Table D-5.1 RESULTS OF PUMPING TESTS ON EXISTING WELL BY JICA STUDY TEAM

WELL NO.	WELL DEPTH (m)	POSITION OF TOP OF SCREEN (m)	TEST DATE	Q (L/s)	SWL (m)	PWL (m)	T (m2/day)	S/C (L/s/m)
BB 3	100.5	24.44	Feb12'89	40.00	18.05	26.73	436*1 843*2	4.61
DK 6	49.00	10.92	Feb15'89	9.83	9.64	11.49	1295*1 1036*2	5.31
GK 4	249.12	46.31	Feb19'89	16.78	26.27	53.95	106*1 86*2	0.61
MH 7	267.00	20.00	Feb20'89	27.83	27.19	- *3	303*2	-

Note; Q; Discharge rate, SWL:Static Water Level, PWL:Pumping Water Level, T: Transmissivility, *1: Calculated from time drawdown test, *2: Calculated from recovery test, S/C: Specific Capacity, *3: No final drawdown measured due to dip tube blocked.

Table D-6.1 STATIC WATER LEVLE TRENDS IN THE STUDY AREA

Year / Month	WELL NUMBER									
	B12	WHO3A	WHO5A	WHO7	BB5	DK1	JP1	GK5	MH6	BH4
1972										
Feb.	17.10	22.80								
Sep.			9.40							
1974										
Feb.				14.10						
1984										
Jan.					1.75	29.38				
May							7.44			
1985										
Feb.										+1.50
May									+1.2	
1988										
Feb.	31.10	36.30	23.18	15.00			7.00	25.20		
Mar.								23.92		
1989										
Jan.								27.00	7.15	12.00
Feb.	33.82			14.80	17.77	42.24	7.59			
Mar.	33.92	41.39	23.61	14.80	17.71	42.35	7.18	27.30	7.86	12.97
Aug.	38.92	46.27		14.35		42.18	7.30	31.33	10.09	15.00
Sep.	38.90					42.26		31.28	12.82	
Dec.									14.12	

Note; Unit in meter below ground surface

Table D-6.2 RESULTS OF SIMULTANEOUS GROUNDWATER LEVEL OBSERVATION (1989)

WELL NO.	GROUND SURFAVE ELEVATION (a.s.l.m)	PIPE HEIGHT (GL.+m)	GROUNDWATER DEPTH (GL.-m) March	August	GROUNDWATER LEVEL ELEVATION (a.s.l.m) March	August
B12	1326.62	1.15	33.92	38.92	1291.55	1286.55
Balaju	1298.49	0.00	0.00 *3	23.63 *4	1298.49	1274.86
SK1	1297.00 *1	0.20	1.01	5.35	1295.79	1291.45
BB3	1315.49	0.67	28.48 *4	23.50 *5	1286.34	1291.32
BB5	1309.89	0.33	17.71	28.33 *5	1291.85	1281.23
BB8	1313.96	0.58	26.29 *5	34.50	1287.09	1278.88
WHO3A	1333.00 *1	0.95	41.39	46.27	1290.66	1285.78
DK1	1336.94	0.43	42.35	42.18	1294.16	1294.33
DK4	1331.72	0.30	28.00 *4	20.00 *5	1303.42	1311.42
DK6	1313.15	0.50	10.90 *5	16.06 *4	1301.75	1296.59
JP	1322.41	0.75	7.18	7.30	1314.48	1314.36
GK1	1345.09	0.26	18.42	36.50 *4	1326.41	1308.33
GK4	1347.69	0.73	55.64 *4	30.50	1291.32	1316.46
GK5	1358.00	0.30	27.30	31.33	1330.40	1326.37
WHO7	1358.80 *2	0.00	14.80	14.35	1344.00	1344.45
MH2	1339.53	0.55	43.40 *4	45.93 *4	1295.58	1293.05
MH6	1316.30	0.37	7.86	10.09	1308.07	1305.84
BH4	1318.67	0.59	12.97	15.00	1305.11	1303.08
PH1	1260.00	0.00	0.00 *3	0.00 *3	1260.00	1260.00
PH2	1250.98	1.07	2.64 *6	2.00	1247.27	1247.91
Pepsi	1320.00 *1	0.43	9.96	10.66	1309.61	1308.91

NOTE; *1: After 1:10,000 scale map
*2:After WHO Report (1973)
*3:Self flowing
*4: Pumping
*5:Within 2 hours after pump stopped
*6:Measured at end of February

TABLE D-8.1 RESULTS OF WATER QUALITY ANALYSIS (1/6)
(EXISTING WELLS)

Well No.	BB2	BB3	BB7	DK3	DK4	DK5
Sample No.	1	2	3	4	5	6
pH	7.18	6.95	6.62	6.68	6.8	6.44
EC(mS/cm)	130	120	160	140	180	160
O.R.P.(mV)*	+550	+550	+540	+560	+530	+540
KMnO4.Con.(mg/l)	4	3.9	8.4	8.6	6.9	5.9
Fe(mg/l)	2.4	0.9	1.1	2.7	2	3
Mn(mg/l)	0.2	<0.1	<0.1	0.1	0.2	0.1
Ca(mg/l)	11	8.4	9.9	11	14	10
Mg(mg/l)	2.6	2.2	3	2.9	3.6	3.2
Na(mg/l)	16	16	22	17	13	11
K(mg/l)	1.2	1.1	1.3	1.3	1.6	1.5
Cl(mg/l)	0.6	1	0.7	1.7	9.4	6.7
Po4(mg/l)	0.5	1.2	1	1.6	0.7	2.4
So4(mg/l)	<5	<5	<5	<5	21	11
H2Co3(mg/l)	17	16	56	22	17	59
HCo3(mg/l)	71	67	75	91	71	79
Co3(mg/l)	0.03	0.03	0.01	0.04	0.03	0.01
NH4(mg/l)	<0.05	<0.05	2.5	<0.05	5.1	6.5
Kjeldahl N(mg/l)**	0.1	0.2	2	0.1	3.7	4.7

NOTE; * Oxidation reduction potentials
** Total Kjeldahl nitrogen

TABLE D-8.1 RESULTS OF WATER QUALITY ANALYSIS (2/6)
(EXISTING WELLS)

Well No.	GK3	MH2	BH1	BID1	YAK&ETI	DMG5
Sample No.	7	8	9	10	11	12
pH	6.68	6.61	6.47	6.54	6.75	6.76
EC(mS/cm)	140	170	210	240	390	1050
O.R.P.(mV)*	+560	+540	+520	+520	+510	+540
KMnO4.Con.(mg/l)	9.2	16	9.6	3	27	46
Fe(mg/l)	1	3.7	1.9	1	0.3	1.4
Mn(mg/l)	<0.1	0.3	0.4	0.2	0.4	0.5
Ca(mg/l)	9.9	8.3	12	33	20	75
Mg(mg/l)	2.6	2.5	3.7	5.4	5.6	14
Na(mg/l)	20	23	23	10	28	66
K(mg/l)	1.2	1.5	1.9	1.3	2.5	5.1
Cl(mg/l)	1.6	1.3	2.4	4.4	1.4	2.9
Po4(mg/l)	1.4	3.4	3.6	<0.1	8.8	23
So4(mg/l)	<5	<5	<5	<5	<5	50
H2Co3(mg/l)	22	46	78	80	63	150
HCo3(mg/l)	94	62	100	110	270	660
Co3(mg/l)	0.04	0.01	0.02	0.02	0.13	0.31
NH4(mg/l)	<0.05	1.8	6.4	2.3	33	78
Kjeldahl N(mg/l)**	0.1	2.3	4.8	<0.1	23	58

NOTE; * Oxidation reduction potentials
** Total Kjeldahl nitrogen

TABLE D-8.1 RESULTS OF WATER QUALITY ANALYSIS (3/6)
(EXISTING WELLS AND SPOUT)

Well No.	H.HIMALA	PEPSICOLA	HIM.CEME	PH1	PH2	SPO/KTM
Sample No.	13	14	15	16	17	18
pH	6.95	6.86	7.11	7.37	7.53	6.41
EC(mS/cm)	990	460	640	330	540	540
O.R.P.(mV)*	+500	+550	+460	+540	+510	+500
KMnO4.Con.(mg/l)	51	22	15	1.3	1.1	5.1
Fe(mg/l)	0.3	0.9	0.9	0.2	0.9	0.1
Mn(mg/l)	0.4	0.8	<0.1	0.1	0.1	<0.1
Ca(mg/l)	56	28	38	57	38	20
Mg(mg/l)	12	7.3	7.3	6.9	5.5	8.5
Na(mg/l)	45	57	48	10	75	48
K(mg/l)	5.1	3.9	2.2	1.5	1.6	57
Cl(mg/l)	2.6	2.3	1.3	1.3	8.1	58
Po4(mg/l)	30	5.9	7.7	<0.1	<0.1	24
So4(mg/l)	<5	<5	58	15	140	13
H2Co3(mg/l)	140	72	71	16	13	100
HCo3(mg/l)	580	310	300	220	180	140
Co3(mg/l)	0.28	0.15	0.14	0.31	0.26	0.02
NH4(mg/l)	100	15	46	0.08	0.36	<0.05
Kjeldahl N(mg/l)**	62	10	33	<0.1	0.2	<0.1

NOTE; * Oxidation reduction potentials
** Total Kjeldahl nitrogen

TABLE D-8.1 RESULTS OF WATER QUALITY ANALYSIS (4/6)
(SPOUTS,SPRINGS AND RIVERS)

Well No.	SPO/LAL	SPO/DHOB	SPR/DOOD	SPR/PHAR	SPR/GODA	BISUNUMA.
Sample No.	19	20	21	22	23	24
pH	6.38	6.7	7.45	7.4	7.15	6.79
EC(mS/cm)	540	380	220	230	260	100
O.R.P.(mV)*	+490	+510	+520	+560	+530	+480
KMnO4.Con.(mg/l)	1.6	2.2	0.4	1.4	0.7	7.8
Fe(mg/l)	<0.1	<0.1	<0.1	0.3	<0.1	1
Mn(mg/l)	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1
Ca(mg/l)	37	31	40	37	55	10
Mg(mg/l)	14	8.7	5.3	8.5	2.7	1.9
Na(mg/l)	40	28	1.1	1	1.2	7.5
K(mg/l)	31	16	0.8	0.8	0.6	1.7
Cl(mg/l)	52	40	0.6	1.1	0.6	4.1
Po4(mg/l)	4.3	1.4	<0.1	<0.1	<0.1	<0.1
So4(mg/l)	31	16	<5	<5	<5	<5
H2Co3(mg/l)	97	23	9.7	9.9	37	9.2
HCo3(mg/l)	130	99	130	130	160	39
Co3(mg/l)	0.02	0.05	0.19	0.19	0.07	0.02
NH4(mg/l)	<0.05	<0.01	0.17	<0.05	0.22	0.11
Kjeldahl N(mg/l)**	<0.1	<0.1	<0.1	<0.1	<0.1	0.5

NOTE; * Oxidation reduction potentials
** Total Kjeldahl nitrogen

TABLE D-8.1 RESULTS OF WATER QUALITY ANALYSIS (5/6)
(RIVERS)

Well No. Sample No.	SUND.JARU 25	BAGMATI 26	MANOHARA 27	GODAWARI 28	KODHU KH. 29	NAKUH KH. 30
pH	7.03	7.45	7.47	7.63	7.53	7.53
EC(mS/cm)	31	51	60	260	210	180
O.R.P.(mV)*	+460	+490	+480	+470	+470	+470
KMnO4.Con.(mg/l)	4.5	6.6	8.4	3.3	0.8	3.7
Fe(mg/l)	0.1	1.1	1.6	0.9	0.1	0.6
Mn(mg/l)	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1
Ca(mg/l)	1.6	2.7	2.3	50	42	32
Mg(mg/l)	0.4	0.8	1	3.5	3	3.1
Na(mg/l)	4.2	6	6.6	3.3	0.9	3.9
K(mg/l)	0.7	1.2	1.8	1	0.8	0.9
Cl(mg/l)	1.1	2.4	2.9	1.8	1.1	1.9
Po4(mg/l)	0.1	0.1	0.2	<0.1	<0.1	0.1
So4(mg/l)	<5	<5	<5	<5	<5	<5
H2Co3(mg/l)	3.5	2	2	12	10	8.2
HCo3(mg/l)	15	26	26	170	130	110
Co3(mg/l)	<0.01	0.04	0.04	0.24	0.2	0.16
NH4(mg/l)	0.08	0.08	<0.05	<0.05	0.08	0.06
Kjeldahl N(mg/l)**	<0.1	0.3	0.4	0.1	<0.1	<0.1

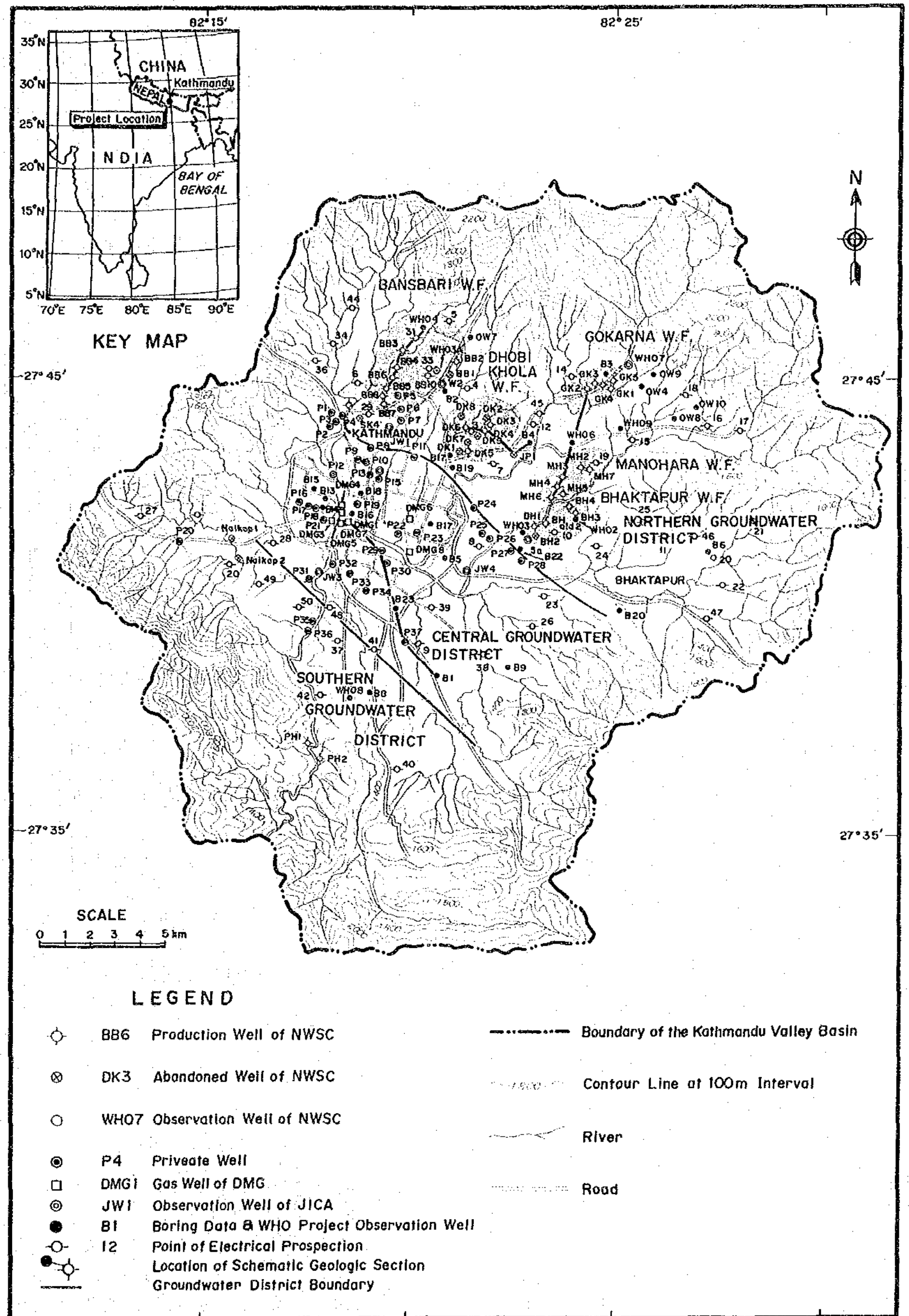
NOTE; * Oxidation reduction potentials
** Total Kjeldahl nitrogen

TABLE D-8.1 RESULTS OF WATER QUALITY ANALYSIS (6/6)
(RIVER,JICA WELLS)

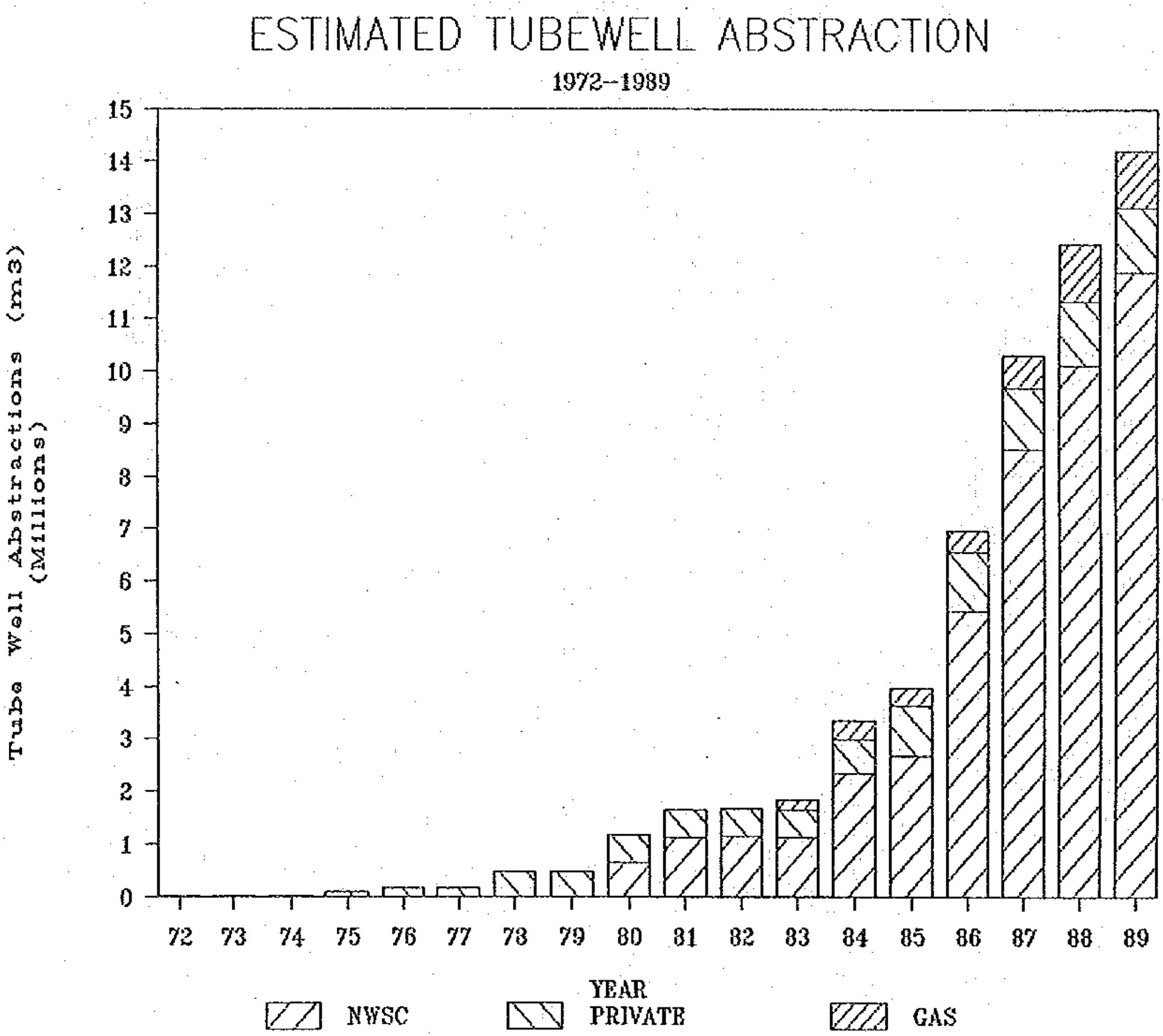
Well No. Sample No.	BHALK KH. 31	JW1	JW2	JW3	JW4
pH	7.74	6.94	7.2	7	6.9
EC(mS/cm)	230	210	140	470	690
O.R.P.(mV)*	+470	+450	+490	+500	+470
KMnO4.Con.(mg/l)	7.7	16	5	28	130
Fe(mg/l)	0.9	1.5	1.8	2.1	7.4
Mn(mg/l)	<0.1	0.3	0.2	<0.1	1.6
Ca(mg/l)	38	1.6	8.3	11	27
Mg(mg/l)	5	2.7	3.8	3.2	9.8
Na(mg/l)	7.2	24	14	75	59
K(mg/l)	1.6	1.8	1.2	3.3	5.5
Cl(mg/l)	6.4	1	2	0.8	14
Po4(mg/l)	0.5	2.2	0.8	24	4.6
So4(mg/l)	<5	<5	<5	5.4	<5
H2Co3(mg/l)	9.5	40	10	67	47
HCo3(mg/l)	130	130	44	280	200
Co3(mg/l)	0.19	0.06	0.02	0.14	0.1
NH4(mg/l)	<0.05	3.3	0.07	16	2.5
Kjeldahl N(mg/l)**	0.1	2.9	0.1	13	22

NOTE; * Oxidation reduction potentials
** Total Kjeldahl nitrogen

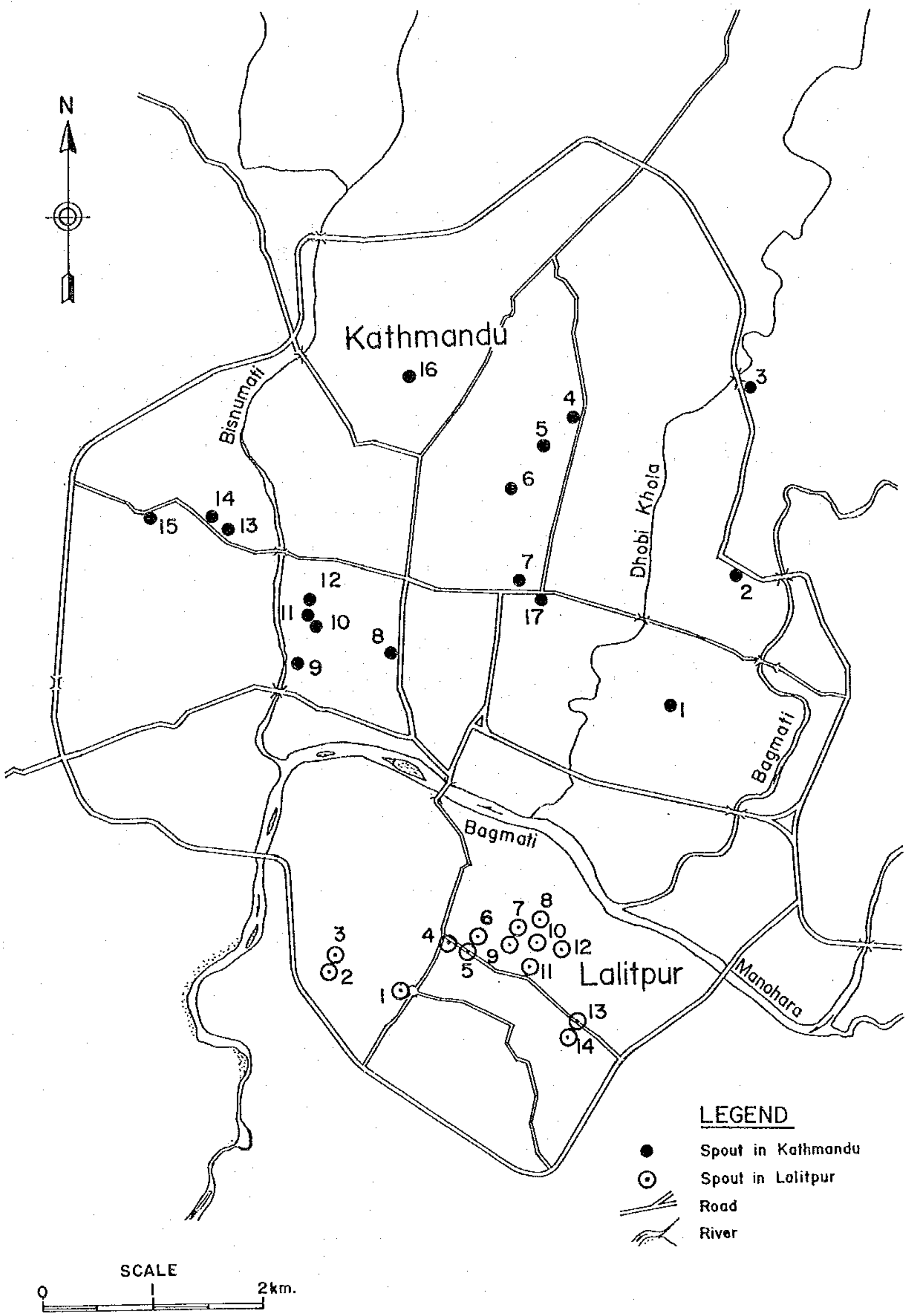
FIGURES



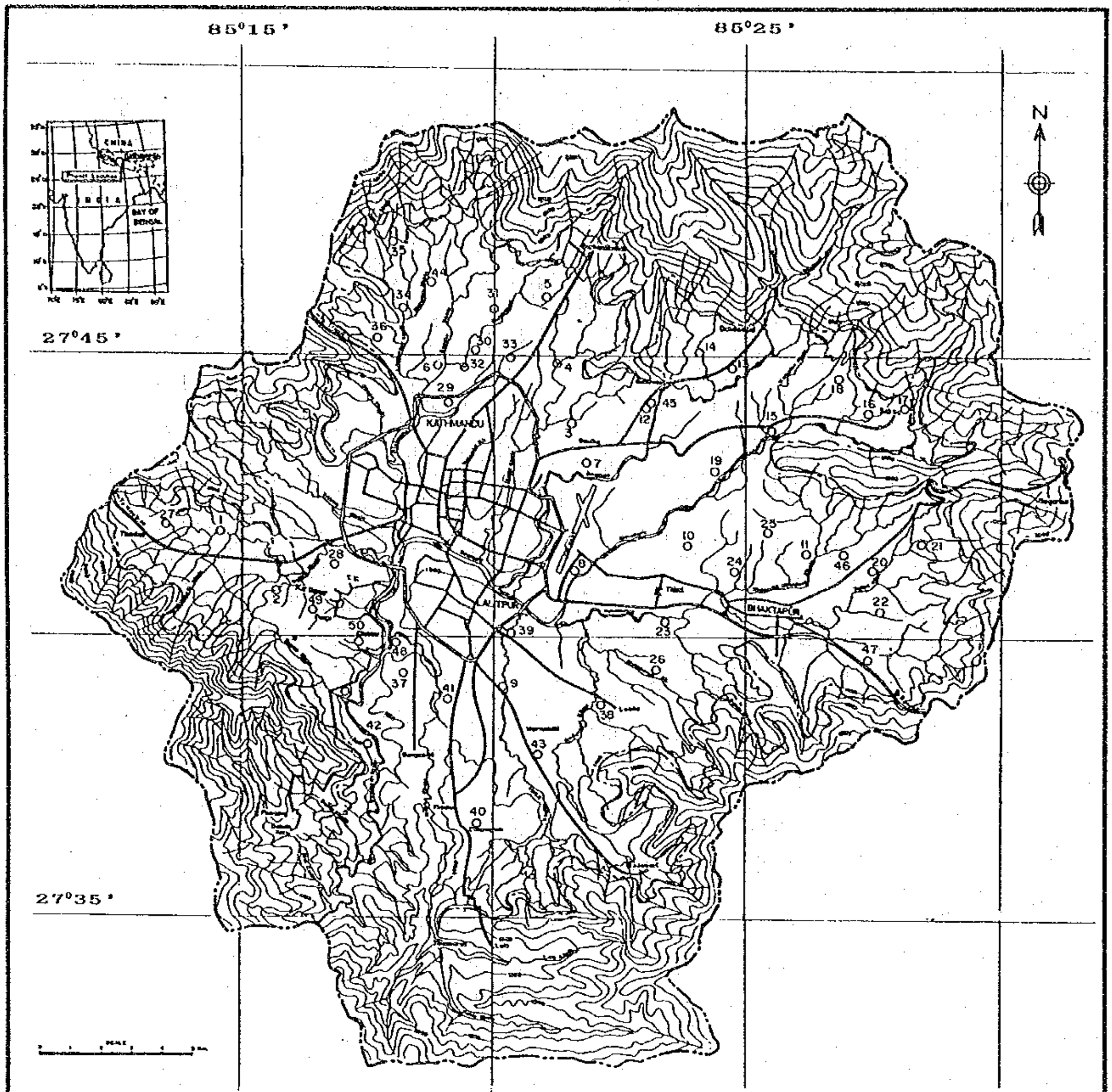
HIS MAJESTY'S GOVERNMENT OF NEPAL GROUND WATER MANAGEMENT PROJECT IN THE KATHMANDU VALLEY	Fig. D−1.1	GENERAL GROUNDWATER LOCATION MAP
JAPAN INTERNATIONAL COOPERATION AGENCY		



