Table 2.3.5 Summary of Aquifers in Banke District

Location/ Formation	Well Depth (m)	Rate (%)	T (m2/d)	S.C. (l/s/m)
North Alluvium				
Bhabar Zone	180	21	390	2.6
Rapti River	120	47	900	3.9
Gangetic Alluvium				
Southern Terai	150	32	750	3.3
Churia Formation				
Central Alv. Plain	240	21	170	0.8

Remarks: T = transmissivity S.C. = Specific Capacity

2.3.3. Representative Area

The representative area is selected among the three district of Jhapa, Mahottari and Banke, based on the area with the highest groundwater potential.

(1) Results of Field Survey

a) Geophysical Prospecting

i) General

Two geophysical prospecting methods, Power-Line Magneto-telluric (PLMT) and resistivity prospecting by the Schlumberger Method, are applied to detect the resistivity layers in the area. The first method is suited to detect the resistivity structure on a comparatively large scale, and the prospecting depth can reach more than 500 m. The second method reaches a prospecting depth of approximately 320 m due to the limit of the applied electrode spacing of AB/2 to 480 m.

Location of the prospecting sites for both methods are shown in Figure 2.3.11.

ii) Magnet-Telluric Prospecting (PLMT)

- Methodology

PLMT was introduced to study large-scale resistivity structures in the area. Although the signal source of investigation depends on both electric and magnetic fields from a commercial high-voltage power line that runs along the E-W Highway and from Birtamod to Bhadrapur with 33 KV. However, the line emits a comparatively weak signal during prospecting due to heavy fluctuations and the unstable supply of voltage, which results in the low reproduction of data, especially in high frequencies (150, 250, 350, 450, and 550 Hz), except for the basic frequency of 50 Hz.

Prospecting sites are distributed in a grid every 1,250 m the Study Area, except in the terrace which is covered by dense forest. The total number of prospecting sites is 219 (Figure 2.3.11).

Of the measured data obtained by PLMT, a relatively large number (149 out of 219) are analyzed by the linear inversion method to derive the theoretical curve which fits the relationship between apparent resistivity and frequency. Apparent resistivity-frequency curves are analyzed and shown in the Appendix.

- Results of Analysis

Two typical resistivity layers, approximately 100 Ωm in the upper layer and 10 Ωm in the lower layer, are obtained by the analysis. The depth to the lower layer ranges from 250 to 500 mbgs. An isobath contour map of the surface topography of the lower layer is shown in Figure 2.3.12.

As seen in the figure, an elevated platform with the shallowest depth of 250 mbgs tends in a north-northwest direction in the central part of the Study Area. The western edge of the platform dips steeply toward the west with a 1:7 gradient and finally reaches a 500 m depth. The north-eastern and south-eastern edges of the platform dips gently toward the north and southeast, respectively, ranging from 400 m to 450 m in depth. Another elevated platform of the basement of the upper layer is observed along the upper part of the Mechi River with a depth of 200 mbgs. The upper layer is deemed to be correlative with the Alluvial Formation and a part of the Churia Group.

The structure of the low resistivity layer is of particular interest to the subsurface geological structure of the Churia Group. For example, the location of the uplifted platform is consistent with the elevated land of the terrace (Figure 2.3.13 Cross-Section of Resistivity Structure A-A). As shown in Figure 2.3.14, a gap in depth of more than 150 m on the top of the lower layer has been analyzed between sites 5-20 and 6-20. It appears that the gap may be the result of a thrust movement. The lower layer seems to be correlative with the Churia Group.

iii)Resistivity Prospecting

- Methodology

The Schlumberger electrode array is applied for resistivity prospecting. The electrode spacing of AB/2 is extended to 480 m, and the MN/2 is set at 1, 5, and 25 m. Although approximately 10 prospecting sites are located near the exploratory wells, the area coverage by prospecting is somewhat wider than that by PLMT. The total number of sites is 152, and the prospecting locations are indicated in Figure 2.3.11, along with the location of PLMT.

- Results of Analysis

The interpretation of the VES curve, resistivity-spacing curve, is done by a theoretical linear inversion fitting with the apparent resistivity and electrode spacing, using a portable computer. All of the data is of good quality for analysis. Based on the interpretation of the VES curve, the area is composed of two to five resistivity layers, and each layers can be explained as follows:

- Shallow high-resistivity layer:

In the uppermost layer, a majority of the resistivity shows more than 1,000 Ωm; sometimes it is less than 1,000, and the thickness is less than 30 m.

- Shallow medium-resistivity layer:

Underlying the shallow high-resistivity layer, resistivity ranges from 100 to 300 Ωm, and the thickness ranges from 50 m to 200 m.

- Middle medium-resistivity layer:

Underlying the shallow middle-resistivity layer is approximately 100 Ωm, and the thickness ranges from 150 m to 300 m.

- Shallow low-resistivity layer:

Intercalated in the shallow high- and middle-resistivity layers, resistivity is less than 100 Ωm, and the thickness is usually less than 40 m.

All resistivity layers are deemed to be correlative to the upper layer detected by PLMT prospecting. In other words, the area basically consists of two resistivity layers: the upper and the lower. The upper layer can be further subdivided into two to five sub-layers (Table 2.3.6).

Based on the interpretations of the geophysical prospecting, profiles of the resistivity structures along several directions have been prepared, as shown in Figure 2.3.13 to Figure 2.3.18. Interpreted geophysical prospecting as well as resistivity profiles are quite consistent with the lithologic interpretation of the exploratory wells.

Figure 2.3.11. Location Map of Geophysical Prospecting

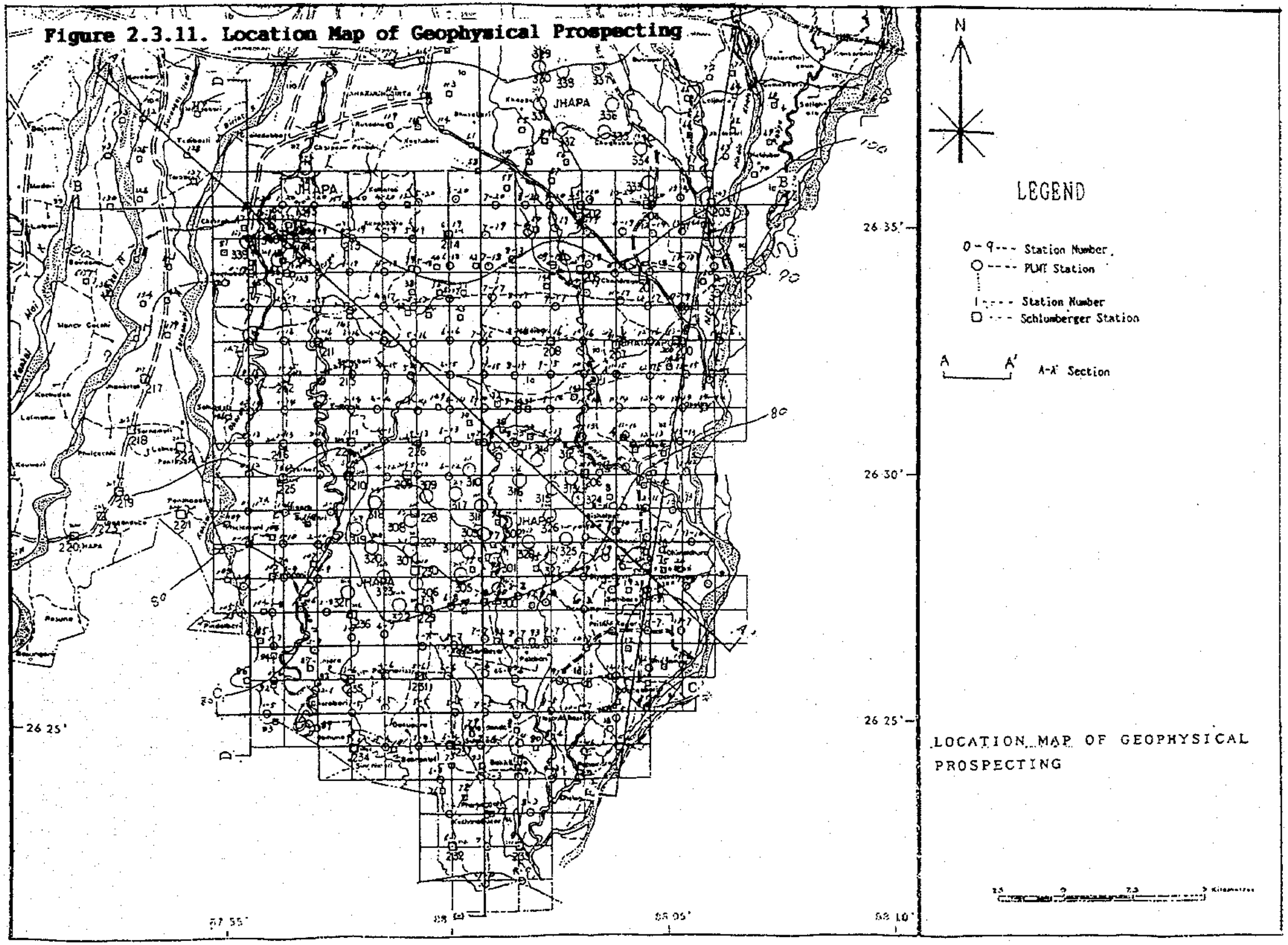


Figure 2.3.12. Surface Topography of Lower Resistivity Layer

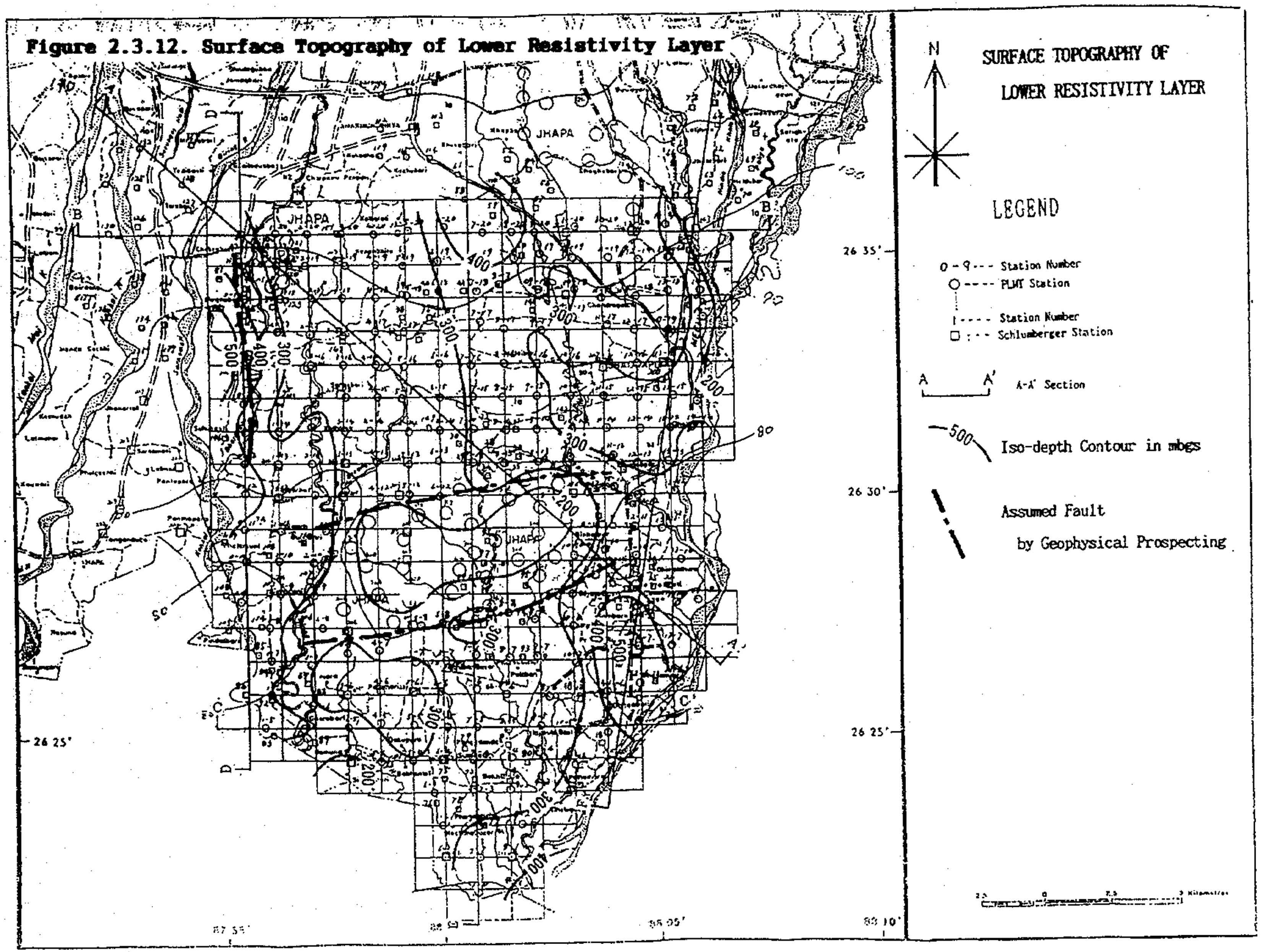


Figure 2.3.13. Resistivity Profile A-A'

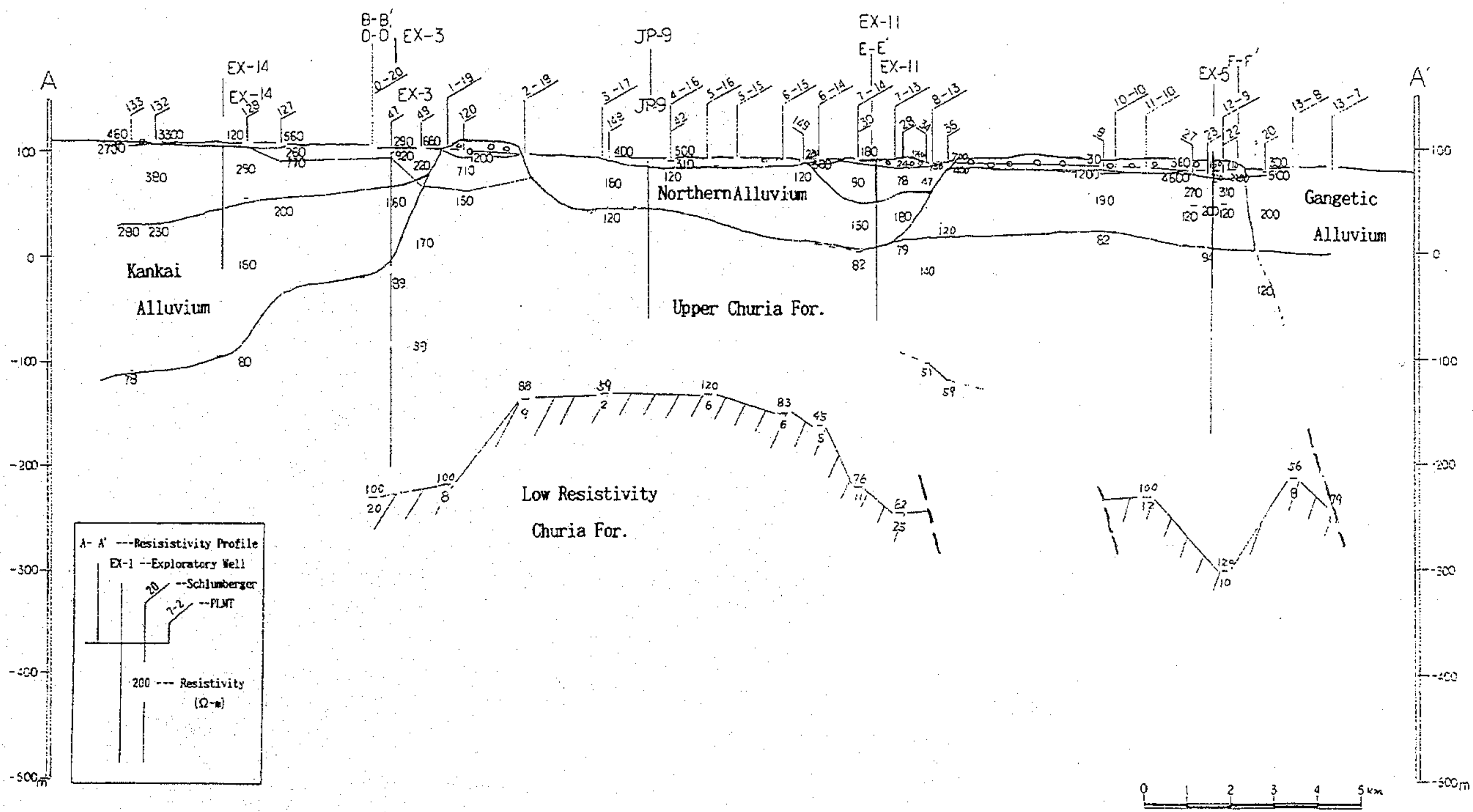


Figure 2.3.14. Resistivity Profile B-B'

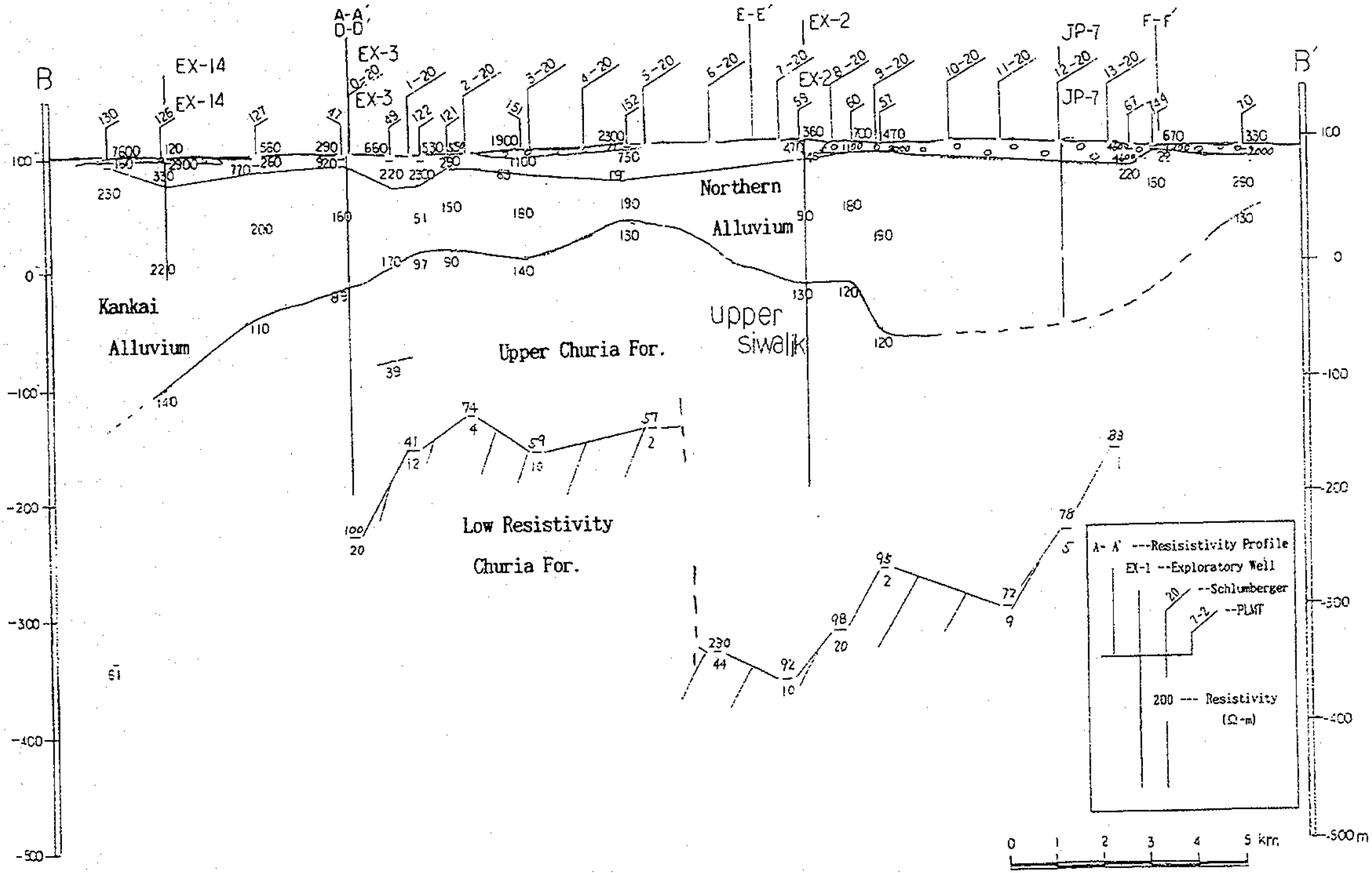


Figure 2.3.15. Resistivity Profile C-C'

