement is modified according to the data and information obtained such as previous flow measurement at the irrigation canal by DIHM, flow measurement and discharge record during the field investigation in 1989 by the JICA team, and information collected by the gate operator and farmer, etc. Figure C-7.4 shows the comparison between calculated and observed water requirement at Tika Bhairab irrigation system, and modified irrigation requirement at irrigation systems in each river basin are shown on Table C-7.4 and summarized below.

Unit:l/sec/ha

River Basin	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Bisnumati, Dhobi	0.4	0.6	0.9	0.7	0.6	1.1	0.9	0.9	0.8	1.0	0.3	0.3
Bagmati	0.4	0.6	0.9	0.7	0.6	1.1	1.0	0.9	0.9	1.0	0.3	0.3
Manohara	0.4	0.6	1.0	0.7	0.6	1.0	0.8	0.6	0.5	0.9	0.3	0.3
Hanumante	0.4	0.6	0.9	0.7	0.5	1.1	0.9	0.8	0.8	0.9	0.3	0.3
Godawari,Khodu,Nakhu	0.4	0.6	1.0	0.8	0.6	1.2	1.1	1.0	1.0	1.0	0.3	0.3
Balkhu	0.4	0.6	1.0	0.7	0.6	1.2	1.1	1.0	1.0	1.0	0.3	0.3

The monthly irrigation water requirement in the period from 1940 through 1986 are incorporated in the water balance simulation study described in Appendix-F. However, it is noted that, in case, if the quantity of river flow is less than the estimated water requirement, quantity of water abstraction is taken as equal to the river flow.

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TABLES

Table C-2.1 METEOROLOGICAL SERVICE STATIONS IN AND AROUND THE VALLEY

Station No.	Station Name	Location	Latitude	Longititude	Elevation (m)	Station Type	Established & Closed	Instrument at Present
1007	Kakani		27°48'	85°15'	2064	C	Jan.1962	SRG,DT,WT,MAT,MIT
1010	Lalitpur		27°41'	85°20'	1303	C	Jan.1965 Sep.1969	
1011	Kathmandu	US Aid	27°42'	85°20'	1335	C	Jan.1954 Feb.1978	
1012	Sundarijal	Power House	27°45'	85°25'	1364	R	May.1940 Jun.1978	
1013	Sundarijal	Reservoir	27°47'	85°26'	1576	R	May.1940 Apr.1978	ARG reestablished in Sep.1985.st.no 1064H
1014	Kathmandu	Indian Embassy	27°44'	85°20'	1324	C	Jan.1921	Unpublished since 1981
1015	Thankot	Forest Nursary	27°41'	85°12'	1630	R	Sep.1966	SRG
1021	Kirtipur	Hurticulture Fire	27°41'	85°18'	1364	C	Jul.1963 Feb.1968	
1022	Godawari	St.Xavier School	27°35'	85°24'	1539	C	May.1952	SRG,DT,WT,MAT,MIT
1029	Kumaltar	Agriculture Resuarch Ce.	27°40'	85°20'	1350	C	May.1967	SRG,DT,WT,MAT,MIT,ST ANM,WV
1030	Kathmandu	Kathmandu Airport	12°42'	85°22'	1336	S	Sep.1967	SRG,ARG,DT,WT,MAT,MIT, ANM,ANG,WV,CSR,TR,HR,BG
1035	Sankhu	Lapsephadi	27°44'	85°28'	1463	R	Sep.1970	SRG
1039	Kathmandu	Pani Pokhari	27°44'	85°21'	1335	C	Apr.1971	SRG,DT,WT,MAT,MIT
1043	Nagarkot	Geodetic Observatory	27°42'	85°31'	2156	C	May.1971	SRG,DT,WT,MAT,MIT,ANM, WV
1052	Bhaktapur	Chochhe	27°44'	85°25'	1330	R	May.1971	SRG
1056	Takha	Danda Gaun	27°48'	85°26'	1790	R	Oct.1972 May.1981	
1065H	Ahale Dara	Army Camp	27°48'	85°18'	2097	R	Oct.1985	SRG,ARG
1066H	Sanga	Sanga	27°38'	85°29'		R	Oct.1985	ARG
1067H	Pharping	Health Post	27°36'	85°16'		R	Aug.1985	ARG
1068H	Maharajgunj		27°44'	85°20'		R	May.1985	ARG
1069H	Babar Mahal	Dept. of Hydrology & Metorology	27°41'	85°20'		C	May.1986	SRG,ARG,DT,WT,MAT,MIT, ANM,WV
	Shaivapuri	Tarebhir	27°46'	85°23'	1885	C	Apr.1987	SRG,ARG,TRG,DT,WT,MAT MIT,ANM,CSR,CAP
	Budhanilakantha	Budhanilakantha School	27°46'	85°21'	1440	C	Jan.1987	SRG,DT,WT,MAT,MIT