HIS MAJESTY'S GOVERNMENT OF NEPAL GROUND WATER MANAGEMENT PROJECT IN THE KATHMANDU VALLEY	Fig. D-1.2	ESTIMATED GROUNDWATER ABSTRACTIONS FROM TUBE WELLS IN THE KATHMANDU VALLEY (1972 - 1989)
JAPAN INTERNATIONAL COOPERATION AGENCY		



HIS MAJESTY'S GOVERNMENT OF NEPAL GROUND WATER MANAGEMENT PROJECT IN THE KATHMANDU VALLEY	Fig. D-1.3	LOCATION MAP OF SPOUT
JAPAN INTERNATIONAL COOPERATION AGENCY		



LEGEND

Electrical Prospecting Point

O 19

Resistivity Contour (ohm-m)

100

Boundary of the Kathmandu Valley Basin

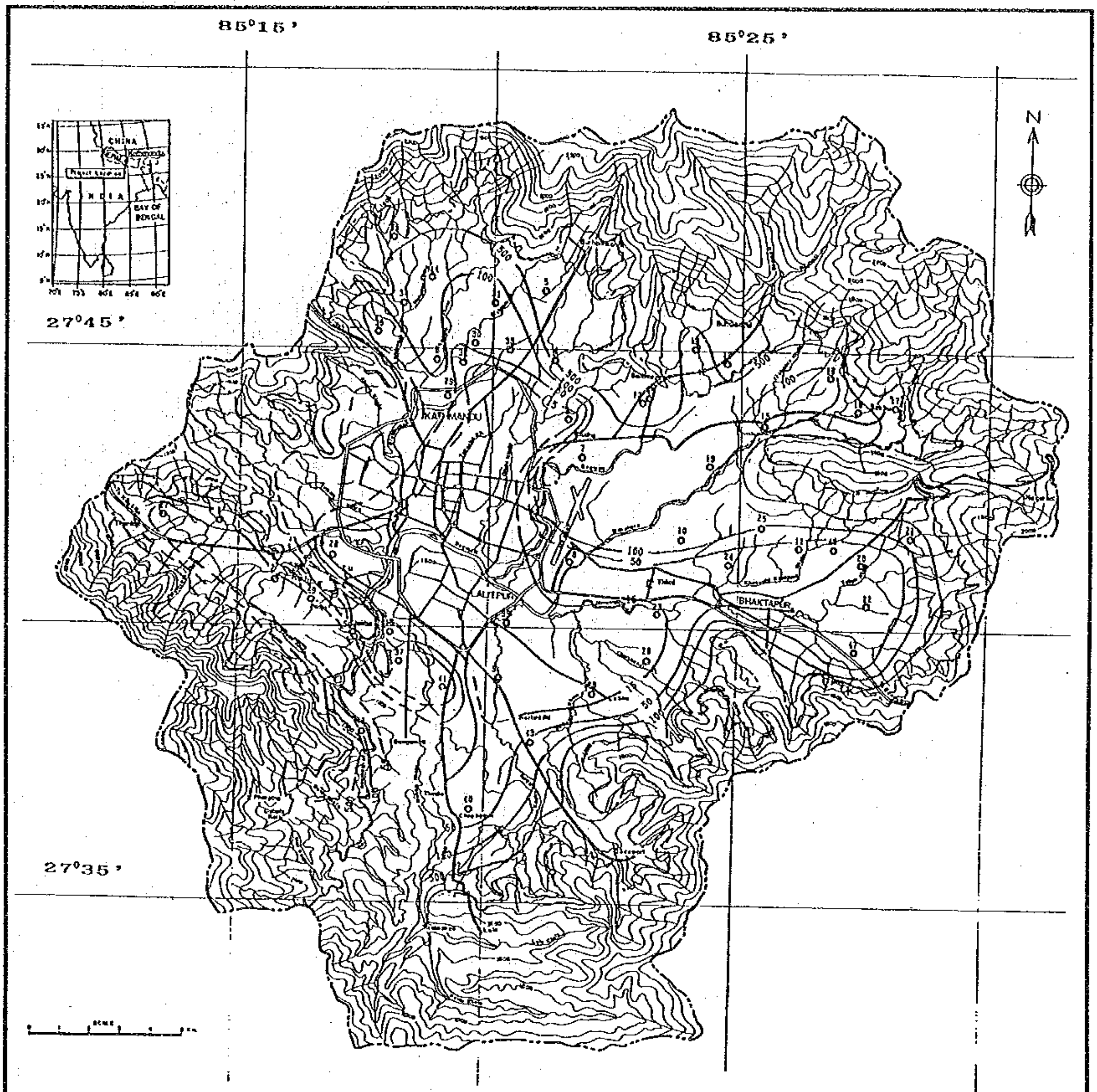
Contour Line at 100m Interval

1,600

River

Road

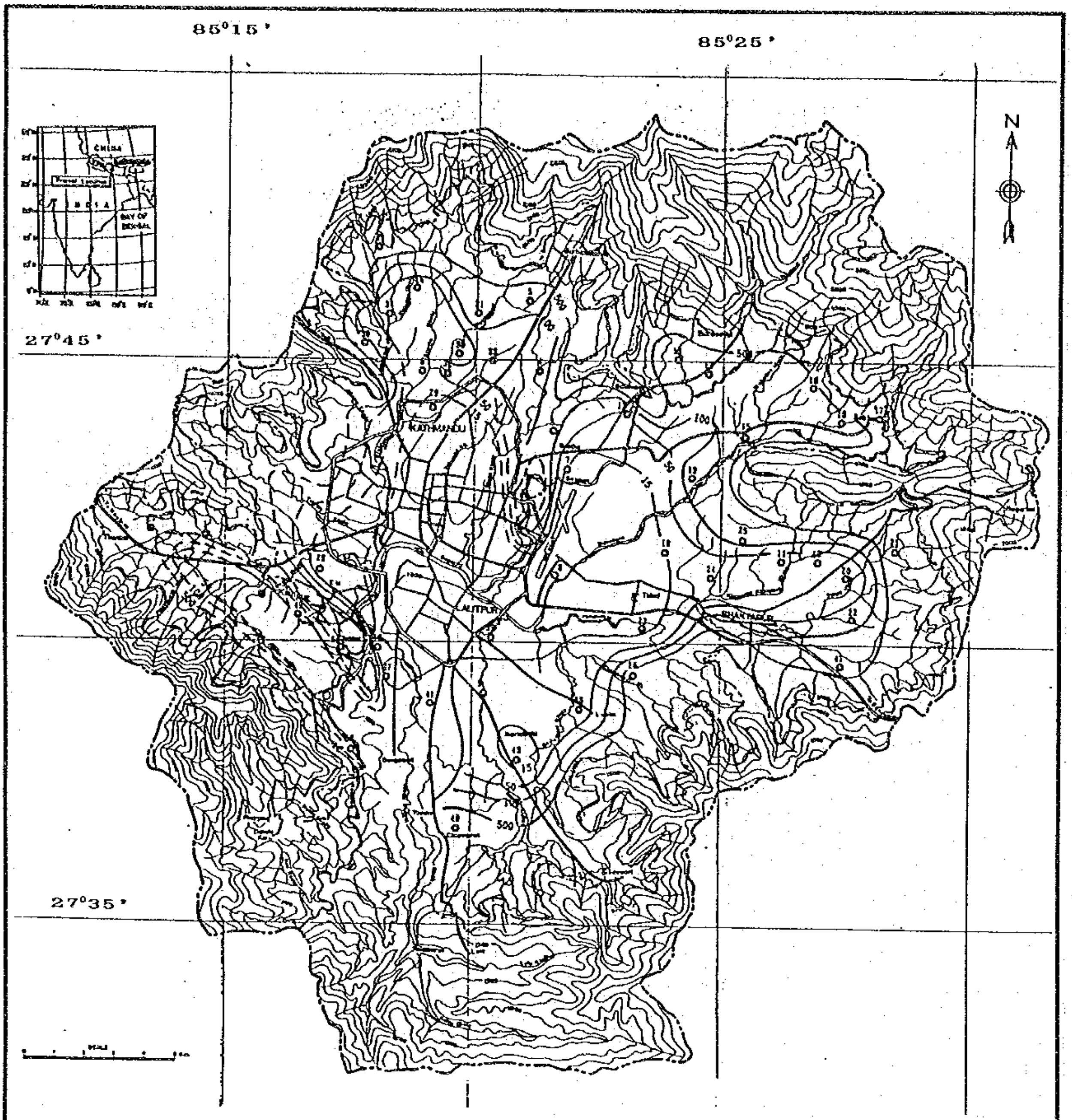
HIS MAJESTY'S GOVERNMENT OF NEPAL GROUND WATER MANAGEMENT PROJECT IN THE KATHMANDU VALLEY JAPAN INTERNATIONAL COOPERATION AGENCY	Fig. D-2.1	LOCATION MAP OF ELECTRICAL PROSPECTING



LEGEND

- Electrical Prospecting Point
  O 19
- Resistivity Contour (ohm-m)
  100
- Boundary of the Kathmandu Valley Basin
- Contour Line at 100m Interval
  1,800
- River
- Road

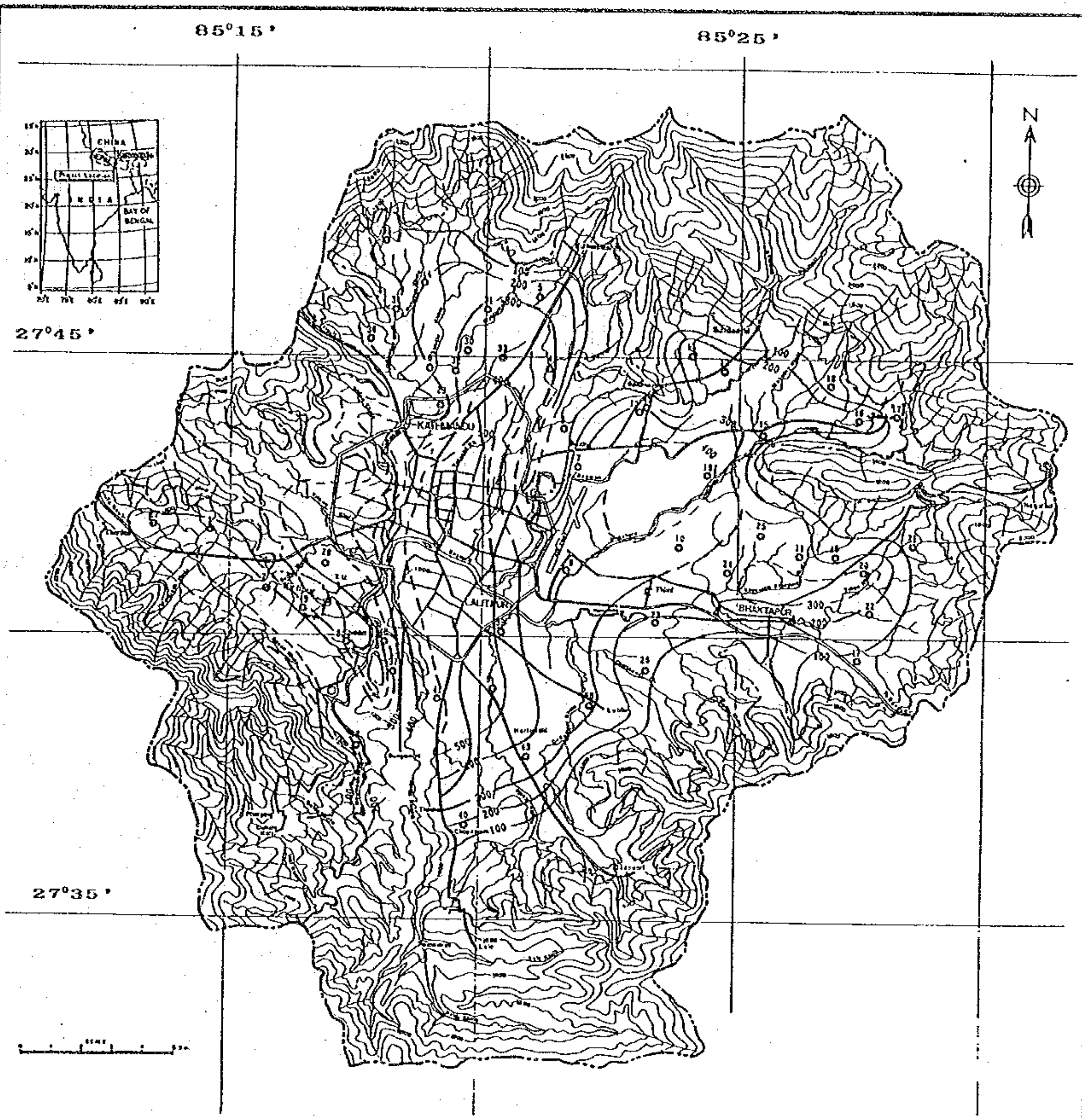
HIS MAJESTY'S GOVERNMENT OF NEPAL GROUND WATER MANAGEMENT PROJECT IN THE KATHMANDU VALLEY JAPAN INTERNATIONAL COOPERATION AGENCY	Fig. D-2.2	RESISTIVITY MAP (10M BELOW SURFACE)



L E G E N D

- Electrical Prospecting Point
  O 19
- Resistivity Contour (ohm-m)
  100
- Boundary of the Kathmandu Valley Basin
- Contour Line at 100m Interval
  1,800
- River
- Road

HIS MAJESTY'S GOVERNMENT OF NEPAL GROUND WATER MANAGEMENT PROJECT IN THE KATHMANDU VALLEY	Fig. D-2.3	RESISTIVITY MAP (1200M A. S. L.)
JAPAN INTERNATIONAL COOPERATION AGENCY		



LEGEND

Electrical Prospecting Point
O 19

Basement Depth Contour (m)
300

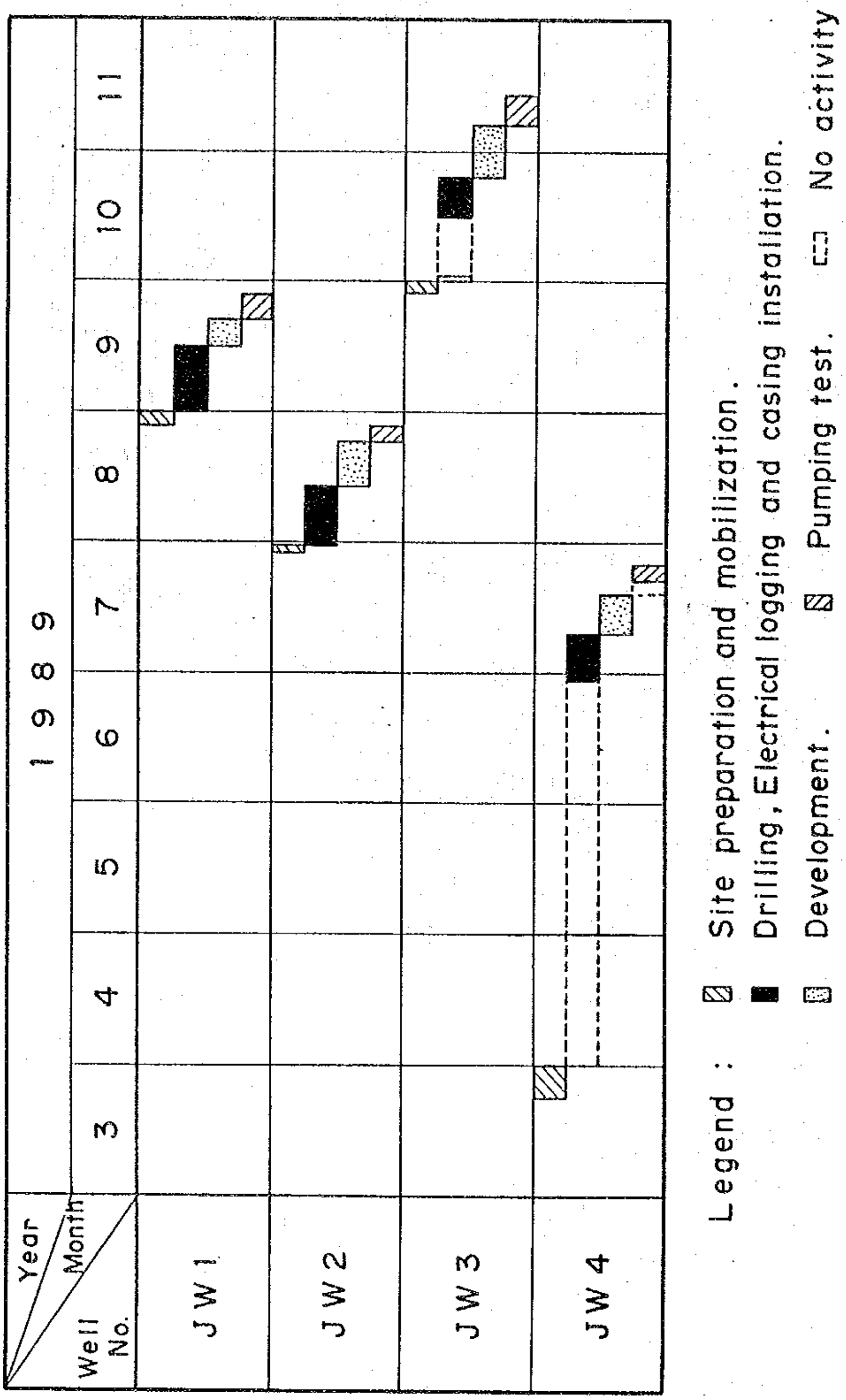
Boundary of the Kathmandu Valley Basin

Contour Line at 100m Interval
1,800

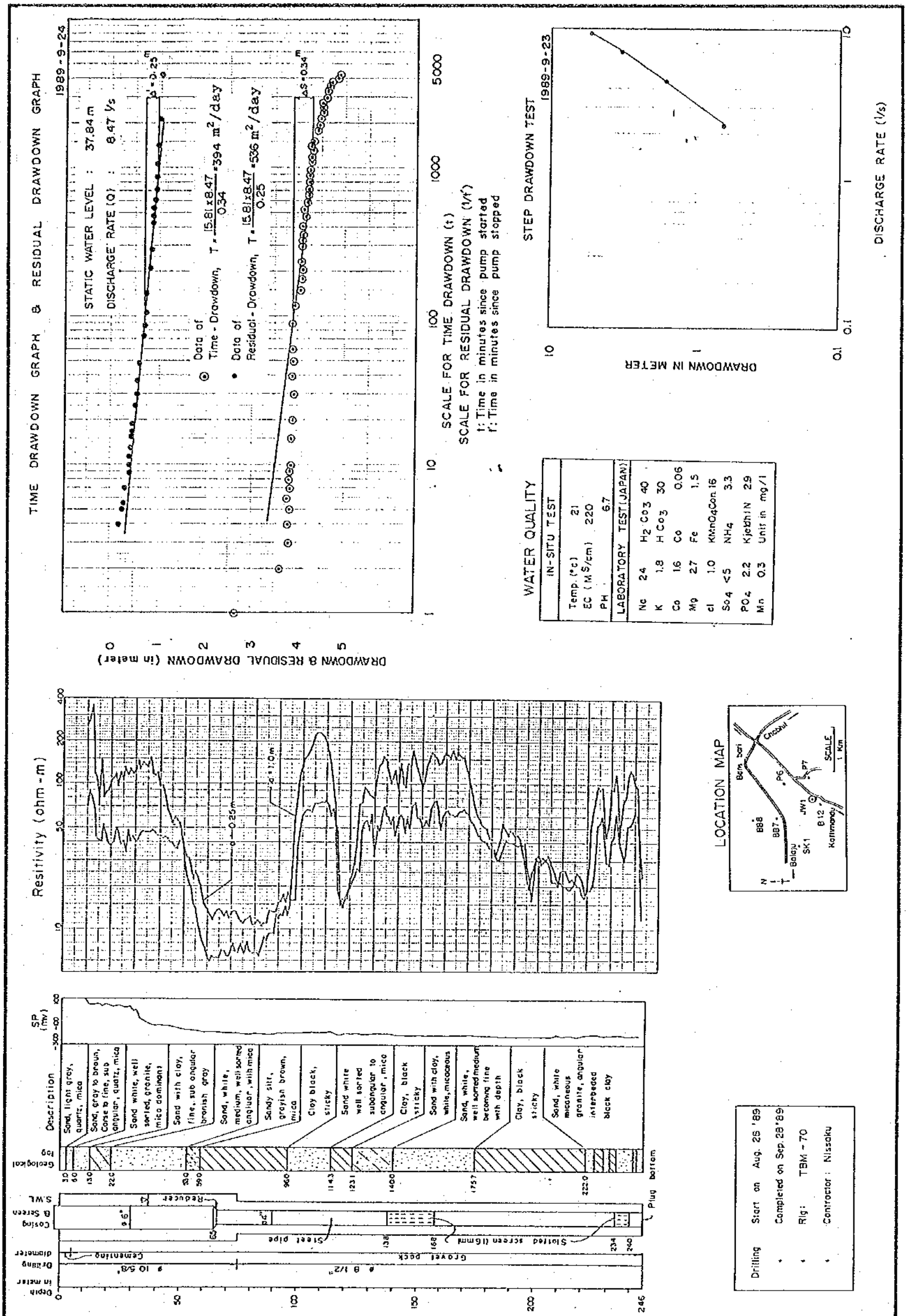
River

Road

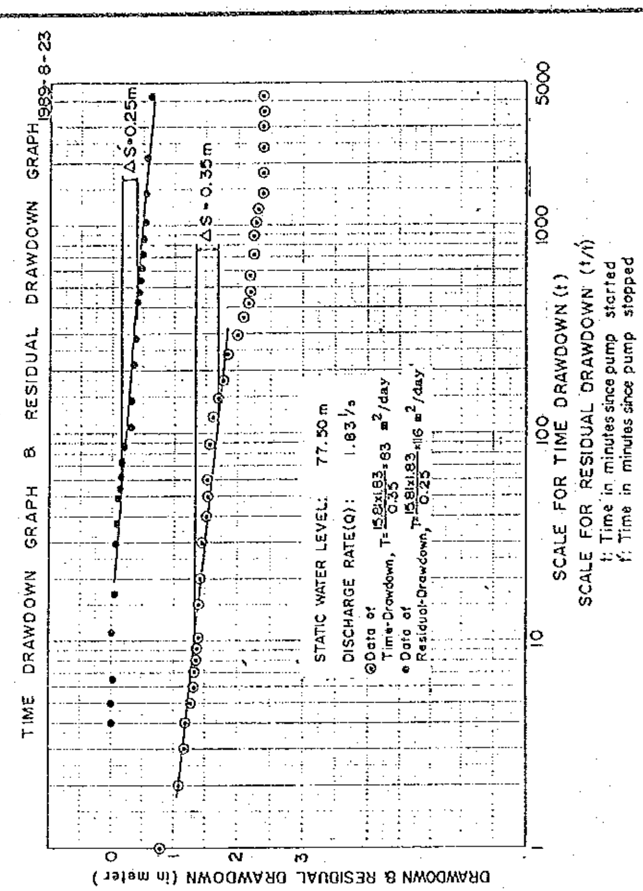
HIS MAJESTY'S GOVERNMENT OF NEPAL GROUND WATER MANAGEMENT PROJECT IN THE KATHMANDU VALLEY	Fig. D-2.4	STRUCTURL BASEMENT ISO - DEPTH MAP
JAPAN INTERNATIONAL COOPERATION AGENCY		

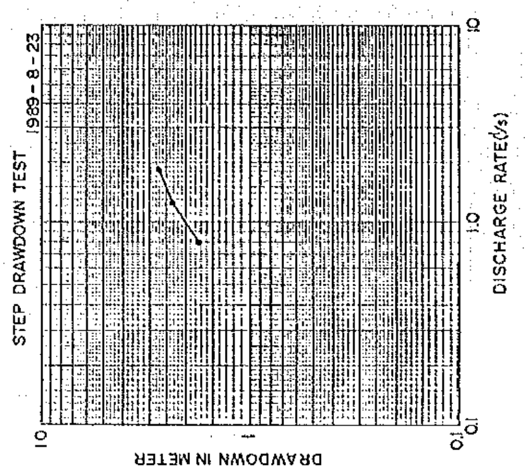


HIS MAJESTY'S GOVERNMENT OF NEPAL GROUND WATER MANAGEMENT PROJECT IN THE KATHMANDU VALLEY	Fig. D-3.1	DIAGRAM OF WELL DRILLING PROGRESS
JAPAN INTERNATIONAL COOPERATION AGENCY		



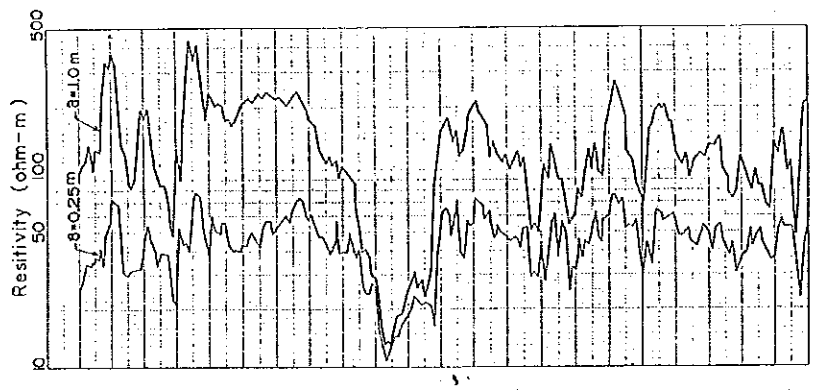
HIS MAJESTY'S GOVERNMENT OF NEPAL GROUND WATER MANAGEMENT PROJECT IN THE KATHMANDU VALLEY	Fig. D-3.2	WELL LOG (JW-1)
JAPAN INTERNATIONAL COOPERATION AGENCY		

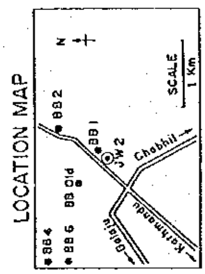


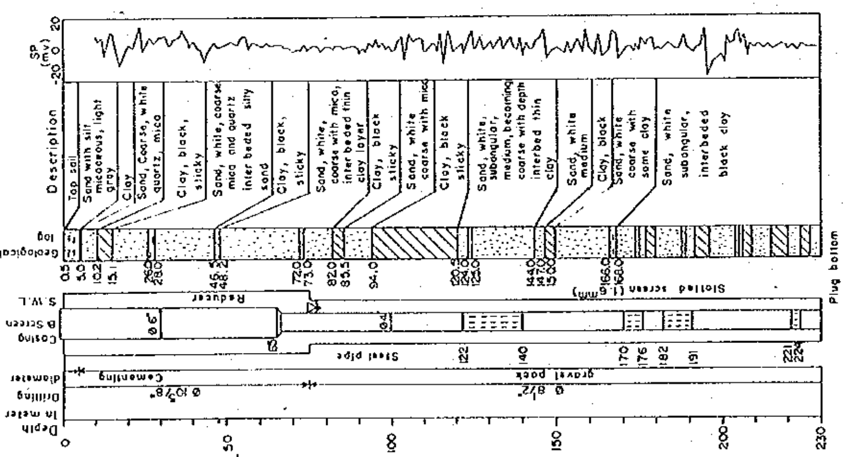


WATER QUALITY

IN-SITU TEST			
Temp.(°c)	21		
EC (μS/cm)	140		
PH	6.9		
LABORATORY TEST(JAPAN)			
Na	14	H_2CO_3	10
K	1.2	HCO_3	44
Ca	8.3	CO_3	0.02
Mg	8.8	Fe	1.8
Cl	2.0	$KMnO_4$Con	5
SO_4	<5	NH_4	0.07
PO_4	0.8	Kjeldhl N	0.1
Mn	0.2	Unit in mg/l	