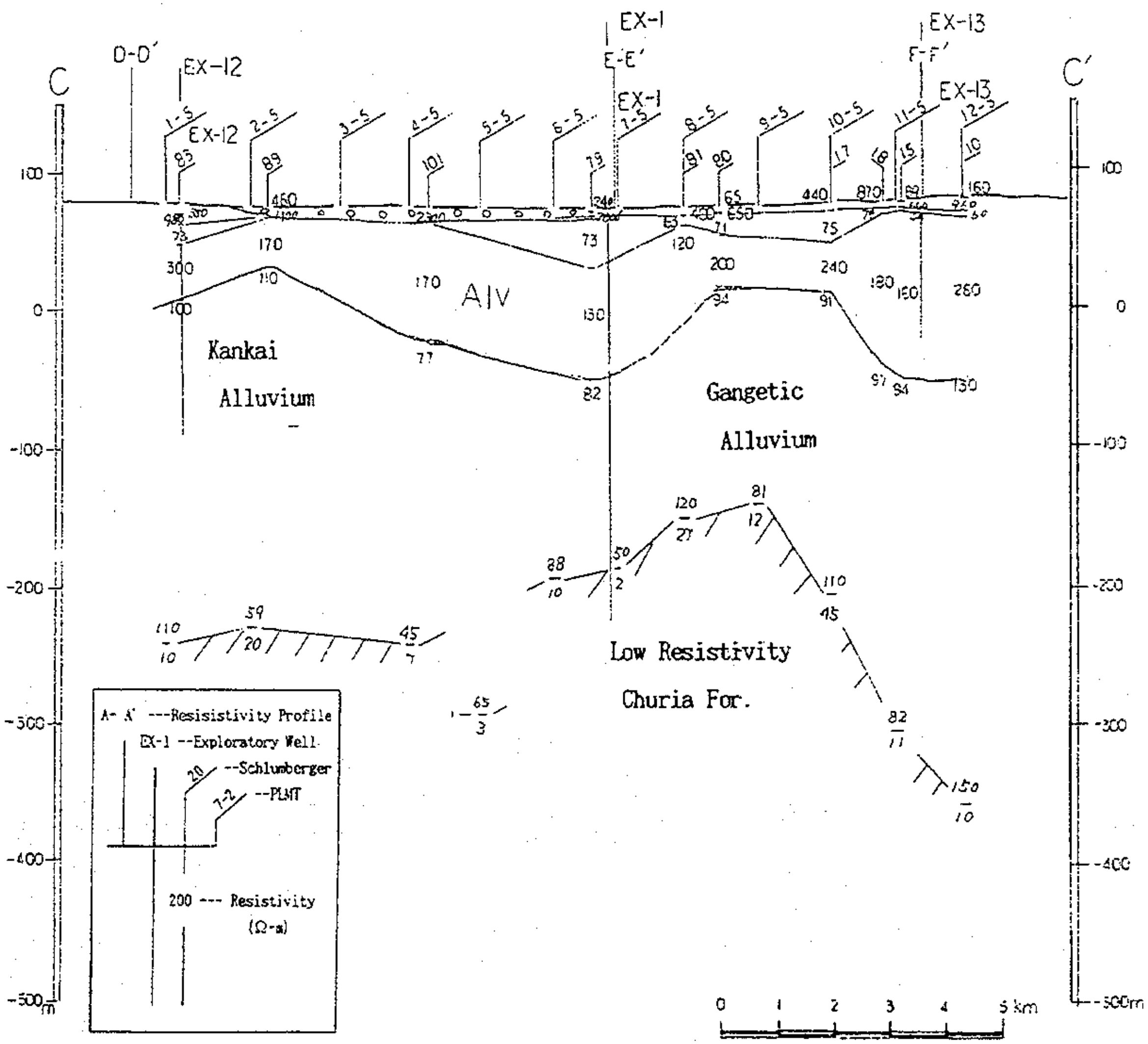


Figure 2.3.16. Resistivity Profile D-D'

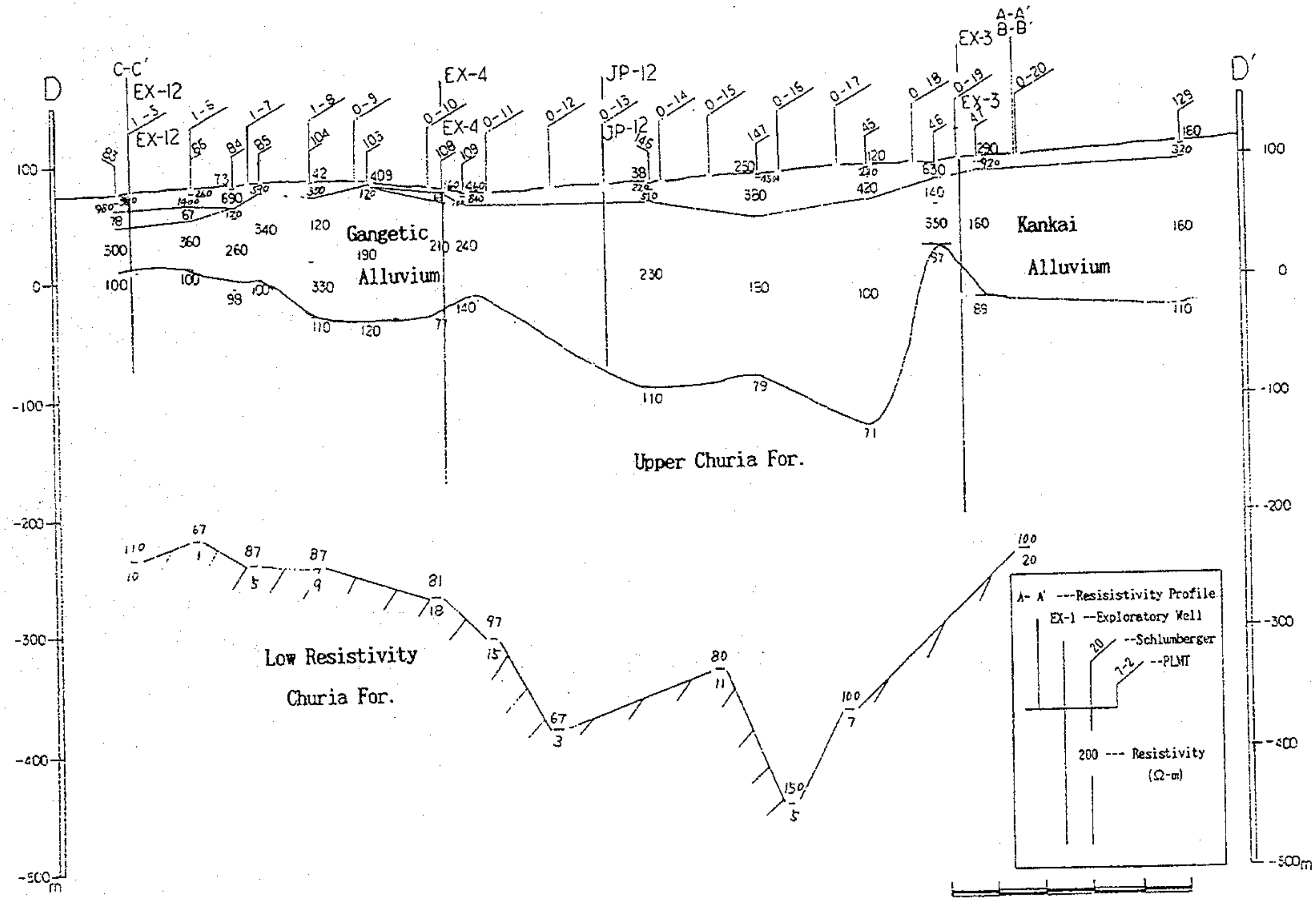


Figure 2.3.17. Resistivity Profile E-E'

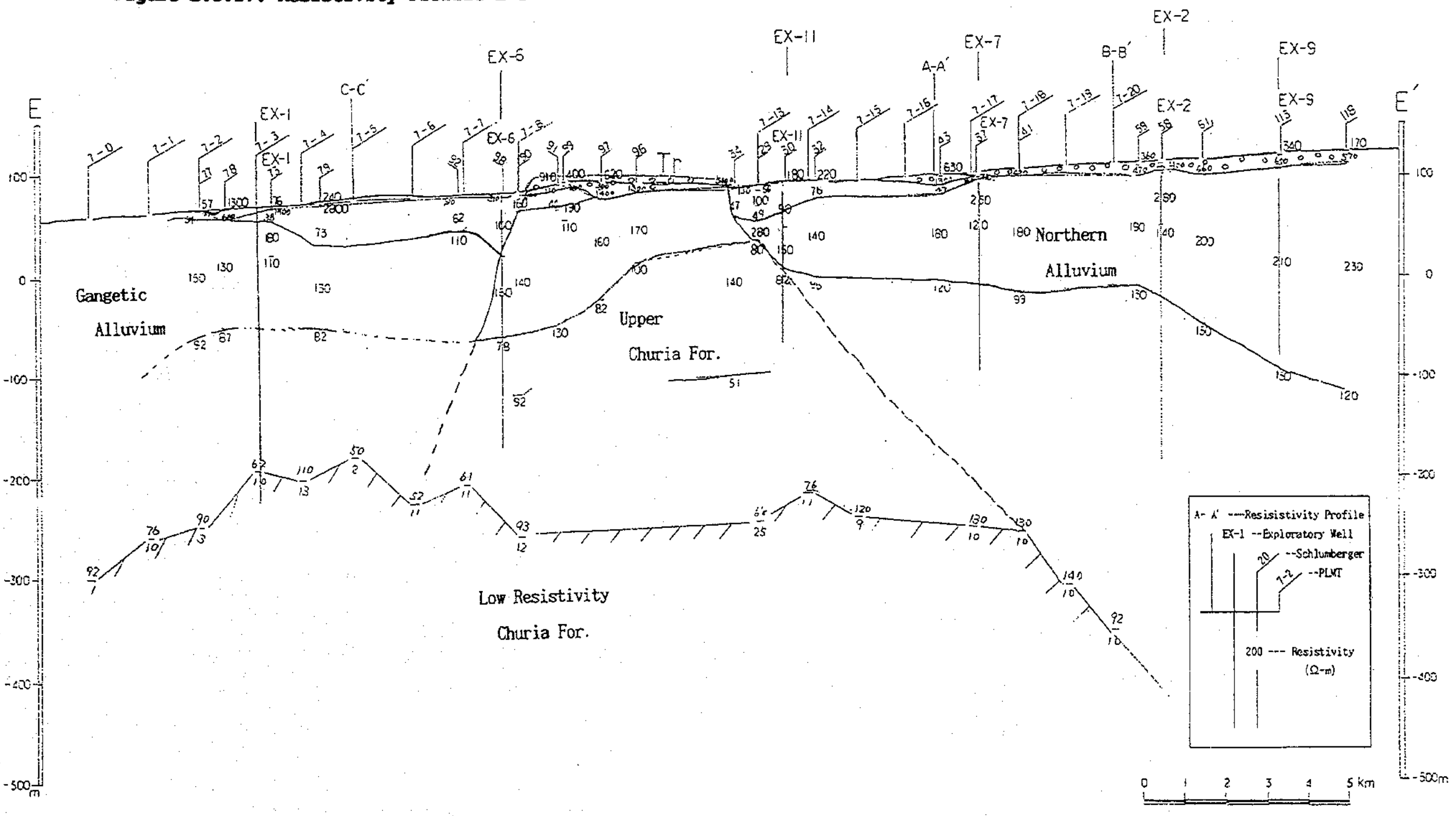


Figure 2.3.18. Resistivity Profile F-F'

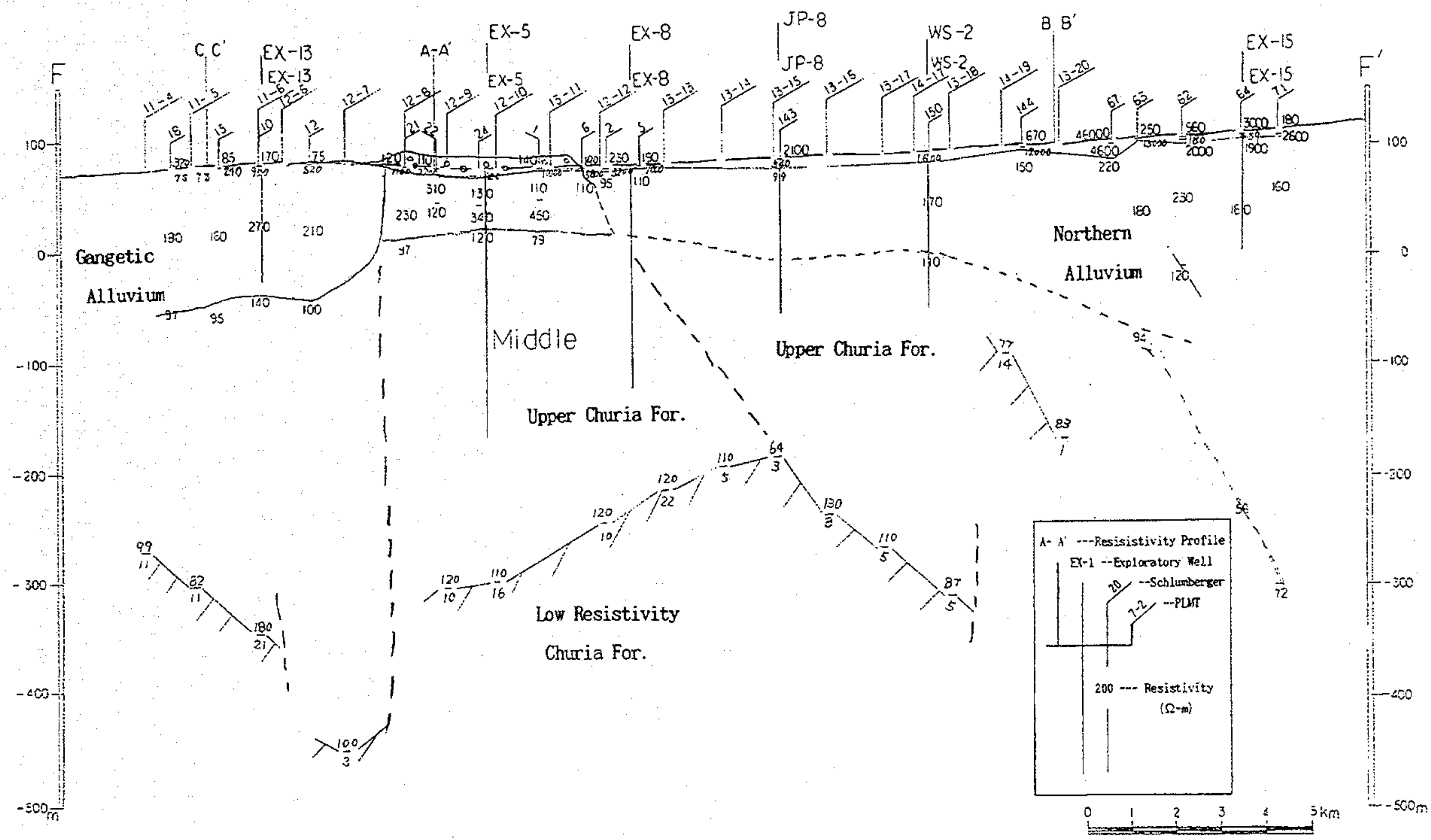


Table 2.3.6 Summary of Resistivity Structure

Resistivity Layer		Resistivity (Ω-m)	Thickness (m)
Upper Layer	Shallow high-resistivity	1,000 <	1 - 30
	Shallow medium-resistivity	300 - 1,000	50 - 200
	Middle medium-resistivity	100 >	150 - 300
	Shallow low-resistivity	100 >	40 >
Lower Layer		10 ±	

b) Exploratory Well Drilling

i) Outline of the Work

The objectives of the work are to obtain the hydrogeological conditions of the Study Area, including,

- to set up hydrogeologic units
- to obtain vertical/horizontal extent of the aquifers,
- to obtain aquifer characteristics and potential
- to obtain groundwater quality

From a hydrogeologic point of view, exploratory wells are located from the Kankai in the western limit and to the E-W Highway in the northern limit, with consideration of the location of deep wells drilled by GWRDB and the Drinking Water Supply Project (see Figure 2.3.19 Location Map of Hydrogeological Study).

Exploratory wells are designed to grasp the productive property of aquifers at each 50 m depth, from 100 m to a maximum of 300 m.

Five observation wells are attached to each different depth of the exploratory wells and installed with pressure log-type automatic water level recorders.

Truck mounted rotary drilling rigs are used for drilling exploratory wells, and water-based drilling fluids with bentonite and polymer are applied during the drilling procedure.

Two types of borehole logging, resistivity and gamma logging, are created to locate aquifers and aquicludes after the drilling is complete. An interpretation of the lithologic logs assists in determining the location of the screens with the above borehole loggings.

After completion of the drilling, steel casings of 150 mm diameter and continuous-slot screens (wire wound) reinforced by a ring base, with 1.5 mm and 2.9 mm slot openings, are installed in the borehole. The percentage of these screens is 39% and 46%, respectively. The housing pipe has a 300 mm diameter and is installed at a depth of 50 and 40 mbgs, depending on the total depth of the well.

The observation wells have a diameter of 100 mm with the steel casing. The depth of screen interval is the same as the exploratory well but a slotted screen is used instead of a continuous-slot screen.
The well structure of the exploratory and observatory wells is shown in Figure 2.3.20 and Figure 2.3.21, and well location are illustrated in Figure 2.3.19.

ii) Results of Drilling

<Lithology of Exploratory Wells>

An interpretation of the lithologic logs reveals that lithologic continuity to both directions, north-south and east-west, is well traced by careful interpretation of the resistivity and gamma loggings. Interruptions or discontinuities of the lithology, if found between the two logs, are probably due to a thrust or fault as a result of tectonic movement. Results of the interpretation are shown in Figure 2.3.22 to Figure 2.3.27 in the geological profiles.

The thickness and composition rate of the permeable and impermeable beds in the exploratory wells and existing wells are summarized in Table 2.3.8. The table shows that the average thickness of the permeable beds is 12 m, and the rate of composition is 64% among the total number of wells. The largest composition rate of permeable bed underlies EX-1 (82%) and EX-13 (90%) in the Gangetic Alluvium. The total length of the permeable beds for these wells is 239 m out of 300 m and 87 m out of 100 m, respectively.

The thickness of each bed with labeling is tabulated in Figure 2.3.9. The table shows that Kankai and Gangetic alluviums have a comparatively larger composition rate of permeable beds at 76% and 77%, respectively. The Churia Formation is lower than the alluvium: 66% in the Central sub-formation and 40% to 50% in the North and West sub-formations. The average composition rate of the alluvium and the Churia Formation is 71% and 53%, respectively. The total thickness of the permeable and semi-permeable beds in each formations is summarized in Table 2.3.10.