Abbreviations:

SRG: Standard Rain Gauge	ARG: Automatic Recording Gauge	TRG: Monthly Total Rain Gauge
DT : Dry Thermometer	WT : Wet Thermometer	MAT: Maximum Thermometer
MIT: Minimum Thermometer	ST : Soil Thermometer	ANM: Anemometer ANG: Anemograph
WV : Wind Van	CSR: Cambell Sunshine Recorder	CAP: Class A Pan
TR : Air Temperature Recorder	HR : Relative Humidity Recorder	BG : Barograph
S : Synopic Station	C : Climatological Station	R : Rain Gauge Station

Table C-2.2 STREAM GAUGING STATIONS WITHIN THE VALLEY

Station Number	Station Name	River	Catchment Area(km2)	Established & Closed Dates	Water Level Observations	Remarks
505	Sundarijal	Bagmati	16.0	Dec. 1962	Staff gauge reading 2 times daily.Recorder equiped since Aug,'75	Cable way for flood flow measurement since June 1971. Mountain catchment with some agricultural developement
507	Mahankal	Nagmati	13.7	Dec. 1962 1972	Staff gauge reading 2 times daily.	Gauging at a diversation weir. Mountain catchment.Partical record station
510	Shyamado	Sialmati	3.34	Dec. 1962 1972	Staff gauge reading 2 times daily.	Low-flow partical recoad station
530	Gauri Ghat	Bagmati	67.8	Jan. 1965	Staff gauge reading 3 times daily	Water supply intake upstream. Mountain Catchment
536.2	Budhanilkanth	Bisnumat	6.43	June 1968	Staff gauge reading 3 times daily	Not suitable site for Gauging station becouse of the irregular bed with rocks
540	Tikabhairab	Nakhu	42.5	Dec. 1962 Apr. 1988	Staff gauge reading 3 times daily	Cable way for flood flow measurement
550	Chobhar	Bagmati	585	July 1962 July 1981	Recorder	Suspendid load Sumpling daily

Table C-2.3 Discharge Measurement in the Field

R. Basin	Stn.No	Location	River	C.A (km2)	Dry Season *1 Measured Dis.(l/s)	Dry Season *1 Spec.Dis. (l/s/km2)	Rainy Season *2 Measured Dis.(l/s)	Rainy Season *2 Spec.Dis. (l/s/km2)
I. Bisunumati	20	Budhanilkantha	Bisnumati	6.5	20.2	3.1	935	143.8
	23	Baniyatar	Bisnumati	14.0	1.4	0.1	1,543	110.2
	24	Baniyatar	Bisnumati	14.5	2.1	0.1	1,863	128.5
	25	Nepaltar	Bisnumati	60.9	51.1	0.8	-	-
	10	Bisnumati Ring Road Bridge	Bisnumati	61.2	34.2	0.6	6,316	103.2
II. Dhobi Kh.	26	Bhangal	Dhobi	10.2	18.5	1.8	1,944	190.6
	27	Bhangaltar	Dhobi	11.4	23.3	2.0	2,084	182.8
	28	Dhumbaharai	Dhobi	23.3	4.1	0.2	4,285	183.9
	14	Dhobi Ring Road Bridge	Dhobi	23.7	8.4	0.4	5,039	212.6
III.Bagmati	19	Gokarna	Bagmati	56.9	233	4.1	7,467	131.2
	5	Gokarna, Sakhu Road Bridge	Bagmati	57.8	246	4.3	7,783	134.7
	18	Gauri Gat	Bagmati	66.6	259	3.9	5,885	88.4
	38	Chobar	Bagmati	588.3	1850	3.1	32,679	55.5
IV. Manohara	21	Multipani	Manohara	58.2	99.9	1.7	3,284	56.4
	22	Nitbarahi	Manohara	62.5	74.2	1.2	3,100	49.6
	6	Manohara Bridge	Manohara	73.8	24	0.3	7,489	101.5
	7	Manohara Ring Road Bridge	Manohara	255.2	177	0.7	18,737	73.4
V. Hanumante	41	Nagarkot Intake	Tabya Kushi	6.8	-	-	682	100.3
	42	Bromhayani Bridge	Tabya Kushi	21.5	-	-	506	23.5
	29	Taikabun	Suidi	2.5	2.4	1.0	37	14.8
	30	Taikabun	Suidi	2.9	6.5	2.2	28	9.7
	16	Hanumante Bridge	Hanumante	78.2	15.5	0.2	1,374	17.6
	13	Sagu Confluence	Godavari	17.2	74.8	4.3	659	38.3
VI. Khodu Kh.	11	Kodku Head Work	Kodku	16.7	154	9.2	479	28.7
	12	Kodku, Lubhu Road Crossing	Kodku	33.5	81.9	2.4	1,535	45.8
VII.Nakhu Kh.	17	Tikabairab No.1 Head Work	Lele	14.8	152	10.3	1,312	88.6
	8	Tikabhairab	Nakhu	42.1	349	8.3	3,418	81.2
	9	Jaulakhel	Nakhu	54.4	166	3.1	3,622	66.6
VIII.Balkhu Kh.	15	Kirtipur-Tinthana Bridge	Balku	36.4	33	0.9	1,869	51.3
	39	Ring Road Bridge	Balku	41.3	-	-	2,094	50.7
IX. Bosan Kh.	40	Parphin Road Crossing	Bosan	7.2	-	-	558	77.5