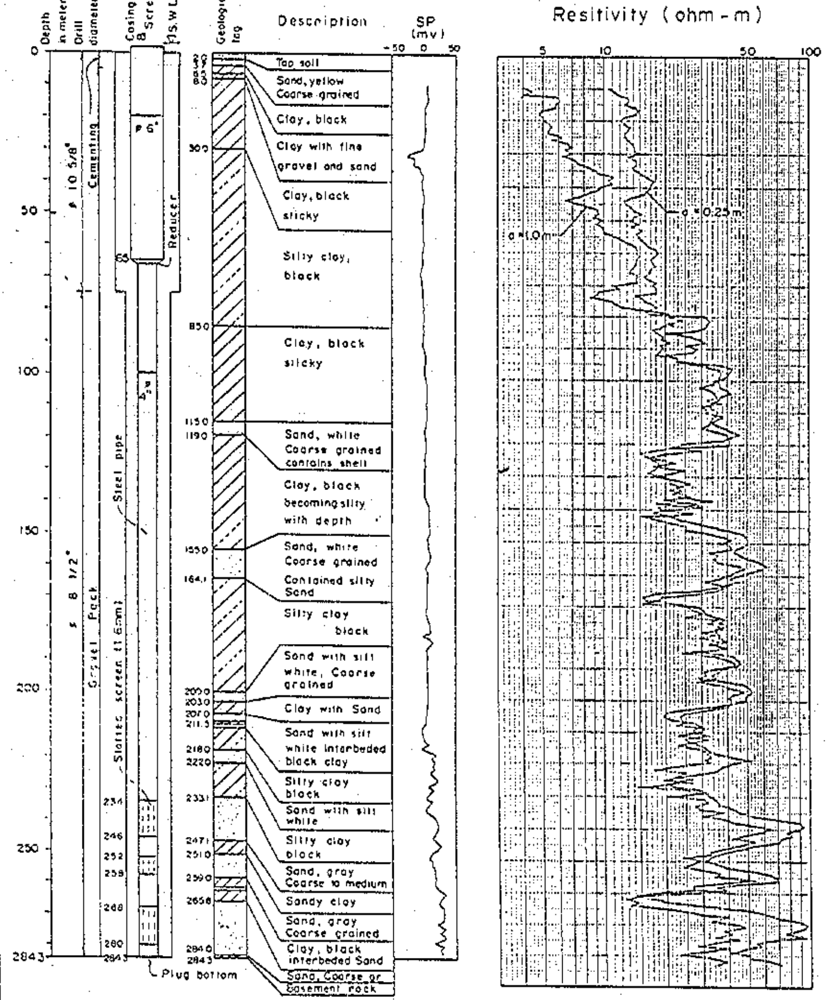






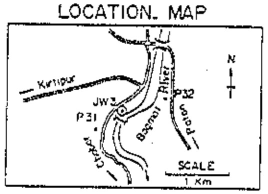
Drilling	
Start on	July 31'89
Completed on	Aug 27'89
Rig	TBM-70
Contractor	Nissaku

HIS MAJESTY'S GOVERNMENT OF NEPAL GROUND WATER MANAGEMENT PROJECT IN THE KATHMANDU VALLEY	Fig. D-3.3	WELL LOG (JW-2)
JAPAN INTERNATIONAL COOPERATION AGENCY		

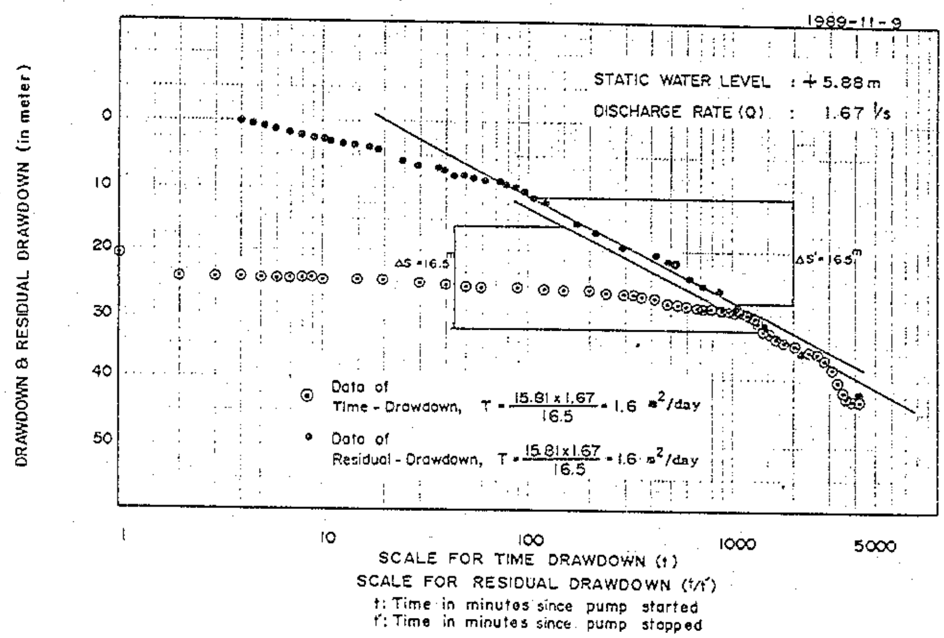


Drilling	
Start on	Sep. 29 '89
Completed on	Nov. 26 '89
Rig:	TBM - 70
Contractor:	Nissaku

LOCATION. MAP



TIME DRAWDOWN GRAPH & RESIDUAL DRAWDOWN GRAPH

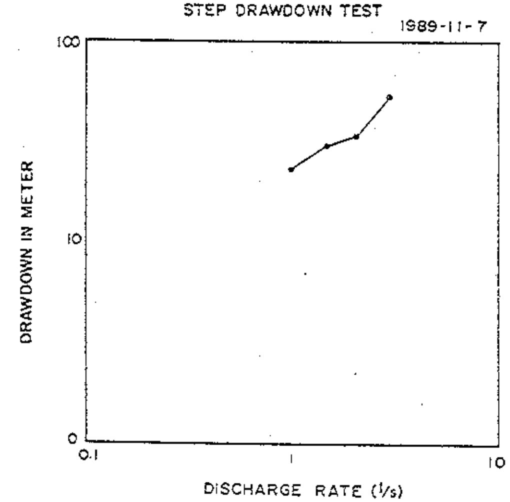


WATER QUALITY

IN-SITU TEST	
Temp. (°c)	20.0
EC (MS/cm)	432
PH	6.9

LABORATORY TEST (JAPAN)			
Na	75	H_2CO_3	67
K	3.3	HCO_3	280
Ca	11	CO_3	0.14
Mg	3.2	Fe	2.1
cl	0.8	$KMnO_4$ Con.	28
SO_4	5.4	NH_4	16
PO_4	24	Kjeldhl N	13
Mn	0.1	Unit in mg/l	

STEP DRAWDOWN TEST

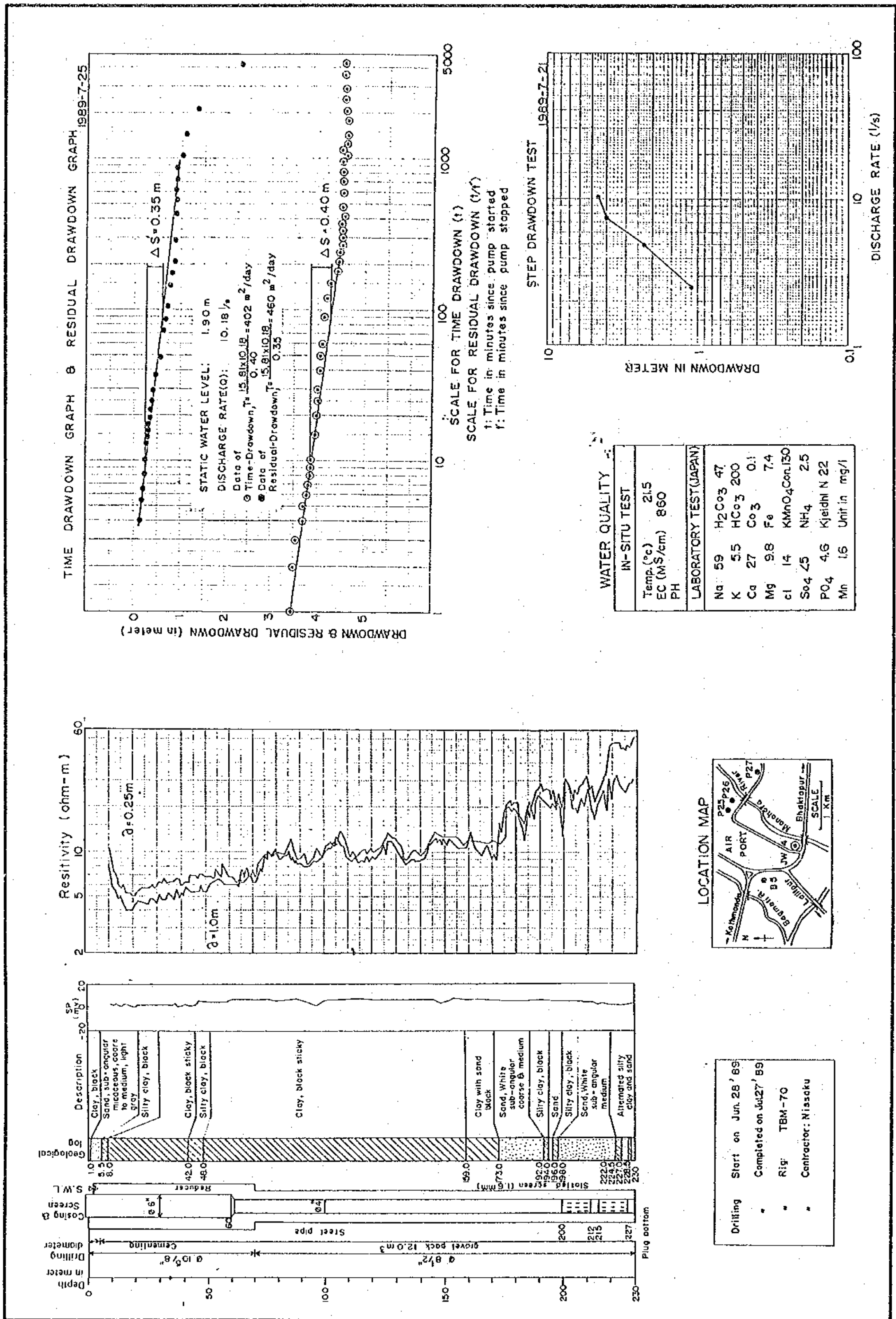


HIS MAJESTY'S GOVERNMENT OF NEPAL
GROUND WATER MANAGEMENT PROJECT
IN THE KATHMANDU VALLEY

JAPAN INTERNATIONAL COOPERATION AGENCY

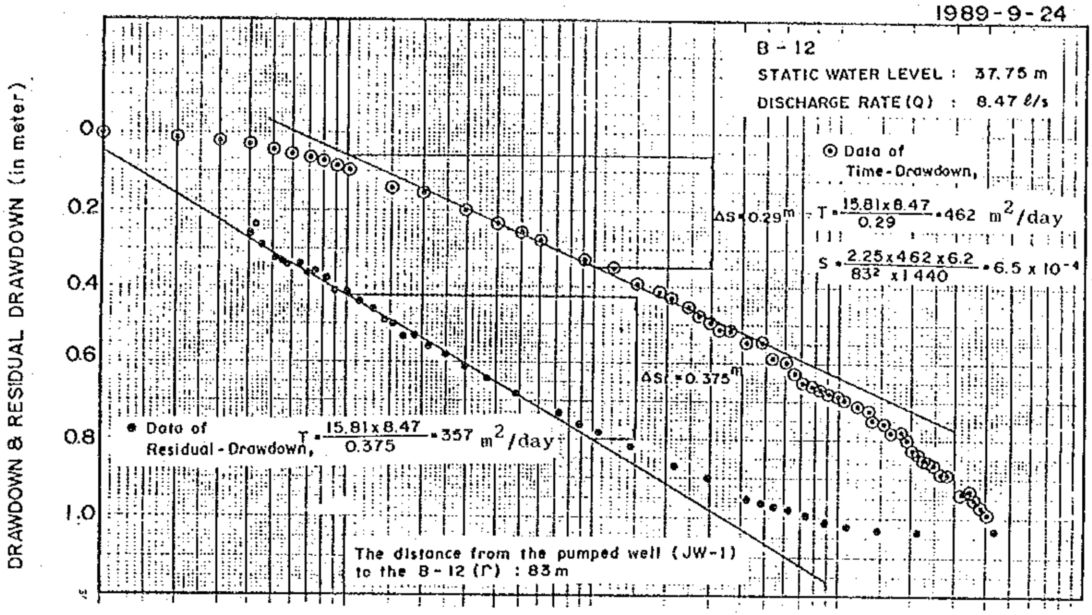
Fig. D-3.4

WELL LOG (JW-3)

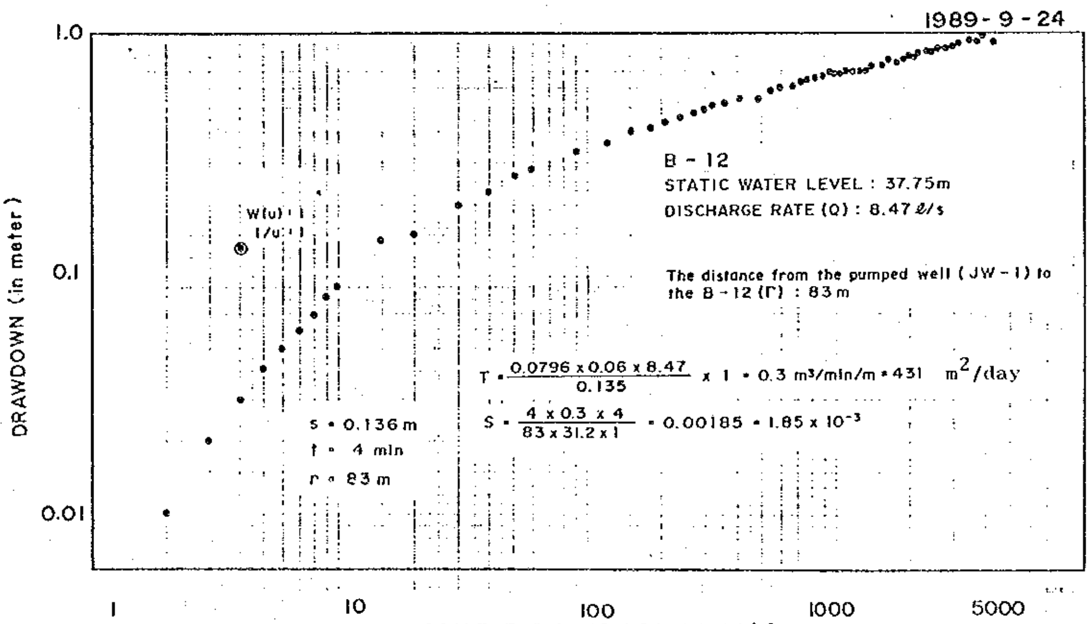


HIS MAJESTY'S GOVERNMENT OF NEPAL GROUND WATER MANAGEMENT PROJECT IN THE KATHMANDU VALLEY	Fig. D-3.5	WELL LOG (JW-4)
JAPAN INTERNATIONAL COOPERATION AGENCY		

TIME DRAWDOWN GRAPH & RESIDUAL DRAWDOWN GRAPH



SCALE FOR TIME DRAWDOWN (t)
SCALE FOR RESIDUAL DRAWDOWN (t/t')
t: Time in minutes since pump started
t': Time in minutes since pump stopped

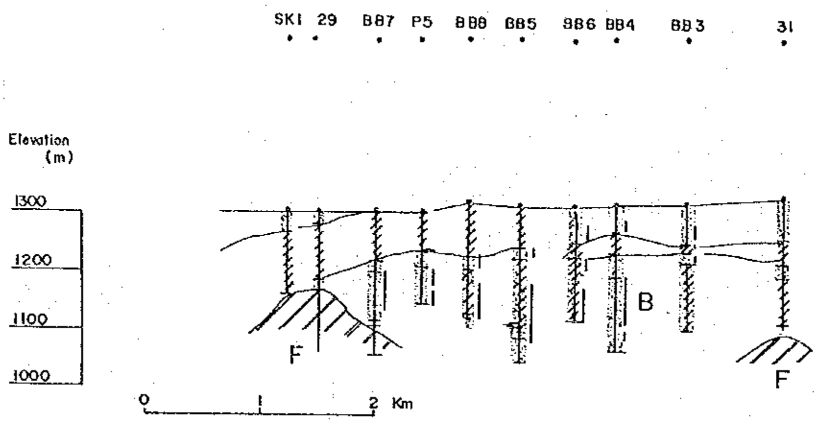


SCALE FOR TIME DRAWDOWN (t)

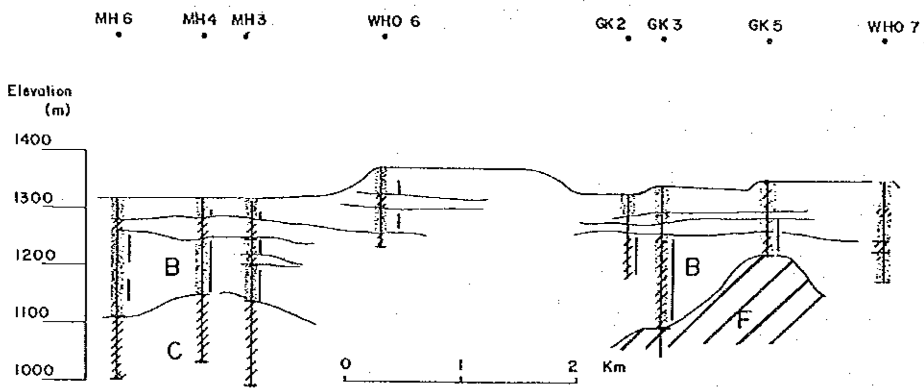
t: Time in minutes since pump started

HIS MAJESTY'S GOVERNMENT OF NEPAL GROUND WATER MANAGEMENT PROJECT IN THE KATHMANDU VALLEY	Fig. D-3.6	RESULTS OF PUMPING TEST ON B12
JAPAN INTERNATIONAL COOPERATION AGENCY		

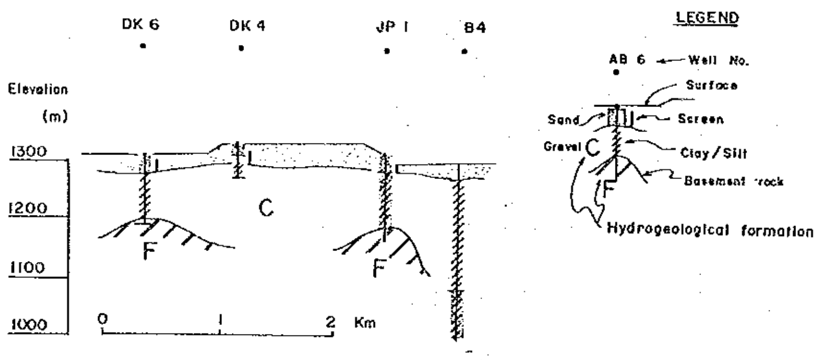
NORTHERN GROUNDWATER DISTRICT (BANSBARI)



NORTHERN GROUNDWATER DISTRICT (MANOHARA)

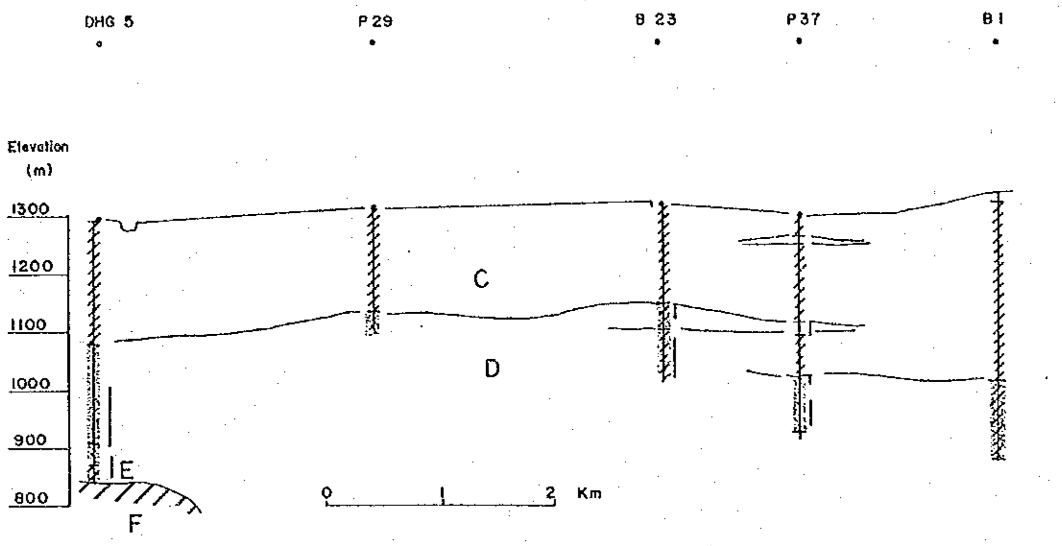


NORTHERN GROUNDWATER DISTRICT (DHOBI KHOLA)

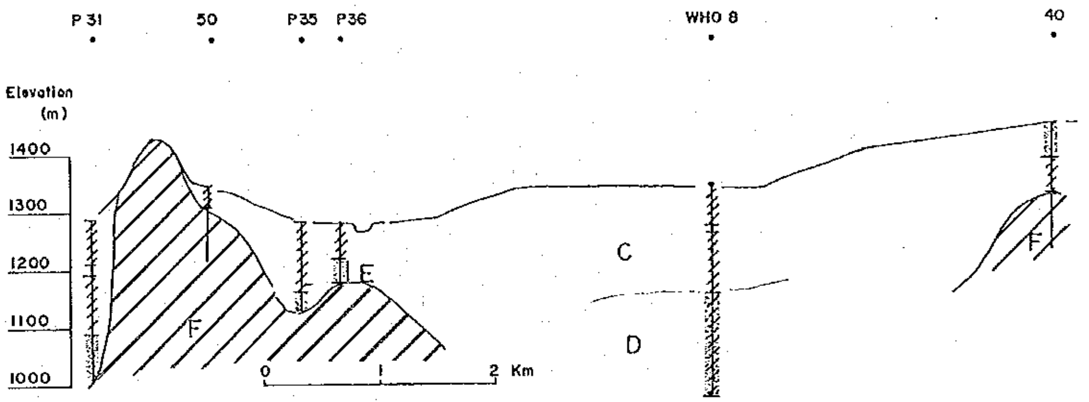


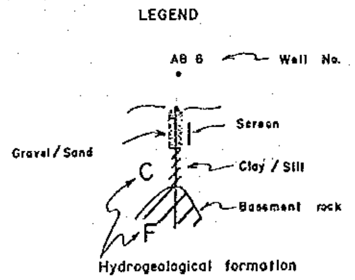
HIS MAJESTY'S GOVERNMENT OF NEPAL GROUND WATER MANAGEMENT PROJECT IN THE KATHMANDU VALLEY JAPAN INTERNATIONAL COOPERATION AGENCY	Fig. D-4.1	SCHEMATIC GEOLOGIC CROSS SECTION (1/2)

CENTRAL GROUNDWATER DISTRICT

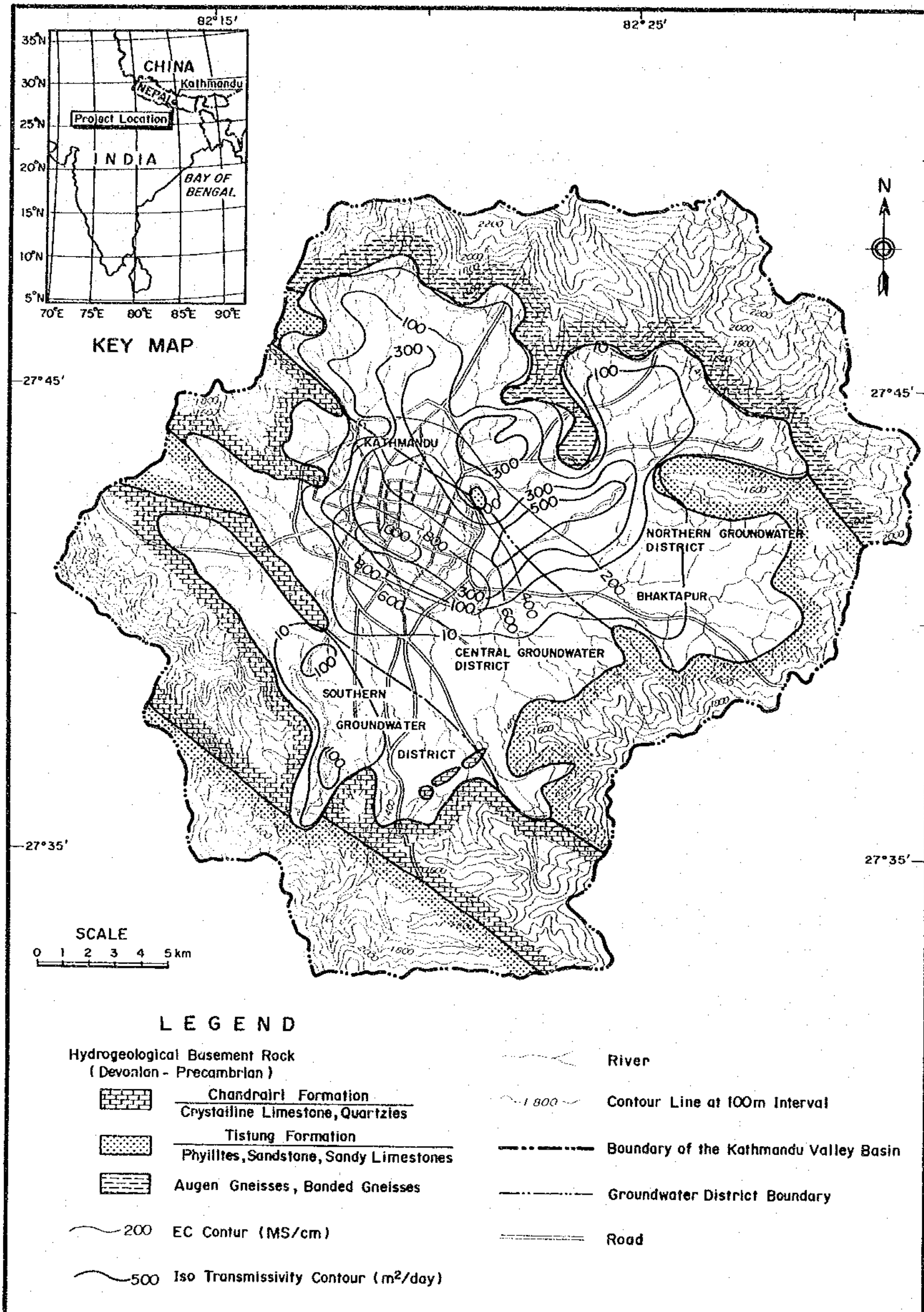


SOUTHERN GROUNDWATER DISTRICT



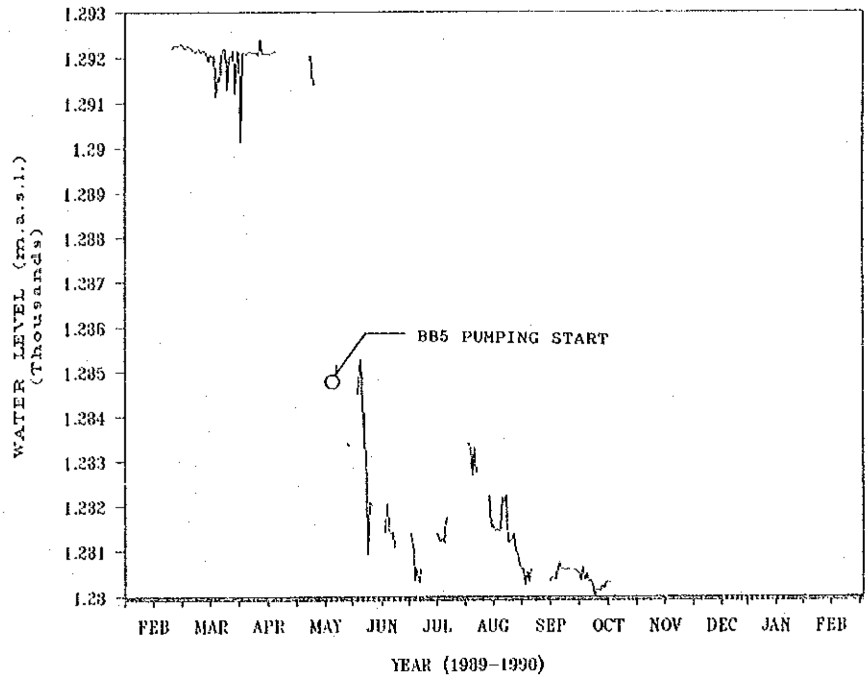


HIS MAJESTY'S GOVERNMENT OF NEPAL GROUND WATER MANAGEMENT PROJECT IN THE KATHMANDU VALLEY	Fig. D-4.1	SCHEMATIC GEOLOGIC CROSS SECTION (2/2)
JAPAN INTERNATIONAL COOPERATION AGENCY		