Figure 2.3.19. Location Map of Hydrogeological Study

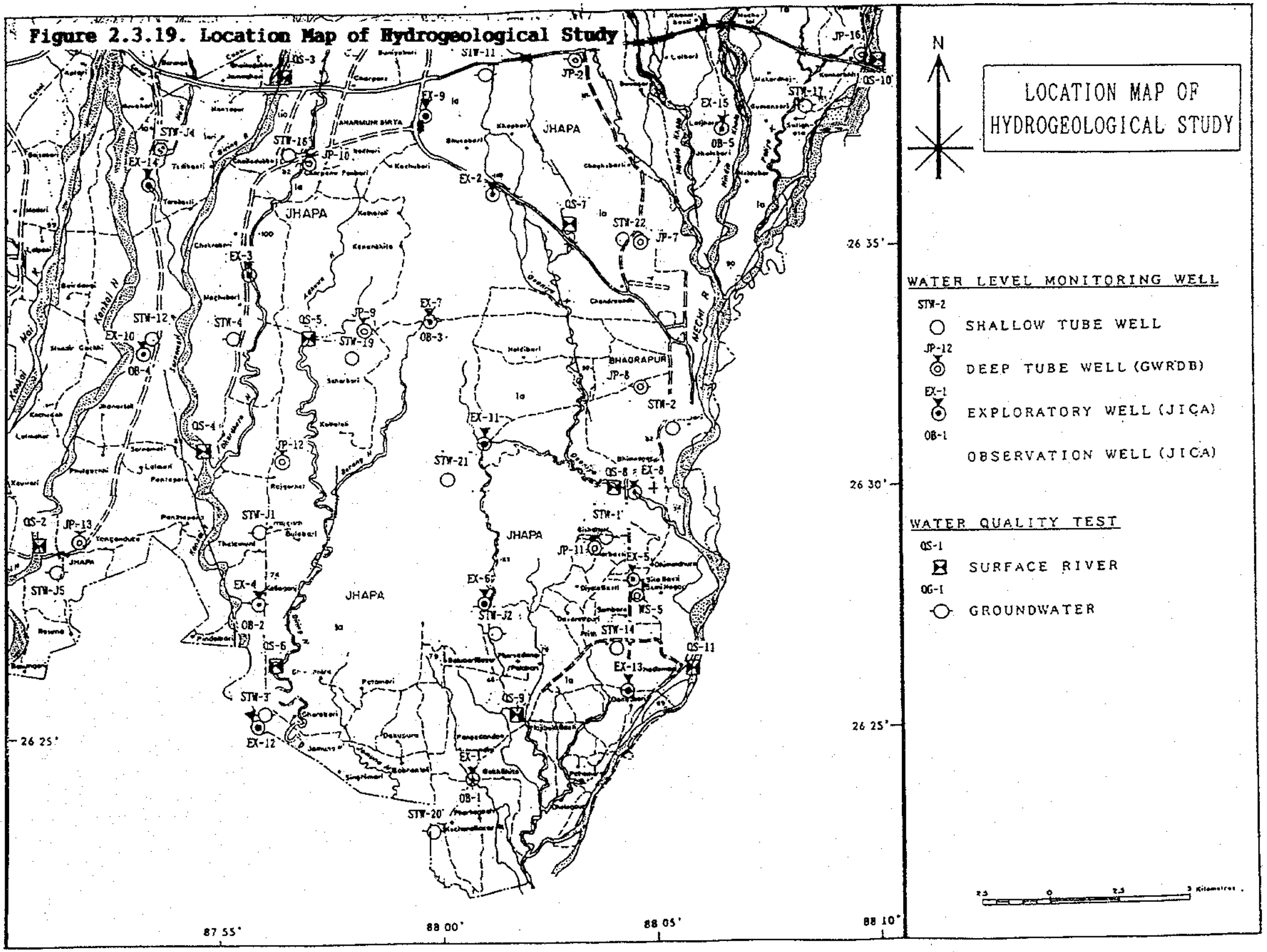


Table 2.3.7. Inventory of Exploratory and Existing Wells in Jhapa District

No.	Location	Coordinate Lat/Lon	Coordinate X Y	G.L. (mamsl)	Depth (m)	Well Dia (mm)	S.L. (m)	SWL (mbg)	Yield (l/s)	D/d (m)	S.C. (l/s/m)	T (m2/d)	S
EX-1	Sunadhi Patharia	26-24-08.3 88-00-35.7	83.16 50.32	64.44	300	250/150	30	+1.46	50.2	27.59	1.82	1,430	
EX-2	Harchana Garamuni	26-36-10.5 88-01-24.4	85.02 74.62	109.32	300	250/150	21	5.13	25.0	14.33	1.74	410	
EX-3	Dangebari Dangebari	26-34-27.3 87-55-35.7	74.41 70.98	96.52	300	250/150	27	18.91	40.0	15.08	2.66	1,200	
EX-4	Bhagdubba Rajgarh	26-27-38.8 87-55-54.6	74.77 57.25	75.04	250	250/150	27	3.97	44.8	16.53	2.71	1,240	
EX-5	Sitachauk Prithvinagar	26-28-07.6 88-04-20.5	90.09 58.48	87.66	250	250/150	24	12.76	40.1	19.19	2.09	520	
EX-6	Dandagaun Balubari	26-27-23.2 88-00-59.9	84.00 56.89	76.30	250	250/150	27	3.08	29.0	17.16	1.69	730	
EX-7	Hamumanbiran Halidibari	26-33-31.4 87-59-50.8	82.10 69.23	96.40	200	250/150	21	+1.22	40.0	29.23	1.37	390	
EX-8	Bhimnager Prithvinagar	26-30-00.1 88-04-22.6	90.22 62.60	80.84	200	250/150	21	+8.55	50.2	24.10	2.08	850	
EX-9	Birtabazar Anarmuni	26-37-37.3 87-59-27.0	81.51 77.48	119.67	200	250/150	21	6.86	30.3	14.84	2.04	380	
EX-10	Balubathan Sarnamati	26-33-18.7 87-53-26.8	70.48 68.65	90.26	150	250/150	18	2.19	40.0	11.91	3.36	1,700	
EX-11	Balua Jalthal	26-30-53.7 88-00-52.4	83.88 63.96	87.08	150	250/150	15	+3.50	20.0	30.84	0.65	1,130	
EX-12	Gherabari Gherabari	26-25-18.0 87-55-52.8	74.64 52.52	71.85	150	250/150	15	3.97	50.2	13.63	3.68	1,240	
EX-13	Dangabari Pathamari	26-25-50.5 88-04-19.2	89.98 53.87	66.44	100	250/150	21	1.25	50.2	8.30	6.05	3,540	
EX-14	Tulshibari Surunga	26-36-21.8 87-53-22.1	70.43 74.76	101.31	100	250/150	0	2.20	30.0	8.88	3.38	2,230	
EX-15	Laljhora Jamirgarhi	26-37-27.2 88-06-26.8	94.21 77.36	107.79	100	250/150	12	1.78	34.7	11.25	3.08	710	
OB-1	Sunadih Patharia	26-24-08.3 88-00-35.7	83.16 50.32	64.57	300	100	30	+1.04	50.2	3.27	15.35	1,430	2.30E-5
OB-2	Bhagdubba Rajgarh	26-27-38.8 87-55-57.7	74.77 57.25	74.96	250	100	27	3.90	44.8	2.44	18.36	1,240	1.30E-5
OB-3	Hanumanbiran Haldibari	26-33-29.0 87-59-50.8	82.10 69.23	96.75	200	100	21	+1.42	40.0	6.70	5.97	390	2.80E-4
OB-4	Balubathan Sarnamati	26-33-20.1 87-53-25.5	70.48 68.65	91.00	150	100	18	2.25	40.0	1.63	24.54	1,700	5.20E-4
OB-5	Laljhora Jamirgarhi	26-37-27.2 88-06-36.8	94.21 77.36	108.12	100	100	12	1.47	34.7	2.49	13.94	710	2.20E-3
JP-1	H.T.Garden Damak	26-39-47.6 87-40-31.7	47.23 81.28	125.0	88.4	250/150	16.9	3.9	1.8	4.42	0.41	80	
JP-2	Charali Army Camp	26-39-09.1 88-03-17.6	88.54 80.69	129.5	124.9	250/150	20.0	6.5	11.5	21.50	0.53	370	
JP-3	Kankai Irr. Office	26-39-21.0 87-51-41.6	67.49 80.73	121.9	85.9	250/150	8.7	8.5	2.5	0.70	3.57	340	
JP-4	Bhalu Gaon Paddy field	26-35-29.1 87-45-48.2	56.67 72.75	103.6	137.2	250/150	17.9	5.7	2.0	1.20	1.67	230	
JP-5	Gwal Dubba pump house	26-30-40.8 87-43-46.9	52.85 63.00	83.8	137.2	250/150	12.5	5.9	41.7	1.80	23.17	1,000	
JP-6	Bhawanipur Field	26-28-38.8 87-43-28.1	52.15 54.86	71.3	137.2	250/150	15.3	3.1	12.9	19.70	0.65	900	
JP-7	Prakashpur Paddy field	26-35-16.5 88-04-34.2	90.73 72.87	104.5	148.4	250/150	18.3	F/F (1.0)	5.3	17.50	0.30	100	
JP-8	Maheshpur Paddy field	26-32-12.0 88-04-41.6	90.86 66.71	86.0	146.3	250/150	24.4	0.7 0.3	14.3 32.7	3.00 16.76	4.77 1.95	590 660	
JP-9	Goldhap pump house	26-33-17.0 87-58-12.0	79.10 68.69	91.4	146.3	250/150	30.3	1.0 0.9	10.0 30.0	5.20 15.70	1.92 1.91	210 340	
JP-10	Challadubba Paddy field	26-36-51.6 87-56-55.6	76.91 75.87	108.2	144.8	250/150	24.4	1.2		20.80			
JP-11	Prithivinagai Enclosed	26-29-06.8 88-03-44.6	89.03 60.45	76.2	155.5	250/150	21.5	7.5	39.0	7.50	5.20	760	
JP-12	Rajgadhat pump house	26-30-37.0 87-56-23.0	75.72 63.26	82.3	187.7	250/150	33.2	2.7 2.7	43.0 38.8	5.10 3.69	8.43 10.51	2,900 3,140	
JP-13	Tangandubа pump house	26-28-53.8 87-51-49.5	67.39 59.65	79.2	158.5	250/150	25.5	1.2 2.7	41.0 36.7	16.80 11.83	2.44 3.10	1,540 2,150	
JP-14	Damak W.S. office	26-40-11.2 87-42-21.4	50.57 82.13	128.0	75.1	350/200	24.1	1.0	25.0	3.00	8.33	540	
JP-15	Sanischare in a house	26-41-13.0 87-59-55.6	82.49 84.75	149.4	73.1	350/200	33.5	2.2					
JP-16	Kakarbhitta Near school			121.9	159.7	350/200	67.0					240	
JP-17	Kohabara				107.1	250/150	30.0	6.0	40.0	8.70	4.60	1,170	
WS-1	Chandragadhi W.S. in field	26-34-22.0 88-03-48.0	89.30 71.05	103.6	150.0	350/200	35.5	1.8	26.3	4.30	6.12	800	
WS-2	Chandragadhi W.S. in field		91.71 70.08	100.6	150.0	350/200	38.5	+1.5	18.0	32.20	0.56	140	
WS-3	Chandragadhi W.S. office	26-34-11.5 88-04-01.4	89.70 70.70	100.6	112.5	250/150	58.9	3.0	19.7	14.50	1.36		
WS-4	Bhadrapur W.S. office	26-33-31.3 88-05-06.4	91.76 69.39	91.7	113.3	250/150	23.5	3.0	19.7	17.00	1.16		
WS-5	Prithivinagai	26-27-54.7 88-04-23.2		88	127.0	300/200		8.6	30.9	5.79	5.34	1,060	2.20E-4
BH-5	Sanischare			150	96.0	300/200		2.2					
BH-8	Kakerbhitta River bed	26-38-37.6 88-09-44.2	100.22 79.82	110	65.0	300/200	23.0	+1.5	22.0	8.69	2.16	290	
JP-18	Bhareghare Paddy field	26-42-09.1 88-06-59.7		166.1									

Table 2.3.8 Lithology and Thickness of Exploratory and Existing Wells

Well	Permeable Bed			Semi-Permeable Bed		
	Thick (m)	Rate (%)	Ave (m)	Thick (m)	Rate (%)	Ave (m)
EX-1	239	82	20 (12)	54	18	5 (11)
EX-2	151	52	7 (21)	139	48	6 (22)
EX-3	137	47	9 (15)	157	53	10 (15)
EX-4	171	69	12 (14)	76	31	6 (13)
EX-5	179	72	12 (15)	68	28	5 (13)
EX-6	152	62	11 (14)	95	38	7 (14)
EX-7	108	56	8 (13)	86	44	6 (14)
EX-8	131	66	12 (11)	69	34	7 (10)
EX-9	116	60	10 (12)	76	40	6 (12)
EX-10	114	79	13 (9)	31	21	3 (9)
EX-11	69	46	9 (8)	81	54	9 (9)
EX-12	102	68	15 (7)	47	32	8 (6)
EX-13	87	90	22 (4)	10	10	3 (3)
EX-14	75	81	12 (6)	18	19	4 (5)
EX-15	44	50	9 (5)	44	50	6 (6)
JP-2	82	75	16 (4)	27	25	5 (4)
JP-3	35	51	9 (4)	34	49	8 (4)
JP-7	98	67	12 (8)	47	33	7 (7)
JP-8	85	58	9 (9)	61	42	7 (8)
JP-9	75	55	11 (7)	61	45	8 (7)
JP-10	95	73	12 (8)	36	27	5 (8)
JP-15	44	63	22 (2)	26	37	9 (3)
WS-1	103	69	13 (8)	47	31	5 (9)
WS-2	56	37	8 (7)	94	63	12 (8)
Average	-	64	12	-	36	7

Remark: ( ) = Number of single beds

Table 2.3.9 Thickness of Single Beds

Northern Alluvium			
Permeable		Semi-Permeable	
Name	Thick	Name	Thick
g1 *	17	c1	9
g2 *	18	c2	5
g3 *	12	c3	6
g4 *	7	c4	7
g5 *	13	c5	6
g6 *	5	c6	6
g7 *	6	c7	7
g8 *	7	c8	10
g9 *	9	c9	5
g10*	9	c10	6
Ave.	10		7
Rate	61		39

Kankai Alluvium			
Permeable		Semi-Permeable	
Name	Thick	Name	Thick
g1	8	c1	4
g2 *	18	c2	5
g3 *	13	c3	5
g4 *	9	c4	8
g5 *	11	c5	4
g6 *	8	c6	3
g7 *	13	c7	3
g8 *	21	c8	3
g9	10	c9	1
Ave.	12		4
Rate	76		24

Gangetic Alluvium			
Permeable		Semi-Permeable	
Name	Thick	Name	Thick
g1	5	c1	5
g2	21	c2	7
g3	9	c3	6
g4	6	c4	3
g5 *	56	c5	6
g6	8	c6	5
g7	14	c7	5
g8	6	c8	15
g9	6	c9	11
g10*	21	c10	5
g11*	30	c11	4
g12*	27		
Ave.	17		6
Rate	77		23

Northern Churia			
Permeable		Semi-Permeable	
Name	Thick	Name	Thick
g0 *	5	c1	11
g1 *	10	c2	5
g2 *	11	c3	7
g3	4	c4	2
g4	8	c5	8
g5	13	c6	8
g6 *	4	c7	5
g7 *	2	c8	2
g8 *	2	c9	4
g9 *	8	c10	8
g10*	7	c11	6
g11*	4	c12	7
Ave.	7		6
Rate	52		48

Western Churia			
Permeable		Semi-Permeable	
Name	Thick	Name	Thick
g1	14	c1	15
g2	2	c2	8
g3	2	c3	7
g4 *	3	c4	10
g5 *	13	c5	40
g6 *	15	c6	6
g7 *	6	c7	7
g8		c8	9
g9	6	c9	4
g10	4	c10	9
g11	4	c11	7
g12*	7	c12	9
g13*	11	c13	3
g14*	18	c14	
Ave.	8		10
Rate	42		58

Central Churia			
Permeable		Semi-Permeable	
Name	Thick	Name	Thick
g1	12	c1	8
g2	8	c2	4
g3	8	c3	10
g4	19	c4	9
g5	8	c5	5
g6	6	c6	4
g7	3	c7	5
g8	16	c8	13
g9	5	c9	6
g10*	9	c10	4
g11*	14	c11	5
g12*	18	c12	3
g13	8	c13	3
g14*	24	c14	4
Ave.	11		6
Rate	66		34

Remark: * = screened bed

Table 2.3.10 Summarized Thickness of Formation

Name of Formation	Permeable Bed			Semi-Permeable Bed		
	Total	Single	Rate (%)	Total	Single	Rate (%)
Alluvium						
North	103	10	61	67	7	39
Kankai	111	12	76	36	4	24
Gangetic	209	17	77	62	6	23
Average	141	13	71	55	6	29
Churia Formation						
North	78	7	52	73	6	48
West	99	8	42	134	10	58
Central	58	11	66	83	6	34
Average	112	9	53	97	7	47

Figure 2.3.20. Design of Exploratory Well

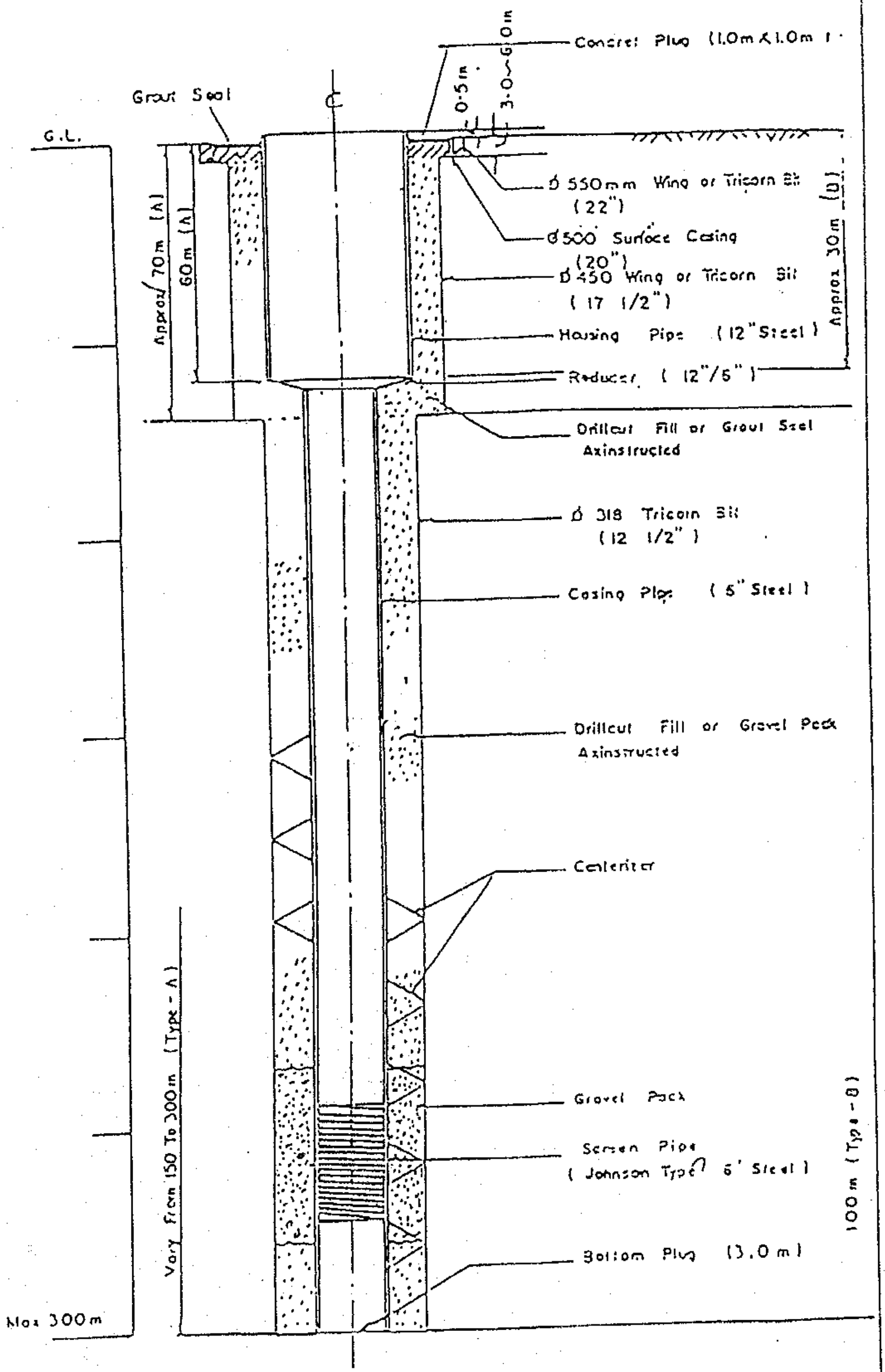


Figure 2.3.21. Design of Observation Well

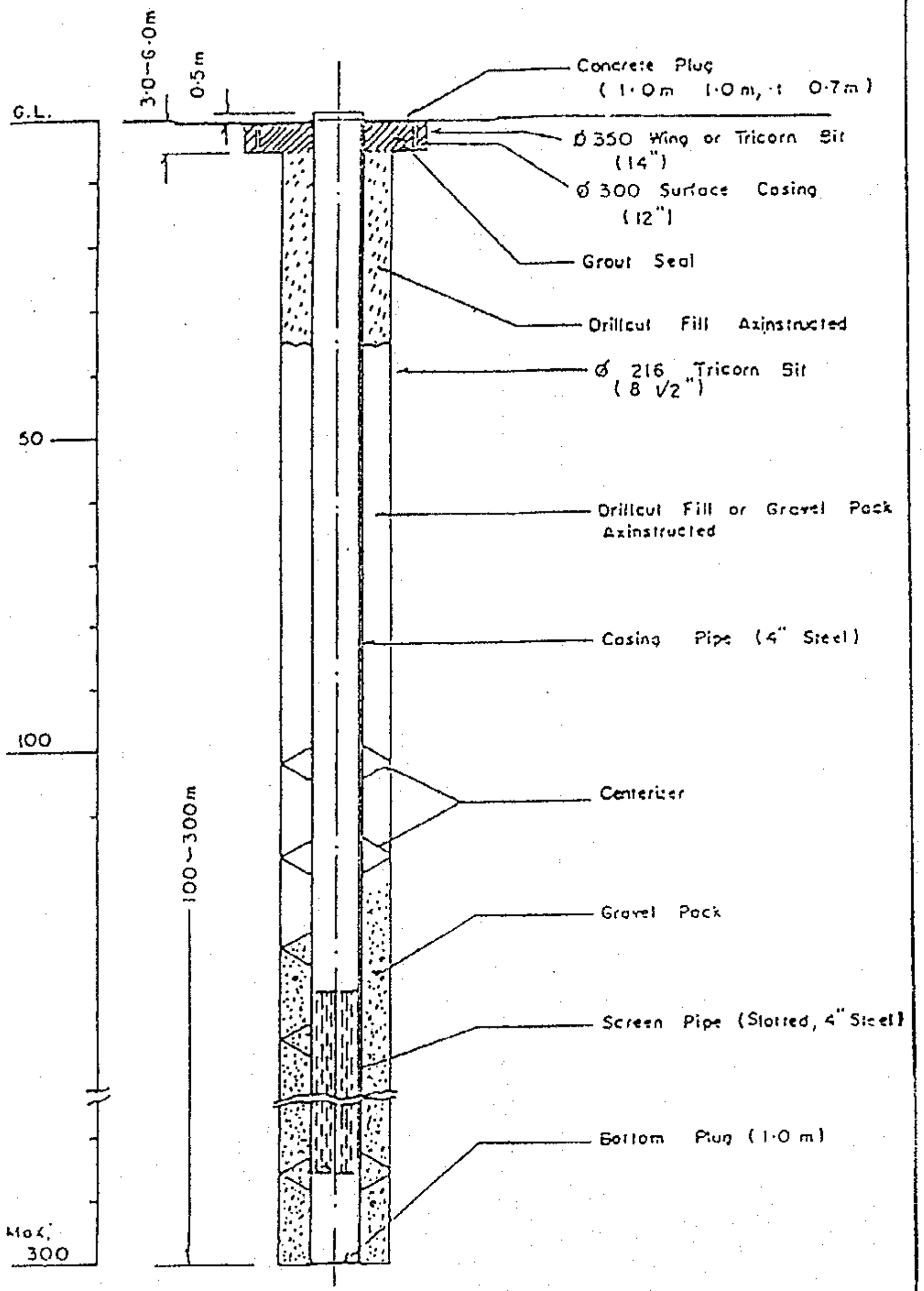


Figure 2.3.22. Geological Profile in Jhapa District A-A'