Remarks: *1 carried out during the period from Feb.28 to Mar.13, 1989
*2 carried out during the period from Sep.16 to Sep.30, 1989

Table C-3.1 REGRESSION COEFFICIENT OF THE RAINFALL DATA

Code	Station Name	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)
												(Rb)
(1) 21007	Kakani	1.00	1.81	1.38	2.29	1.45	2.10	1.56	1.39	1.88	2.41	1.56
(2) 21056	Tokha	0.66	1.00	0.75	--	0.81	1.23	0.87	0.73	1.26	1.51	0.95
(3) 21013	Sundarijal Res.	0.78	1.61	1.00	1.69	1.23	1.73	1.15	1.26	1.57	1.24	1.34
(4) 21014	Indian Embassy	0.52	--	0.66	1.00	0.83	1.09	0.74	0.85	1.03	1.24	0.76
(5) 21035	Sankhu	0.80	1.68	0.86	1.32	1.00	1.59	1.17	1.07	1.38	1.82	1.14
(6) 21030	Kathmandu Airport	0.52	0.91	0.62	0.94	0.72	1.00	0.77	0.71	0.91	1.16	0.72
(7) 21043	Nagarkot	0.76	1.42	0.96	1.54	1.00	1.47	1.00	0.96	1.31	1.62	1.05
(8) 21015	Thankot	0.86	1.81	0.93	1.27	1.15	1.58	1.21	1.00	1.48	1.80	1.13
(9) 21052	Bhaktapur	0.61	0.98	0.68	1.02	0.82	1.20	0.91	0.82	1.00	1.38	0.87
(10)21029	Khumaltar	0.46	0.81	0.55	0.83	0.63	0.90	0.69	0.64	0.80	1.00	0.65
(11)21022	Godavari	0.72	1.27	0.88	1.41	1.00	1.47	1.12	1.10	1.29	1.65	1.00
	(Ra)											