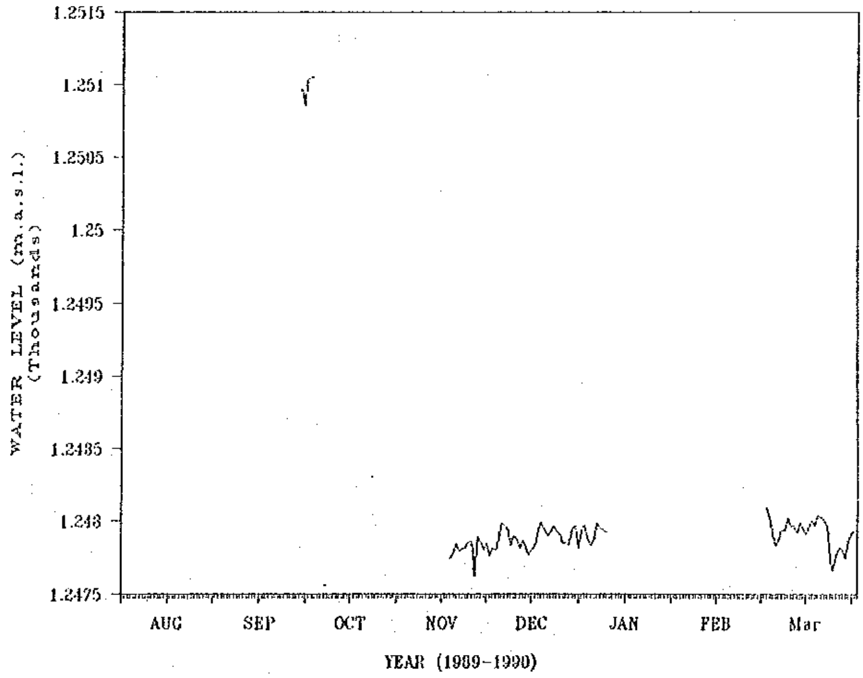


HIS MAJESTY'S GOVERNMENT OF NEPAL GROUND WATER MANAGEMENT PROJECT IN THE KATHMANDU VALLEY	Fig. D-4.2	HYDROGEOLOGICAL MAP
JAPAN INTERNATIONAL COOPERATION AGENCY		

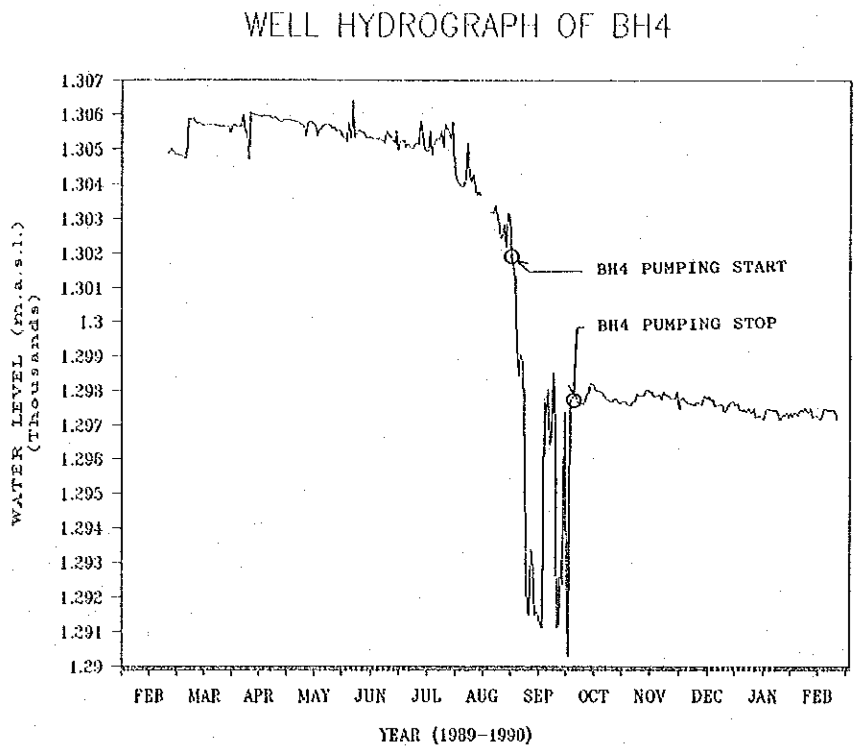
WELL HYDROGRAPH OF BB5

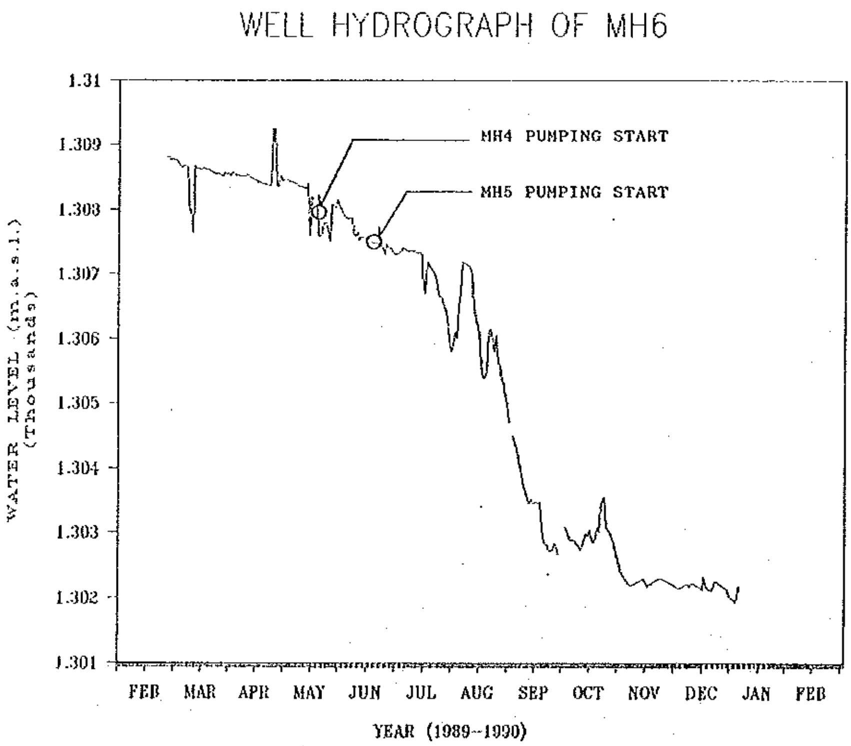


WELL HYDROGRAPH OF DK1



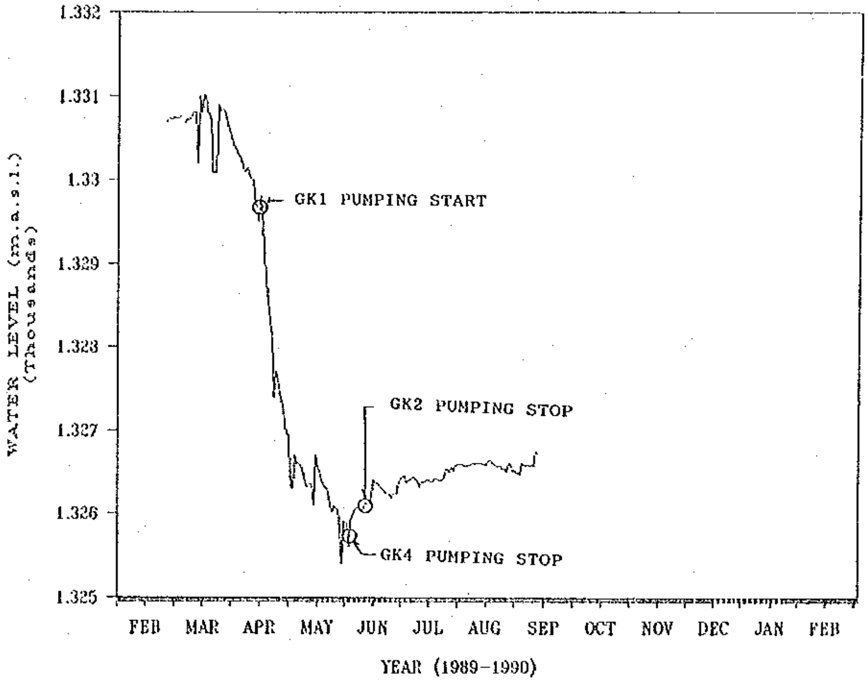
HIS MAJESTY'S GOVERNMENT OF NEPAL GROUND WATER MANAGEMENT PROJECT IN THE KATHMANDU VALLEY	Fig. D-6.1	WELL HYDROGRAPH (1/4)
JAPAN INTERNATIONAL COOPERATION AGENCY		



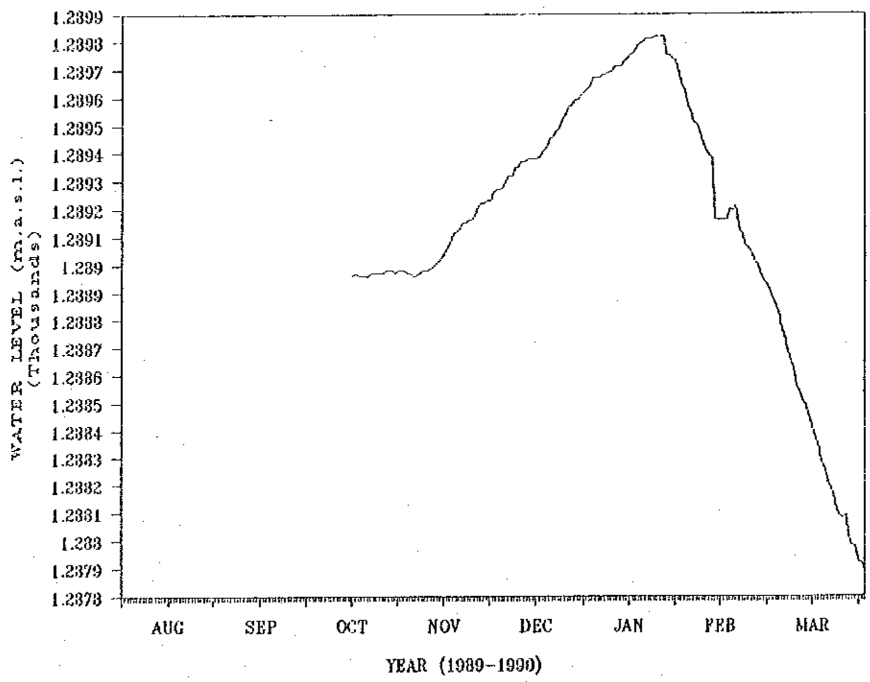


HIS MAJESTY'S GOVERNMENT OF NEPAL GROUND WATER MANAGEMENT PROJECT IN THE KATHMANDU VALLEY	Fig. D-6.1	WELL HYDROGRAPH (2/4)
JAPAN INTERNATIONAL COOPERATION AGENCY		

WELL HYDROGRAPH OF GK5

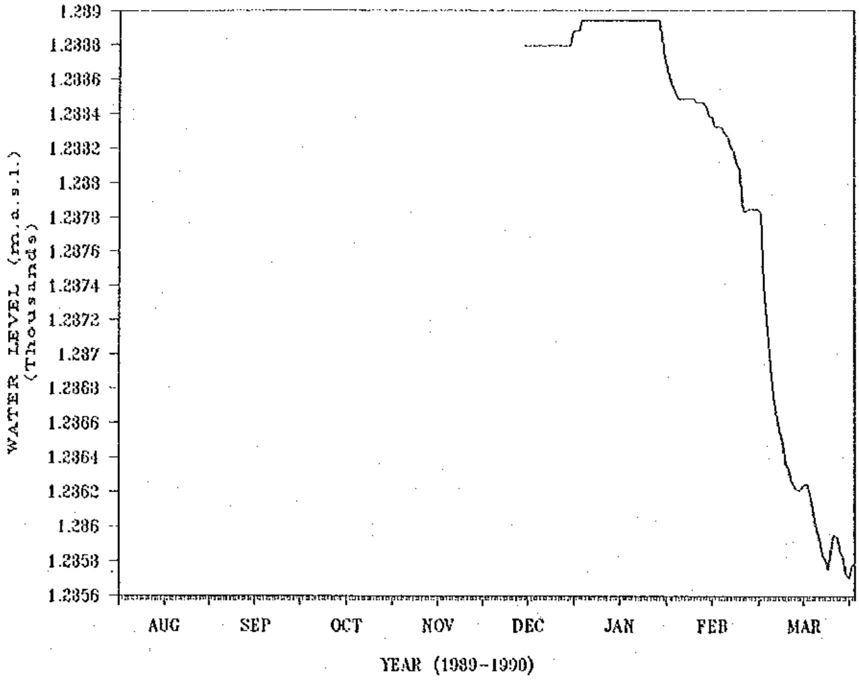


WELL HYDROGRAPH OF JW1

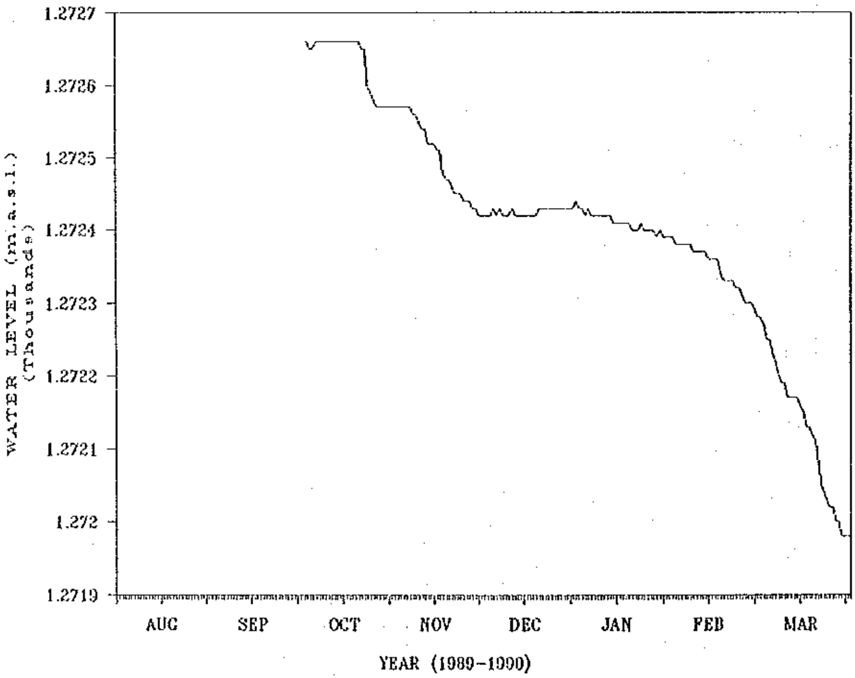


HIS MAJESTY'S GOVERNMENT OF NEPAL GROUND WATER MANAGEMENT PROJECT IN THE KATHMANDU VALLEY	Fig. D-6.1	WELL HYDROGRAPH (3/4)
JAPAN INTERNATIONAL COOPERATION AGENCY		

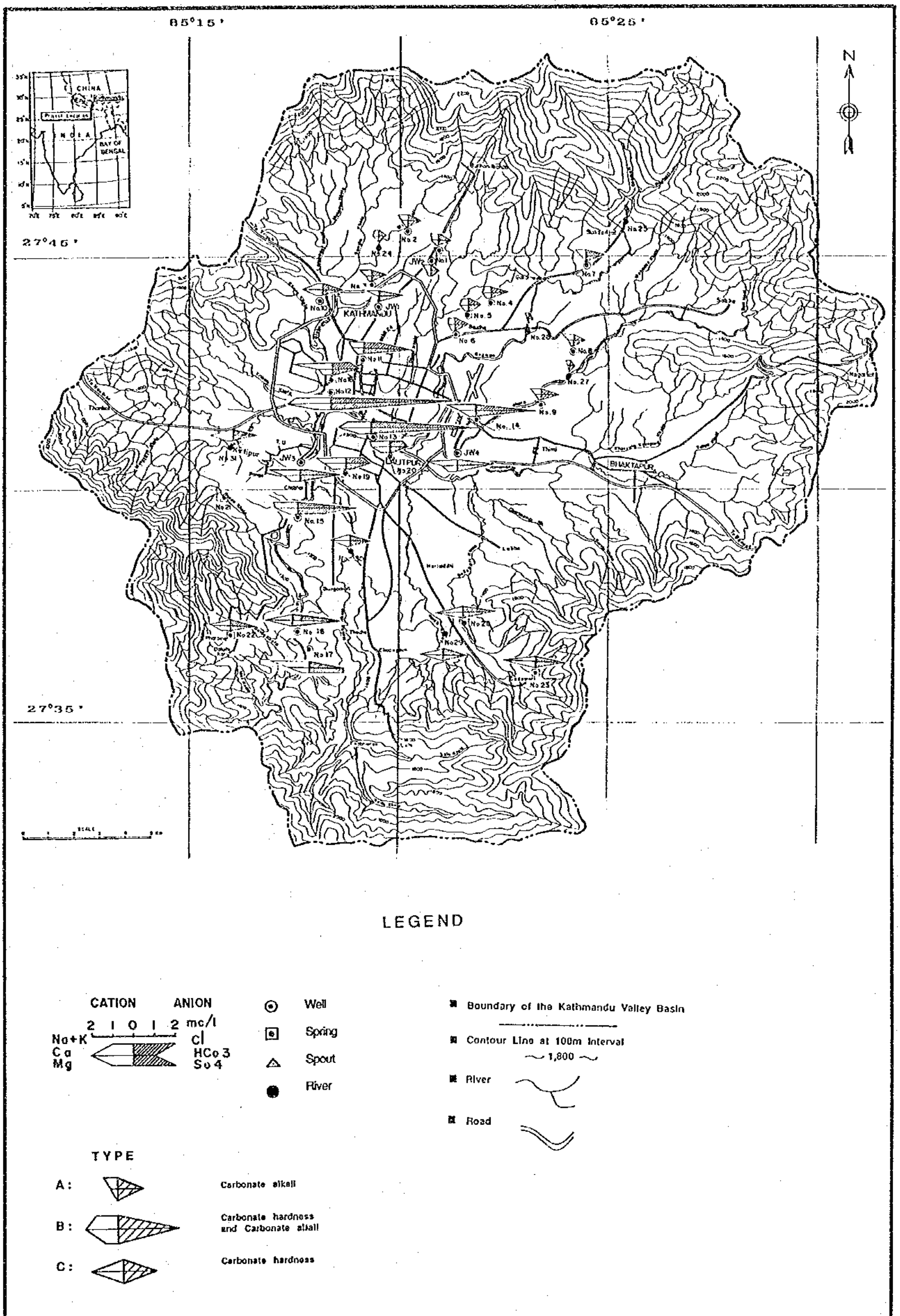
WELL HYDROGRAPH OF JW2



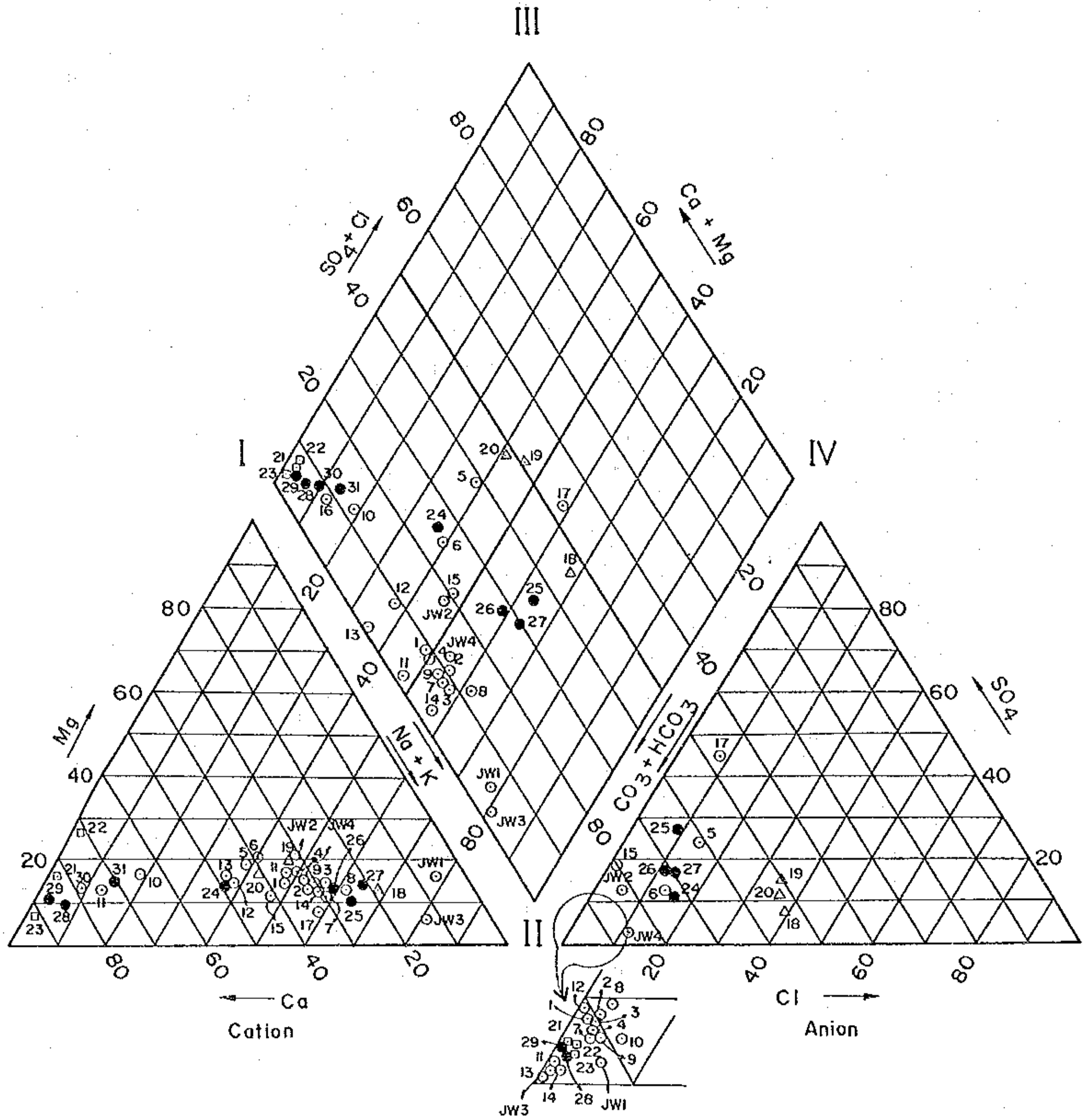
WELL HYDROGRAPH OF JW4



HIS MAJESTY'S GOVERNMENT OF NEPAL GROUND WATER MANAGEMENT PROJECT IN THE KATHMANDU VALLEY	Fig. D-6.1	WELL HYDROGRAPH (4/4)
JAPAN INTERNATIONAL COOPERATION AGENCY		



HIS MAJESTY'S GOVERNMENT OF NEPAL GROUND WATER MANAGEMENT PROJECT IN THE KATHMANDU VALLEY	Fig. D-8.1	STIFF'S HEXA-DIAGRAM
JAPAN INTERNATIONAL COOPERATION AGENCY		



TYPE

I Ca$(HCO_3)_2$

II NaHCO_3

III $CaSO_4$, $CaCl_2$

IV Na_2SO_4, NaCl

LEGEND

⊙ Well

⊡ Spring

△ Spout

● River

HIS MAJESTY'S GOVERNMENT OF NEPAL GROUND WATER MANAGEMENT PROJECT IN THE KATHMANDU VALLEY JAPAN INTERNATIONAL COOPERATION AGENCY	Fig. D-8.2	TRILINEAR DIAGRAM

APPENDIX E
GROUNDWATER SIMULATION

APPENDIX E
GROUNDWATER SIMULATION

LIST OF TABLES

LIST OF FIGURES

1. OBJECTIVES OF THE STUDY

The groundwater basin in the Kathmandu Valley (hereinafter called "the groundwater basin") is isolated and independent of other groundwater systems outside the valley. The main aquifer ranges from EL. 900 m to El. 1350 m and is confined by lacustrine deposits some 50 to 200 m in depth, or alluvial fans less developed in some places along the margin of gentle hills in the northern and south-eastern part of the valley. The total area of the groundwater basin is 326 km^2, divided into three sub-basins from the standpoint of geography, geology and exploitablility as mentioned in section APPENDIX D. Those are Northern, Central and Southern district, whose areas are 156 km^2,114 km^2 and 56 km^2 respectively. Fig.E-2.1 shows the basin and boundaries of the three districts.

NWSC has constructed 38 production wells mainly in the Northern district, of them 25 tube wells have been continually operated in 1989 for drinking water. This groundwater abstraction has recently caused a rapid drawdown of groundwater level, which may have serious consequences on water supply to the valley in the near feature. Notwithstanding this phenomenon, no appropriate assessment on basin-wide exploitability has been conducted up to the present because of lack of information on geology and hydrogeology of the valley.

This study aims at the following three items by means of mathematical model simulation (FEM) based on the field investigation and hydrogeological analysis ;

1) To simulate the original groundwater level,or condition before abstraction by NWSC (year 1972),

2) To simulate the present groundwater level which as the results from abstraction in the last two decades (year 1989),

3) To establish the optimum management plan for groundwater use including the pump operation program for existing tube wells

2. GROUNDWATER BASIN OF KATHMANDU VALLEY

2.1 General

The deposits within the valley are predominantly lacustrine. Furthermore,the ground surface of the relatively lower and flat area is covered with silty clay. Therefore even infiltration of rainfall into the shallow aquifer is quite limited. Permeability of rainfall for each district are:

Central district

The Central district is confined by clay of 200 m in thickness and its surface is covered with nearly impervious deposit. Therefore rainfall can hardly permeate into the ground. The south-eastern part of the district near Godawari is covered with sand or gravel deposit and this is the only possible area where infiltration takes place in the district;

Northern district

Northern area of the Northern district is partially covered with arenaceous deposits which is relatively pervious. Pervious area of rainfall into unconfined aquifer is estimated to be 59 km^2,or 38 percent of total area of the Northern district(156 km^2);

Southern district

Eastern area of the Southern district is also covered with sand or gravel deposits. Area of this portion, or estimated recharge area for unconfined aquifer is 21 km^2 ,or 37 percent of total area of the Southern district (56 km^2).