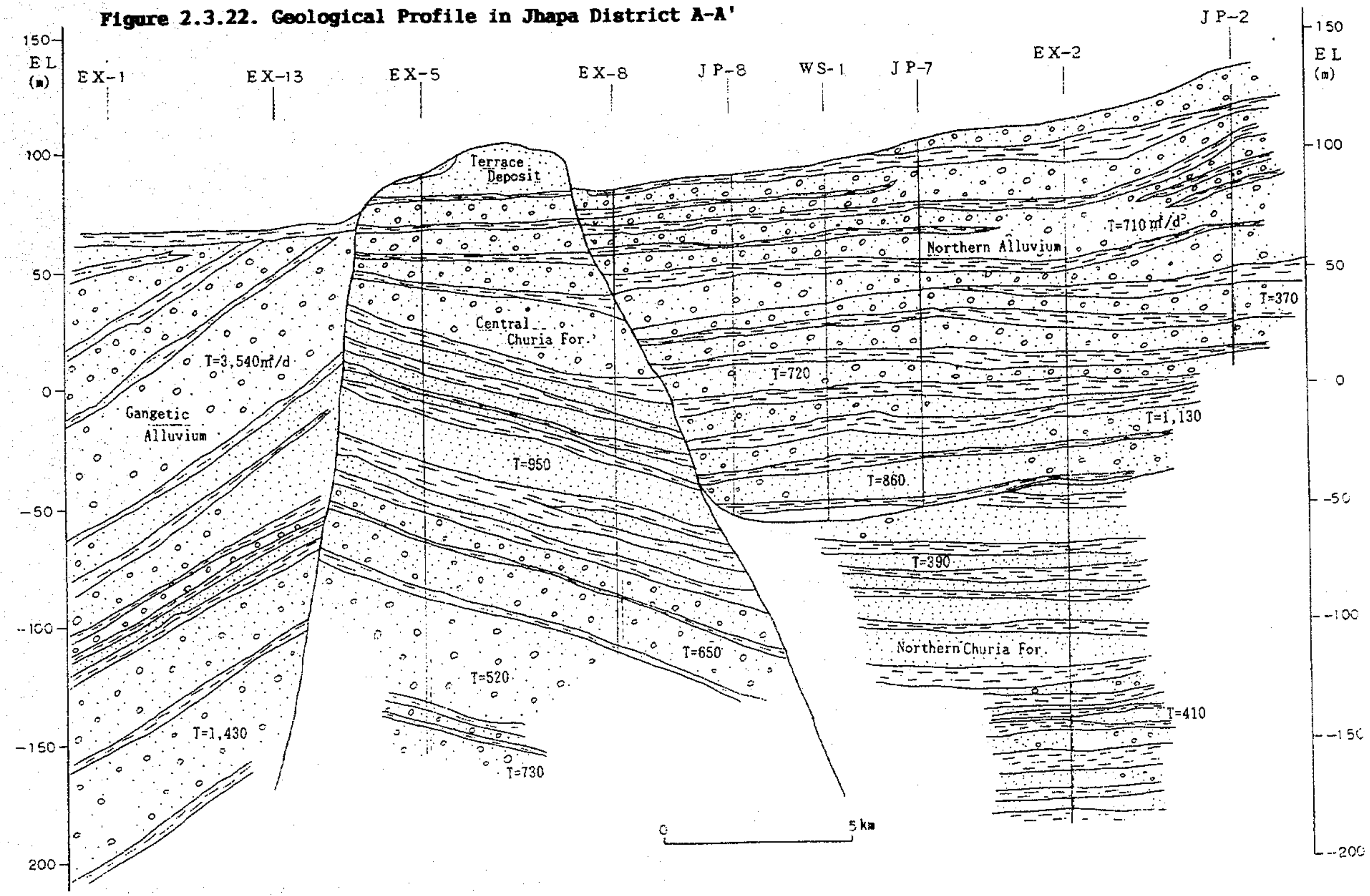


Figure 2.3.23. Geological Profile in Jhapa District B-B'

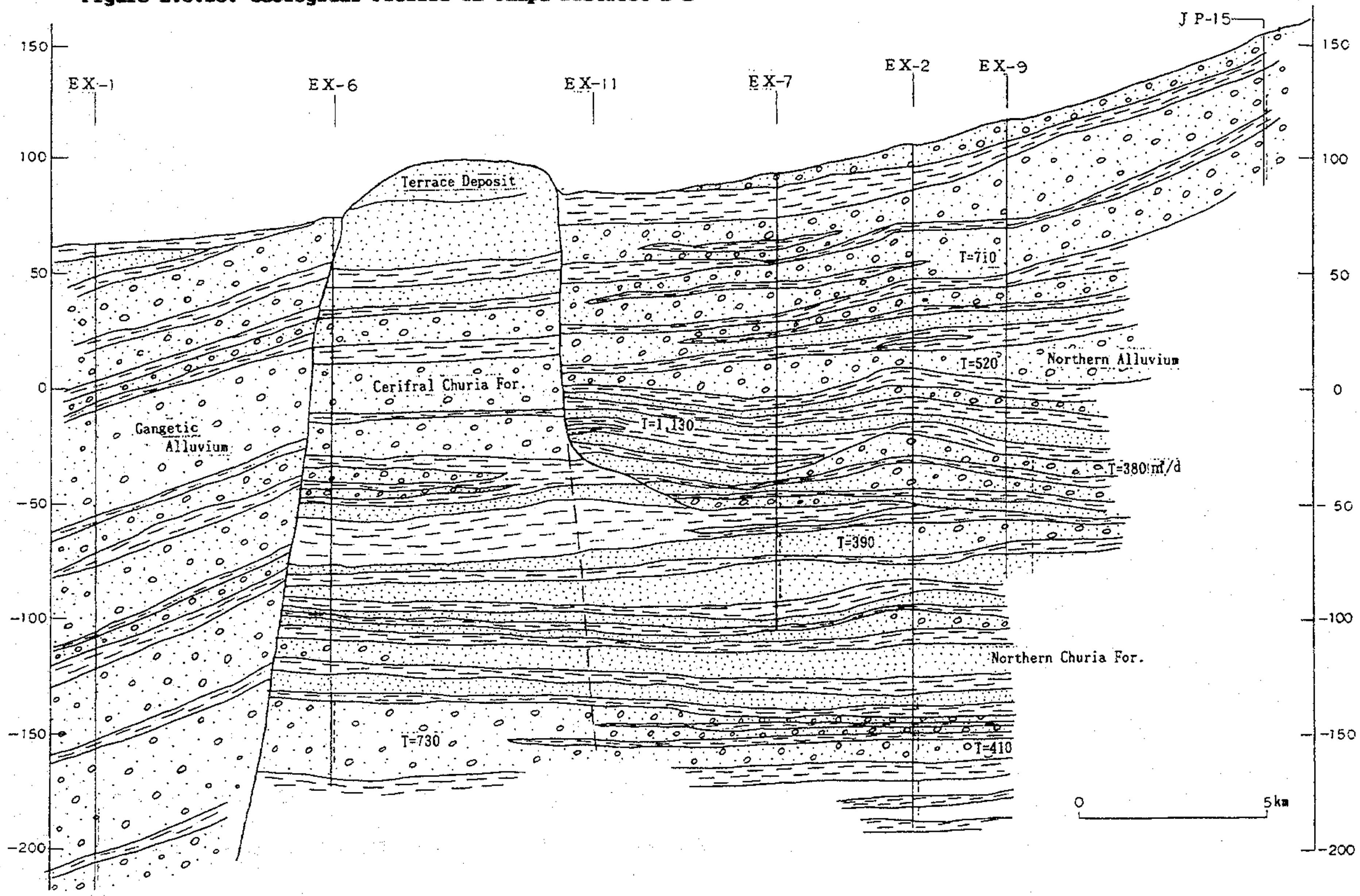


Figure 2.3.24. Geological Profile in Jhapa District C-C'

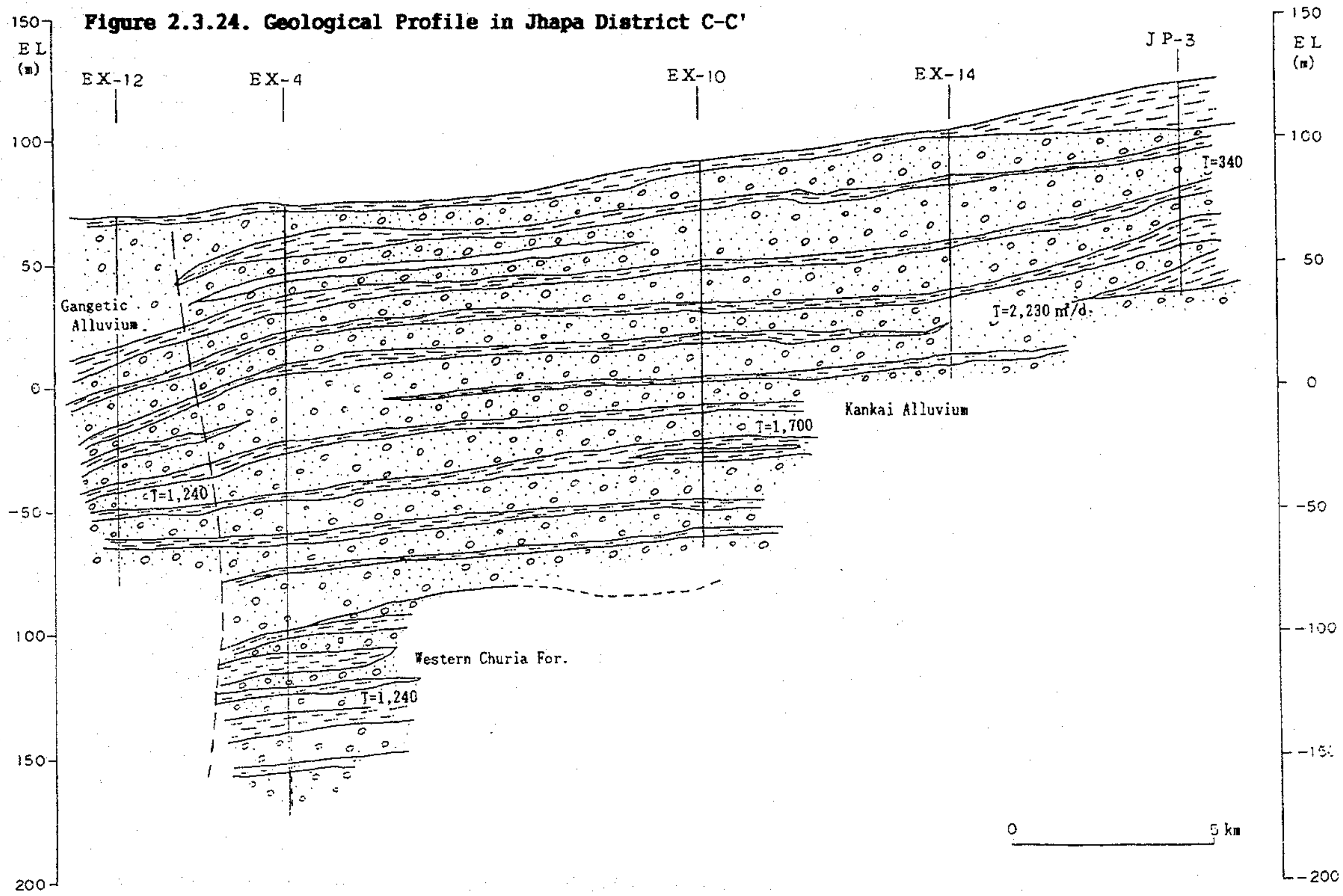


Figure 2.3.25. Geological Profile in Jhapa District D-D'

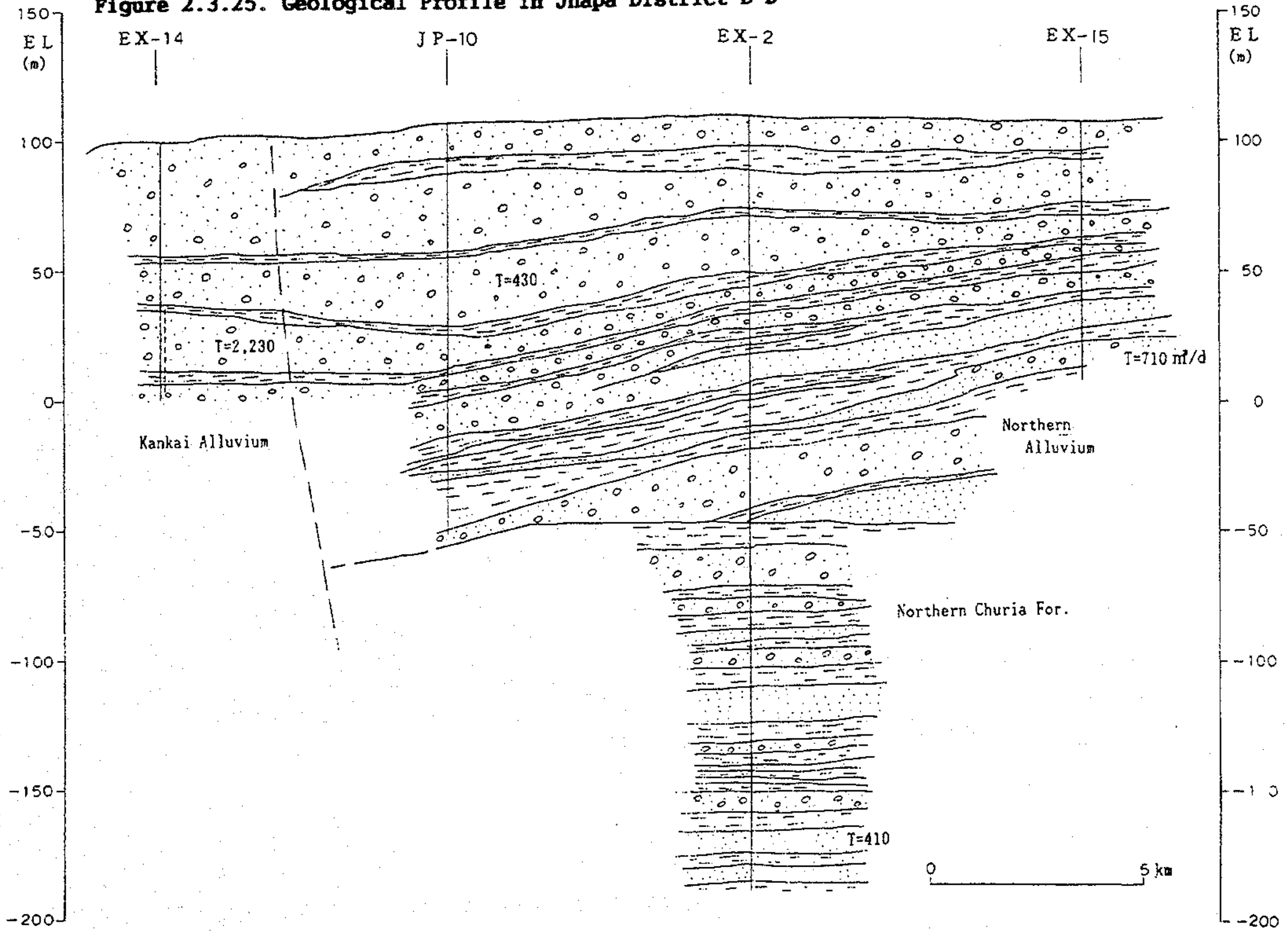


Figure 2.3.26 Geological Profile in Jhapa District E-E'

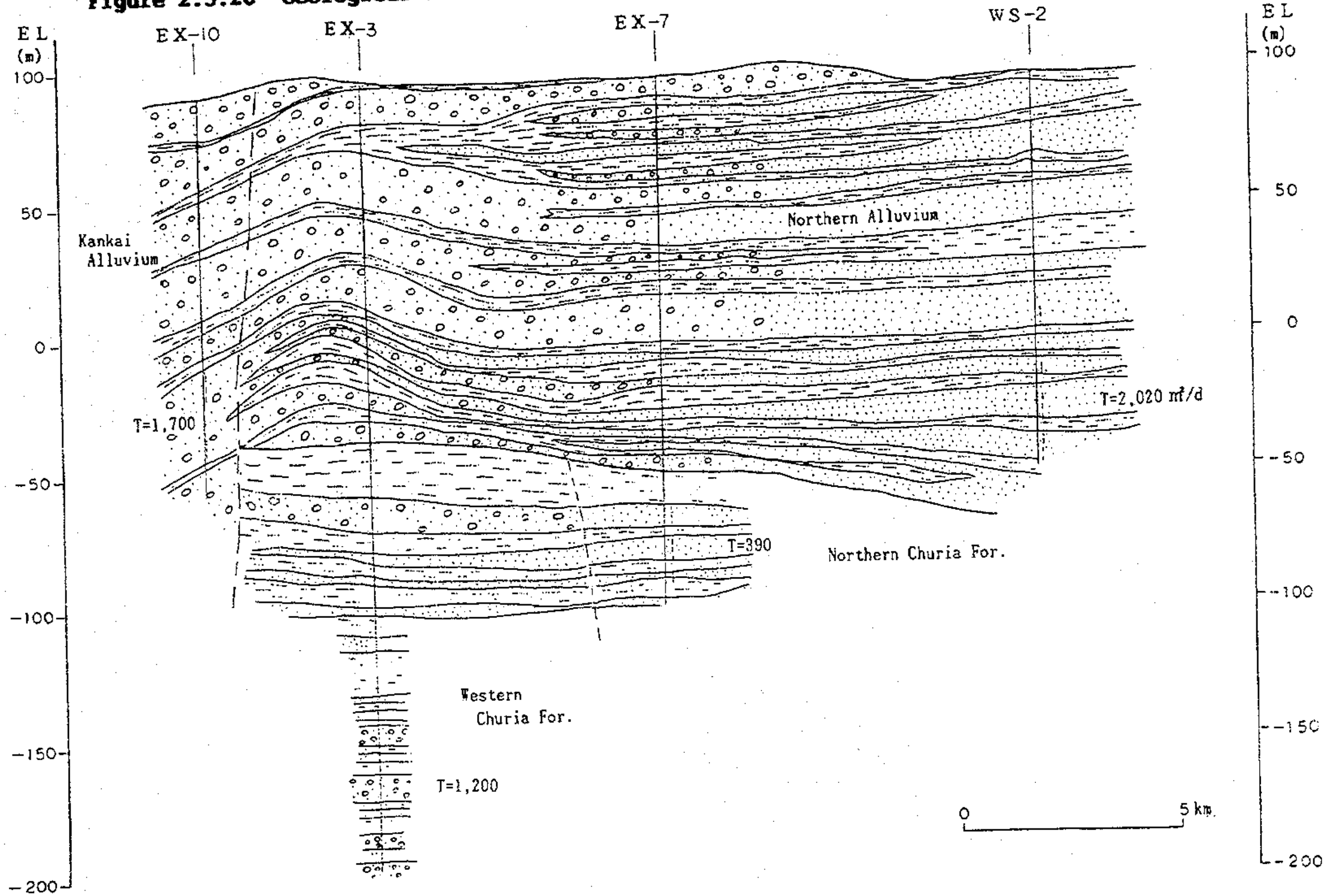
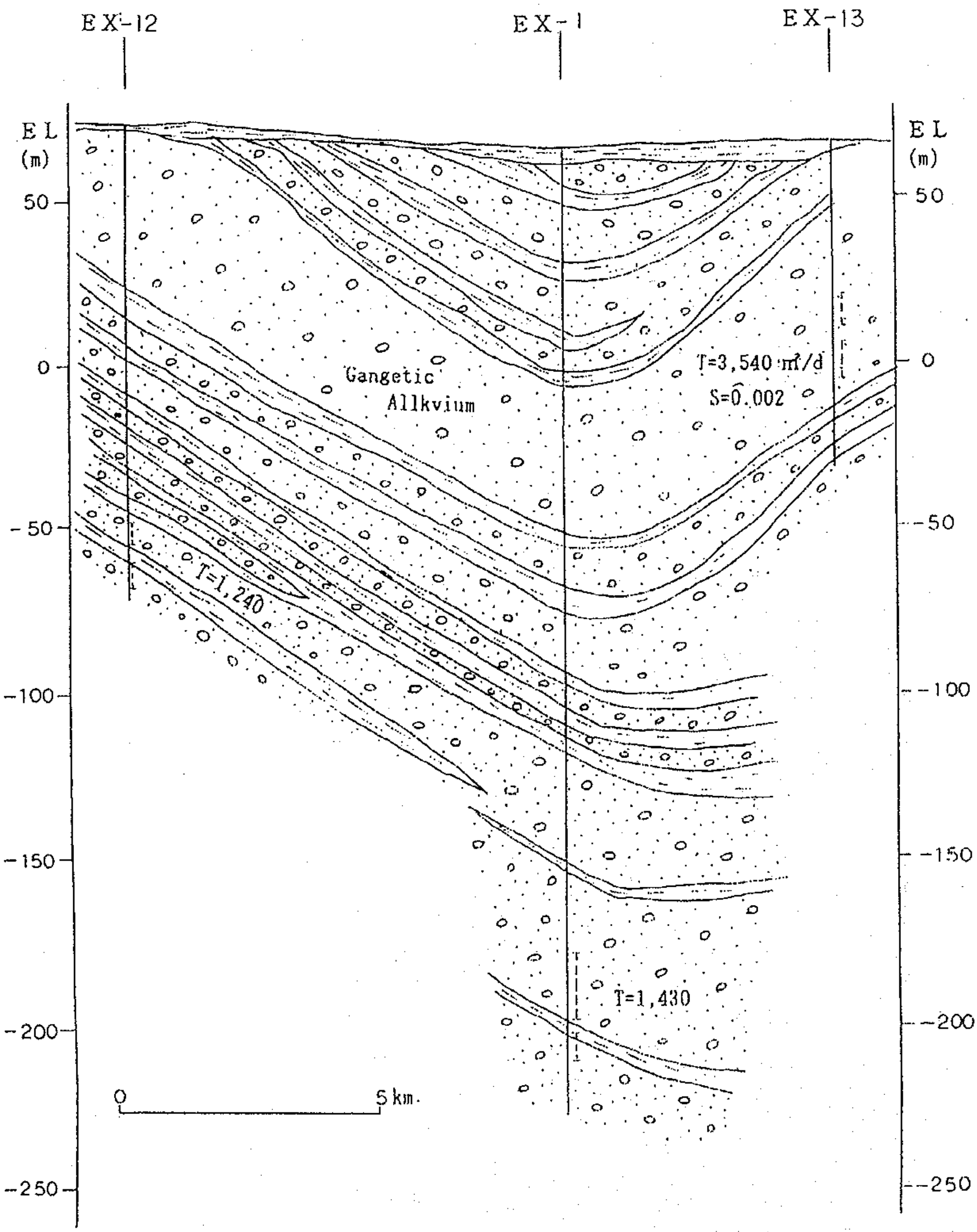


Figure 2.3.27. Geological Profile in Jhapa District F-F'



c) Groundwater Monitoring

Groundwater monitoring of the existing shallows and deep wells has been conducted by DOI/GWRDB since 1987. However, some discontinuity and inaccurate data have been observed among this data. The Study Team decided to set up a revised monitoring network in the area in order evaluate the groundwater resources. Revised monitoring commenced at the end of November 1992.