Ref) Ra = A * Rb

( ) Numbers of Samples

Table C-3.2 CORRELATION COEFFICIENTS OF THE RAINFALL DATA

Code	Station Name	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)
(1) 21007	Kakani	1.000	0.871	0.944	0.867	0.884	0.922	0.871	0.861	0.890	0.919	0.900
		(226)	(60)	(117)	(95)	(178)	(178)	(177)	(178)	(177)	(165)	(184)
(2) 21056	Tokha	0.871	1.000	0.859	--	0.780	0.920	0.840	0.794	0.844	0.847	0.855
		(60)	(96)	(24)	(0)	(60)	(60)	(60)	(60)	(60)	(60)	(45)
(3) 21013	Sundarijal Reservoir	0.944	0.859	1.000	0.917	0.954	0.937	0.915	0.876	0.944	0.935	0.931
		(117)	(24)	(437)	(328)	(82)	(116)	(77)	(124)	(74)	(111)	(202)
(4) 21014	Indian Embassy	0.867	--	0.917	1.000	0.927	0.986	0.891	0.933	0.958	0.976	0.944
		(95)	(0)	(328)	(342)	(60)	(94)	(55)	(102)	(52)	(89)	(205)
(5) 21035	Sankhu	0.884	0.780	0.954	0.927	1.000	0.894	0.872	0.841	0.898	0.889	0.898
		(178)	(60)	(82)	(60)	(192)	(191)	(186)	(192)	(184)	(178)	(168)
(6) 21030	Kathmandu Airport	0.922	0.920	0.937	0.986	0.894	1.000	0.903	0.899	0.925	0.960	0.947
		(178)	(60)	(116)	(94)	(191)	(226)	(185)	(221)	(183)	(212)	(174)
(7) 21043	Nagarkot	0.871	0.840	0.915	0.891	0.872	0.903	1.000	0.878	0.865	0.902	0.875
		(177)	(60)	(77)	(55)	(186)	(185)	(186)	(186)	(183)	(172)	(162)
(8) 21015	Thankot	0.861	0.794	0.876	0.933	0.841	0.899	0.878	1.000	0.848	0.880	0.890
		(178)	(60)	(124)	(102)	(192)	(221)	(186)	(234)	(184)	(212)	(179)
(9) 21052	Bhaktapur	0.890	0.844	0.944	0.958	0.898	0.925	0.865	0.848	1.000	0.919	0.910
		(177)	(60)	(74)	(52)	(184)	(183)	(183)	(184)	(184)	(171)	(160)
(10)21029	Khumaltar	0.919	0.847	0.935	0.976	0.889	0.960	0.902	0.880	0.919	1.000	0.945
		(165)	(60)	(111)	(89)	(178)	(212)	(172)	(212)	(171)	(221)	(169)
(11)21022	Godavari	0.900	0.854	0.931	0.944	0.898	0.947	0.875	0.890	0.910	0.945	1.000
		(184)	(45)	(202)	(205)	(168)	(174)	(162)	(179)	(160)	(169)	(322)

Remark: Figures in parenthesis show the number of samples

Table C-3.3 Mean Monthly Rainfall at Respective Stations

Unit:mm

Station	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Total
Kakani	21.1	24.0	40.0	88.1	155.2	463.6	780.4	874.4	437.0	86.5	7.2	6.3	2983.8
Tokha	17.5	19.5	32.0	66.1	115.3	283.3	458.7	413.8	201.8	61.7	7.8	7.8	1685.2
Sundarijal	15.9	18.2	30.8	71.8	134.5	346.6	607.8	639.6	317.8	68.8	8.2	5.6	2265.7
Indian Embassy	15.6	17.3	27.7	60.1	102.2	250.8	399.6	372.5	187.4	54.5	6.4	6.2	1500.3
Sanku	13.6	19.6	24.9	60.8	112.1	305.9	529.0	557.8	272.0	60.0	7.1	3.9	1966.7
Kathmandu Airport	15.2	16.8	27.2	55.6	95.1	232.2	373.5	345.9	173.7	51.8	6.2	6.0	1399.2
Nagarkot	14.2	17.0	26.1	67.7	113.2	325.7	551.9	583.2	286.4	65.2	6.5	3.8	2061.0
Thankot	22.9	25.3	38.9	85.9	146.2	329.8	558.6	530.7	285.0	75.2	8.6	9.7	2116.8
Bhaktapur	17.2	20.2	30.7	65.2	119.2	269.9	439.3	409.5	198.5	60.9	5.5	6.5	1642.7
Khumaltar	13.9	15.8	22.5	53.3	87.3	200.1	334.3	303.3	156.5	46.4	4.7	7.1	1245.1
Godawari	21.7	20.7	32.1	70.8	127.2	330.2	542.6	509.7	264.7	73.1	5.1	9.1	2006.8