The total infiltration area for the unconfined shallow aquifer in the Kathmandu valley mentioned above is 86 km^2,or 26 percent of the total area of the whole groundwater basin. Fig.E-2.2 shows the geological conditions in the valley and estimated permeable area.

The main aquifer for exploitation is confined and isolated both laterally and vertically. Therefore the recharge sources of the main aquifer are squeezed water from the confining strata or leakage water of unconfined aquifer through confining strata, both of which lie above the main aquifer. This water movement is caused by the difference between the total heads of the concerned strata. The amount of this groundwater flow is quite small if groundwater is not abstracted artificially from the main aquifer,or under natural conditions. But drawdown of the piezometric head of the main aquifer by artificial abstraction as conducted now will allow increased supplementary recharge from above. The hydrogeological structure of the groundwater basin is described in detain in APPENDIX-D.

2.2 Seasonal Fluctuation of Piezometric Head of the Main Aquifer

Continuous observation on groundwater levels at several tube wells has been carried out by JICA team since March 1989. From October 1989, automatic water level recorders have also been installed at four observation wells which were constructed during the study by JICA team. These data,however, do not cover one hydrological cycle so far. Therefore, previous well hydrograph data are used to assess the seasonal fluctuation of groundwater level and recharge into main aquifer. Those are;

Well	District	period
B12	North	Dec.1971 - Nov.1972
WHO 7A	North	Jun.1972 - Nov.1973

To assess the annual fluctuation of groundwater level in the long term, tank model simulation is carried out which develops the relationship between rainfall and groundwater level. The model is first calibrated with the observed well hydrograph and corresponding rainfall data. Long term data on groundwater levels are then synthesized by the model and observed rainfall data. Fig.E-2.3, Table E-2.1 and Table E-2.2 show the final results of tank model simulation and observed and estimated groundwater level. Annual fluctuation (Maximum groundwater level - Minimum groundwater level) of long term average at these two sites are deduced. That is,

Well	Area	Assessed Period	Estimated Mean Annual Fluctuation
WHO 7A	Sundarijal	Jan.1940- Dec.1986	1500 mm
B12	Maharajganj	Jan.1947- Dec.1975	457 mm

WHO 7A is located at the northern rim of the Northern district as seen in Fig.E-2.2, whose ground elevation is 1359 m. A screen was installed in deep layers in the well, therefore fluctuation of the groundwater level represent that of the main aquifer. The groundwater level has an annual cycle. Maximum water level occurs in September, and minimum in the end of June or beginning of July. Average annual fluctuation of water level is 1500 mm.

B12 ,whose elevation is about 1320 m, is located at the western part of the Northern district called Maharajganj. Adjacent to B12, constructed JICA team's observation well (JW1) which has screen only in deep aquifer,or,the main aquifer. During pump test of JW1, piezometric heads of B12 and JW1 coincided with each other, which indicates that B12 also has screen only in deep confined aquifer. Therefore fluctuation of the groundwater head of B12 is thought to represent recharged water of the main aquifer as well as WHO 7A. The water level has annual cycle and maximum water level occurs in October, and minimum in the end of June or beginning of July. Average annual fluctuation of the water level of the well during recent 29 years is estimated to be 457 mm.

2.3 Aquiclude Leakage

A confined aquifer lying between impermeable layers cannot be recharged, even if the piezometric head of the aquifer is lower than that of adjacent layers. The layer above the main aquifer in the valley is, however, thought to be an aquiclude, though not impermeable. Therefore, the difference in piezometric head between the main aquifer and the upper aquifer may cause basin-wide movement of groundwater called aquiclude leakage as illustrated in Fig.E-2.4. The possible causes of differences of head are thought to be

1) physiographic effectiveness , and 2) artificial abstraction from the main aquifer.

80 percent of the annual rainfall in the valley is concentrated from June to September (the Monsoon season), and the ground surface in the valley is mostly in saturated condition during the period. On the other hand, ground water level decline gradually after the Monsoon season. This annual fluctuation of water level in the shallow aquifer causes fluctuation in the piezometric head of the main aquifer in deep strata in the valley. The Leakage factor, or permeability of the aquitard layer on the main aquifer, is calculated by the following equation based on the abovementioned phenomenon;

$$S \frac{h1}{T} = k' \frac{(h2-h1)}{L} \cong k' \frac{(h-hm)}{L}$$

$$\text{or,} \quad k' \cong \frac{L\,S}{(h-hm)} \frac{h1}{T}$$

where, k': permeability of aquitard layer
S : storage coefficient
h1: piezometric head of the main aquifer
hm: annual average of h1
h2: groundwater level of shallow aquifer
h : ground level
L : thickness of aquitard

Based on this equation, the permeabilities of the aquitard in the groundwater basin at well WHO 7A and B12 was estimated to be 0.00032 m/day (3.7×10^{-7} cm/sec) and 0.00034 m/day (3.9×10^{-7} cm/sec) respectively. Fig.E-2.5 indicates the observed well hydrograph and illustrates the basic concept to estimate leakage factor.

2.4 Present Pumping and Drawdown

Artificial abstraction in the basin started in 1972 at Kathmandu in the Central district. Succeeding exploitation has been mainly in the Northern district. Total volume of artificial abstraction up to the present reaches 53.7×10^6 m^3. Total drawdown during corresponding period at B12 observation well is 21.92 m. Therefore, basin-wide storage coefficient including leakage factor is calculated roughly as follows;

$$A \times S \times D = Q \text{ ,or}$$
$$S = Q/(A \times D)$$
$$= 0.00752$$

where, S : Storage coefficient
Q : Total abstraction (m^3)
A : Area of the main aquifer (= 325.9 km^2)
D : Total draw down (m)

2.5 Groundwater Flow in the Northern District

Groundwater in the Northern district has been developed mainly in a recent decade and groundwater table and its flow pattern may change and become locally disturbed by abstraction from some 30 tube wells. Therefore, piezometric groundwater level data in 1972-1984 are used to develop groundwater level contour map as shown in Fig E-2.6. In the early stage of 1980's few deep tube wells were operated and these data are thought to be represent original and steady condition groundwater flow in the area. Groundwater flow is calculated based on Darcy's equation;

$$F = T \times L \times H / D$$

where,
- F : groundwater flow through a contour line (m^3/day)
- T : transmissivity from pump test (m^2/day)
- L : width of flow channel parallel to groundwater level contour lines (m)
- D : distance of adjacent contour lines (m)
- H : decrease of piezometric head between two contour lines (m)

Groundwater flow through ground elevation contour line 1,320 - 1,310 is estimated by means of the equation. Dimensions of each factor and the result are shown in Fig.E-2.7 and Table E-2.3, which gives the total amount of 25,000 m^3/day in the northern part of the Northern district. Average velocity of the groundwater is some 10 m/year

3. NUMERICAL MODEL AND CALIBRATION

3.1 Aquifer Modeling

The main aquifer in the valley is considered to be one confined body according to the hydrogeological survey and chronological analysis of groundwater abstracted from the aquifer as mentioned APPENDIX-D. Therefore one confined aquifer model with a leakage factor is applied in this study as illustrated in Fig.E-2.5.

3.2 Dominant Equation

3.2.1 Dominant equation

Partial differentiation equation for groundwater flow is derived two fundamental equations, or, equation of continuity and Darcy's equation as bellow;

$$\frac{\partial Vx}{\partial x} + \frac{\partial Vy}{\partial y} + \frac{dn}{dt} + q = 0 \qquad (1)$$

$$Vx = - Kx\frac{\partial h}{\partial x}, \qquad Vy = - Ky\frac{\partial h}{\partial y} \qquad (2)$$

where,
- Vx, Vy : flow velocity in the x,y direction
- n : unit water content
- h : piezometric head
- Kx,Ky : permeability in the x,y direction
- q : recharge depth

These two equations are simplified as follows,

$$\frac{\partial}{\partial x}\left(Kx \frac{\partial h}{\partial x} \right) + \frac{\partial}{\partial y}\left(Ky \frac{\partial h}{\partial y} \right) = S\frac{\partial h}{\partial t} + q \qquad (3)$$

where, S ; storage coefficient defined by dn/dh

This equation can be numerically solved if boundary condition and initial condition are properly given. If aquifer is not single, equations which represent the aquifers are to be solved in consideration of reciprocal relation of piezometric heads of adjacent aquifers.

3.2.2 Vertical movement (quasi-three-dimensional factor)

Leakage from unconfined aquifer into the main confined aquifer through aquitard is the main vertical movement of the main aquifer of the groundwater basin. The aquitard is assumed to be more or less incompressible so that water released from storage therein is negligible. The rate of vertical leakage is proportionate to the difference in head between the water table of the unconfined aquifer table and piezometric surface of the aquifer, or,

$$q = \frac{k'}{b'}(H - h) \qquad (4)$$

where,
- q : leakage in depth
- h : piezometric head of confined aquifer
- H : Elevation of unconfined aquifer
- k': permeability of the aquitard
- b': thickness of the aquitard

Substituting in equation (3) the above, gives the following dominant equation,

$$\frac{\partial}{\partial x}\left(Kx \frac{\partial h}{\partial x} \right) + \frac{\partial}{\partial y}\left(Ky \frac{\partial h}{\partial y} \right) = S\frac{\partial h}{\partial t} + \frac{k'}{b'}(H - h) \qquad (5)$$

3.3 Difference Approximation by Finite Element Method (FEM)

3.3.1 Modeling by Galerkin's method

For difference approximation, Galerkin's method is applied to Laplace's equation. The first step is to define an approximate or trial function, h(x,y,t)of the form

$$h(x,y,t)= [N(x,y)]\{f(t)\} \;\ldots\ldots\ldots\ldots\ldots\ldots\ldots\;(1)$$

where; {f(t)} : head vector with a form of column matrix
[N(x,y)]: basis function with a form of row matrix

This form of the trial solution shows the separation between the space and time variables. At any instant time, the basis functions interpolate the nodal heads over the problem domain. Galerkin's method requires that, when the trial solution is substituted into the differential equation, the residual, when weighted by each of the basis functions,be zero.

$$\iiint_v [N(x,y)]^t\left(\frac{\partial h}{\partial x}(Tx \frac{\partial h}{\partial x}) + \frac{\partial h}{\partial y}(Ty \frac{\partial h}{\partial y}) - S \frac{\partial h}{\partial t} - W \right)dV = 0$$

where the suffix ^{t} signifies the invert matrix and the $_v$ specifies that the integration is done over the entire problem domain.

3.3.2 Matrix differential equation

Through the integration by elements, above equation can be finally written in the following matrix form;

$$[T]\{f\} + [S]\{\frac{f}{t}\} - \{Q\} = \{0\}$$

where,

$$[T] = \iiint_v T \left(\frac{\partial [N]^t}{\partial x}\frac{\partial [N]}{\partial x} + \frac{\partial [N]^t}{\partial y}\frac{\partial [N]}{\partial y} + k'[N]^t [N] \right) dV$$

$$[S] = \iiint_v S\, [N]^t [N]\, dV$$

$$\{Q\} = \iiint_v \frac{k'}{b'} H[N]^t\, dV$$

The [T] matrix is the conductance coefficient matrix. The {f} matrix is a column matrix of nodal heads at time t. The [S] matrix is a square matrix which accounts for the storage term in the transient flow equation. The { f/ t} matrix is a column matrix of the time derivatives. The {Q} matrix is a column matrix composed of the inflow/outflow within the entire problem domain and the boundary conditions. The boundary conditions are evaluated from the boundary integral; i.e. a weight average of the flux normal to the boundary.

In the implementation of the said modeling, the isoparametric quadrilateral elements will be applied because a meshes element in this study are geometrically irregular.

Adopting the Crank-Nicolson approximation for the time derivative of equation above, the solution is given by;

$$([T] + 2 [S]/Dt)\{f_{k+1}\} = (2[S]/Dt - [T])\{f_k\} + \{Q_k\} + \{Q_{k+1}\}$$

where suffixes k and k+1 specify time levels of t_k and t_k+Dt

3.3.3 Meshwork of the basin

The boundary of the whole groundwater basin is identifiable from the geology as shown in Fig.E-2.1. The outer rim of the whole groundwater basin coincides with ground level contour of El. 1,400 m in the Northern and Central districts. In the Southern district, the ground level of the outer rim ranges from El.1,400 to 1,500 m .

The area inside the boundary is divided into 1212 rectangular or triangular elements,each of which is formed by three or four nodes. These nodes represent the boundary of the whole groundwater basin/sub-basin, existing production well sites and observation well sites. The FEM Meshwork developed is shown in Fig.E-3.1.

3.4 Geophysical Parameters

Each element has average transmissivity which represents the transmissivity of the area of the element. The average transmissibilities are classified into 7 categories. those are;

Category	Average Transmissivity
1	10 m^2/day
2	25 m^2/day
3	75 m^2/day
4	150 m^2/day
5	300 m^2/day
6	500 m^2/day
7	700 m^2/day

Classification of transmissivity by the category is conducted based on the spatial distribution of transmissivity in the basin developed through hydrogeological study mentioned in APPENDIX D. Classified zones in the mesh map is shown in Fig.E-3.2.

Top elevation, bottom elevation and the thickness of the main aquifer are also given at each node point, which is used to calculate leakage. If a thickness of the aquifer at a node is less than 40 m, the value is modified by 40 m for stability of calculation.

3.5 Boundary Conditions

The groundwater basin is isolated from other groundwater bodies outside the valley,therefore recharge outside the valley is thought to be negligible. On the other hand, vertical leakage through aquitard may play an important role in the recharge of the main aquifer. This leakage is caused by the difference of head between water table of unconfined aquifer and the main aquifer. The head of the main aquifer is an unknown variable and the elevation of unconfined aquifer should be given as a quasi-three dimensional boundary condition. The unconfined aquifer changes with the annual cycle , but this fluctuation is relatively small for the thickness of the aquitard. In the rainy season the elevation rises nearly to ground surface. Thus the water level of the unconfined aquifer is temporally set to be the ground elevation at the corresponding node. This elevation has to be finally fixed by calibration of the model. The boundary conditions are summarized below;

1) the basin boundary ---
   discharge zero at all the nodes on the basin boundary,

2) elevation of unconfined aquifer -----
   ground level at all the nodes within the basin as initial values.

3.6 Calibration under Steady Condition

The ground water level may have been in nearly steady condition in the early stages of the 1980's, say 1983 because no pump was operated in the Northern district except for a tube well named BBOLD. Therefore, ground water level data at 19 pump wells mainly in the Northern district which were constructed as production wells before 1984 are selected for calibration of the calculated groundwater level under steady state condition of 1983.

Calibration under steady condition can be carried out by changing a leakage factor of the aquitard layer lying above the main aquifer, and the ground water level above the main aquifer. Changing of transmissivity category is also used for fine adjustment.

In this study, the leakage factor is fixed at 0.00033 m/day, or the average value of leakage factor at well WHO 7a and B12 (see section 2.3). Groundwater level above the main aquifer is assumed to be a function of the ground elevation. This function is selected by try-and-error method in order to make the calculated groundwater level of the main aquifer coincide with the observed one. Finally the function is selected as follow;

$$H = 1280.0 + (h - 1280.0) * 0.7 \quad (h < 1300.0\ m)$$
$$H = 1294.0 + (h - 1300.0) * 0.2 \quad (1300.0\ m \leq h \leq 1330.0\ m)$$
$$H = 1300.0 + (h - 1330.0) * 0.6 \quad (1330.0\ m < h)$$

where H : groundwater level of aquitard layer (m)
h : ground elevation (m)

The calibration result is shown in Table E-3.1 and Table E-3.2. Based on the model and selected parameters mentioned above, groundwater level in following three steady state conditions are calculated:

1: Pump operation of tube wells as at the end of 1972
2: Pump operation of tube wells as at the end od 1983
3: Pump operation of tube wells according to optimum operation (see section 4.1)

The first case represents the original groundwater level of the main aquifer. The second one is the condition before exploitation of the Third Project Wells. The third one is the condition under optimum operation of existing wells which is described in section 4.1

Water level began to decline even in 1983 even when abstraction volume was only 13 percent of that in 1989. Centers of drawdown of groundwater are Bansbari, Balaju , Baneswar and Bhaktapur and the drawdown area is quite limited. Maximum drawdowns of the areas are 2 m, 3 m, 1.5 m and 3 m ,respectively. Groundwater contour map in 1972 and 1983 are shown in Fig.E-3.3 and E-3.4. Drawdown counter is also shown in Fig.E-3.10.

3.7 Recharge Area

As mentioned in section 2.3, the recharge of the main aquifer depends on difference in the piezometric head between the main aquifer and the aquifer above,or

$$DH = H_{upper} - H_{main}$$

where DH : difference of piezometric head
H_{upper} : piezometric head of aquitard
H_{main} : piezometric head of the main aquifer

The value of DH is positive in mountainous area,which is recharge area. On the other hand, this value is negative in the central ,or relatively low area in the valley where no recharge may occur nor artificial recharge do. For effective artificial recharge the recharge site should be located in the recharge area in the mountainous area. Fig.E-3.5 shows counter line of DH value and the possible artificial recharge area which is identified by the area where DH value is more than 10 m. Identified potential recharge area is 170 km^2 including mountainous area in the valley.

3.8 Calibration under Non-Steady Condition

Abstraction of groundwater by pumping has increased in recent years, especially since 1984. The non-steady state model is therefore calibrated by the actual drawdown from 1983 to 1989 on the assumption that groundwater level was in a steady condition in 1983.

The parameter for non-steady state simulation is storage coefficient which indicates the sensitivity between piezometric head and abstracted water volume. Table E-3.3 shows the coefficient deduced from pumping test in a few wells, and comparison of observed and calculated drawdown.

The minimum values among the results of actual pump tests $2.3x10^{-4}$ also match well. Therefore this value was finally selected as typical for the whole valley.

Based on the selected value of storage coefficient, drawdown levels from 1983 to 2001 were calculated. The change in groundwater levels at production wells from 1985 to 1989 are shown in Table E-3.4.

Serious drawdown occurs at Bansbari in 1987 and the drawdown area spreads mainly in northern to north-western directions around Bansbari. The area where drawdown is more than 10 m appears only in this area. On the other hand, drawdown of more than 10 m extends to the whole the Northern district in 1989. In 2001, the drawdown area of more than 10 m does not extend so much compared with drawdown in 1989. But the drawdown become worse in the area where huge drawdown occurred in 1989.

Groundwater contour maps for 1985, 1987, 1989 and 2001 are shown in Fig.E-3.6 to and E-3.9. Drawdown contour in corresponding years are shown in Fig.E-3.11 to Fig.E-3.14.

4. OPTIMIZATION OF EXISTING PUMP OPERATION

4.1 Method

Referring to simplified equation in section 3.2 for steady state, the matrix differential equation for the steady-state flow is represented as follows;

$$[T]\{h\} = \{Q\} - \{B\} \quad \text{or,}$$

The head matrix of {h} can be divided into two column matrices as follows;

$$\begin{bmatrix} T11 & T12 \\ T21 & T22 \end{bmatrix} \begin{pmatrix} h_d \\ h_c \end{pmatrix} = \begin{pmatrix} q_d \\ q_c \end{pmatrix} - \begin{pmatrix} b_d \\ b_c \end{pmatrix}$$

where,
- T_{ij} : partitioned conductance matrices,
- h_d : vector of heads where pumping operations are to be managed,
- h_c : vector of heads where no change or additional development is considered,
- b_d : vector of constant where pumping operations are to be managed,
- b_c : vector of constant where no change or additional development is considered.

Consequently above equation is simplified through the relation between h_d and q_d :

$$[T']\{h_d\} = \{q_d\} - \{c\}$$

or,

$$\{h_d\} = [A]\{q_d\} - \{a\}$$

where,

$$[T'] = [T_{11}] - [T_{12}][T_{22}]^{-1}[T_{21}]$$
$$\{c\} = \{b_d\} + [T_{12}][T_{22}]^{-1}\{b_c\}$$
$$[A] = [T']^{-1}$$
$$\{a\} = [A]\{c\}$$

Defining that $\{h_{sus}\}$,$\{h_{loss}\}$ matrices are column matrices consisting of the sustained heads and well losses at points for optimization, the following inequality of constraints on water level can be deduced ;

$$\{h_{actual}\} = \{h_d\} - \{h_{loss}\} > \{h_{sus}\}$$

In addition, assuming that well loss is proportional to total drawdown;

$$\{h_{loss}\} = \beta\ (\{h_{org}\} - \{h_{actual}\})$$

where, β $(0 \le \beta \le 1)$: a rate of well loss to total drawdown
$\{h_{org}\}$: original groundwater level

Substituting (4-4) and (4-8) into (4-7) ,the inequality is finally summarized as follows;

$$[A]\{q_d\} \geq \{a'\}$$

where , $\{a'\}: \{a\} + (1-\beta)\{h_{sus}\} + \beta\,\{h_{org}\}$

The above inequality of constraints should be satisfied in any set of pumping operation ,or $\{q_d\}$, so that total draw down of each well concerned is within the limit. Furthermore $\{q_d\}$ has also limitation determined by installed pump capacity. Optimization is realized through maximization of total pumping volume under conditions and constraints mentioned above. This problem discussed here is equivalent to the following LP (Linear Programming) problem which can be solved by means of the Simplex Method.

Objective Function	: $G = q_1+q_2+\ldots\ldots+q_n$
Variables	: $\{q\} = \{q_1,q_2,\ldots\ldots,q_n\}^t$
Constraint	: $[A]\{q\} \geq \{a'\}$
	$\{0\} \leq \{q\} \leq \{q_{max}\}$

Sustained heads is decided by higher elevation of the upper rim of the main aquifer or location of strainer. Conditions for optimization is summarized in Table E-4.1. Well loss factor is changeable by wells and it depends on design and construction. The well loss factor of tube wells in the Northern district is ranged from 40 percent to 60 percent. Thus optimization by several well loss factors are estimated in order to check sensitivity of the factor. The optimum pumping volume of 40% ,50% and 60% are 18,900 m^3/day, 15,600 m^3/day and 11,900 m^3/day, respectively. Finally the case of 50 % of well loss is applied to develop optimum pump operation as relatively safety side.

Table E.4-2 shows contribution of each well under several optimum operation.

4.2 Optimum Pumping Operation

Optimum operation of existing wells with assumptions mentioned above is for perennial operation. Actually required groundwater volume depends on water demand and supply from surface water sources. Surface water is abound in the Monsoon season, thus pumping operation will be executed mainly in dry season,say ,January to April to meet the demand. In order to consider an effect of concentrated pumping operation in few months of a year, groundwater levels and drawdowns of the following two cases in the year 2001 are simulated ;

Case 1 : Perennial pumping operation (ideal condition)

Abstraction volume from each well field

Bansbari well field	6,936 m^3/day
Balaju well field	1,000 m^3/day
Gokarna/Manohara well field	6,093 m^3/day
Pharping well field	1,600 m^3/day
Total	15,629 m^3/day

Case 2 : Seasonal pumping operation (January to April)
(actually recommended pumping operation)

Abstraction volume from each well field

Bansbari well field	13,053 m^3/day
Balaju well field	648 m^3/day
Gokarna/Manohara well field	13,746 m^3/day
Pharping well field	3,132 m^3/day
Total	30,579 m^3/day
(Annual average	10,193 m^3/day)

Abstracted volume in Case 2 exceed the optimum abstraction volume during a season in operation,but the annual average keeps the limitation from the standpoint of total volume. Fig.E-4.2 and Fig.E-4.4 show drawdown at the end of year 2001 in these two cases. Actually recommended operation (Case 2) does not give severer results than that in Case 1.

Present abstraction volume of groundwater reaches 39,000 m^3/day, which is twice as much as optimum pumping (Case 1). Recharge source of the main aquifer is leakage water or squeezed water from the aquitard layer which consists of lacustrine deposit such as clay or silt. Therefore extreme or concentrated abstraction results in rapid drawdown of piezometric head of the main aquifer which may cause land subsidence. Therefore, leveling survey in order to monitor subsidence is required in case of necessity.