Selected monitoring wells are classified into two categories: shallow wells of less than 30 m depth, and deep wells of more than 30 m depth. Ten shallow monitoring wells of DOI have been selected for the new network, while eight new wells have been added to supplement the network. Although DOI/GWRDB have drilled 11 wells in the Study Area, only five wells are convenient for monitoring purposes; two deep wells drilled by the Water Supply Office are also included in the new network. In addition to the above wells, the exploratory and observation wells drilled under this Study have been included into the network.

The total number of shallow wells and deep wells in the monitoring network is 18 and 19, respectively, as listed in Table 2.3.11.

The pressure head in artesian wells EX-8 and EX-11 has been measured rather than a water level measurement. Although the pressure is converted to the water level above the ground surface, the measurement is not precise due to the rough reading scale of the pressure gauge.

The water level is measured manually once a week for both shallow and deep wells, and pressure loggers (long-term automatic water level recorder) have been installed in five observatory wells.

The observed records show that the water level lowers continuously until early May and that it attains a maximum level in the middle of August. Changes in the water level in shallow and deep wells are shown in Figure 2.3.28 and Figure 2.3.29.

The location and inventory of monitoring wells are shown in Figure 2.3.19 and Table 2.3.11, respectively. The water level record is attached to the Appendix.

d) Measurement of Free-Flowing Discharge

Free-flowing discharge in artesian wells has been measured in four artesian wells, EX-1, EX-7, EX-8, and EX-11. The time-series rate of discharge should be consistent with the water level (see Figure 2.3.30); however, the turning date for increased discharge is delayed approximately one month compare with the water level. The flowing discharge measured at the above four wells is summarized in Table 2.3.12.

Table 2.3.11. Inventory of Monitoring Wells

A) Water Level Measurement

1)SHALLOW TUBEWELL

Well No.	Location	Coordinate		Depth	M.P.	G.L.	Max. WL	Min. WL	Dif. WL
		Lat.	Long.	(mbgs)	(mags)	(masl)	(masl)	(masl)	(m)
STW-1	Prithvinagar	N26-29-08.8	E88-03-45.0	25.1	0.51	97.64	95.878	89.159	6.719
STW-2	Maheshpur	N26-31-23.5	E88-00-18.7	19.2	0.68	83.61	83.846	81.931	1.915
STW-3	Gherabari	N26-25-30.3	E87-55-55.7	13.7	0.64	71.91	71.049	68.124	2.925
STW-4	Phulbari	N26-33-32.2	E87-55-32.7	14.7	0.42	74.89	75.312	71.722	3.590
STW-11	Buttabari	N26-38-41.3	E88-01-09.3	27.5	0.66	127.96	125.587	123.322	2.265
STW-12	Balubattan	N26-33-12.8	E87-53-35.0	18.9	0.69	90.27	89.997	88.217	1.780
STW-13	Sanichare	N26-41-34.2	E88-00-22.3	22.6	0.26	159.26	156.735	153.700	3.035
STW-14	Sangambasti	N26-26-56.4	E88-03-56.4	19.9	1.07	73.26	74.122	72.332	1.790
STW-16	Ghiladubba	N26-36-51.2	E87-56-30.4	13.1	0.70	108.22	107.904	106.529	1.375
STW-17	Satighatta	N26-37-45.5	E88-08-27.3	32.0	0.48	111.41	109.558	107.728	1.830
STW-19	Goldhap	N26-32-47.5	E87-58-08.7	23.9	0.63	91.36	91.459	90.029	1.430
STW-20	Kechana	N26-23-15.0	E87-59-48.6	13.2	0.20	64.44	64.217	61.677	2.540
STW-21	Jalthal	N26-30-30.7	E88-00-09.9	15.1	0.69	87.94	88.631	87.316	1.315
STW-22	Prakashpur	N26-35-10.6	E88-04-13.7	27.4	0.26	101.14	99.450	97.390	2.060
STW-J1	Rajgarh	N26-29-23.1	E87-56-00.3	10.3	0.72	79.01	79.008	76.948	2.060
STW-J2	Balubari	N26-26-58.8	E88-01-03.7	26.0	1.33	72.35	72.507	70.717	1.790
STW-J4	Gohikhadi	N26-37-13.8	E87-53-34.8	11.9	1.09	150.70	149.697	148.157	1.540
STW-J5	Kumarkhod	N26-28-22.1	E87-51-23.4	12.6	0.51	78.13	78.274	74.964	3.310

2)DEEP TUBEWELL DRILLED BY GWRDB AND WATER SUPPLY OFFICE

Well No.	Location	Coordinate		Depth	M.P.	G.L.	Max. WL	Min. WL	Dif. WL
		Lat.	Long.	(mbgs)	(mags)	(masl)	(masl)	(masl)	(m)
JP-9	Goldhap	N26-33-17.2	E87-58-12.0	146.0	0.10	94.71	94.729	93.244	1.485
JP-10	Ghailadubba	N26-36-51.6	E87-56-55.6	145.0	0.72	107.74	108.450	107.249	1.201
JP-11	Prithivinagar	N26-29-06.8	E88-03-44.6	155.0	0.14	100.54	85.057	82.432	2.625
JP-12	Rajgadhat	N26-30-37.0	E87-56-23.0	168.0	0.82	83.10	82.723	80.583	2.140
JP-13	Tangandubba	N26-28-53.6	E87-51-49.5	158.0	0.16	78.81	77.564	75.914	1.650
JP-14	Sanichare	N26-40-11.2	E87-42-21.4	73.1	1.86	149.79	148.772	145.497	3.275
WS-5	Prithivinagar	N26-27-54.7	E88-04-23.2	150.0	1.55	83.17	77.015	74.760	2.255
WS-14	Sanichare	N26-41-13.0	E87-59-55.6	150.0	1.86	149.462	149.717	147.792	1.925

3)DEEP TUBEWELL DRILLED BY HMG/JICA

Well No.	Location	Coordinate		Depth	M.P.	G.L.	Max. WL	Min. WL	Dif. WL
		Lat.	Long.	(mbgs)	(mags)	(masl)	(masl)	(masl)	(m)
EX-2	Garamuni	N26-36-10.5	E88-01-24.4	300	0.33	109.19	105.409	104.674	0.735
EX-3	Dangebari	N26-34-27.3	E87-55-35.7	300	0.30	96.46	78.872	77.817	1.055
EX-4	Rajgarh	N26-27-38.8	E87-55-54.6	250	0.62	74.93	72.367	71.007	1.360
EX-5	Prithivinagar	N26-28-07.6	E87-04-20.5	250	0.23	87.62	77.296	74.726	2.570
EX-6	Balubari	N26-27-23.2	E88-00-59.9	250	0.98	75.73	72.151	71.441	0.710
EX-9	Birtabazar	N26-37-37.3	E87-59-27.0	200	0.53	119.49	112.545	111.530	1.015
EX-10	Balubathan	N26-33-20.1	E87-53-26.8	150	0.28	90.20	89.212	87.847	1.365
EX-12	Gherabari	N26-25-18.0	E87-55-52.8	150	0.52	71.74	69.417	67.697	1.720
EX-13	Pathamari	N26-25-50.5	E88-04-19.2	100	1.74	66.55	66.497	65.037	1.460
EX-14	Surunga	N26-36-21.8	E87-53-22.1	100	0.45	101.06	99.979	98.834	1.145
EX-15	Jamirgarhi	N26-37-27.2	E88-06-26.8	100	0.27	107.52	107.599	105.349	2.250

B) Piezometric Pressure Measurement

Well No.	Location	Coordinate		Depth	G.L.	Max. P.	Min. P.	Dif. P.
		Lat.	Long.	(mbgs)	(masl)	(kg/cm2)	(kg/cm2)	(kg/cm2)
EX-8	Prithivinagar	N26-30-10.1	E88-04-22.6	200	80.84	0.85	0.75	0.100
EX-11	Jalthal	N26-30-53.7	E88-00-52.4	150	87.08	0.34	0.26	0.080

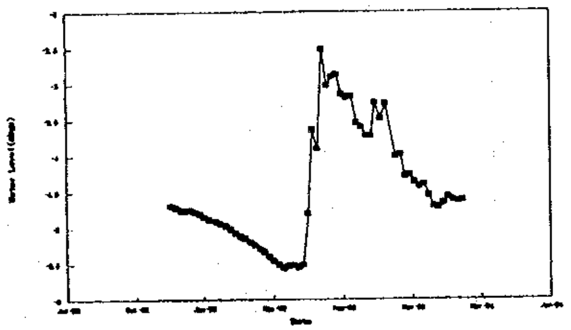
C) Discharge Measurement of Free Flowing

Well No.	Location	Coordinate		Depth	G.L.	Max. Dis	Min. Dis	Dif. Dis
		Lat.		(mbgs)	(masl)	(l/s)	(l/s)	(l/s)
EX-1	Pathapari	N26-24-08.3	E88-00-37.5	300	64.44	14.00	11.1	2.900
EX-7	Halidibari	N26-33-31.4	E87-59-50.8	200	96.40	25.00	13.5	11.500
EX-8	Prithivinagar	N26-30-10.1	E88-04-22.6	200	80.84	5.10	3.1	2.000
EX-11	Jalthal	N26-30-53.7	E88-00-52.4	150	87.08	6.20	5.3	0.900

Figure 2.3.28. Well Hydrograph of Selected Shallow Well in Jhapa

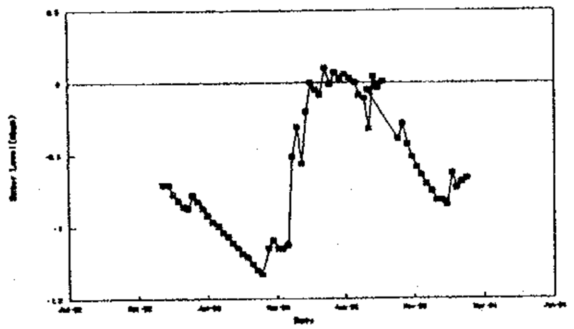
BHABAR ZONE

STW-13 SANISHCHARE



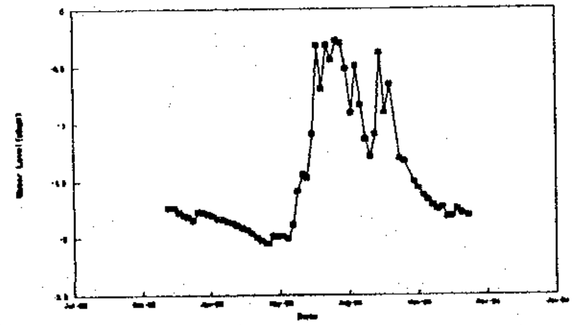
NORTHERN ALLUVIUM

STW-19 GOLDHAP



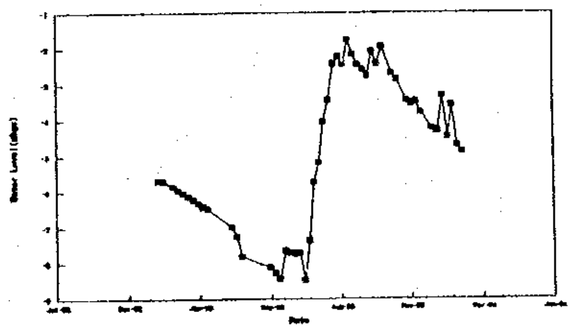
KANKAI ALLUVIUM

STW-12 BALUBATHAN



TERRACE

STW-1 PRITHIVINAGAR



GANGETIC ALLUVIUM

STW-20 KECHANA

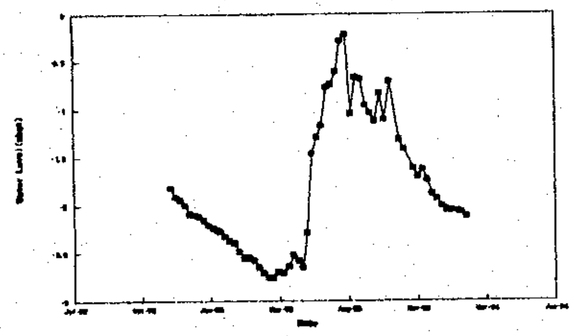
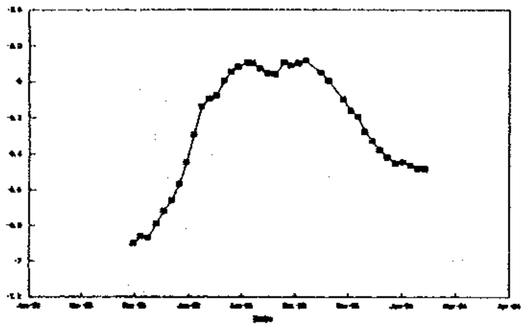


Figure 2.3.29. Well Hydrography of Selected Deep Well in Jhapa

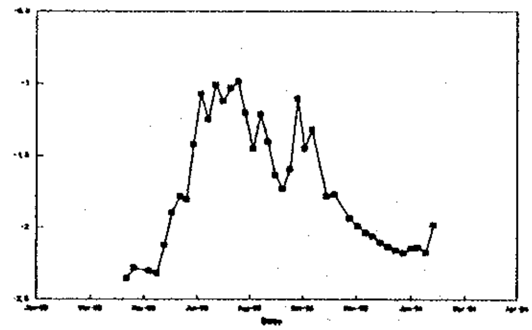
NORTHERN ALLUVIUM

EX-9 BIRTABAZAR



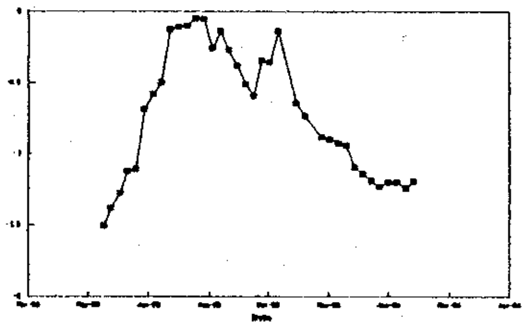
KANKAI ALLUVIUM

EX-10 BALUBATHAN



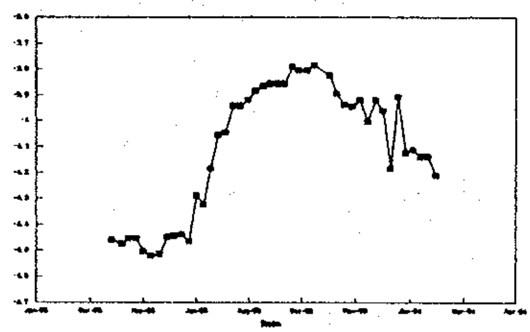
GANGETIC ALLUVIUM

EX-13 PATHAMARI



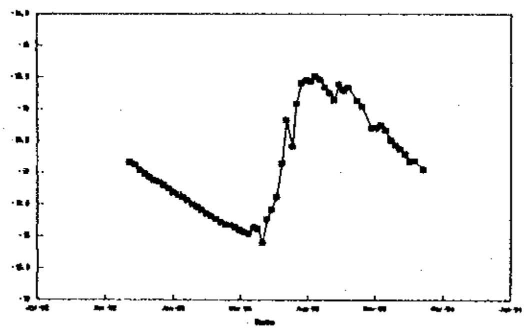
NORTHERN CHURIA FORMATION

EX-2 GARAMUNI



CENTRAL CHURIA FORMATION

JP-11 PRITHIVINAGAR



WESTERN CHURIA FORMATION

EX-3 DANGIBARI

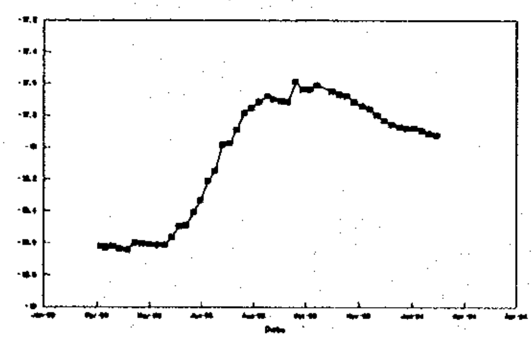
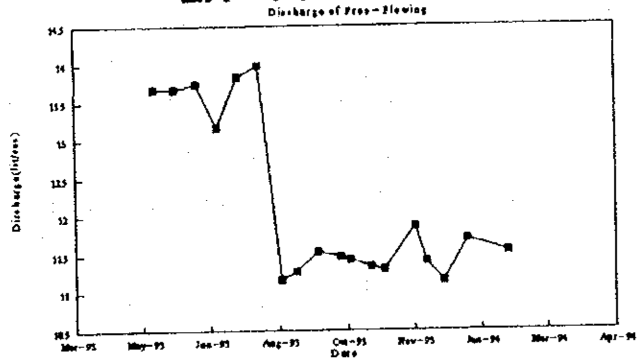
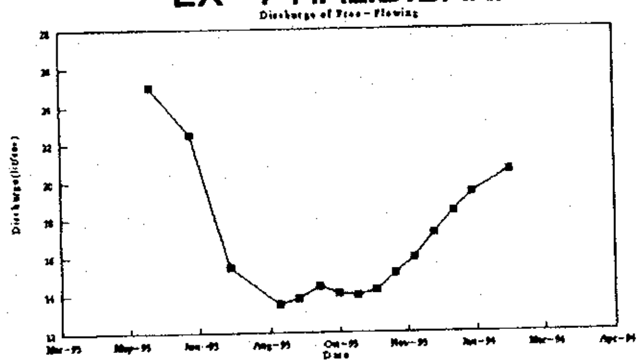


Figure 2.3.30. Discharge of Free-Flowing Wells

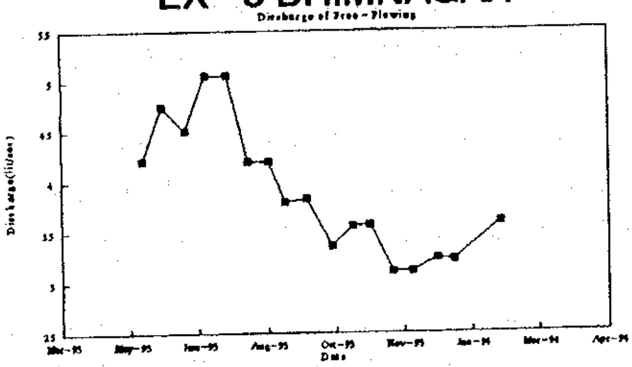
EX-1 PATHAPARI



EX-7 HALIDIBARI



EX-8 BHIMNAGAR



EX-11 BALUA-KHOLA

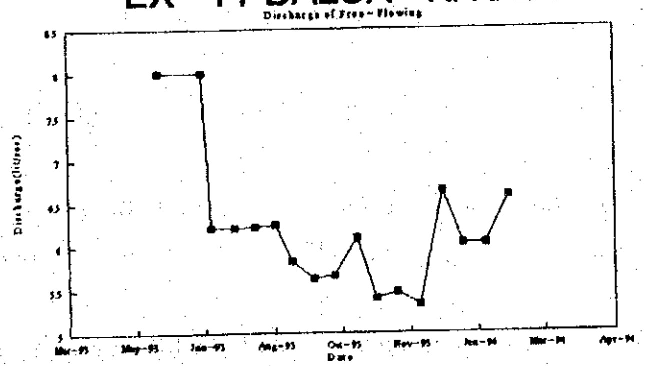


Table 2.3.12 Summary of Free-Flowing Discharge

Discharge (l/s)	EX-1	EX-7	EX-8	EX-11
Minimum Date	11.1 '93-12-14	13.5 '93-08-26	3.1 '93-11-19	5.3 '93-12-04
Maximum Date	14.0 '93-08-05	25.0 '93-05-27	5.1 '93-06-06	5.3 '93-05-28
Average	12.2	16.9	3.9	6.2

e) Results of Pumping Tests

Aquifers are tested by three types of pumping tests: step-drawdown test, constant-rate test, and the recovery test. Tested wells include 15 exploratory wells, four existing deep wells of GWRDB, and one water supply well.

Four steps of increasing discharge and three steps of decreasing discharge at regular three hour intervals are applied for the step-drawdown test. Usually, a maximum discharge of the pump will set the fourth step. For artesian wells, the artesian discharge is regarded as the first step.

The discharge for the constant-rate test is usually the same as a discharge for the fourth step in the step-drawdown test. Water is continuously pumped for 24 hours, and when pumping stops, recovery of the water level is measured until it attains a static water level.

Submersible pumps with capacity of 45 to 50 l/s with a 40 m TDH are used for testing in exploratory wells, and vertical turbine pumps are especially used for the existing wells. Discharge is measured by an orifice weir with a piezometer pipe.

Drawdown data is plotted versus the time to obtain the transmissivity and storativity, and the results are analyzed by Jacob, Theis, and Hantush-Leakage model, depending on the presence of an observation well and a leaky effect through the program of "GW" provided by UN. Analysis charts are attached in APPENDICES. Results of the tests are summarized in Table 2.3.13.

The representative values on "T" and "S" were decided by the following criteria:

i) if there is only one result, use it.
ii) if there are plural results, use the result of the most reliable result chart.
iii) if all the results are almost equally reliable, use the result of recovery test.

Transmissivity from each formation is consistent with the lithologic characteristics of the formations as shown below.