Table C-3.4 ANNUAL RAINFALL AT RESPECTIVE STATIONS

Unit : mm

Year	Kakani (21007)	Tokha (21056)	Sundarijal Water.Res. (21013)	Indian Embassy (21014)	Sankhu (21035)	Kathmandu Airport (21030)	Nagarkot (21043)	Thankot (21015)	Bhaktapur (21052)	Khumaltar (21029)	Godawari (21022)
1941	*3478	*1887	2525	*1660	*2165	*1539	*2418	*2425	*1842	*1380	*2257
1942	*3870	*2091	2809	*1848	*2410	*1705	*2691	*2687	*2042	*1529	*2500
1943	*4145	*2281	3010	*1979	*2582	*1861	*2883	*2931	*2228	*1668	*2728
1944	*3340	*1821	2425	*1594	*2079	*1487	*2321	*2341	*1778	*1331	*2178
1945	*4007	*2207	2909	*1913	*2495	*1800	*2786	*2836	*2155	*1614	*2639
1946	*4489	*2444	3260	*2143	*2795	*1994	*3121	*3141	*2386	*1786	*2923
1947	*3597	*1836	+2611	+1607	*2239	*1498	*2500	*2361	*1791	*1342	*2196
1948	*4305	*2057	3126	1793	*2680	*1678	*2993	*2646	*2008	*1504	*2460
1949	*3413	*1577	2478	1369	*2124	*1288	*2373	*2029	*1539	*1153	*1886
1950	*1981	*1773	1439	1536	*1233	*1446	*1376	*2280	*1730	*1296	*2119
1951	*2330	*1413	1692	1224	*1451	*1153	*1620	*1817	*1378	*1033	*1689
1952	*3171	*1466	2302	1280	*1975	*1197	*2204	*1887	*1431	*1071	*1753
1953	*3065	*1564	2225	1364	*1909	*1276	*2131	*2012	*1526	*1143	1764
1954	*3518	*1830	2553	1594	*2191	*1492	*2445	*2353	*1785	*1338	2084
1955	*3574	*1294	+2594	1131	*2225	*1056	*2484	*1665	*1262	* 945	2064
1956	*3181	*2037	2309	1776	*1980	*1662	*2211	*2621	*1988	*1489	2394
1957	*2083	*1145	1512	1001	*1297	* 935	*1448	*1474	*1117	* 836	1398
1958	*2096	*1298	+1522	1134	*1305	*1061	*1456	*1671	*1267	* 949	1456
1959	*2748	*1389	1995	1195	*1711	*1135	*1909	*1786	*1357	*1015	1633
1960	*2331	*1399	1692	1202	*1450	*1142	*1619	*1798	*1365	*1022	1766
1961	*2684	*1977	1947	1705	*1670	*1613	*1864	*2542	*1931	*1446	+2346
1962	3501	*1466	2367	1262	*2030	*1197	*2266	*1885	*1432	*1071	+2337
1963	3069	*1505	2263	1314	*1941	*1229	*2167	*1936	*1469	*1101	+1607
1964	2959	*1620	1904	1385	*1632	*1322	*1823	*2083	*1582	*1184	+1443
1965	1791	*1528	1649	1334	*1413	*1247	*1578	*1964	*1492	*1117	+1815
1966	*2380	*1403	1729	1224	*1522	*1145	*1654	+1798	*1369	*1025	+1448
1967	*2839	*1547	2062	1349	*1768	*1262	*1974	+1563	*1510	+ 998	+1556
1968	*3368	*1690	2445	1539	*2098	1380	*2342	+1495	*1650	1335	+2033
1969	*2655	*1445	1929	1131	*1653	1179	*1846	1189	*1411	922	*1727
1970	*3123	*1669	2268	1440	*1944	1362	*2171	1590	*1630	1233	+1985
1971	*3280	*1851	2383	1682	2335	1511	+1718	1811	+1890	1364	1993
1972	2988	*1545	1779	1510	1942	1261	1641	1852	1466	1197	1927
1973	3119	*2206	+2736	1969	2133	1800	3644	2633	+1934	+1429	2430
1974	+2130	*1500	2007	1141	1850	1225	1915	2207	+1409	*1097	+2094
1975	2956	*1746	2541	1527	2092	1425	2025	2092	1445	1428	+2156
1976	2653	1485	2333	*1619	1853	1491	2126	2643	1537	1089	+2096
1977	2393	1174	1900	*1407	1354	1297	1809	2288	1282	1144	+1638
1978	3158	1454	*2994	*1689	3425	1556	2708	2911	1913	1698	2210
1979	1740	1441	*1895	*1472	2013	1356	1697	2641	1211	960	1584
1980	2842	1701	*1994	*1455	2098	1341	1783	2216	1275	970	1766
1981	2374	*1681	*1969	*1489	965	1372	1066	1344	1258	1159	1698
1982	+2082	*1432	*1693	*1269	1949	1169	1047	918	1082	1160	1670
1983	2985	*1777	*3101	*1574	2525	1450	1264	1564	2381	1309	1917
1984	2670	*1609	*2451	*1426	1997	1314	1433	1949	1793	1329	2212
1985	3287	*2189	*2553	*1939	2079	1785	+1833	2637	2107	1533	2553
1986	3053	*1825	*2078	*1617	1694	1489	2088	2500	1881	1365	1909

Remarks *: Calculated based on the correlation analysis because no record observed throughout year
+: Filled-in data based on the correlation analysis at the missing data

Figures in parenthesis show station No.