Estimated maximum drawdowns of piezometric head from the original condition of the main aquifer in the year 2001 are;

Perennial Operation (Case 1)	Seasonal Operation (Case 2)		Present Operation
End of 2001	End of Apr., 2001	End of 2001	End of 2001
19.0 m	20.0 m	5.0 m	25.0 m

TABLES

Table E-2.1 ESTIMATED ANNUAL FLUCTUATION OF WATER LEVEL (WELL WHO 7a)

Year	Rainfall (mm)	Groundwater level Max (El. m)	Groundwater level Min (El. m)	Fluctuation (mm)
1940	2311.7	1346.38	1344.71	1672.0
1941	2525.1	1346.23	1344.63	1595.7
1942	2808.9	1346.39	1344.59	1796.7
1943	3010.0	1346.39	1344.64	1750.3
1944	2425.1	1346.19	1344.65	1539.7
1945	2909.3	1346.38	1344.62	1758.7
1946	3259.9	1346.43	1344.73	1706.7
1947	2632.8	1346.20	1344.73	1461.7
1948	3125.6	1346.49	1344.70	1788.7
1949	2478.2	1346.26	1344.71	1548.3
1950	1439.4	1345.60	1344.61	990.7
1951	1692.3	1345.81	1344.51	1301.3
1952	2302.4	1346.15	1344.52	1627.7
1953	2224.9	1346.06	1344.59	1474.7
1954	2553.4	1346.25	1344.59	1660.0
1955	2597.4	1346.33	1344.59	1744.3
1956	2309.0	1346.08	1344.63	1450.3
1957	1516.8	1345.78	1344.57	1215.0
1958	1527.5	1345.49	1344.51	980.3
1959	1994.5	1346.02	1344.51	1511.7
1960	1691.7	1345.69	1344.56	1131.0
1961	1947.4	1345.97	1344.53	1437.0
1962	2366.7	1346.19	1344.54	1644.0
1963	3246.8	1346.40	1344.57	1829.7
1964	1904.1	1345.99	1344.61	1382.0
1965	1649.3	1345.77	1344.55	1219.0
1966	1728.8	1345.96	1344.53	1421.0
1967	2061.7	1346.12	1344.54	1575.7
1968	2445.1	1346.30	1344.59	1713.7
1969	1929.0	1345.94	1344.57	1368.3
1970	2267.8	1346.04	1344.58	1456.3
1971	2382.5	1346.24	1344.59	1653.0
1972	1779.2	1345.66	1344.58	1079.3
1973	2736.6	1346.29	1344.55	1736.3
1974	2007.1	1345.90	1344.64	1265.3
1975	2540.8	1346.26	1344.56	1696.7
1976	2333.0	1346.17	1344.66	1506.0
1977	1900.0	1345.78	1344.60	1186.3
1978	3390.1	1346.49	1344.57	1914.7
1979	2186.6	1346.08	1344.68	1404.7
1980	2575.4	1346.31	1344.57	1739.3
1981	1184.0	1345.30	1344.56	735.0
1982	2391.6	1346.19	1344.49	1698.0
1983	2975.1	1346.30	1344.57	1732.7
1984	2368.4	1346.27	1344.70	1574.0
1985	2548.6	1346.20	1344.59	1611.3
1986	2078.2	1345.86	1344.62	1241.0
Average				
1940-86	2303.4	1346.10	1344.60	1500.5
1971-86	2336.1	1346.08	1344.60	1485.9

TABLE E-2.2 ESTIMATED ANNUAL FLUCTUATION OF WATER LEVEL (WELL B12)

Year	Rainfall (mm)	Groundwater level Max (El. m)	Groundwater level Min (El. m)	Fluctuation (mm)
1947	1599.2	1310.86	1310.44	420.0
1948	1793.4	1311.02	1310.39	622.7
1949	1368.9	1310.87	1310.43	441.3
1950	1536.1	1310.91	1310.33	582.0
1951	1224.4	1310.75	1310.36	392.7
1952	1280.4	1310.70	1310.33	371.3
1953	1363.6	1310.71	1310.32	391.3
1954	1593.7	1310.88	1310.33	556.7
1955	1130.6	1310.68	1310.37	307.3
1956	1776.4	1310.96	1310.34	624.0
1957	1003.2	1310.79	1310.40	383.3
1958	1131.8	1310.64	1310.28	356.0
1959	1195.3	1310.64	1310.31	332.0
1960	1201.5	1310.67	1310.34	330.7
1961	1704.7	1310.90	1310.33	569.3
1962	1261.5	1310.76	1310.44	320.0
1963	1313.5	1310.71	1310.30	411.3
1964	1384.8	1310.88	1310.34	533.3
1965	1333.5	1310.73	1310.37	350.7
1966	1223.8	1310.74	1310.32	417.3
1967	1348.6	1310.81	1310.33	482.7
1968	1539.2	1310.92	1310.36	564.7
1969	1131.2	1310.71	1310.37	339.3
1970	1439.9	1310.75	1310.31	442.0
1971	1681.5	1310.85	1310.37	484.0
1972	1509.5	1310.74	1310.35	383.3
1973	1969.2	1311.11	1310.35	766.7
1974	1140.5	1310.98	1310.46	520.7
1975	1526.7	1310.88	1310.33	552.0
Average				
1947-75	1403.7	1310.8	1310.4	456.9
1971-75	1565.5	1310.9	1310.4	541.3

Table E-2.3 GROUNDWATER FLOW IN THE NORTHERN DISTRICT

Area	Well Name	Transmissivity (m^2/d)	Command length (m)	Gradient	Flow (m^3/d)
I	BB3	319.7 Aver.=	2200	5 /1200	3025
	BB4	340.4 (330.0)			
II	BB2	43.5	2500	5 / 700	777
III	DK2	313.0 Aver.=	2000	5 /1000	4140
	DK3	515.0 (414.0)			
IV	JP1	180.3 Aver.=	2500	5 / 750	6883
	BH4	645.9 (413.1)			
V	MH6	464.7	2500	5 /1000	5809
VI	BH1	315.6	2000	5 / 750	4208
Total	-	-	-	-	24842

Table E-3.1 GROUNDWATER LEVEL 1972

Leakage Permeability = 0.00033 m/day
Abstraction Condition : Year 1972

NO.	NODE	NAME	H(CAL) (m)	DATE (m)	H(OBS.) (m)	ERR (OBS-CAL)	H(PRES.) (m)	ERR (PRES.-CAL)
1	278	BB3------	1313.86	3 30 84	1314.13	0.27	1297.40	-16.46
2	280	BB4	1312.25	12 26 84	1311.01	-1.24	-	-
3	336	BB6	1311.60	4 13 84	1308.63	-2.97	-	-
4	284	WH03A	1311.98	2 72	1308.79	-3.19	-	-
5	335	BB5	1310.37	1 18 85	1308.14	-2.23	1292.10	-18.27
6	388	BB8	1309.06	9 7 84	1307.88	-1.18	-	-
7	284	BBOLD	1311.98	2 12 72	1305.79	-6.19	1292.30	-19.68
8	437	BB7	1307.85	3 19 85	1303.58	-4.27	-	-
9	285	JW2	1311.12	8 23 89	-	-	1287.10	-24.02
10	484	JW1/B12	1304.43	9 24 89	1310.60	6.17	1288.60	-15.83
11	293	DK2---*-	1311.81	5 7 84	1319.60	7.79	-	-
12	294	DK3	1311.06	2 13 84	1325.71	14.65	-	-
13	295	DK4	1310.27	4 30 84	1325.92	15.65	-	-
14	347	DK6	1309.44	1 29 84	1311.20	1.76	1303.50	-5.94
15	399	DK5	1308.23	12 28 83	1308.14	-0.09	-	-
16	446	DK1	1307.66	1 17 84	1307.56	-0.10	1294.50	-13.16
17	345	DK8 *	1309.64	3 1 84	1303.60	-6.04	-	-
18	352	JK1	1311.40	5 22 84	1314.97	3.57	-	-
19	19	WH07----	1338.04	5 3 72	1344.00	5.96	-	-
20	62	GK1	1334.69	12 24 85	1336.49	1.80	1326.60	-8.09
21	83	GK2	1334.37	5 31 84	1333.77	-0.60	-	-
22	60	GK3	1334.57	7 4 84	-	-	-	-
23	61	GK4	1334.80	7 15 85	1337.66	2.86	1321.40	-13.40
24	41	GK5	1335.80	6 8 84	1337.84	2.04	1330.70	-5.10
25	198	MH2-----	1320.71	10 18 84	1322.03	1.32	-	-
26	200	MH7 *	1321.58	11 4 85	1322.62	1.04	1297.80	-23.78
27	250	MH3	1318.01	11 26 84	1322.73	4.72	-	-
28	305	MH4	1315.73	11 1 85	1323.93	8.20	-	-
29	306	MH5	1315.50	4 13 85	1319.96	4.46	-	-
30	359	MH6	1313.87	5 4 85	1317.50	3.63	1308.40	-5.47
31	461	BH1-----	1312.59	12 8 84	1321.12	8.53	-	-
32	363	BH3	1315.75	2 3 85	1320.89	5.14	1308.00	-7.75
33	362	BH4	1315.75	2 26 85	1320.17	4.42	1305.70	-10.05
34	459	WH05A	1310.70	3 8 72	1311.23	0.53	1308.70	-2.00
35	1080	PH2-----	1318.29	2 12 77	-	-	1248.30	-69.99
36	585	P2 ---*-	1300.76	8 17 84	1288.70	-12.06	1287.70	-13.06
37	389	P5 *	1308.31	3 27 88	1295.90	-12.41	-	-
38	390	P6 *	1306.69	85	1285.74	-20.95	-	-
39	439	P7 *	1305.75	7 30 88	1290.40	-15.35	-	-
40	553	P8 *	1301.05	72	1305.77	4.72	-	-
41	589	P9 *	1299.85	1 11 87	1286.25	-13.60	-	-
42	592	P10 *	1300.01	75	1298.40	-1.61	-	-
43	487	P11 *	1302.98	78	1305.90	2.92	1293.30	-9.68
44	594	P15 *	1299.53	80	1299.24	-0.29	-	-
45	740	P17 *	1296.55	4 24 87	1290.90	-5.65	-	-
46	740	P18 *	1296.55	8 26 86	1288.25	-8.30	-	-
47	676	P19 *	1297.74	10 20 87	1286.00	-11.74	-	-
48	685	P23 *	1299.66	1 24 78	1300.00	0.34	1285.00	-14.66
49	566	P24 *	1304.05	7 27 86	1310.50	6.45	-	-
50	568	P25 *	1305.14	6 2 86	1293.00	-12.14	-	-
51	568	P26 *	1305.14	10 2 86	1297.45	-7.69	1290.00	-15.14
52	571	P27 *	1306.19	83	1310.90	4.71	-	-
53	572	P28 *	1307.30	82	1317.00	9.70	-	-
54	750	P29 *	1297.59	85	1294.90	-2.69	1288.60	-8.99
55	816	P32 *	1293.93	89	1277.07	-16.86	-	-
56	818	P33 *	1295.00	78	1278.00	-17.00	-	-
57	821	P34 *	1295.92	12 79	1313.90	17.98	-	-
58	961	P36 *	1300.45	5 10 87	1278.50	-21.95	-	-
59	827	P37 *	1302.77	7 27 87	1297.50	-5.27	-	-
60	714	DMG1 *	1297.13	1 11 87	1276.25	-20.88	-	-
61	712	DMG4	1297.16	6 9 86	1285.68	-11.48	-	-
62	712	DMG5 *	1297.16	7 7 86	1290.65	-6.51	-	-
63	635	DMG6	1298.21	88	1299.50	1.29	-	-
64	814	JW3	1292.93	11 9 89	1281.10	-11.83	-	-
65	648	JW4	1301.93	7 25 89	1291.65	-10.28	-	-

Remark *: observed data is uncertain

Table E-3.2 GROUNDWATER LEVEL IN 1983

Leakage Permeability = 0.00033 m/day
Abstraction Condition : Year 1983

NO.	NODE	NAME	H(CAL) (m)	DATE (m)	H(OBS.) (m)	ERR (OBS-CAL)	H(PRES.) (m)	ERR (PRES.-CAL)
1	278	BB3-----	1312.27	3 30 84	1314.13	1.86	1297.40	-14.87
2	280	BB4	1310.56	12 26 84	1311.01	0.45	-	-
3	336	BB6	1309.83	4 13 84	1308.63	-1.20	-	-
4	284	WH03A	1308.62	2 72	1308.79	0.17	-	-
5	335	BB5	1308.61	1 18 85	1308.14	-0.47	1292.10	-16.51
6	388	BB8	1307.26	9 7 84	1307.88	0.62	-	-
7	284	BBOLD	1308.62	2 12 72	1305.79	-2.83	1292.30	-16.32
8	437	BB7	1306.07	3 19 85	1303.58	-2.49	-	-
9	285	JW2	1308.94	8 23 89	-		1287.10	-21.84
10	484	JW1/B12	1302.92	9 24 89	1310.60	7.68	1288.60	-14.32
11	293	DK2---*-	1310.81	5 7 84	1319.60	8.79	-	-
12	294	DK3	1310.05	2 13 84	1325.71	15.66	-	-
13	295	DK4	1309.23	4 30 84	1325.92	16.69	-	-
14	347	DK6	1308.35	1 29 84	1311.20	2.85	1303.50	-4.85
15	399	DK5	1307.11	12 28 83	1308.14	1.03	-	-
16	446	DK1	1306.52	1 17 84	1307.56	1.04	1294.50	-12.02
17	345	DK8 *	1308.51	3 1 84	1303.60	-4.91	-	-
18	352	JK1	1310.33	5 22 84	1314.97	4.64	-	-
19	19	WH07----	1337.80	5 3 72	1344.00	6.20	-	-
20	62	GK1	1334.36	12 24 85	1336.49	2.13	1326.60	-7.76
21	83	GK2	1334.04	5 31 84	1333.77	-0.27	-	-
22	60	GK3	1334.25	7 4 84	-	-	-	-
23	61	GK4	1334.47	7 15 85	1337.66	3.19	1321.40	-13.07
24	41	GK5	1335.51	6 8 84	1337.84	2.33	1330.70	-4.81
25	198	MH2-----	1319.37	10 18 84	1322.03	2.66	-	-
26	200	MH7 *	1320.27	11 4 85	1322.62	2.35	1297.80	-22.47
27	250	MH3	1316.48	11 26 84	1322.73	6.25	-	-
28	305	MH4	1314.00	11 1 85	1323.93	9.93	-	-
29	306	MH5	1313.63	4 13 85	1319.96	6.33	-	-
30	359	MH6	1311.92	5 4 85	1317.50	5.58	1308.40	-3.52
31	461	BH1-----	1309.76	12 8 84	1321.12	11.36	-	-
32	363	BH3	1313.60	2 3 85	1320.89	7.29	1308.00	-5.60
33	362	BH4	1313.63	2 26 85	1320.17	6.54	1305.70	-7.93
34	459	WH05A	1308.45	3 8 72	1311.23	2.78	1308.70	0.25
35	1080	PH2-----	1318.29	2 12 77	-	-	1248.30	-69.99
36	585	P2 ---*-	1299.19	8 17 84	1288.70	-10.49	1287.70	-11.49
37	389	P5 *	1306.54	3 27 88	1295.90	-10.64	-	-
76	390	P6 *	1305.06	85	1285.74	-19.32	-	-
39	439	P7 *	1304.21	7 30 88	1290.40	-13.81	-	-
40	553	P8 *	1299.53	72	1305.77	6.24	-	-
41	589	P9 *	1298.30	1 11 87	1286.25	-12.05	-	-
42	592	P10 *	1298.31	75	1298.40	0.09	-	-
43	487	P11 *	1301.65	78	1305.90	4.25	1293.30	-8.35
44	594	P15 *	1297.81	80	1299.24	1.43	-	-
45	740	P17 *	1295.73	4 24 87	1290.90	-4.83	-	-
46	740	P18 *	1295.73	8 26 86	1288.25	-7.48	-	-
47	676	P19 *	1296.41	10 20 87	1286.00	-10.41	-	-
48	685	P23 *	1297.25	1 24 78	1300.00	2.75	1285.00	-12.25
49	566	P24 *	1302.60	7 27 86	1310.50	7.90	-	-
50	568	P25 *	1303.67	6 2 86	1293.00	-10.67	-	-
51	568	P26 *	1303.67	10 2 86	1297.45	-6.22	1290.00	-13.67
52	571	P27 *	1304.60	83	1310.90	6.30	-	-
53	572	P28 *	1305.58	7 82	1317.00	11.42	-	-
54	750	P29 *	1296.11	85	1294.90	-1.21	1288.60	-7.51
55	816	P32 *	1292.97	89	1277.07	-15.90	-	-
56	818	P33 *	1293.50	78	1278.00	-15.50	-	-
57	821	P34 *	1295.06	12 79	1313.90	18.84	-	-
58	961	P36 *	1300.42	5 10 87	1278.50	-21.92	-	-
59	827	P37 *	1302.64	7 27 87	1297.50	-5.14	-	-
60	714	DMG1 *	1295.90	1 11 87	1276.25	-19.65	-	-
61	712	DMG4	1295.98	6 9 86	1285.68	-10.30	-	-
62	712	DMG5 *	1295.98	7 7 86	1290.65	-5.33	-	-
63	635	DMG6	1296.81	88	1299.50	2.69	-	-
64	814	JW3	1292.19	11 9 89	1281.10	-11.09	-	-
65	648	JW4	1300.65	7 25 89	1291.65	-9.00	-	-

Remark * : Observed groundwater level is uncertain.

TABLE E-3.3 DECISION OF STORAGE COEFFICIENT

(1: Simulation Result)

Name	Period	Drawdown (m)							
		Observed	S=0.0001	S=0.0005	S=0.001	S=0.002	S=0.005	S=0.0075	S=0.01
BB5	Jan.,1985 - Mar.,1989	16.04	17.06	17.024	16.962	16.79	15.556	14.344	13.252
JW1/B12	Aug.,1972 - Sep.,1989	22.00	13.326	13.24	13.072	12.609	12.986	9.835	8.839
GK5	Jun.,1984 - Feb.,1989	7.14	6.71	6.6	6.33	5.54	3.695	2.88	2.37
MH6	May, 1985 - Feb.,1989	9.10	8.51	8.462	8.29	7.61	5.634	4.548	3.804
BH3	Feb.,1985 - Mar.,1989	12.89	9.878	9.854	9.691	8.991	6.788	5.544	4.684
BH4	Feb.,1985 - Mar.,1989	14.47	10.009	9.97	9.807	9.107	6.915	5.678	4.802

(2: Pump Test Result)

WELL NAME	Storage Coefficient	Method	Conducted by	Date
WHO 3	0.0019	JACOB	B&P	5/20 Feb.'72
	0.00243	WALTON	-do-	
WHO 5	0.00086	JACOB	-do-	7/17 Mar.'72
	0.00412			
	0.0037	THEIS	-do-	
WHO 7	0.000232	JACOB	-do-	1/6 Jun. '72
JW1/B12	0.00065	JACOB	JICA	
	0.00185	HANTUSH/JACOB		

MAXIMUM 0.00412 ; MINIMUM 0.000232

Table E-3.4 NON-STEADY STATE CONDITION (1/3)

Storage Coefficient S= 0.0002 Leakage Permeability = 0.00033 m/day
Steady Condition (year 1985)

NO.	NODE	NAME	H(1983) (m)	H(CAL) (m)	DRAWDOWN (m)	DATE	H(OBS.) (m)	ERR (OBS-CAL)	H(PRES.) (m)	ERR (PRES.-CAL)
1	278	BB3-----	1313.45	1310.30	-3.15	3 30 84	1314.13	3.83	1297.44	-12.86
2	280	BB4	1311.23	1308.79	-2.44	12 26 84	1311.01	2.22		
3	336	BB6	1308.61	1307.84	-0.77	4 13 84	1308.63	0.79		
4	284	WHO3A	1308.89	1306.13	-2.76	2 72	1308.79	2.66		
5	335	BB5	1309.72	1306.92	-2.80	1 18 85	1308.14	1.22	1292.18	-14.74
6	388	BB8	1308.73	1305.57	-3.17	9 7 84	1307.88	2.31		
7	284	BBOLD	1308.89	1306.13	-2.76	2 12 72	1305.79	-0.34	1292.33	-13.80
8	437	BB7	1305.79	1303.97	-1.82	3 19 85	1303.58	-0.39		
9	285	JW2	1308.62	1306.09	-2.54	8 23 89			1287.12	-18.97
10	484	JW1/B12	1304.09	1300.76	-3.33	9 24 89	1310.60	9.84	1288.68	-12.08
11	293	DK2---*-	1309.57	1306.81	-2.76	5 7 84	1319.60	12.79		
12	294	DK3	1310.81	1306.15	-4.66	2 13 84	1325.71	19.56		
13	295	DK4	1310.05	1305.86	-4.19	4 30 84	1325.92	20.06		
14	347	DK6	1307.36	1304.32	-3.04	1 29 84	1311.20	6.88	1303.51	-0.81
15	399	DK5	1307.15	1302.42	-4.73	12 28 83	1308.14	5.72		
16	446	DK1	1305.02	1302.37	-2.65	1 17 84	1307.56	5.19	1294.59	-7.78
17	345	DK8 *	1307.06	1304.79	-2.27	3 1 84	1303.60	-1.19		
18	352	JK1	1309.66	1307.75	-1.90	5 22 84	1314.97	7.22		
19	19	WHO7----	1339.18	1338.31	-0.87	5 3 72	1344.00	5.69		
20	62	GK1	1334.47	1334.36	-0.12	12 24 85	1336.49	2.13	1326.67	-7.69
21	83	GK2	1333.98	1333.98	0.00	5 31 84	1333.77	-0.21		
22	60	GK3	1334.64	1334.25	-0.39	7 4 84				
23	61	GK4	1334.25	1334.42	0.18	7 15 85	1337.66	3.24	1321.42	-13.00
24	41	GK5	1334.92	1335.51	0.59	6 8 84	1337.84	2.33	1330.70	-4.81
25	198	MH2-----	1321.77	1318.89	-2.88	10 18 84	1322.03	3.14		
26	200	MH7 *	1318.67	1319.45	0.78	11 4 85	1322.62	3.17	1297.81	-21.64
27	250	MH3	1317.38	1316.07	-1.31	11 26 84	1322.73	6.66		
28	305	MH4	1315.17	1313.47	-1.70	11 1 85	1323.93	10.46		
29	306	MH5	1313.99	1313.10	-0.89	4 13 85	1319.96	6.86		
30	359	MH6	1312.46	1311.33	-1.13	5 4 85	1317.50	6.17	1308.44	-2.89
31	461	BH1-----	1309.08	1309.21	0.12	12 8 84	1321.12	11.91		
32	363	BH3	1313.63	1313.12	-0.52	2 3 85	1320.89	7.77	1308.04	-5.08
33	362	BH4	1313.17	1313.06	-0.12	2 26 85	1320.17	7.11	1305.70	-7.36
34	459	WHO5A	1308.18	1307.81	-0.38	3 8 72	1311.23	3.42	1308.79	0.98
35	1080	PH2-----	1315.83	1308.67	-7.16	2 12 77			1248.34	-60.33
36	585	P2 ---*-	1302.99	1293.42	-9.57	8 17 84	1288.70	-4.72	1287.71	-5.71
37	389	P5 *	1307.26	1304.60	-2.66	3 27 88	1295.90	-8.70		
38	390	P6 *	1306.55	1302.92	-3.62	85	1285.74	-17.18		
39	439	P7 *	1304.15	1301.95	-2.20	7 30 88	1290.40	-11.55		
40	553	P8 *	1299.79	1297.16	-2.62	72	1305.77	8.61		
41	589	P9 *	1298.05	1295.78	-2.27	1 11 87	1286.25	-9.53		
42	592	P10 *	1299.05	1295.92	-3.13	75	1298.40	2.48		
43	487	P11 *	1302.53	1299.34	-3.19	78	1305.90	6.56	1293.30	-6.04
44	594	P15 *	1298.42	1295.10	-3.32	80	1299.24	4.14		
45	740	P17 *	1296.45	1293.90	-2.55	4 24 87	1290.90	-3.00		
46	740	P18 *	1296.45	1293.90	-2.55	8 26 86	1288.25	-5.65		
47	676	P19 *	1297.08	1293.56	-3.52	10 20 87	1286.00	-7.56		
48	685	P23 *	1297.36	1295.76	-1.60	1 24 78	1300.00	4.24	1285.00	-10.76
49	566	P24 *	1301.54	1301.62	0.08	7 27 86	1310.50	8.88		
50	568	P25 *	1302.55	1302.77	0.22	6 2 86	1293.00	-9.77		
51	568	P26 *	1302.55	1302.77	0.22	10 2 86	1297.45	-5.32	1290.04	-12.73
52	571	P27 *	1304.23	1303.78	-0.45	83	1310.90	7.12		
53	572	P28 *	1304.60	1304.76	0.16	7 82	1317.00	12.24		
54	750	P29 *	1295.81	1293.60	-2.21	85	1294.90	1.30	1288.60	-5.00
55	816	P32 *	1292.04	1291.43	-0.61	89	1277.07	-14.36		
56	818	P33 *	1293.15	1292.27	-0.89	78	1278.00	-14.27		
57	821	P34 *	1294.42	1294.44	0.02	12 79	1313.90	19.46		
58	961	P36 *	1298.87	1299.58	0.71	5 10 87	1278.50	-21.08		
59	827	P37 *	1299.64	1302.65	3.02	7 27 87	1297.50	-5.15		
60	714	DMG1 *	1296.32	1291.91	-4.41	1 11 87	1276.25	-15.66		
61	712	DMG4	1296.30	1292.52	-3.78	6 9 86	1285.68	-6.84		
62	712	DMG5 *	1296.30	1292.52	-3.78	7 7 86	1290.65	-1.87		
63	635	DMG6	1297.32	1294.30	-3.02	88	1299.50	5.20		
64	814	JW3	1291.67	1290.87	-0.80	11 9 89	1281.10	-9.77		
65	648	JW4	1300.38	1300.06	-0.31	7 25 89	1291.65	-8.41		

Remark * : Observed groundwater level is uncertain

Table E-3.4 NON-STEADY STATE CONDITION (2/3)

Storage Coefficient S= 0.0002 Leakage Permeability = 0.00033 m/day
Steady Condition (year 1987)

NO.	NODE	NAME	H(1983) (m)	H(CAL) (m)	DRAWDOWN (m)	DATE	H(OBS.) (m)	ERR (OBS-CAL)	H(PRES.) (m)	ERR (PRES.-CAL)
1	278	BB3-----	1313.45	1294.83	-18.62	3 30 84	1314.13	19.30	1297.44	2.61
2	280	BB4	1311.23	1293.55	-17.68	12 26 84	1311.01	17.46		
3	336	BB6	1308.61	1291.12	-17.49	4 13 84	1308.63	17.51		
4	284	WH03A	1308.89	1296.26	-12.63	2 72	1308.79	12.53		
5	335	BB5	1309.72	1292.10	-17.62	1 18 85	1308.14	16.04	1292.18	0.08
6	388	BB8	1308.73	1289.77	-18.96	9 7 84	1307.88	18.11		
7	284	BBOLD	1308.89	1296.26	-12.63	2 12 72	1305.79	9.53	1292.33	-3.93
8	437	BB7	1305.79	1288.19	-17.60	3 19 85	1303.58	15.39		
9	285	JW2	1308.62	1298.15	-10.48	8 23 89			1287.12	-11.03
10	484	JW1/B12	1304.09	1292.71	-11.38	9 24 89	1310.60	17.89	1288.68	-4.03
11	293	DK2---*-	1309.57	1302.17	-7.41	5 7 84	1319.60	17.43		
12	294	DK3	1310.81	1301.40	-9.41	2 13 84	1325.71	24.31		
13	295	DK4	1310.05	1300.49	-9.56	4 30 84	1325.92	25.43		
14	347	DK6	1307.36	1299.65	-7.72	1 29 84	1311.20	11.55	1303.51	3.86
15	399	DK5	1307.15	1298.06	-9.09	12 28 83	1308.14	10.08		
16	446	DK1	1305.02	1298.08	-6.94	1 17 84	1307.56	9.48	1294.59	-3.49
17	345	DK8 *	1307.06	1300.05	-7.02	3 1 84	1303.60	3.55		
18	352	JK1	1309.66	1303.88	-5.78	5 22 84	1314.97	11.09		
19	19	WH07----	1339.18	1335.56	-3.62	5 3 72	1344.00	8.44		
20	62	GK1	1334.47	1330.01	-4.46	12 24 85	1336.49	6.48	1326.67	-3.34
21	83	GK2	1333.98	1328.32	-5.66	5 31 84	1333.77	5.45		
22	60	GK3	1334.64	1328.59	-6.05	7 4 84				
23	61	GK4	1334.25	1329.36	-4.88	7 15 85	1337.66	8.30	1321.42	-7.94
24	41	GK5	1334.92	1331.58	-3.34	6 8 84	1337.84	6.26	1330.70	-0.88
25	198	MH2-----	1321.77	1312.92	-8.86	10 18 84	1322.03	9.11		
26	200	MH7 *	1318.67	1312.59	-6.08	11 4 85	1322.62	10.03	1297.81	-14.78
27	250	MH3	1317.38	1311.15	-6.23	11 26 84	1322.73	11.58		
28	305	MH4	1315.17	1308.90	-6.27	11 1 85	1323.93	15.03		
29	306	MH5	1313.99	1308.50	-5.49	4 13 85	1319.96	11.46		
30	359	MH6	1312.46	1306.94	-5.52	5 4 85	1317.50	10.56	1308.44	1.50
31	461	BH1-----	1309.08	1302.61	-6.47	12 8 84	1321.12	18.51		
32	363	BH3	1313.63	1308.58	-5.05	2 3 85	1320.89	12.31	1308.04	-0.54
33	362	BH4	1313.17	1308.48	-4.70	2 26 85	1320.17	11.69	1305.70	-2.78
34	459	WH05A	1308.18	1303.52	-4.66	3 8 72	1311.23	7.71	1308.79	5.27
35	1080	PH2-----	1315.83	1308.67	-7.16	2 12 77			1248.34	-60.33
36	585	P2 ---*-	1302.99	1288.43	-14.56	8 17 84	1288.70	0.27	1287.71	-0.72
37	389	P5 *	1307.26	1290.31	-16.95	3 27 88	1295.90	5.59		
38	390	P6 *	1306.55	1292.57	-13.97	85	1285.74	-6.83		
39	439	P7 *	1304.15	1293.21	-10.94	7 30 88	1290.40	-2.81		
40	553	P8 *	1299.79	1291.97	-7.82	72	1305.77	13.80		
41	589	P9 *	1298.05	1291.26	-6.79	1 11 87	1286.25	-5.01		
42	592	P10 *	1299.05	1291.36	-7.70	75	1298.40	7.04		
43	487	P11 *	1302.53	1294.58	-7.95	78	1305.90	11.32	1293.30	-1.28
44	594	P15 *	1298.42	1290.94	-7.48	80	1299.24	8.30		
45	740	P17 *	1296.45	1289.31	-7.14	4 24 87	1290.90	1.59		
46	740	P18 *	1296.45	1289.31	-7.14	8 26 86	1288.25	-1.06		
47	676	P19 *	1297.08	1289.69	-7.39	10 20 87	1286.00	-3.69		
48	685	P23 *	1297.36	1293.09	-4.27	1 24 78	1300.00	6.91	1285.00	-8.09
49	566	P24 *	1301.54	1298.63	-2.91	7 27 86	1310.50	11.87		
50	568	P25 *	1302.55	1299.60	-2.96	6 2 86	1293.00	-6.60		
51	568	P26 *	1302.55	1299.60	-2.96	10 2 86	1297.45	-2.15	1290.04	-9.56
52	571	P27 *	1304.23	1300.67	-3.56	83	1310.90	10.23		
53	572	P28 *	1304.60	1301.59	-3.01	7 82	1317.00	15.41		
54	750	P29 *	1295.81	1291.08	-4.73	85	1294.90	3.82	1288.60	-2.48
55	816	P32 *	1292.04	1290.03	-2.01	89	1277.07	-12.96		
56	818	P33 *	1293.15	1290.77	-2.38	78	1278.00	-12.77		
57	821	P34 *	1294.42	1293.26	-1.16	12 79	1313.90	20.64		
58	961	P36 *	1298.87	1298.87	0.00	5 10 87	1278.50	-20.37		
59	827	P37 *	1299.64	1302.45	2.81	7 27 87	1297.50	-4.95		
60	714	DMG1 *	1296.32	1287.27	-9.05	1 11 87	1276.25	-11.02		
61	712	DMG4	1296.30	1288.22	-8.08	6 9 86	1285.68	-2.54		
62	712	DMG5 *	1296.30	1288.22	-8.08	7 7 86	1290.65	2.43		
63	635	DMG6	1297.32	1290.71	-6.61	88	1299.50	8.79		
64	814	JW3	1291.67	1289.66	-2.01	11 9 89	1281.10	-8.56		
65	648	JW4	1300.38	1297.63	-2.75	7 25 89	1291.65	-5.98		