Table 2.3.13. Summary of Pumping Test

SUMMARY OF THE PUMPING TEST (done by the Team)

	Well depth (m)	Static W.L (mbgs)	Yield (m3/d) (l/s)	D/d (m)	Sp.C (m3/d/m) (l/s/m)	Transmissivity (m2/day) Theis	Transmissivity Jacob	Transmissivity Rec.	Transmissivity H-L	Storage Coefficient Theis	Storage Coefficient H-L	Representative T (m2/day)	Representative S
EX-1	300	+1.46	4,333.0 50.2	27.59	157.05 1.82	-	850	850	-	-	-		
Ob-1	300	+1.04		3.27		1,430	1,430	1,050	-	0.23E-4	-	1,430	2.3E-5
EX-2	300	5.13	2,160.0 25.0	14.33	150.73 1.74	-	290	410	-	-	-	410	
EX-3	250	18.91	3,456.0 40.0	15.06	229.48 2.66	-	780	1,200	-	-	-	1,200	
EX-4	250	8.97	3,869.9 44.8	16.53	234.11 2.71	-	1,080	1,220	-	-	-		
Ob-2	250	3.90		2.44		1,270	1,270	1,240	1,200	0.13E-3	0.16E-3	1,240	1.3E-4
EX-5	250	12.76	3,464.2 40.1	19.19	180.52 2.09	-	520	490	-	-	-	520	
EX-6	250	3.08	2,507.3 29.0	17.16	148.11 1.69	-	690	730	-	-	-	730	
EX-7	200	+1.22	3,456.0 40.0	29.23	118.23 1.37	-	290	390	-	-	-		
Ob-3	200	+1.42		6.70		330	330	390	300	0.21E-3	0.28E-3	390	2.8E-4
EX-8	200	+8.55	4,333.0 50.2	24.10	179.79 2.08	-	650	450	-	-	-	650	
EX-9	200	6.86	2,616.2 30.3	14.84	176.29 2.04	-	370	380	-	-	-	380	
EX-10	150	2.19	3,456.0 40.0	11.91	290.18 3.36	-	1,140	2,940	-	-	-		
Ob-4	150	2.25		1.63		1,700	1,700	2,810	930	0.77E-4	0.52E-3	1,700	5.2E-4
EX-11	150	+3.5	1,728.0 20.0	30.84	56.03 0.65	-	1,130	-	-	-	-	1,130	
EX-12	150	3.97	4,333.0 50.2	13.63	317.90 3.68	-	900	1,240	-	-	-	1,240	
EX-13	100	1.25	4,338.0 50.2	8.30	522.05 6.04	-	2,400	3,540	-	-	-	3,540	
EX-14	100	2.20	2,592.0 30.0	8.88	291.89 3.38	-	2,230	-	-	-	-	2,230	
EX-15	100	1.78	2,998.1 34.7	11.25	266.50 3.08	-	300	750	-	-	-		
Ob-5	100	1.47		2.49		670	710	630	710	0.21E-2	0.22E-2	710	2.2E-3

SUMMARY OF THE PUMPING TEST (done by DOI/UN)

	Well depth (m)	Static W.L (mbgs)	Yield (m3/d) (l/s)	D/d (m)	Sp.C (m3/d/m) (l/s/m)	Transmissivity (m2/day) Theis	Transmissivity Jacob	Transmissivity Rec.	Transmissivity H-L	Storage Coefficient Theis	Storage Coefficient H-L	Representative T (m2/day)	Representative S
JP-1	68	3.9	155.5 1.8	4.42	35.19 0.41	-	40	80	-			80	
JP-2	125	6.5	993.6 11.5	21.48	46.26 0.54	-	690	370 630	-			370	
JP-3	66	8.5	216.0 2.5	0.73	295.89 3.42	-	420	- -	340			340	
JP-4	137	5.7	172.8 2.0	1.24	139.35 1.61	-	230 290	- -	-			230	
JP-5	137	5.9	3,602.9 41.7	1.84	1958.09 22.66	-	920	1,000 1,320	-			1,000	
JP-6	137	3.1	1,114.6 12.9	19.73	56.49 0.65	-	900	440 370	-			900	
JP-7	148	+	457.9 5.3	17.52	26.14 0.30	-	800	100 90	-			100	
JP-8	146	0.7	1,235.5 14.3	3.06	403.76 4.67	-	590	510	590			590	
JP-9	146	1.0	864.0 10.0	5.16	167.44 1.94	-	220	210 270	210			210	
JP-10	145	1.2	7,776.0 90.0	20.80	373.85 4.33	-	430	230	-			230	
JP-11	156	7.5	3,369.6 39.0	7.92	425.45 4.92	-	360	760	-			760	
JP-12	168	2.7	3,715.2 43.0	5.07	732.78 8.48	-	2,180	2,910 2,720	1,210			2,900	
JP-13	159	1.2	3,542.4 41.0	17.37	203.94 2.36	-	1,540	720 -	-			1,540	
JP-14	75	2.2	1,728.0 20.0	3.48	496.55 5.75	-	540	230 710	-			540	
JP-15	73	2.2	-	-		-	-	-	-			-	
JP-16	165	-	1,382 16.0	6	228.12 2.64	-	240	-	-			240	
JP-17	107	6.0	3,456.0 40.0	8.90	388.31 4.49	-	800	1,170 1,170	-			1,170	
WS-1	150	1.8	2,272.3 26.3	6.00	378.72 4.38	-	860	350	-			860	
WS-2	150	+1.5	1,555.2 18.0	30.20	51.50 0.60	-	140	170	90			140	
WS-KK	64	+2.0	1,382.4 16.0	6.06	228.12 2.64	-	240	-	-			240	

SUMMARY OF THE PUMPING TEST (done by Team, JAN. 1994)

	Well depth (m)	Static W.L (mbgs)	Yield (m3/d) (l/s)	D/d (m)	Sp.C (m3/d/m) (l/s/m)	Transmissivity (m2/day) Theis	Transmissivity Jacob	Transmissivity Rec.	Transmissivity H-L	Storage Coefficient Theis	Storage Coefficient H-L	Representative T (m2/day)	Representative S
JP-8	108	0.28	2,825.0 32.7	16.76	168.56 1.95	-	690	660				660	
JP-9	146	0.89	2,592.0 30.0	15.70	165.10 1.91	-	340	340				340	
JP-12	168	2.70	3,352.0 38.8	3.69	908.40 10.51	-	2,460	3,140				3,140	
JP-13	159	2.65	3,171.0 36.7	11.83	268.05 3.10	-	2,140	4,500				2,160	
WS-5	150	8.60	2,668.0 30.9	5.79	460.79 5.33	-	1,030	860				1,060	
WS-5'	150	8.02	2,668.0 30.9	1.49		-	1,050	910		2.2E-4		1,050	2.2E-4

Name of formation	Transmissivity (m2/d)	Name of tested wells
Ganges Alluvium	1,240 - 3,540	EX-1,-12,-13
Kankai Alluvium	1,700 - 2,230	EX-10,-14
Northern Alluvium	710 - 1,130	EX-11,-15
Northern Churia	380 - 410	EX-2,-7,-9
Central Churia	520 - 730	EX-5,-6,-8
Western Churia	1,200 - 1,240	EX-3,-4

Gangetic and Kankai alluviums indicate excellent transmissivity where aquifers are subject to recharge by surface rivers. The Churia Group shows a comparatively low transmissivity, except for the Western Churia where surface river systems are concentrated.

2.4. Water Quality

2.4.1. Water Quality in Jhapa District

(1) General

The water quality of exploratory wells, existing deep wells, shallow wells, and surface rivers is analyzed by three types of methods: in-situ test, Hach kit, and a laboratory test. Water samples from most of the deep wells are taken at the final stage of the pumping tests. Some samples from the artesian wells and shallow wells are analyzed twice during the dry and rainy seasons.

The following are the names of surface rivers used for the analysis: the upper and downstream reaches of the Kankai, Biring, Deoniya, and Mechi rivers, and one site each at the Saramanati, Adhuwa, and Norojhora rivers. The total number of sites for river sampling is 11.

The locations of the sampling sites are listed in Figure 2.3.19 Location Map of Hydrogeological Study, and the results of analysis are shown in Table 2.4.1 and Table 2.4.2. The items of analysis for the in-situ and laboratory tests are listed as follow:

In-situ test : pH, EC, water temperature

Laboratory test : HCO3, Cl, Ca, Mg, SO4, NO3, NH4, Fe, Mn, Na, K

(2) Results of Analysis

a) Water Quality of Surface River

Table 2.4.1. Results of Water Quality Test in Exploratory Wells in Jhapa

	Laboratory Test (mg/l)												In-situ Test		
	Ca	Mg	Na	K	HCO3	Cl	SO4	Mn	Fe	NO3	NH4	SiO2	pH	EC	T
EX-1	4.00	1.00	82.00	0.38	224.0	5.50	4.80	0.05	0.04	0.100	0.261	47.2	8.8	361.0	32.2
EX-2	10.00	5.00	10.00	1.70	78.0	4.00	4.40	0.05	0.01	0.020	0.237	50.7	7.6	192.0	27.0
EX-3	24.00	7.00	31.00	2.00	173.0	4.00	3.80	0.77	1.41	0.108	0.508	90.9	6.9	316.0	27.9
EX-4	18.00	7.00	22.00	3.00	137.0	3.00	7.00	0.64	1.62	0.150	0.156	71.0	7.9	198.1	27.2
EX-5	15.00	2.00	27.00	1.70	137.0	3.00	0.30	0.05	0.27	0.036	0.175	93.0	8.0	219.0	32.7
EX-6	16.00	1.00	36.00	1.50	141.0	3.00	1.17	0.05	0.17	0.045	0.267	93.0	8.4	232.0	31.0
EX-7	17.00	3.00	6.00	1.00	94.0	3.00	4.00	0.45	0.47	0.720	0.330	83.0	7.4	145.0	27.0
EX-8	19.00	3.00	31.00	2.00	157.0	3.00	2.00	0.10	0.01	0.070	0.150	57.0	8.1	282.0	33.3
EX-9	12.00	6.00	15.00	2.00	98.0	3.00	5.00	0.32	0.29	0.050	0.175	71.0	8.0	150.0	29.1
EX-10	19.00	2.00	12.00	2.00	63.0	3.00	12.00	0.71	0.01	0.400	0.088	68.0	7.3	136.0	28.0
EX-11	19.00	6.00	19.00	2.00	122.0	3.00	0.83	0.18	0.46	0.120	0.500	107.0	7.8	204.0	29.0
EX-12	15.00	5.00	18.00	2.00	106.0	3.00	7.00	0.75	0.89	0.080	0.312	89.0	7.6	178.1	28.6
EX-13	11.00	5.10	16.00	1.80	86.0	3.00	4.00	0.16	0.01	0.017	0.200	39.0	6.9	158.0	28.1
EX-14	24.00	4.00	9.00	2.00	98.0	4.00	15.00	0.39	0.01	0.070	0.156	64.0	7.2	190.0	29.3
EX-15	13.60	9.00	21.00	1.80	122.0	4.00	3.00	0.04	0.18	0.048	0.175	64.0	7.9	190.3	26.1

Table 2.4.2. Results of Water Quality Test in Surface River, Shallow Wells and Existing Deep Wells in Jhapa(Jan.1994)

1)SURFACE RIVER

NO.	Name of River	Temp. (C)	pH	EC mS/cm	HCO3 mg/L	CO3 mg/L	TDS mg/L	Cl mg/L	Ca mg/L	Mg mg/L	SO4 mg/L	NO3 mg/L	NH4 mg/L	SiO2 mg/L	Fe mg/L	Mn mg/L	Na mg/L	K mg/L
QS-1	Kankai /UP	21.5	7.2	120	40	–	100	0.7	13.2	2.2	8.4	–	0.04	17	0.04	–	4.7	2.7
QS-2	Kankai /DN	28.7	8.9	130	57	–	93	2.0	13.6	2.9	2.5	–	0.14	28	0.42	0.28	6.1	3.1
QS-3	Biring /UP	25.0	7.8	135	52	–	72	1.4	14.4	2.7	5.3	–	0.08	17	0.48	0.02	6.3	1.8
QS-4	Serana-mati/DN	27.2	7.2	150	34	–	98	5.4	4.8	2.9	2.7	–	0.38	25	1.15	–	6.5	5.9
QS-5	Adhuwa /N	27.8	8.6	2,780	26	–	77	2.0	3.2	1.2	0.4	–	0.18	27	0.96	–	8.4	2.9
QS-6	Biring N	21.7	6.7	69	27	–	63	2.0	3.2	2.4	1.4	–	0.01	28	0.35	0.07	6.1	1.9
QS-7	Deoniya /UP	25.7	6.7	90	21	–	66	2.0	4.6	1.9	5.8	0.1	0.50	21	0.15	–	6.7	1.8
QS-8	Deoniya /DN	21.2	6.7	63	24	–	66	2.7	3.2	1.5	1.4	–	0.01	19	0.18	–	5.4	1.8
QS-9	Borojhora Khola	20.9	6.9	98	43	–	103	2.0	4.8	3.4	1.0	–	0.17	31	0.98	0.35	7.7	3.0
QS-10	Mechi /UP	21.9	6.7	74	14	0.8	63	1.4	3.2	1.5	6.6	–	0.14	14	–	–	3.6	2.8
QS-11	Mechi /DN	26.6	8.6	98	27	–	77	2.0	5.2	1.7	3.1	–	0.01	20	0.72	–	4.7	2.8

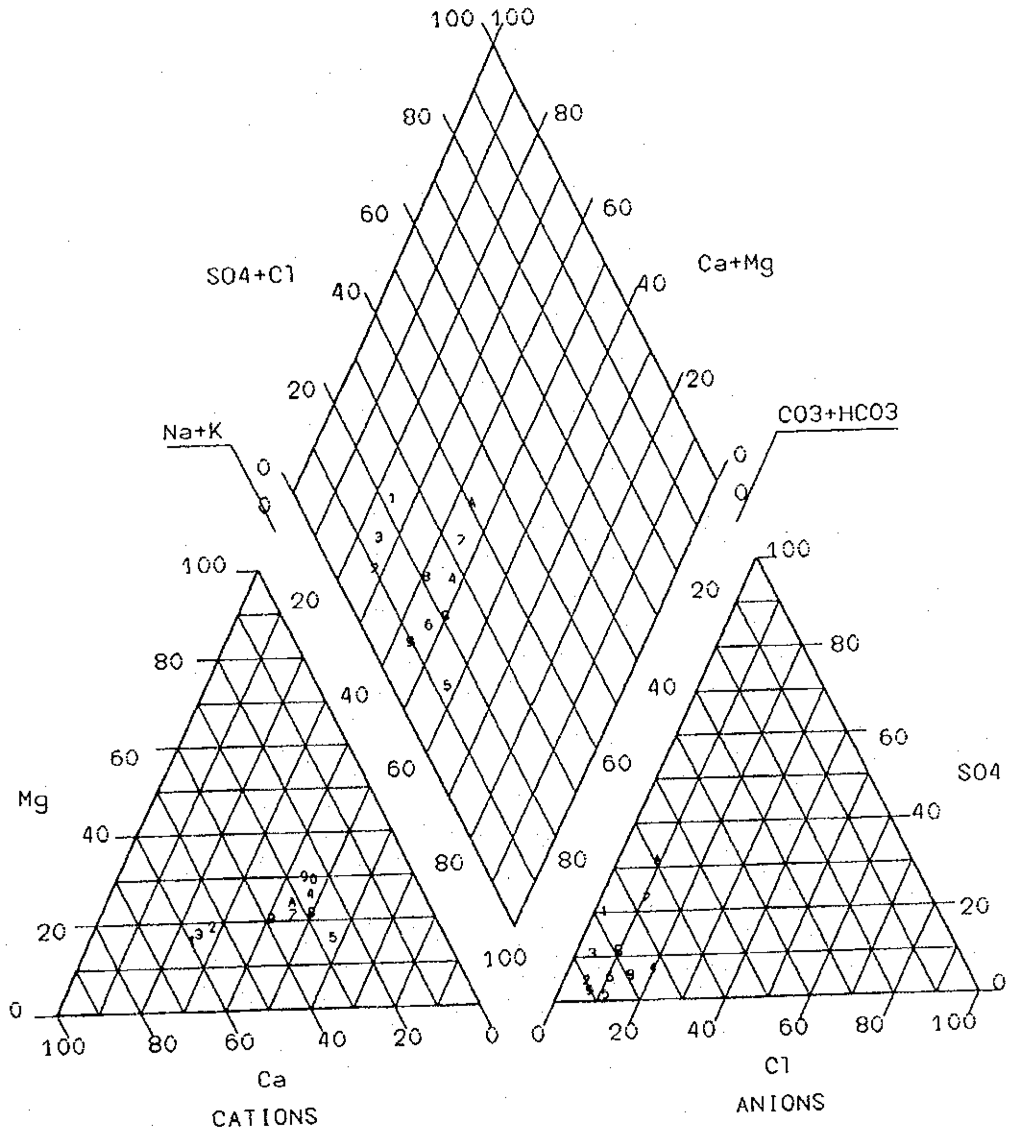
2)SHALLOW GROUNDWATER

NO.	Name of Well	Temp. (C)	pH	EC mS/cm	HCO3 mg/L	CO3 mg/L	TDS mg/L	Cl mg/L	Ca mg/L	Mg mg/L	SO4 mg/L	NO3 mg/L	NH4 mg/L	SiO2 mg/L	Fe mg/L	Mn mg/L	Na mg/L	K mg/L
QGS-1	STW-1	28.0	5.7	58	17	–	68	3.4	1.8	1.4	–	4.5	0.09	32	0.21	–	5.8	0.7
QGS-2	STW-3	26.9	6.3	120	37	–	108	6.1	9.6	3.4	3.5	10.5	0.37	24	0.35	–	5.4	4.7
QGS-4	STW-4	25.4	6.3	138	64	–	99	2.0	16.4	3.6	3.9	–	0.17	19	0.10	–	5.5	4.4
QGS-3	STW-11	27.7	6.1	11	57	–	124	0.7	11.2	4.1	2.7	1.9	1.00	44	3.50	–	11.0	1.9
QGS-5	STW-17	26.3	6.4	10	39	–	76	2.0	4.0	2.9	1.0	–	0.17	34	4.56	0.17	7.5	1.8
QGS-6	STW-20	23.6	6.0	120	33	–	104	11.6	3.2	4.4	0.8	2.3	0.27	19	1.07	–	5.6	7.7
QGS-7	STW-J1	26.9	6.1	90	34	–	77	3.4	4.0	2.8	0.4	1.4	0.03	28	0.23	–	6.9	2.2
QGS-8	STW-J2	27.2	6.4	196	64	–	158	–	8.0	3.4	–	–	1.39	56	14.25	0.07	9.2	2.9
QGS-9	STW-J4	28.3	6.7	250	98	–	155	6.1	33.7	2.7	0.4	–	1.44	21	6.45	0.63	3.9	5.7
QGS-10	STW-J5	29.6	6.0	120	30	–	90	–	7.2	2.7	3.7	1.9	0.03	23	0.52	–	4.9	5.2

3)DEEP GROUNDWATER

NO.	Name of Well	Temp. (C)	pH	EC mS/cm	HCO3 mg/L	CO3 mg/L	TDS mg/L	Cl mg/L	Ca mg/L	Mg mg/L	SO4 mg/L	NO3 mg/L	NH4 mg/L	SiO2 mg/L	Fe mg/L	Mn mg/L	Na mg/L	K mg/L
	UP-8	25.2	7.1	220	106	–	169	–	16.0	6.3	–	0.4	0.60	42	1.20	–	19.5	1.9
	UP-9	27.5	6.6	170	75	–	165	0.7	10.4	3.4	–	–	0.62	55	3.21	0.10	14.5	2.4
	UP-12	23.8	6.5	172	66	–	158	–	10.4	2.2	–	0.3	0.90	56	7.70	–	15.0	1.9
	UP-13	25.4	6.3	136	57	–	146	–	10.0	6.0	–	4.1	0.50	54	2.60	0.08	11.2	2.0
	WS-2	27.7	7.2	200	98	–	185	0.7	3.5	6.1	0.2	–	0.22	51	0.22	0.07	18.0	2.5
	WS-5	25.2	6.4	25	51	–	130	0.7	6.8	2.6	–	–	0.90	51	5.60	–	12.0	1.8
	EX-1	30.0	8.7	360	165	10.3	242	2.0	4.0	–	0.8	–	0.08	17	–	–	76.0	0.5
	EX-7	29.0	7.2	150	21	–	59	2.7	1.8	1.7	0.4	–	0.04	23	0.16	–	5.2	1.8
	EX-8	31.7	7.7	243	117	–	176	0.7	16.0	3.8	0.4	–	0.17	34	–	–	31.2	2.0
	EX-11	26.8	6.9	21	96	–	169	0.7	16.8	4.9	–	–	0.41	51	1.67	0.10	17.8	2.6

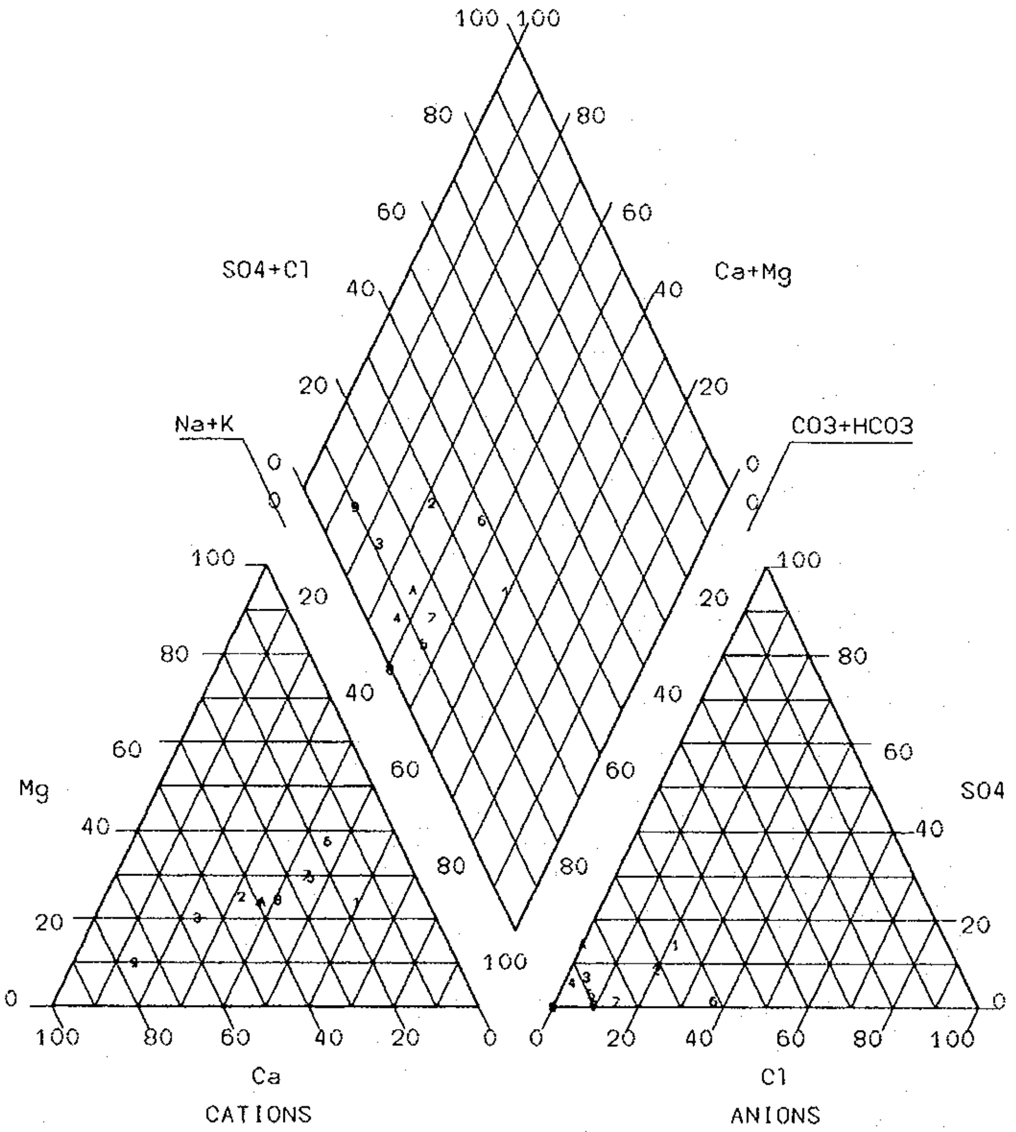
Figure 2.4.1. Trilinear Plotting for Laboratory Test of Surface Water, Jhapa Jhapa District



Label	Seq.No	Sample Identification
1	1	QS-1 KANKAI/UP
2	2	QS-2 KANKAI/DN
3	3	QS-3 BIRING/UP
4	4	QS-4 SARANAMATI/DN
5	5	QS-5 ADHUWA N
6	6	QS-6 BIRING N
7	7	QS-7 DEONIYA/UP
8	8	QS-8 DEONIYA/DN
9	9	QS-9 BOROJHORA
A	10	QS-10 MECHI/UP
B	11	QS-11 MECHI/DN

Surface River by Laboratory Test, 1994

Figure 2.4.2. Trilinear Plotting for Laboratory Test of Shallow Groundwater, Jhapa District



Label	Seq.No	Sample Identification
1	1	STW-1 PRITHIVINAGAR
2	2	STW-3 GHERABARI
3	3	STW-4 PHULBARI
4	4	STW-11 BUTTABARI
5	5	STW-17 SATIGATTA
6	6	STW-20 KECHANA
7	7	STW-J1 RAJGARH
8	8	STW-J2 BALUBARI
9	9	STW-J4 GOHIKHADI
A	10	STW-J5 KUMARKHOD

Results of the laboratory test are plotted on the Trilinear Diagram and the Pattern Diagram (see Figure 2.4.1. and the Appendix). The Trilinear Diagram shows water samples from Adhuwa River and downstream of Deoniya River plotted on a carbonate alkalic zone, which is generally represented by the quality of deep groundwater. The source of these two rivers is the natural springs located at the terminal of the Bhabar Zone. Four other samples from the downstream of Saramachi and Biring rivers and the upper stream of Deoniya and Borojhora rivers are also plotted near the carbonate alkalic zone. These rivers, except for the Saramachi, flow from the same type of spring. The other samples of the rivers from the Churia Hill are plotted on a carbonate hardness zone, which is represented by the water quality of typical surface rivers and alluvial shallow aquifers. Results are summarized as follows.

Table 2.4.3 Hydrochemical Type of Surface River in Jhapa

Name of Sample	Name of River	Type of Quality		SAR
		Trilinear	Pattern	
QS-1	Kankai/up	Carb. Hard.	Carb. Bicarb.	0.32
QS-2	Kankai/dn	Carb. Hard.	Carb. Bicarb.	0.40
QS-3	Biring/up	Carb. Hard.	Carb. Bicarb.	0.40
QS-4	Saranamati	Carb. Hard.	Sodium Bicarb.	0.58
QS-5	Adhuwa	Carb. Al.	Sodium Bicarb.	0.77
QS-6	Biring	Carb. Hard.	Sodium Bicarb.	0.63
QS-7	Deoniya/up	Carb. Hard.	Sodium Bicarb.	0.66
QS-8	Deoniya/dn	Carb. Al.	Sodium Bicarb.	0.62
QS-9	Borojhora	Carb. Hard.	Sodium Bicarb.	0.66
QS-10	Mechi/up	Carb. Hard.	Sodium Bicarb.	0.42
QS-11	Mechi/dn	Carb. Hard.	Sodium Bicarb.	0.46

b) Water Quality of Shallow Wells

Results of the laboratory test are plotted on the Trilinear Diagram and the Pattern Diagram (see Figure 2.4.2 and the Appendix). The Trilinear Diagram shows water samples from the terrace terrain (STW-1) plotted on a carbonate alkalic zone, which is generally represented by the quality of deep groundwater. The other samples are plotted on a carbonate hardness zone, which is represented by the water quality of typical surface river water and alluvial shallow aquifers.

The Pattern Diagram shows samples from the fan deposits near Kakarbitta and the terrace terrain plotted on a sodium bicarbonate zone, which is represented by the quality of deep groundwater.

Results are summarized in Table 2.4.4

Table 2.4.4 Hydrochemical Type of Shallow Wells in Jhapa

Name of Sample	Location of Wells	Type of Quality		SAR
		Trilinear	Pattern	
STW-1	Prithvinagr	Carb. Al.	Sodium Bicarb.	0.84
STW-3	Gherabari	Carb. Hard.	Cal. Bicarb.	0.38
STW-4	Phulbari	Carb. Hard.	Cal. Bicarb.	0.32
STW-11	Buttabari	Carb. Hard.	Cal. Bicarb.	0.71
STW-17	Satigatta	Carb. Hard.	Sodium Bicarb.	0.70
STW-20	Kechana	Carb. Hard.	Sodium Bicarb.	0.48
STW-J1	Rajgarh	Carb. Hard.	Sodium Bicarb.	0.64
STW-J2	Balubari	Carb. Hard.	Cal. Bicarb.	0.67
STW-J4	Gohikhadi	Carb. Hard.	Cal. Bicarb.	0.17
STW-J5	Kumarkhod	Carb. Hard.	Cal. Bicarb.	0.40

c) Water Quality of Deep Well

Hydrochemistry has greatly contributed to the understanding of groundwater flow. In an interpretation of the water quality data, analyses must be correlated with one another and related information. As the subsurface flow begins from shallow to deeper artesian groundwater, the water quality is altered by three modifications: dissolution reduction, base exchange, and concentration. These changing processes of water quality is called the "hydrochemical evolution of groundwater."

The Trilinear Diagram (Piper Diagram) is a useful representation to indicate differences or similarities among water, ie., classification of water. The plotting area in the Trilinear Diagram shows the hydrochemical evolution of groundwater in terms of elapsed time after it has been recharged by the surface water system.

Based on the hydrochemical evolution, groundwater can be classified into the following four categories.

- Category A: Water directly subjected to recharge from surface river systems.
- Category B: Groundwater subjected to artesian condition.
- Category C: Groundwater under heavy artesian conditions.
- Category D: Groundwater flowing in aquifers far from the recharge zone.

i) Chemical change caused by dissolution and base exchange

As groundwater flows down in aquifers over a long distance, so increases the ratio of HCO3 to the total anion and Na+K to the total cation due to an acceleration of dissolution and base exchange. Therefore, it is easy to understand the hydrochemical evolution of each sample when the multiplied two ratios are plotted for respective well samples on a graph. Figure 2.4.3 indicates the ratio to the exploratory wells. The ratio can be adapted to the above four categories:

1) Category A with a ratio from 1.0 to 1.1 for EX-7, EX-10, and EX-14
2) Category B with a ratio from 1.2 to 1.4 for EX-2, EX-3, EX-4, EX-9, EX-11, EX-12, and EX-13
3) Category C with a ratio from 1.5 to 1.6 for EX-5, EX-6, EX-8, and EX-15
4) Category D with a ratio more than 1.8 for EX-1

ii) Plotting on the Trilinear Diagram

The Trilinear Diagram can be divided into five hydrochemical areas:

1) Carbonate hardness
2) Carbonate alkali
3) Non-carbonate hardness
4) Non-carbonate alkali
5) Intermediate

In general, the hydrochemical evolution of groundwater is directed from 1) to 2), except for salt-tainted and mineralized groundwater.

The samples from the exploratory wells are plotted on the diagram, as shown in Figure 2.4.4. Wells are categorized as follows:

1) Category A for EX-2, EX-7, EX-10 ,and EX-14
2) Category B for EX-3, EX-4, EX-9, EX-11, EX-12, and EX-13
3) Category C for EX-5, EX-6, EX-8, and EX-15
4) Category D for EX-1

iii)Interpretation of groundwater flow

The categorized groundwater conditions based on the hydrochemical interpretation supports the geological interpretation of the exploratory wells.The wells of Category A are located in the alluvial plain, especially in the Kankai River system and most of the aquifers screened in Kankai Alluvium. The wells of Category B are located in the Northern Alluvial Plain, and screened aquifers are the Northern Churia Formation.

The wells of Category C are located in the Terrace terrain, and screened aquifers are the Central Churia Formation.

The wells of Category D are located in the Ganges plain and aquifers screened in Gangetic Alluvium.

The hydrochemical type of the exploratory and existing deep wells is listed in Table 2.4.5.

Table 2.4.5 Hydrochemical Type of Exploratory Wells in Jhapa

Well	Location	Taken Depth (m)	Type of Quality		SAR
			Trilinear	Pattern	
EX-1	Patharia	248-282	Carb. Al.	Sodium Bicarb.	9.50
EX-2	Faramuni	243-293	Carb. Hard.	Calcium Bicarb.	0.64
EX-3	Dangebari	202-288	--ditto--	Sodium Bicarb.	1.43
EX-4	Rajgarh	202-244	--ditto--	--ditto--	1.11
EX-5	Prithivinag	206-243	Carb. Al.	--ditto--	1.74
EX-6	Balubari	214-241	--ditto--	--ditto--	2.36
EX-7	Halidibari	140-186	Carb. Hard.	Calcium Bicarb.	0.35
EX-8	Prithivinag	167-193	Carb. Al.	Sodium Bicarb.	1.74
EX-9	Anarmuni	146-197	Carb. Hard.	--ditto--	0.88
EX-10	Sarnamati	100-134	--ditto--	Calcium Bicarb.	0.70
EX-11	Jalthal	94-130	--ditto--	--ditto--	0.97
EX-12	Gherabari	123-145	--ditto--	Sodium Bicarb.	1.03
EX-13	Pathamari	46- 72	--ditto--	--ditto--	1.00
EX-14	Surunga	57- 95	--ditto--	Calcium Bicarb.	0.45
EX-15	Jamirgarhi	39- 94	--ditto--	--ditto--	0.50
JP-8	Maheshpur	43-109	--ditto--	Sodium Bicarb.	1.02
JP-9	Goldhap	35-108	--ditto--	--ditto--	0.96
JP-12	Rajgadhat	32-123	Carb. Al.	--ditto--	1.10
JP-13	Tanganduba	33-126	Carb. Hard.	Magnesium Bicarb	0.63
WS-1	Bhadrapur	72-142	Carb. Al.	Sodium Bicarb.	1.35
WS-5	Prithivinag	37- 95	--ditto--	--ditto--	0.98

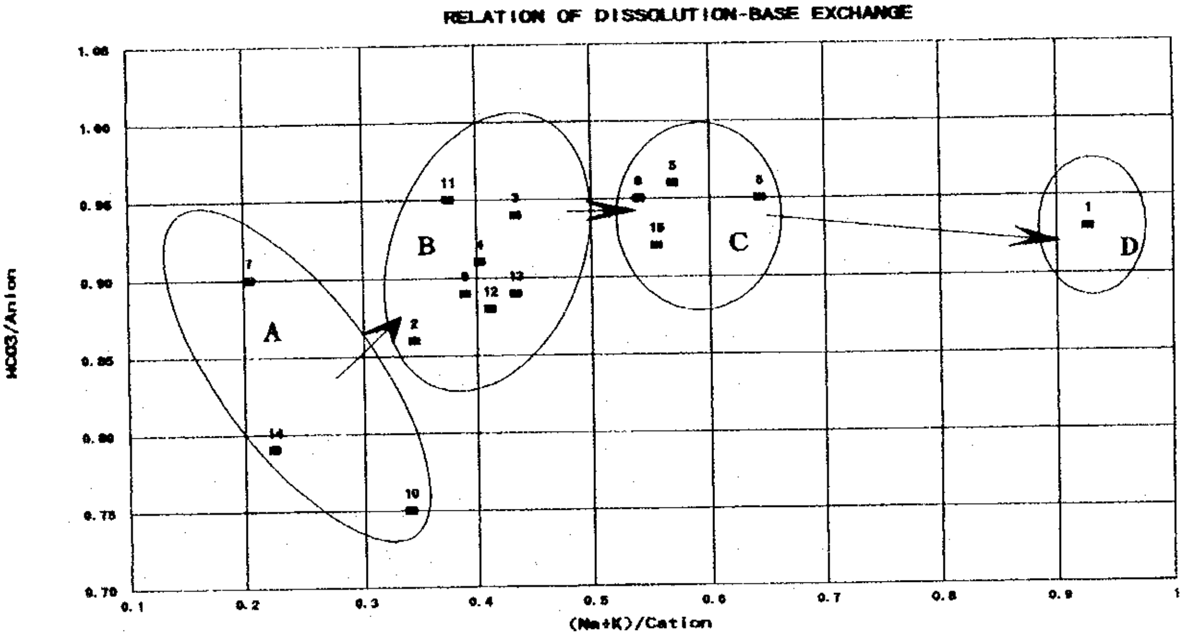
(3) Water Quality Assessment

An assessment of the water quality for the purposes of drinking and irrigation has been attempted based on the results of analysis. A permissible limit of WHO standards is applied for the criteria of drinking water, but bacteriological analysis has not been conducted. An amount less than 250 mS/cm or 200 mg/l for electric conductance(EC) as well as the total dissolved solids (TDS) are applied to the limitations for irrigation purposes. All samples analyzed are within the above limitations for EC and TDS.

a) Quality of Surface Rivers

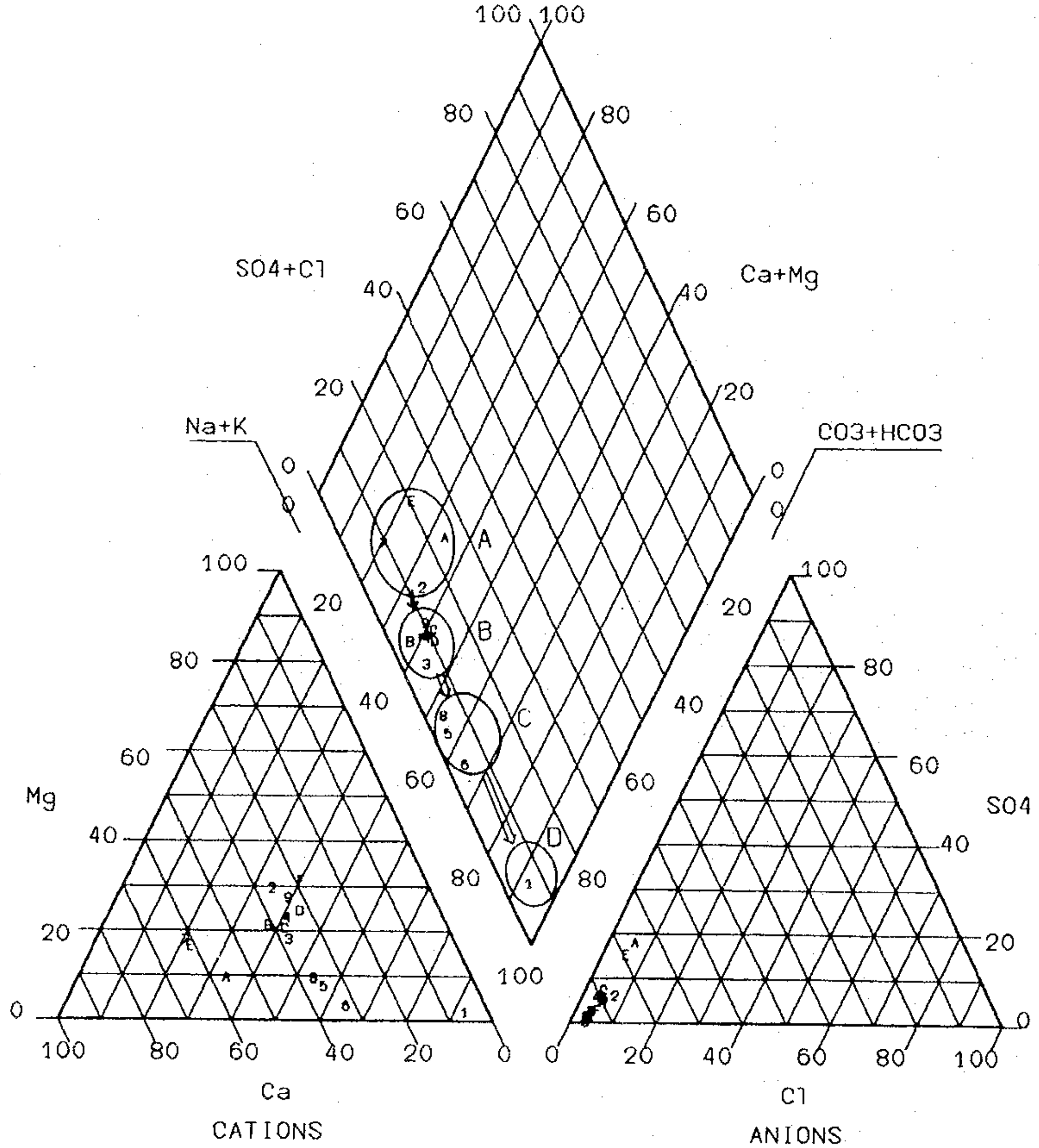
The water samples of the Kankai, Mechi and Deoniya rivers, taken from the outskirts of the hills, meet the drinking standards. The concentration of Fe and Mn is greater than the drinking limitations, especially in the Bojhora, Adhuwa and Saranamachi rivers where Fe has a concentration of more than 1 mg/l. These rivers flow from the terminal of the Bhabar Zone.

Figure 2.4.3. Relation of Dissolution and Base-Exchange in Jhapa Deep Wells



1) No. shows Exploratory Well No.
2) Samples in area A were taken from Kankai Alluvium
   Samples in area B were taken from Northern Alluvium
   Samples in area C were taken from Central Churia Formation
   Samples in area D were taken from Gangetic Alluvium

Figure 2.4.4. Trilinear Plotting for Laboratory Test in Exploratory Wells, Jhapa District



Area A : Groundwater is recharged by surface water system

EX-2(2), EX-7(7), EX-9(A), EX-13(D)

Area B : Slightly confined groundwater

EX-3(3), EX-4(4), EX-10(A), EX-11(B), EX-12(C), EX-14(E), EX-15(F)

Area C : Heavily confined groundwater

EX-5(5), EX-8(8), EX-6(6)

Area D : Groundater is flowing far from recharge area

EX-1(1)

b) Quality of Shallow Wells

The water quality from seven shallow tubewells is beyond the drinking standards, especially in the excessive concentrations of iron (Fe), manganese (Mn), and anmonium (NH4). This is caused not only by the conditions of the aquifers but by human contamination through daily use by farmers. Unsuitable samples have been taken from STW-3, STW-11, STW-17, STW-20, STW-J2, STW-J4, and STW-J5, and no particular geographic characteristics could be identified in their locations.

c) Quality of Deep Wells

Unsuitable chemical substances in drinking water are identified as iron (Fe) and manganese (Mn). Greater concentrations of manganese are found in the wells screened from 100 m to 150 m in depth, except for EX-15. The question arises whether this is caused by characteristics of the aquifers or by contamination from the shallow aquifers. The water quality of EX-1, EX-2, EX-5, EX-6, and EX-8, which are screened at more than 200 m or are located in terrace terrain, is suitable for drinking.

2.4.2. Water Quality of Mahottari District

The following three elements have been measured in artesian deep wells: pH, EC, and water temperature. Results are listed in Table 2.4.6.

Table 2.4.6. Results of Water Quality Testing in Mahottari

Well	Depth of Well (m)	Screen Depth	Temp. (°C)	pH	EC (mS/cm)	Remark
M-7	152	62-141	24	9.0	120	JICA, 1987
M-9	138	36- 90	27	7.0	86	JICA, 1987
M-10	123	16-122	25	6.8	190	JICA, 1987
M-11	150	71-116	26	6.2	180	JICA, 1987
M-13	113	68-111	26	6.3	190	
M-14	135	65-107	24	7.1	390	JICA, 1987
M-24	182	97-152	25	6.4	214	
M-25	182	84-146	25	6.9	315	
M-32	113	52-113	25	6.8	213	
M-35	213	166-210	26	7.6	330	
M-36	222	172-216	25	7.9	275	
M-39	209	186-203	26	7.4	277	
M-40	200	179-196	26	7.2	249	
M-44	184	165-181	25	7.8	273	

As shown in the table, the water temperature is 27°C in the rather shallow aquifers while it is 25°C to 26°C in the deeper aquifers. The lower EC indicates 120 and 86 mS/cm found in M-7 and M-9 in the southern end of the Bhabar Zone. In general, EC increases towards the SWW and attains a maximum of 390 mS/cm in M-14.

The pH ranges from 6.2 to 7.8, except for the 9.0 in M-7, and it also shows the same trend in increasing towards the SWW, from alkalic to acidic values. Distribution of the values of EC and pH are identical with the aquifer characteristics and groundwater potentials.