Remark * : Observed groundwater level is uncertain

Storage Coefficient S= 0.0002 Leakage Permeability = 0.00033 m/day
Steady Condition (year 1989)

NO.	NODE	NAME	H(1983) (m)	H(CAL) (m)	DRAWDOWN (m)	DATE	H(OBS.) (m)	ERR (OBS-CAL)	H(PRES.) (m)	ERR (PRES.-CAL)
1	278	BB3-----	1313.45	1293.01	-20.44	3 30 84	1314.13	21.12	1297.44	4.43
2	280	BB4	1311.23	1291.42	-19.82	12 26 84	1311.01	19.59		
3	336	BB6	1308.61	1288.59	-20.03	4 13 84	1308.63	20.04		
4	284	WH03A	1308.89	1294.36	-14.53	2 72	1308.79	14.43		
5	335	BB5	1309.72	1288.56	-21.17	1 18 85	1308.14	19.58	1292.18	3.62
6	388	BB8	1308.73	1287.50	-21.23	9 7 84	1307.88	20.38		
7	284	BBOLD	1308.89	1294.36	-14.53	2 12 72	1305.79	11.43	1292.33	-2.03
8	437	BB7	1305.79	1286.84	-18.95	3 19 85	1303.58	16.74		
9	285	JW2	1308.62	1296.30	-12.32	8 23 89			1287.12	-9.18
10	484	JW1/B12	1304.09	1290.97	-13.12	9 24 89	1310.60	19.63	1288.68	-2.29
11	293	DK2---*-	1309.57	1300.67	-8.90	5 7 84	1319.60	18.93		
12	294	DK3	1310.81	1299.59	-11.22	2 13 84	1325.71	26.12		
13	295	DK4	1310.05	1298.41	-11.64	4 30 84	1325.92	27.51		
14	347	DK6	1307.36	1297.84	-9.52	1 29 84	1311.20	13.36	1303.51	5.67
15	399	DK5	1307.15	1296.13	-11.02	12 28 83	1308.14	12.01		
16	446	DK1	1305.02	1296.32	-8.70	1 17 84	1307.56	11.24	1294.59	-1.73
17	345	DK8 *	1307.06	1298.28	-8.78	3 1 84	1303.60	5.32		
18	352	JK1	1309.66	1300.87	-8.79	5 22 84	1314.97	14.10		
19	19	WH07----	1339.18	1331.17	-8.01	5 3 72	1344.00	12.83		
20	62	GK1	1334.47	1321.93	-12.54	12 24 85	1336.49	14.56	1326.67	4.74
21	83	GK2	1333.98	1322.27	-11.71	5 31 84	1333.77	11.50		
22	60	GK3	1334.64	1321.43	-13.21	7 4 84				
23	61	GK4	1334.25	1322.33	-11.92	7 15 85	1337.66	15.33	1321.42	-0.91
24	41	GK5	1334.92	1325.44	-9.49	6 8 84	1337.84	12.40	1330.70	5.26
25	198	MH2-----	1321.77	1299.97	-21.81	10 18 84	1322.03	22.06		
26	200	MH7 *	1318.67	1302.51	-16.16	11 4 85	1322.62	20.11	1297.81	-4.70
27	250	MH3	1317.38	1293.89	-23.49	11 26 84	1322.73	28.84		
28	305	MH4	1315.17	1296.52	-18.65	11 1 85	1323.93	27.41		
29	306	MH5	1313.99	1297.65	-16.34	4 13 85	1319.96	22.31		
30	359	MH6	1312.46	1298.25	-14.21	5 4 85	1317.50	19.25	1308.44	10.19
31	461	BH1-----	1309.08	1296.22	-12.86	12 8 84	1321.12	24.90		
32	363	BH3	1313.63	1299.40	-14.24	2 3 85	1320.89	21.49	1308.04	8.64
33	362	BH4	1313.17	1299.32	-13.85	2 26 85	1320.17	20.85	1305.70	6.38
34	459	WH05A	1308.18	1298.10	-10.08	3 8 72	1311.23	13.13	1308.79	10.69
35	1080	PH2-----	1315.83	1308.66	-7.16	2 12 77			1248.34	-60.32
36	585	P2 ---*-	1302.99	1287.21	-15.78	8 17 84	1288.70	1.49	1287.71	0.50
37	389	P5 *	1307.26	1288.35	-18.91	3 27 88	1295.90	7.55		
38	390	P6 *	1306.55	1290.70	-15.84	85	1285.74	-4.96		
39	439	P7 *	1304.15	1291.33	-12.82	7 30 88	1290.40	-0.93		
40	553	P8 *	1299.79	1290.23	-9.56	72	1305.77	15.54		
41	589	P9 *	1298.05	1289.49	-8.56	1 11 87	1286.25	-3.24		
42	592	P10 *	1299.05	1289.55	-9.50	75	1298.40	8.85		
43	487	P11 *	1302.53	1292.76	-9.77	78	1305.90	13.14	1293.30	0.54
44	594	P15 *	1298.42	1288.96	-9.46	80	1299.24	10.28		
45	740	P17 *	1296.45	1287.83	-8.62	4 24 87	1290.90	3.07		
46	740	P18 *	1296.45	1287.83	-8.62	8 26 86	1288.25	0.42		
47	676	P19 *	1297.08	1287.27	-9.81	10 20 87	1286.00	-1.27		
48	685	P23 *	1297.36	1290.74	-6.62	1 24 78	1300.00	9.26	1285.00	-5.74
49	566	P24 *	1301.54	1295.42	-6.12	7 27 86	1310.50	15.08		
50	568	P25 *	1302.55	1296.03	-6.53	6 2 86	1293.00	-3.03		
51	568	P26 *	1302.55	1296.03	-6.53	10 2 86	1297.45	1.42	1290.04	-5.98
52	571	P27 *	1304.23	1296.87	-7.36	83	1310.90	14.03		
53	572	P28 *	1304.60	1297.60	-6.99	7 82	1317.00	19.40		
54	750	P29 *	1295.81	1288.99	-6.81	85	1294.90	5.91	1288.60	-0.39
55	816	P32 *	1292.04	1289.02	-3.02	89	1277.07	-11.95		
56	818	P33 *	1293.15	1289.64	-3.52	78	1278.00	-11.64		
57	821	P34 *	1294.42	1292.31	-2.11	12 79	1313.90	21.59		
58	961	P36 *	1298.87	1298.84	-0.03	5 10 87	1278.50	-20.34		
59	827	P37 *	1299.64	1302.24	2.61	7 27 87	1297.50	-4.74		
60	714	DMG1 *	1296.32	1284.96	-11.36	1 11 87	1276.25	-8.71		
61	712	DMG4	1296.30	1286.03	-10.28	6 9 86	1285.68	-0.35		
62	712	DMG5 *	1296.30	1286.03	-10.28	7 7 86	1290.65	4.62		
63	635	DMG6	1297.32	1287.45	-9.87	88	1299.50	12.05		
64	814	JW3	1291.67	1288.81	-2.86	11 9 89	1281.10	-7.71		
65	648	JW4	1300.38	1294.95	-5.43	7 25 89	1291.65	-3.30		

Remark * : Observed groundwater level is uncertain

Table E-4.1 CONDITIONS FOR OPTIMIZATION

No.	Node	Name	Limits on Elevation (m) Pump Elevation	Upper limit of Aquifer	Pump Capacity (m^3/day)
1	231	BB2	1294.0	1302.2	1728.0
2	278	BB3	1291.0	1279.7	3456.0
3	280	BB4	1292.0	1277.8	3168.0
4	336	BB6	1283.0	1266.0	3602.0
5	335	BB5	1275.0	1269.6	3168.0
6	388	BB8	1276.0	1244.8	2952.0
7	284	BBLD	1285.0	1273.7	1368.0
8	437	BB7	1275.0	1199.1	2952.0
9	480	BALAJU	1265.0	1195.5	1000.0
32	293	DK2	1305.0	1317.9	-
33	446	DK1	1305.0	1277.3	-
10	294	DK3	1305.0	1317.5	504.0
11	295	DK4	1317.0	1318.3	1128.0
12	347	DK6	1300.0	1299.4	720.0
13	399	DK5	1295.0	1290.7	1560.0
14	62	GK1	1300.0	1315.9	2760.0
15	83	GK2	1314.0	1318.0	2424.0
16	60	GK3	1314.0	1316.7	1992.0
17	61	GK4	1307.0	1315.9	1440.0
18	41	GK5	1327.0	1319.9	1440.0
19	198	MH2	1299.0	1280.1	3456.0
20	200	MH7	1302.0	1280.2	2160.0
21	250	MH3	1293.0	1280.1	3120.0
22	305	MH4	1310.0	1278.7	3024.0
23	306	MH5	1278.0	1271.8	3456.0
24	359	MH6	1294.0	1273.8	2400.0
28	1080	PH2	1225.0	1163.1	2900.0
29	1064	PH1	1245.0	1167.3	864.0
65	414	BHOLD	1306.0	1263.8	1600.0
25	461	BH1	1306.0	1264.2	1283.0
26	363	BH3	1288.0	1265.3	1473.0
27	362	BH4	1284.0	1266.6	1300.0

TABLE E-4.2 OPTIMUM PUMP OPERATION OF EXISTING WELLS (1/5)

OPTIMUM PUMP ABSTRACTION= 21845.0 m^3/day

WELL LOSS : 30 % OF TOTAL DRAWDOWN

NAME	PUMP CAPACITY (m^3/day)	OPTIMUM CASE (m^3/day)	TOTAL HEAD (m)	CRITICAL EL. (m)	ALLOWANCE (m)	DRAWDOWN (m)	WELL LOSS (m)
BB2	1728.000	289.344	1302.160	1302.160	0.000	10.320	3.093
BB3	3456.000	1318.633	1291.000	1291.000	0.000	25.003	8.059
BB4	3168.000	206.666	1287.000	1287.000	0.000	25.710	7.848
BB6	3602.000	1888.556	1283.000	1283.000	0.000	25.945	7.423
BB5	3168.000	3168.000	1278.893	1275.000	3.893	31.500	9.309
BB8	2952.000	2952.000	1279.242	1276.000	3.242	29.869	9.147
BALAJU	1000.000	1000.000	1274.687	1265.000	9.687	32.500	9.003
GK1	2760.000	49.123	1324.286	1315.910	8.375	13.937	4.820
GK2	2424.000	430.414	1318.000	1318.000	0.000	19.621	5.805
GK3	1992.000	1310.305	1316.690	1316.690	0.000	21.364	6.325
GK4	1440.000	0.000	1324.772	1315.910	8.862	13.096	4.886
GK5	1440.000	0.000	1327.000	1327.000	0.000	11.560	4.167
MH3	3120.000	2519.153	1293.000	1293.000	0.000	33.197	11.834
MH5	3456.000	3456.000	1297.686	1278.000	19.686	22.456	8.636
MH7	2160.000	1656.888	1302.000	1302.000	0.000	24.547	8.069
PH2	1600.000	1600.000	1276.792	1225.000	51.792	29.564	8.866

TABLE E-4.2 OPTIMUM PUMP OPERATION OF EXISTING WELLS (2/5)

OPTIMUM PUMP ABSTRACTION= 18857.1 m^3/day
WELL LOSS : 40 % OF TOTAL DRAWDOWN

NAME	PUMP CAPACITY (m^3/day)	OPTIMUM CASE (m^3/day)	TOTAL HEAD (m)	CRITICAL EL. (m)	ALLOWANCE (m)	DRAWDOWN (m)	WELL LOSS (m)
BB2	1728.000	309.790	1302.160	1302.160	0.000	10.320	4.124
BB3	3456.000	861.475	1291.000	1291.000	0.000	25.003	10.745
BB4	3168.000	0.000	1287.000	1287.000	0.000	25.710	10.464
BB6	3602.000	1208.714	1283.688	1283.000	0.688	25.257	9.623
BB5	3168.000	3168.000	1277.194	1275.000	2.194	33.199	13.092
BB8	2952.000	2952.000	1277.018	1276.000	1.018	32.093	13.085
BALAJU	1000.000	1000.000	1271.760	1265.000	6.760	35.427	13.175
GK1	2760.000	0.000	1324.230	1315.910	8.320	13.992	6.449
GK2	2424.000	359.854	1318.000	1318.000	0.000	19.621	7.740
GK3	1992.000	1072.479	1316.752	1316.690	0.062	21.302	8.409
GK4	1440.000	0.000	1324.798	1315.910	8.888	13.070	6.504
GK5	1440.000	0.000	1327.000	1327.000	0.000	11.560	5.556
MH3	3120.000	1766.730	1293.000	1293.000	0.000	33.197	15.779
MH5	3456.000	3456.000	1295.663	1278.000	17.663	24.479	12.324
MH7	2160.000	1102.065	1302.000	1302.000	0.000	24.547	10.759
PH2	1600.000	1600.000	1271.866	1225.000	46.866	34.490	13.792

TABLE E-4.2 OPTIMUM PUMP OPERATION OF EXISTING WELLS (3/5)

OPTIMUM PUMP ABSTRACTION= 15631.5 m^3/day
WELL LOSS : 50 % OF TOTAL DRAWDOWN

NAME	PUMP CAPACITY (m^3/day)	OPTIMUM CASE (m^3/day)	TOTAL HEAD (m)	CRITICAL EL. (m)	ALLOWANCE (m)	DRAWDOWN (m)	WELL LOSS (m)
BB2	1728.000	346.072	1302.160	1302.160	0.000	10.320	5.155
BB3	3456.000	468.474	1291.000	1291.000	0.000	25.003	13.431
BB4	3168.000	0.000	1287.000	1287.000	0.000	25.710	13.080
BB6	3602.000	510.471	1285.171	1283.000	2.171	23.774	11.287
BB5	3168.000	3168.000	1275.881	1275.000	0.881	34.512	17.021
BB8	2952.000	2444.399	1276.000	1276.000	0.000	33.111	16.865
BALAJU	1000.000	1000.000	1268.539	1265.000	3.539	38.648	18.079
GK1	2760.000	0.000	1324.038	1315.910	8.128	14.184	8.157
GK2	2424.000	326.010	1318.000	1318.000	0.000	19.621	9.675
GK3	1992.000	745.197	1317.224	1316.690	0.534	20.830	10.275
GK4	1440.000	0.000	1324.872	1315.910	8.962	12.996	8.093
GK5	1440.000	0.000	1327.000	1327.000	0.000	11.560	6.945
MH3	3120.000	1016.882	1293.000	1293.000	0.000	33.197	19.723
MH5	3456.000	3456.000	1292.850	1278.000	14.850	27.292	16.811
MH7	2160.000	550.023	1302.000	1302.000	0.000	24.547	13.448
PH2	1600.000	1600.000	1264.970	1225.000	39.970	41.386	20.688

TABLE E-4.2 OPTIMUM PUMP OPERATION OF EXISTING WELLS (4/5)

OPTIMUM PUMP ABSTRACTION= 11865.9 m^3/day

WELL LOSS : 60 % OF TOTAL DRAWDOWN

NAME	PUMP CAPACITY (m^3/day)	OPTIMUM CASE (m^3/day)	TOTAL HEAD (m)	CRITICAL EL. (m)	ALLOWANCE (m)	DRAWDOWN (m)	WELL LOSS (m)
BB2	1728.000	391.614	1302.160	1302.160	0.000	10.320	6.289
BB3	3456.000	58.162	1291.000	1291.000	0.000	25.003	16.386
BB4	3168.000	0.000	1287.000	1287.000	0.000	25.710	15.958
BB6	3602.000	179.948	1287.025	1283.000	4.025	21.920	12.639
BB5	3168.000	2853.266	1275.000	1275.000	0.000	35.393	21.303
BB8	2952.000	1653.033	1276.000	1276.000	0.000	33.111	20.576
BALAJU	1000.000	915.188	1265.000	1265.000	0.000	42.187	24.215
GK1	2760.000	0.000	1323.715	1315.910	7.805	14.507	10.149
GK2	2424.000	287.566	1318.000	1318.000	0.000	19.621	11.804
GK3	1992.000	390.335	1317.997	1316.690	1.307	20.057	12.064
GK4	1440.000	0.000	1324.995	1315.910	9.085	12.873	9.799
GK5	1440.000	0.000	1327.000	1327.000	0.000	11.560	8.473
MH3	3120.000	80.869	1293.972	1293.000	0.972	32.225	23.470
MH5	3456.000	3456.000	1288.328	1278.000	10.328	31.814	23.268
MH7	2160.000	0.000	1302.000	1302.000	0.000	24.547	16.407
PH2	1600.000	1600.000	1253.300	1225.000	28.300	53.056	32.358

TABLE E-4.2 OPTIMUM PUMP OPERATION OF EXISTING WELLS (5/5)

OPTIMUM PUMP ABSTRACTION= 7555.3 m^3/day

WELL LOSS : 70 % OF TOTAL DRAWDOWN

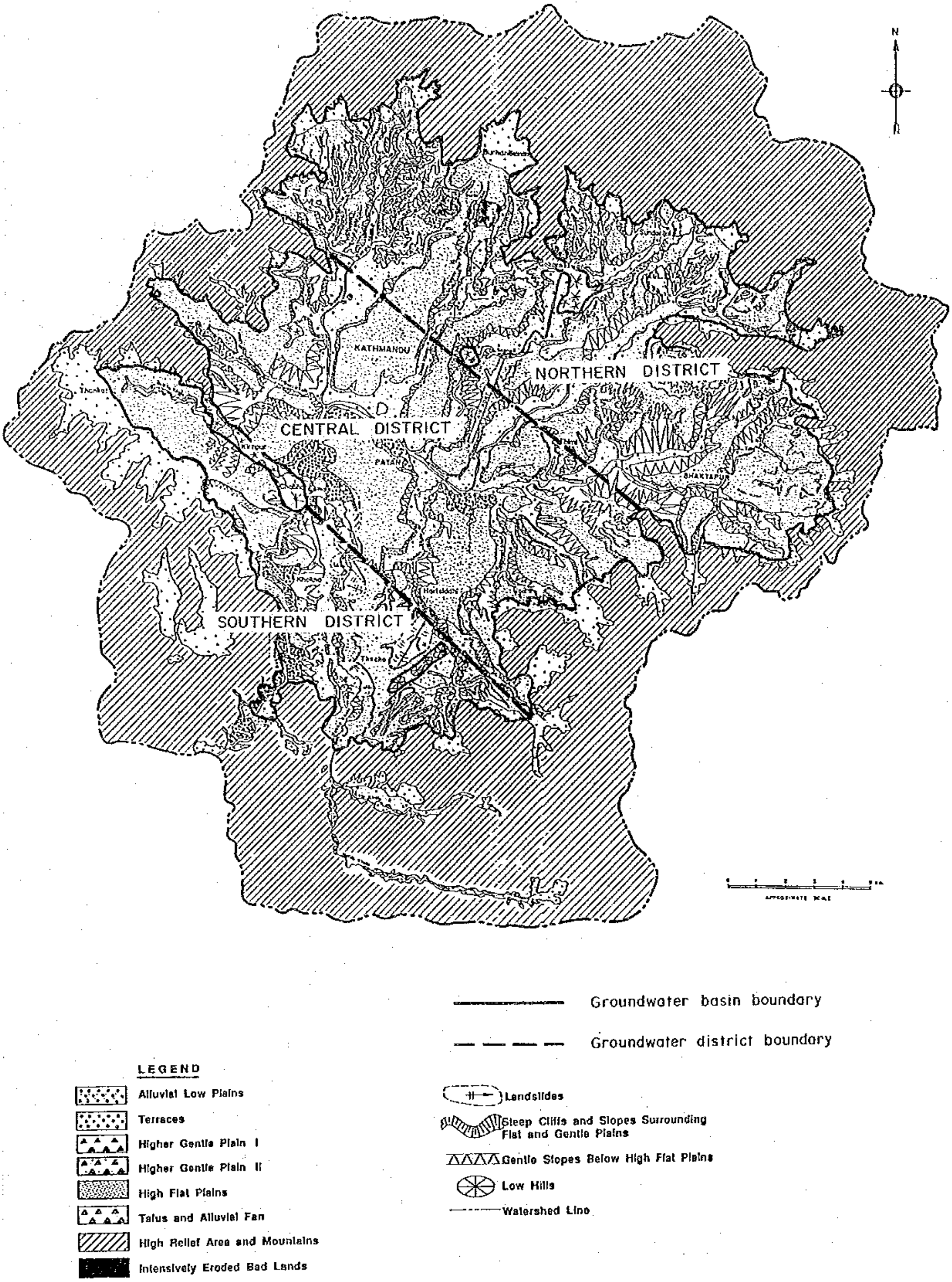
NAME	PUMP CAPACITY (m^3/day)	OPTIMUM CASE (m^3/day)	TOTAL HEAD (m)	CRITICAL EL. (m)	ALLOWANCE (m)	DRAWDOWN (m)	WELL LOSS (m)
BB2	1728.000	466.894	1302.160	1302.160	0.000	10.320	7.217
BB3	3456.000	0.000	1291.000	1291.000	0.000	25.003	18.804
BB4	3168.000	0.000	1288.859	1287.000	1.859	23.851	17.010
BB6	3602.000	0.000	1291.979	1283.000	8.979	16.966	11.036
BB5	3168.000	1241.428	1279.222	1275.000	4.222	31.171	21.490
BB8	2952.000	1877.334	1276.000	1276.000	0.000	33.111	23.612
BALAJU	1000.000	631.161	1265.000	1265.000	0.000	42.187	27.788
GK1	2760.000	0.000	1323.289	1315.910	7.379	14.933	11.944
GK2	2424.000	249.017	1318.000	1318.000	0.000	19.621	13.546
GK3	1992.000	126.784	1318.867	1316.690	2.177	19.187	13.235
GK4	1440.000	0.000	1325.135	1315.910	9.225	12.733	11.146
GK5	1440.000	0.000	1327.000	1327.000	0.000	11.560	9.723
MH3	3120.000	0.000	1292.991	1293.000	-0.009	33.206	27.619
MH5	3456.000	1362.782	1293.386	1278.000	15.386	26.756	23.160
MH7	2160.000	0.000	1302.000	1302.000	0.000	24.547	18.828
PH2	1600.000	1600.000	1237.387	1225.000	12.387	68.969	48.271

Table E-4.3 STEADY STATE CONDITION IN OPTIMUM CONDITION

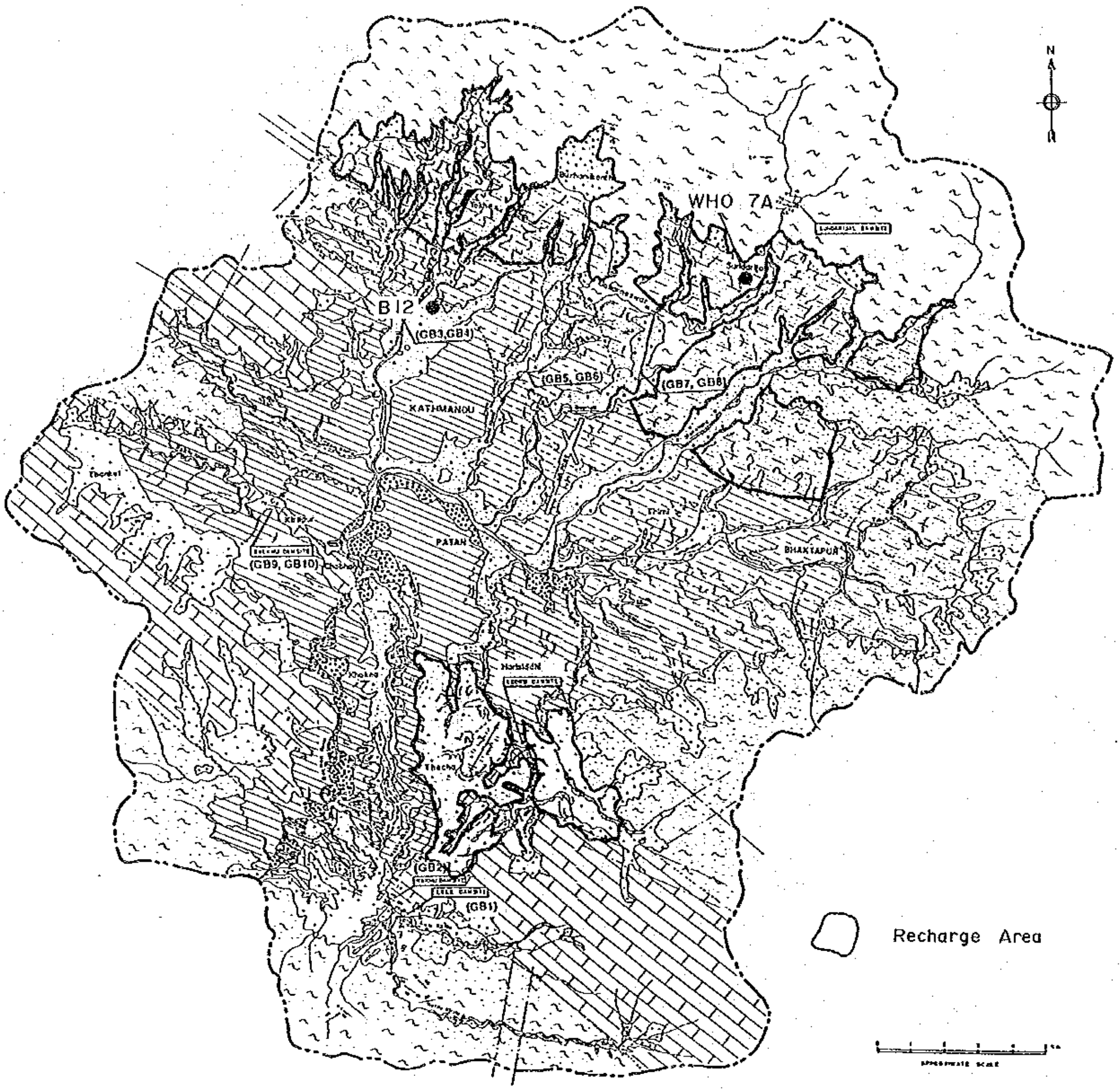
Leakage Permeability = 0.00033 m/day
Abstraction Condition : OPTIMUM CASE

NO.	NODE	NAME	H(CAL) (m)	DATE	H(OBS.) (m)	ERR (OBS-CAL)	H(PRES.) (m)	ERR (PRES.-CAL)
1	278	BB3-----	1304.19	3 30 84	1314.13	9.94	1297.40	-6.79
2	280	BB4	1301.12	12 26 84	1311.01	9.89		
3	336	BB6	1299.00	4 13 84	1308.63	9.63		
4	284	WH03A	1303.62	2 72	1308.79	5.17		
5	335	BB5	1294.27	1 18 85	1308.14	13.87	1292.10	-2.17
6	388	BB8	1292.82	9 7 84	1307.88	15.06		
7	284	BBOLD	1303.62	2 12 72	1305.79	2.17	1292.30	-11.32
8	437	BB7	1295.52	3 19 85	1303.58	8.06		
9	285	JW2	1304.10	8 23 89			1287.10	-17.00
10	484	JW1/B12	1296.92	9 24 89	1310.60	13.68	1288.60	-8.32
11	293	DK2---*-	1308.89	5 7 84	1319.60	10.71		
12	294	DK3	1308.31	2 13 84	1325.71	17.40		
13	295	DK4	1307.44	4 30 84	1325.92	18.48		
14	347	DK6	1305.81	1 29 84	1311.20	5.39	1303.50	-2.31
15	399	DK5	1304.68	12 28 83	1308.14	3.46		
16	446	DK1	1303.86	1 17 84	1307.56	3.70	1294.50	-9.36
17	345	DK8 *	1305.72	3 1 84	1303.60	-2.12		
18	352	JK1	1308.27	5 22 84	1314.97	6.70		
19	19	WH07----	1336.17	5 3 72	1344.00	7.83		
20	62	GK1	1331.38	12 24 85	1336.49	5.11	1326.60	-4.78
21	83	GK2	1328.92	5 31 84	1333.77	4.85		
22	60	GK3	1328.71	7 4 84				
23	61	GK4	1331.08	7 15 85	1337.66	6.58	1321.40	-9.68
24	41	GK5	1332.79	6 8 84	1337.84	5.05	1330.70	-2.09
25	198	MH2-----	1314.58	10 18 84	1322.03	7.45		
26	200	MH7 *	1315.43	11 4 85	1322.62	7.19	1297.80	-17.63
27	250	MH3	1308.74	11 26 84	1322.73	13.99		
28	305	MH4	1308.10	11 1 85	1323.93	15.83		
29	306	MH5	1305.28	4 13 85	1319.96	14.68		
30	359	MH6	1306.98	5 4 85	1317.50	10.52	1308.40	1.42
31	461	BH1-----	1307.52	12 8 84	1321.12	13.60		
32	363	BH3	1309.61	2 3 85	1320.89	11.28	1308.00	-1.61
33	362	BH4	1309.10	2 26 85	1320.17	11.07	1305.70	-3.40
34	459	WH05A	1306.16	3 8 72	1311.23	5.07	1308.70	2.54
35	1080	PH2-----	1282.50	2 12 77			1248.30	-34.20
36	585	P2 ---*-	1290.42	8 17 84	1288.70	-1.72	1287.70	-2.72
37	389	P5 *	1295.71	3 27 88	1295.90	0.19		
38	390	P6 *	1297.57	85	1285.74	-11.83		
39	439	P7 *	1297.64	7 30 88	1290.40	-7.24		
40	553	P8 *	1294.75	72	1305.77	11.02		
41	589	P9 *	1293.68	1 11 87	1286.25	-7.43		
42	592	P10 *	1293.82	75	1298.40	4.58		
43	487	P11 *	1297.85	78	1305.90	8.05	1293.30	-4.55
44	594	P15 *	1293.52	80	1299.24	5.72		
45	740	P17 *	1290.72	4 24 87	1290.90	0.18		
46	740	P18 *	1290.72	8 26 86	1288.25	-2.47		
47	676	P19 *	1291.57	10 20 87	1286.00	-5.57		
48	685	P23 *	1294.17	1 24 78	1300.00	5.83	1285.00	-9.17
49	566	P24 *	1299.99	7 27 86	1310.50	10.51		
50	568	P25 *	1300.94	6 2 86	1293.00	-7.94		
51	568	P26 *	1300.94	10 2 86	1297.45	-3.49	1290.00	-10.94
52	571	P27 *	1302.16	83	1310.90	8.74		
53	572	P28 *	1303.27	7 82	1317.00	13.73		
54	750	P29 *	1292.08	85	1294.90	2.82	1288.60	-3.48
55	816	P32 *	1290.75	89	1277.07	-13.68		
56	818	P33 *	1291.46	78	1278.00	-13.46		
57	821	P34 *	1293.81	12 79	1313.90	20.09		
58	961	P36 *	1299.11	5 10 87	1278.50	-20.61		
59	827	P37 *	1302.79	7 27 87	1297.50	-5.29		
60	714	DMG1 *	1290.34	1 11 87	1276.25	-14.09		
61	712	DMG4	1290.94	6 9 86	1285.68	-5.26		
62	712	DMG5 *	1290.94	7 7 86	1290.65	-0.29		
63	635	DMG6	1291.43	88	1299.50	8.07		
64	814	JW3	1290.24	11 9 89	1281.10	-9.14		
65	648	JW4	1298.47	7 25 89	1291.65	-6.82		

FIGURES



HIS MAJESTY'S GOVERNMENT OF NEPAL GROUND WATER MANAGEMENT PROJECT IN THE KATHMANDU VALLEY	Fig. E-2.1	GROUNDWATER BASIN OF THE KATHMANDU VALLEY
JAPAN INTERNATIONAL COOPERATION AGENCY		



LEGEND

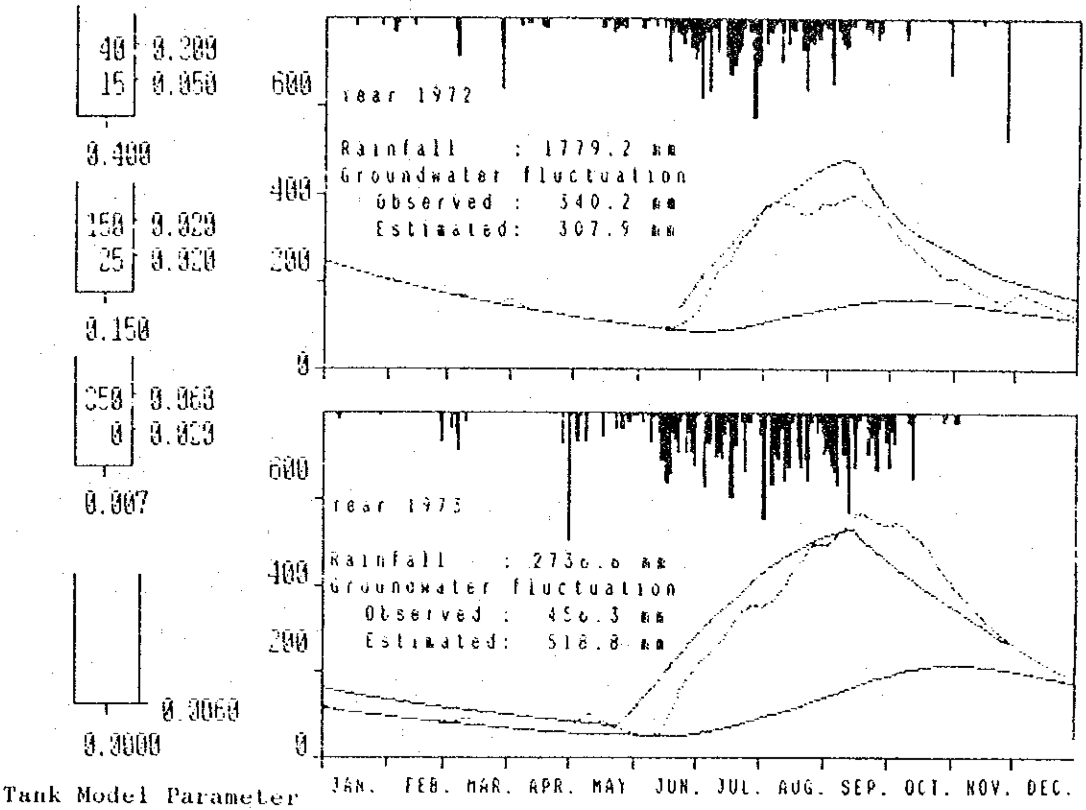
Quaternary
- River Deposits
- Talus Deposits and Fan Deposits
- Terrace Deposits
- Predominant Gravel Deposits
- Gravel and Clay Deposits
- Arenaceous Deposits (Lacustrine Deposits)
- Intermediate Type of Arenaceous and Argillaceous Deposits (Lacustrine Deposits)
- Argillaceous Deposits (Lacustrine Deposits)

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

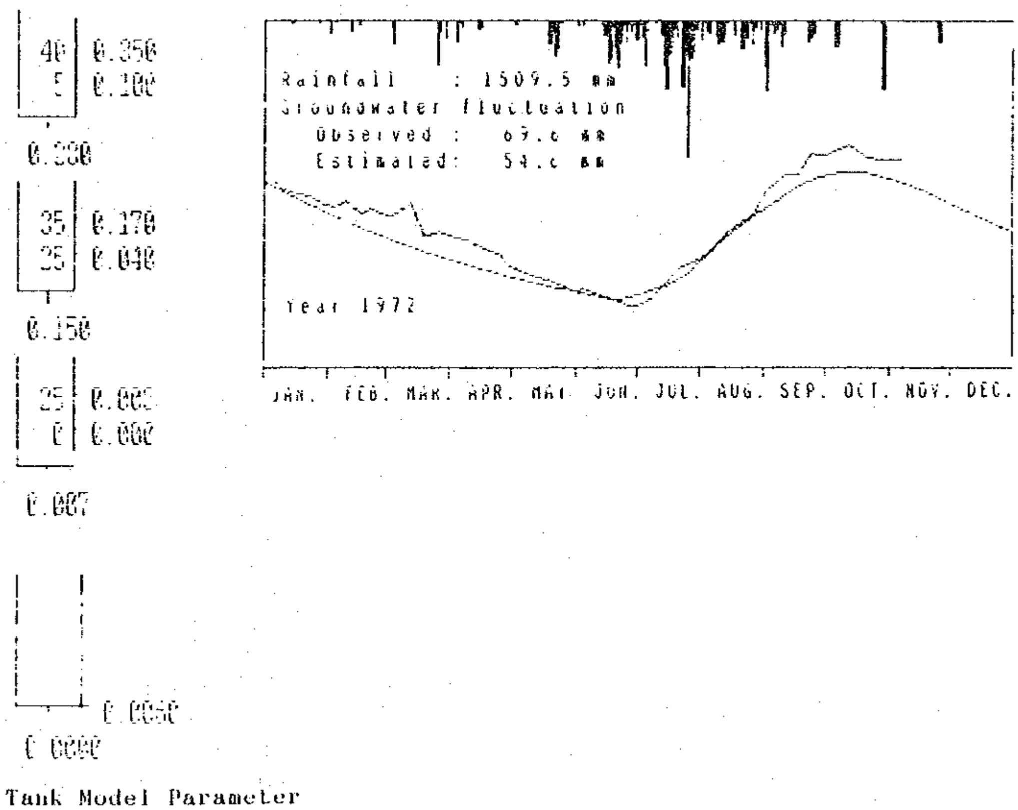
- Landslides
- Steep Cliffs
- Gentle Cliffs
- Watershed Line
- Dip and strike of Bedding Planes and Schistosity
- Water Spring
- Lineaments
- (GB1) Boreholes in this Study

HIS MAJESTY'S GOVERNMENT OF NEPAL GROUND WATER MANAGEMENT PROJECT IN THE KATHMANDU VALLEY	Fig. E-2.2	PERMEABLE AREA IN THE KATHMANDU VALLEY
JAPAN INTERNATIONAL COOPERATION AGENCY		

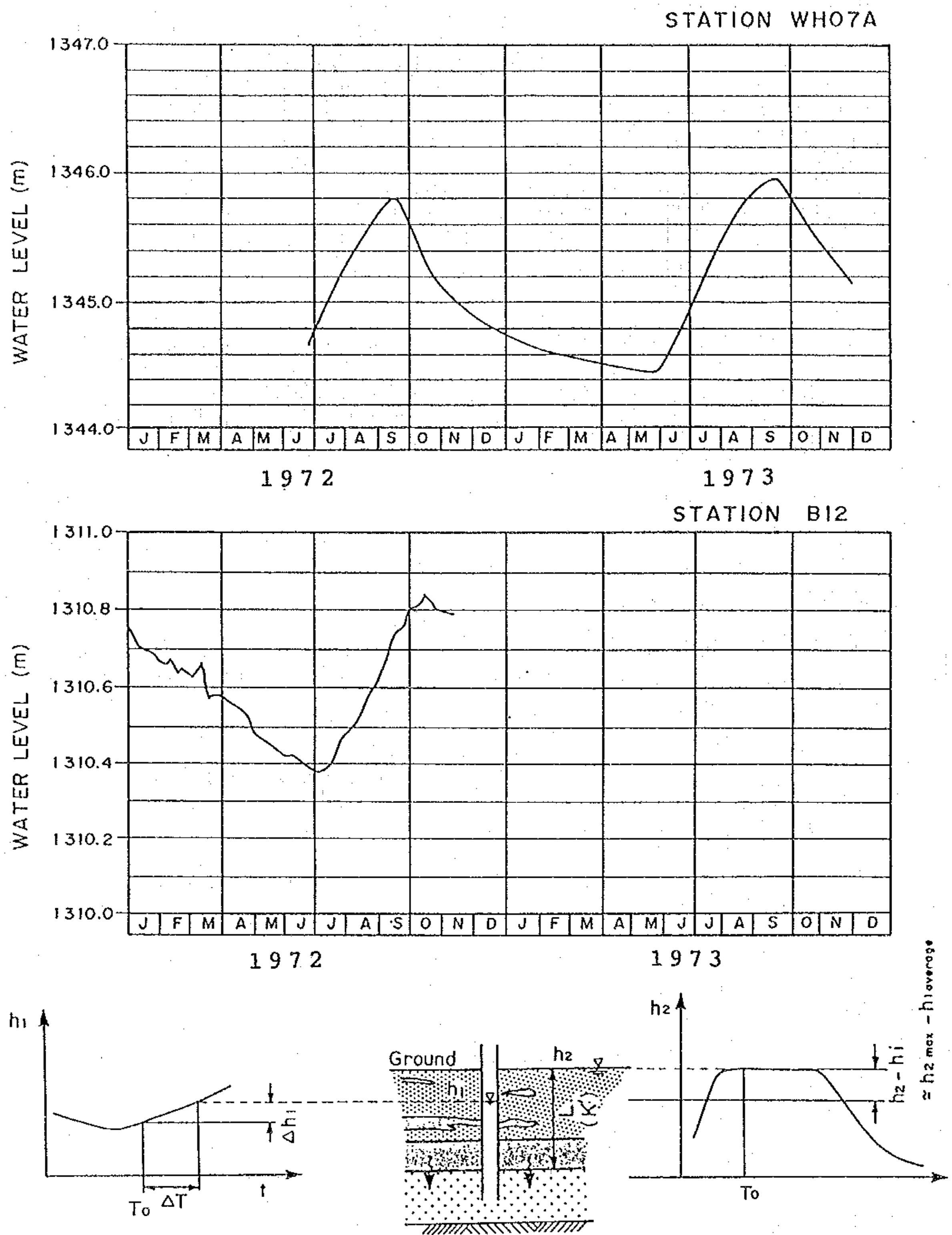
Tube well (WHO 7A)



Tube well (B12)



HIS MAJESTY'S GOVERNMENT OF NEPAL GROUND WATER MANAGEMENT PROJECT IN THE KATHMANDU VALLEY JAPAN INTERNATIONAL COOPERATION AGENCY	Fig. E-2.3	WELL HYDROGRAPH SIMULATION (TANK MODEL)



$$n \frac{\Delta h_1}{\Delta T} = K' \frac{(h_2 - h_1)}{L} \simeq K' \frac{h_{2\,max} - h_{1\,average}}{L}$$

$$K' = \frac{L}{h_{2\,max} - h_{1\,average}} \cdot n \frac{\Delta h_1}{\Delta T}$$

n : Porosity (≈0.15)
L : Thickness of Aquitard
K Permeability
h_1 : Piezometric head of confined Aquifer
h_2 : Water Table of un-confined Aquifer

HIS MAJESTY'S GOVERNMENT OF NEPAL GROUND WATER MANAGEMENT PROJECT IN THE KATHMANDU VALLEY	Fig. E-2.4	WELL HYDROGRAPH AND GROUNDWATER RECHARGE
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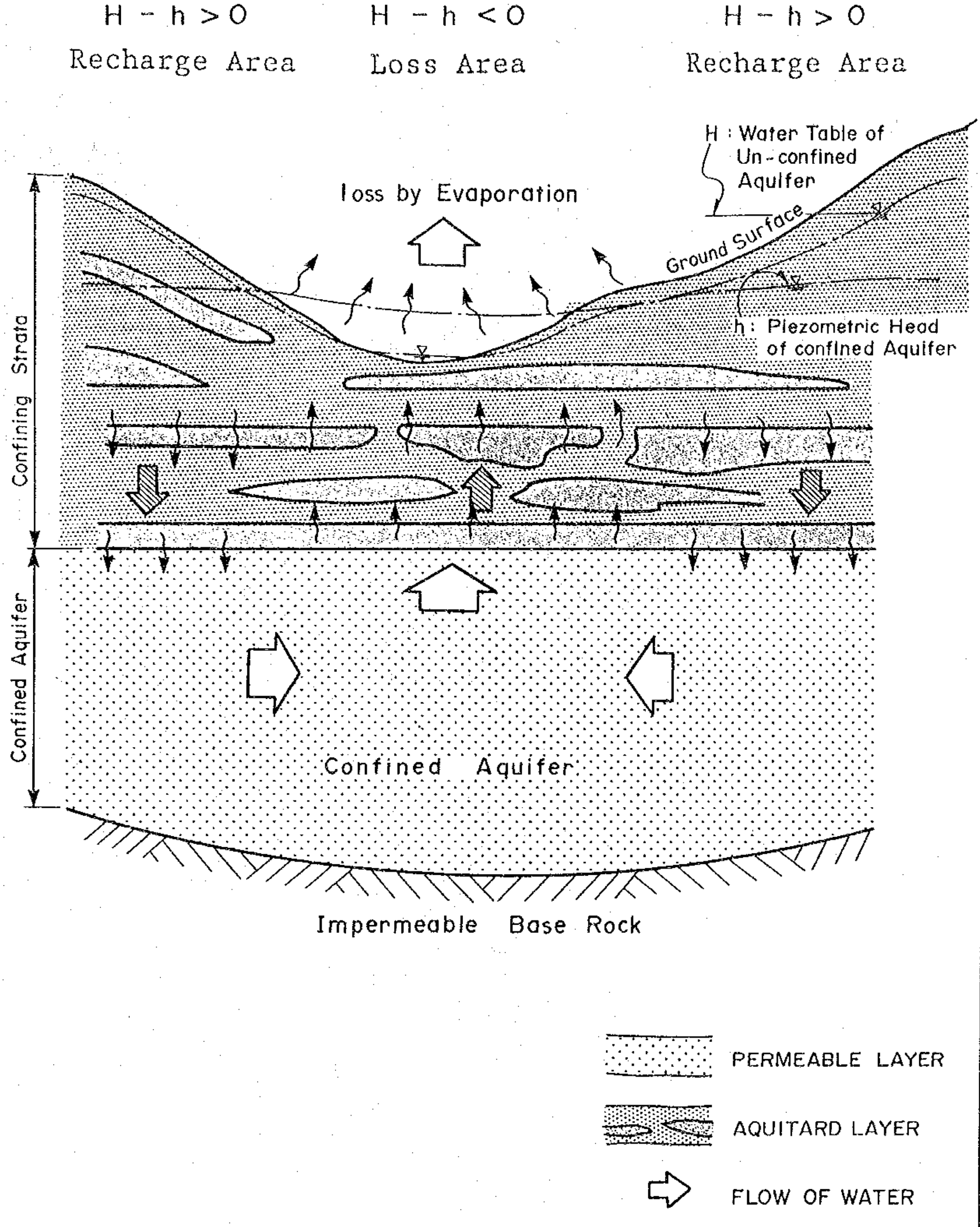
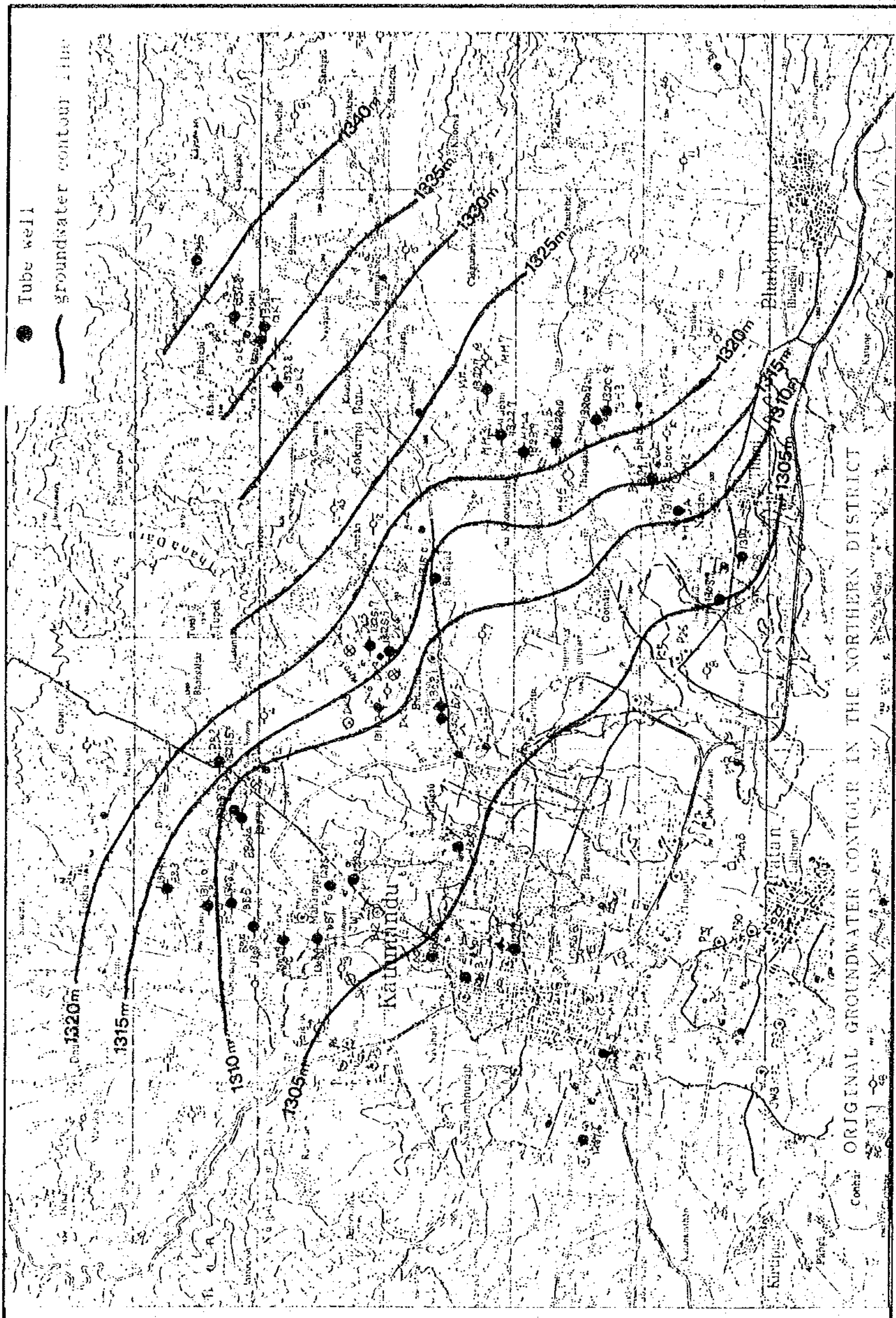
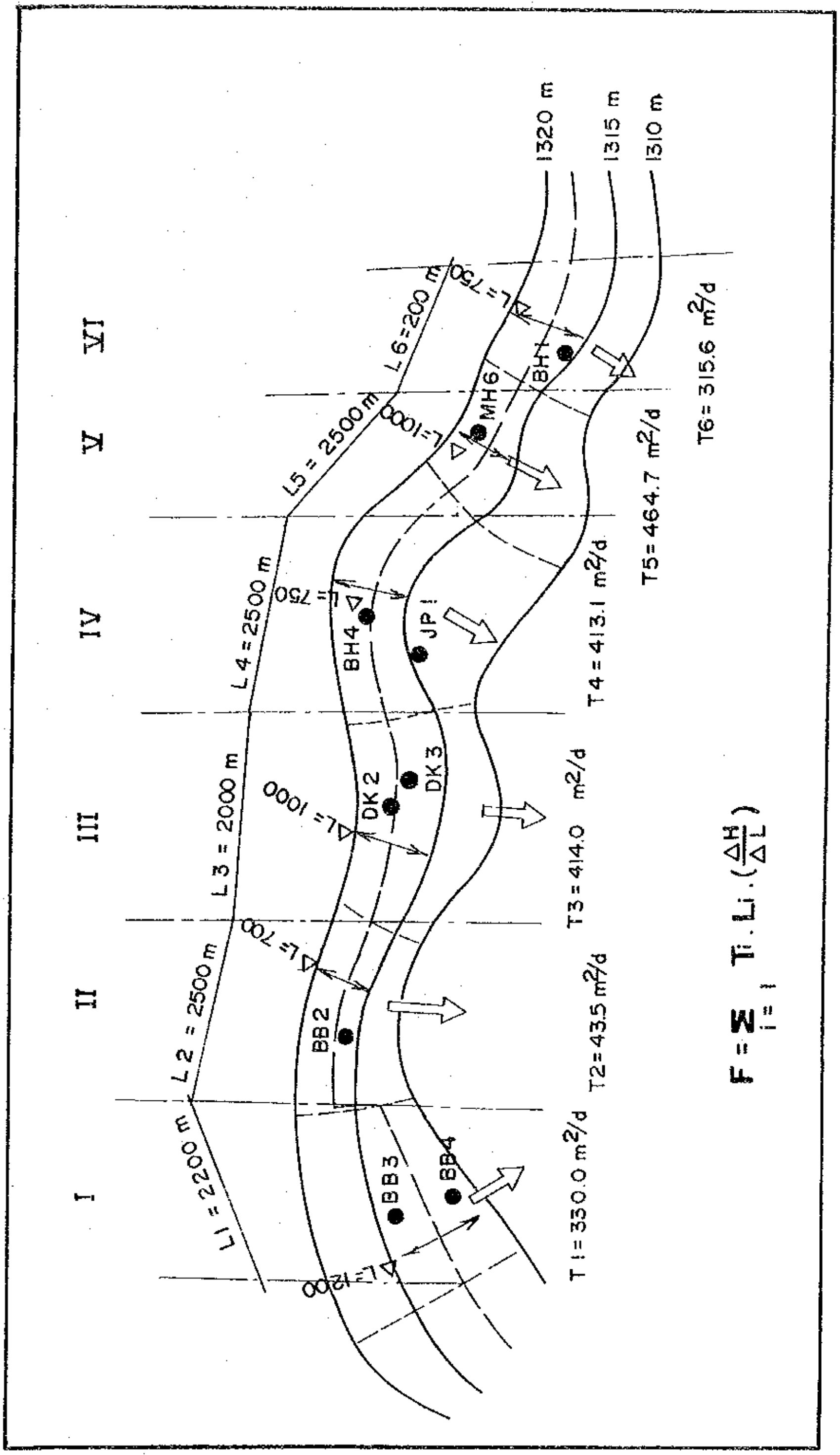


HIS MAJESTY'S GOVERNMENT OF NEPAL GROUND WATER MANAGEMENT PROJECT IN THE KATHMANDU VALLEY JAPAN INTERNATIONAL COOPERATION AGENCY	Fig. E-2.5	CONFINED AQUIFER WITH AQUITARD DEPOSIT



HIS MAJESTY'S GOVERNMENT OF NEPAL GROUND WATER MANAGEMENT PROJECT IN THE KATHMANDU VALLEY	Fig. E-2.6	GROUNDWATER COUNTER LINES IN THE NORTHERN DISTRICT
JAPAN INTERNATIONAL COOPERATION AGENCY		



$$F = \sum_{i=1} T_i \cdot L_i \cdot \left(\frac{\Delta H}{\Delta L}\right)$$

HIS MAJESTY'S GOVERNMENT OF NEPAL GROUND WATER MANAGEMENT PROJECT IN THE KATHMANDU VALLEY	Fig. E-2.7	GROUNDWATER FLOW IN THE NORTHERN DISTRICT
JAPAN INTERNATIONAL COOPERATION AGENCY		