2.4.3. Water Quality of Banke District

Laboratory tests were conducted in 29 exploratory wells by GWRDB in 1973. Results of the analysis are shown in Table 2.4.7. As shown in the table, all samples meet with WHO Drinking Water Standards for Fe, except for 0.6 mg/l in well B-5/4 which slightly exceeds the standard of 0.3 mg/l. Ten samples indicate more than 500 mg/l of TDS, which exceeds the 500 mg/l of the standard; well B-2/6 near the town of Nepalganj in particular shows a level of 872 mg/l. Most wells in the northern part of the Bhabar Zone are suitable for drinking purposes.

Results are plotted on a Trilinear Diagram, as shown in Figure 2.4.5 and Figure 2.4.6. The figures show samples from the Northern and Gangetic alluviums in the Rapti and Babai floodplains and the Gangetic alluvial plain plotted on a carbonate hardness zone. These samples are subject to recharge from the surface river system. The samples from the Upper Churia Formation underlying the central part of alluvial plain are plotted on the carbonate alkalic zone, which is represented by the quality of deep groundwater. As explained in 2.4.1 Water Quality of Jhapa District, the recharge condition of aquifers can be clarified by an interpretation of the chemical data of the groundwater.

Table 2.4.7. Results of Water Quality Test in Banke District

Well	Location	Date of Sampling	Fe	Ca	Mg	Na+K	HCO3	SO4	Cl	CO3	TDS	H'dness CaCO3	Alkality	EC (μS/cm)	pH	SAR	HCO3 Hazard
1/1	Piprahawa	Feb/01/73	0.01	107	1	-	192	Nil	8	0	316	289	157	271	7.9	-	-
1/2	Daspurwa	Mar/05/73	0.01	68	18	3	296	Nil	6	0	552	224	243	466	8.1	0.06	-
1/4	Halbaldoli	Jan/22/73	0.00	97	1	5	298	Nil	6	11	406	244	261	426	8.5	0.08	0.30
1/5	Kandi	Jun/30/73	0.04	20	41	22	316	Nil	5	0	322	218	269	488	7.3	0.34	0.81
1/7	Manda	Apr/13/73	-	40	30	60	422	Nil	6	0	398	222	346	683	8.0	1.59	2.46
1/8	Udain	Mar/09/73	0.00	22	12	21	160	6	3	6	208	106	141	255	8.5	0.60	0.74
2/1	Jamunaha	Dec/16/72	0.00	8	41	99	402	26	38	26	642	187	372	918	8.8	3.95	3.69
2/3	Punchayat	Jul/14/7	-	8	31	64	326	Nil	5	8	340	148	267	569	8.6	2.26	2.66
2/6	Police Tr.	Jan/04/73	0.00	67	1	124	458	28	24	42	872	168	444	979	8.9	4.85	5.43
2/8	Ranjha		-	7	26	119	414	18	18	10	504	126	339	598	8.5	1.12	4.63
2/9	Army Camp		-	40	30	137	614	4	7	0	646	222	503	738	7.2	1.49	5.59
2/11	Kokalpurwa	Feb/14/73	0.03	12	21	91	314	29	11	0	324	104	257	488	8.2	2.36	2.82
2/12	Thukali	Dec/13/73	-	78	29	6	388	4	4	0	384	316	318	523	7.1	-	0.02
3/1	Sainik Gaon	nov/18/73	-	36	27	132	576	Nil	15	0	704	202	472	837	7.5	1.42	5.42
3/3	Odrapur	Apr/02/73	0.00	29	22	186	604	58	6	0	596	162	495	1,025	8.1	5.46	6.64
3/4	Agr. Farm	Feb/12/73	0.10	8	21	216	656	33	9	58	722	108	630	1,175	9.0	9.34	8.63
3/5	Agr. Farm	Feb/08/73	-	20	27	-	372	Nil	6	0	368	161	305	513	8.3	1.27	2.88
3/8	Modaha	Mar/19/73	0.01	88	0	-	216	Nil	5	8	230	220	190	326	8.5	0.01	-
3/10	Amohia	Mar/25/73	0.04	15	22	60	304	Nil	5	0	430	126	249	513	7.9	2.27	2.42
4/1	Kanthapur	Apr/23/73	-	68	18	3	296	Nil	6	0	552	244	243	466	8.1	0.06	-
4/2	Dauraha	Apr/27/73	0.00	40	20	86	440	Nil	8	0	616	182	361	609	8.1	1.81	3.57
4/5	Dhakela	Apr/30/73	-	23	32	38	320	Nil	6	0	352	188	262	569	7.6	1.39	1.47
5/1	Indrapur	May/03/73	0.01	75	40	-	400	Nil	6	0	386	354	328	539	7.8	0.01	-
5/2	Belbhar	May/07/73	-	13	79	-	194	162	8	14	220	143	159	293	8.6	0.01	0.62
5/4	Belbhar	Jun/08/73	0.60	76	0	36	242	11	6	0	280	190	198	367	8.2	0.01	0.18
5/5	Jabdahawa	Jun/10/73	0.00	23	28	95	450	Nil	8	0	466	174	360	603	7.8	1.97	3.93
6/1	Taratal	Jun/06/73	0.00	22	2	46	270	Nil	9	6	-	138	-	243	8.5	0.92	0.37
6/3	Belwa	May/18/73	0.05	-	22	76	238	168	8	0	304	214	195	476	7.9	0.35	-
6/5	Bhurkia	May/24/73	0.08	-	22	19	204	22	6	4	220	264	174	331	8.4	0.01	0.16

sourse:Groundwater Resources Investigations in Bheri Zone, Far Western Terai, Nepal DOI
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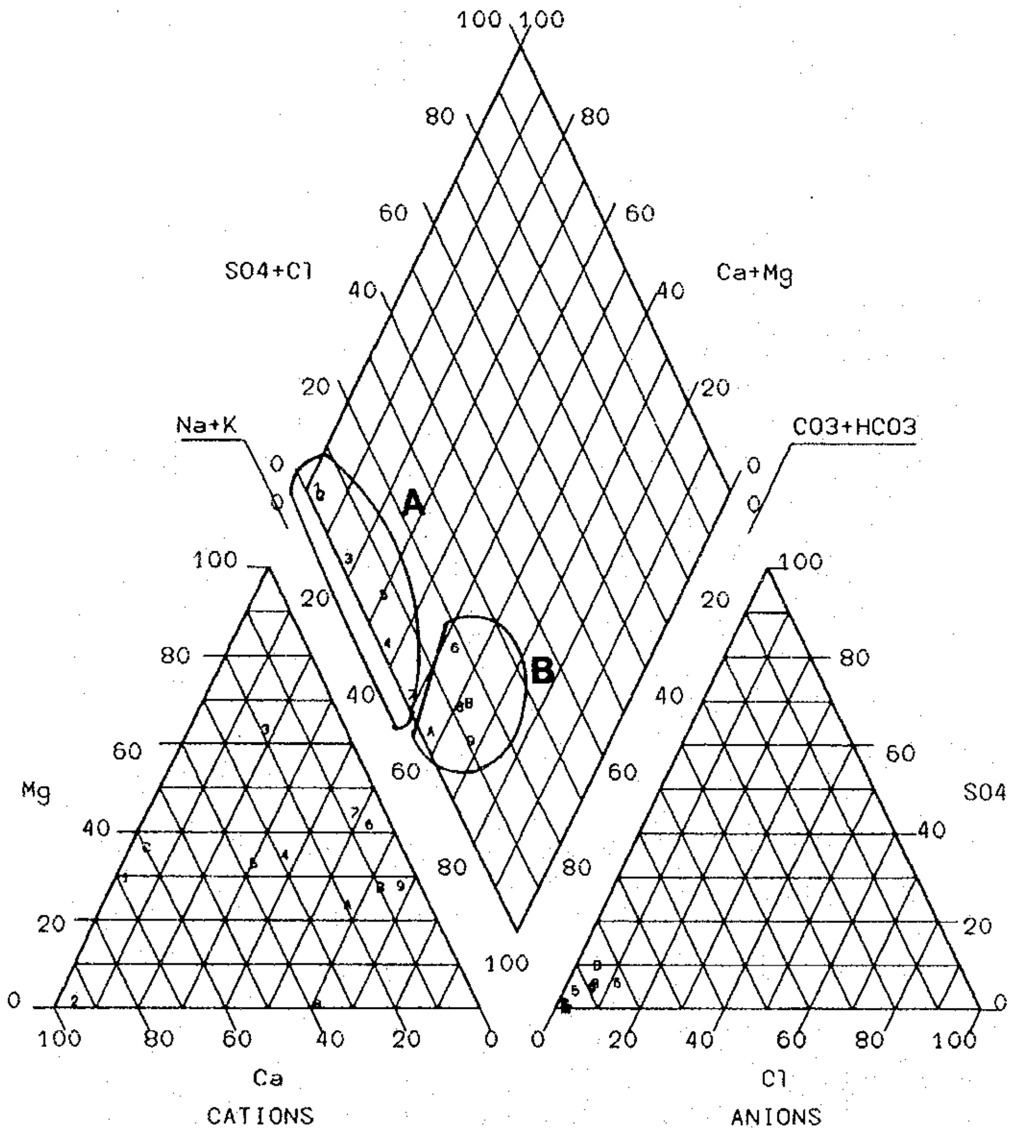
Figure 2.4.5. Trilinear Plotting for Laboratory Test in Existing Wells, Banke District(B1/2-B2/12)

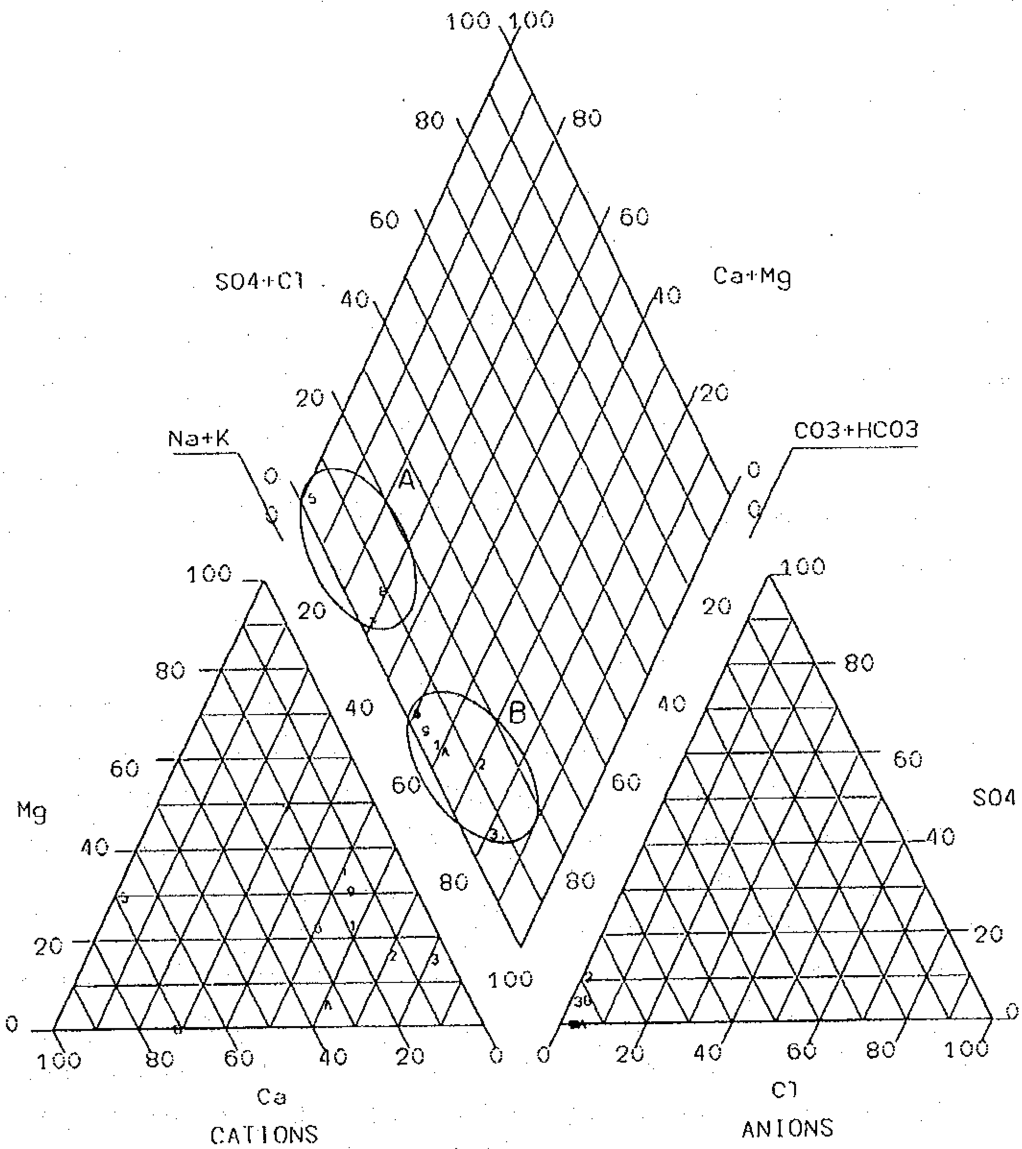


Label	Well No	Label	Well No	Label	Well No
1	B-1/2	5	B-1/8	9	B-2/8
2	B-1/4	6	B-2/1	A	B-2/9
3	B-1/5	7	B-2/3	B	B-2/11
4	B-1/7	8	B-2/6	C	B-2/12

Area A : Groundwater is recharged by surface water system
B-1/2, B-1/4, B-1/5, B-1/7, B-1/8, B-2/12

Area B : Groundater is flowing far from recharge area
B-2/1, B-2/3, B-2/6, B-2/8, B-2/9, B-2/11

Figure 2.4.6. Trilinear Plotting for Laboratory Test in Existing Wells, Banke District(B3/1-B6/1)



Label	Well No	Label	Well No	Label	Well No
1	B-3/1	5	B-4/1	9	B-5/4
2	B-3/3	6	B-4/2	A	B-6/1
3	B-3/4	7	B-4/5	B	
4	B-3/10	8	B-5/4	C	

Area A : Groundwater is recharged by surface water system
B-4/1, B-5/5, B-6/1

Area B : Groundater is flowing far from recharge area
B-3/1, B-3/3, B-3/4, B-3/10, B-4/2, B-5/4, B-6/1

2.5. Groundwater Potential

2.5.1. Jhapa District

(1) Groundwater Movement

a) Discharge of Artesian Wells

The discharge of artesian wells in EX-1, EX-7, EX-8, and EX-11 has been measured once a week since May 1993. The maximum discharge is recorded at the end of May in EX-7 and EX-11, and at the end of July to early August in EX-1 and EX-8 (see Figure 2.3.30 and Table 2.3.12). The former wells are screened in the Northern Churia Formation and the latter in the Gangetic Alluvium and the Central Churia Formation, which is subject to the thrusting. There is more than a two month difference in the maximum discharge between two groups because of the location of the recharge areas. The maximum discharge among four artesian wells is 25 l/s.

b) Fluctuation of Groundwater Levels

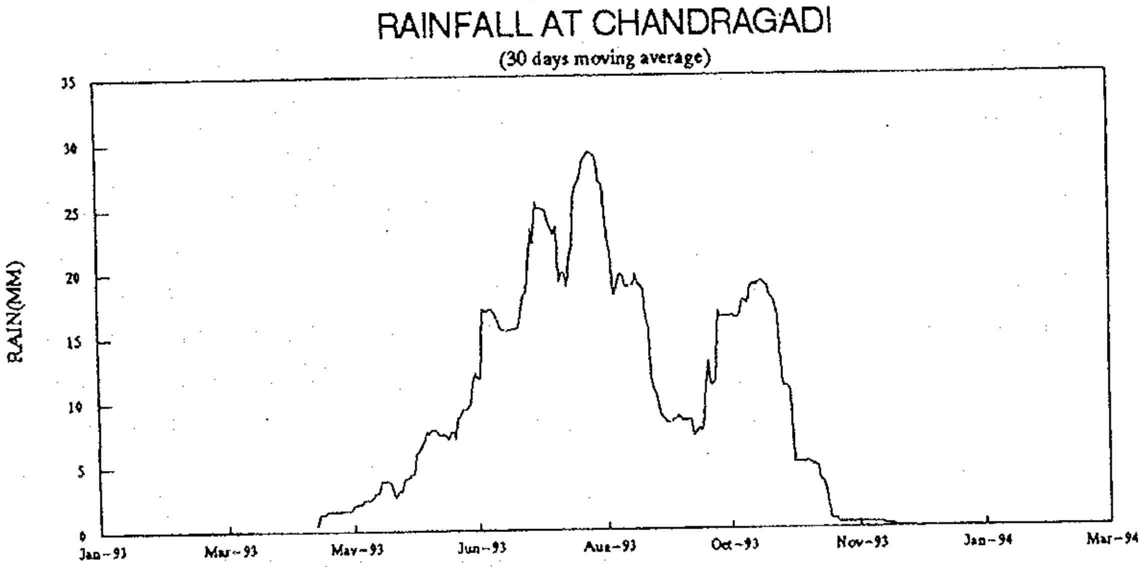
Practically all groundwater, especially shallow groundwater, is subject to direct recharge by surface water and precipitation. This can be verified by a graphical interpretation of the relationship between groundwater levels and precipitation. The rainfall record in Chandragadhi for 1993 shows that the monsoon begins in April and that the total rainfall in April and May is 42 mm and 123 mm, while a maximum of 736 mm is recorded in August. The total rainfall from April to November is 2,521 mm.

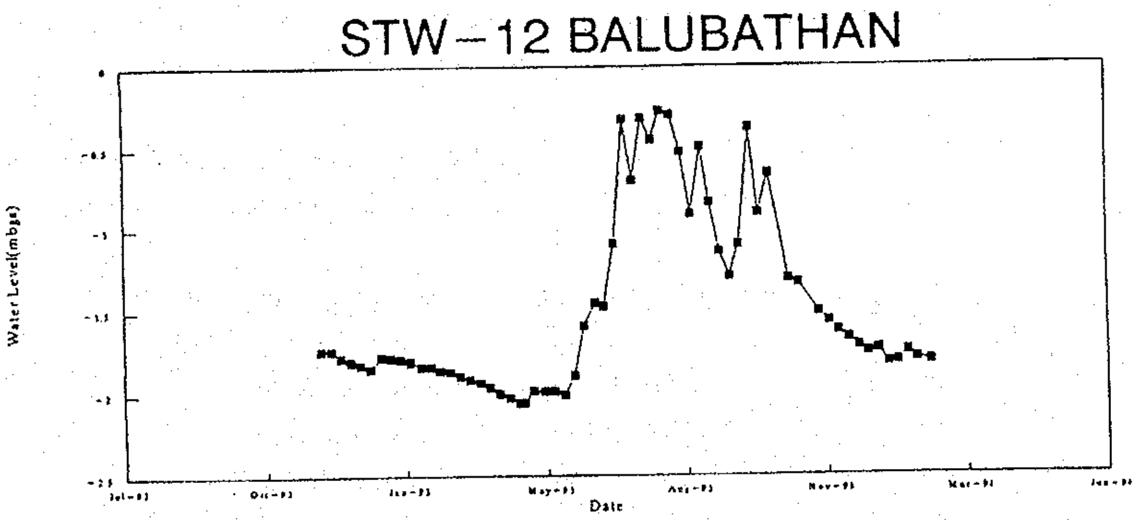
Some of the aquifers in monitoring shallow wells are confined, with depths less than 30 m. The rise of water levels in these wells is not consistent with volume of rainfall because infiltrating rainfall does not directly come into contact with these shallow aquifers. For example, the water levels rises at the end of May, although the rainy season begins one month later.

An attempt was made to study the time lag between the rise of water levels and the volume of rainfall. Figure 2.5.1 shows the relationship between groundwater levels and daily rainfall where a 30 day moving average is applied to daily rainfall. The changes in the water level in the deep aquifers are also consistent with the volume of rainfall, however the rise in the water level is approximately one month later.

The magnitude of the water level fluctuation depends on the rate of recharge to the aquifers; it also is greatly affected by the aquifer material. The magnitude of the shallow groundwater level ranges from 1.32 m to 2.52 m, with an average of 2.52 m, while the magnitude of the deep groundwater level ranges from 1.05 m to 3.28 m, with 1.68 m on average. Wells in the Terrace and the Bhabar Zone generally show a great range of fluctuation in (see Figure 2.3.28).

Figure 2.5.1. Relation Between Rainfall and Water Levels





(2) Groundwater Potential

a) Lithology of Aquifers

The subsurface geological information is basically obtained from a driller's log, but records of borehole loggings, resistivity, and natural gamma also greatly contribute to geological interpretation. Although the borehole diameter and the chemical property of the drilling fluid will affect the record of the logging, lithologic changes between the permeable and impermeable beds are determined by 100 Ωcm in resistivity and 20 cpm in natural gamma, respectively. The final corrected well logs are attached in the Appendix.

Lithologic continuity to both directions, north-south and east-west, is well traced by the well logs, as shown in Figure 2.3.22 to Figure 2.3.27. Discontinuity of the beds is probably caused by faults or thrusts. The composition rate of the permeable beds in the exploratory and existing wells is 64% in total, and the length of single beds averages 12 m, while the rate ranges from 82% to 90% in the Gangetic Alluvium (see Table 2.3.8).

Table 2.3.9 summarizes the average thickness of single beds in each geologic formation. Each single permeable and semi-permeable bed is titled with the prefix "g" and "c." The composition rate of the permeable beds in the Kankai and Gangetic alluviums shows 76% and 77%, respectively, however it decreases to 61% in the Northern Alluvium. The rate further decreases to 52% and 42% in the Northern and Western Churia formations, while it indicates 66% in the Central Churia Formation in the terrace terrain. The features described above that some difference in the composition rate is clarified between the alluvium and the Churia Formation is 71% and 53% among the total wells.

b) Aquifer Characteristics

Practically all groundwater potential is assessed by specific capacity; however, many hydrogeologist's understanding is that specific capacity is interrelated with transmissivity.

Results of pumping test are shown in Table 2.3.13. As shown by the table, calculated transmissivities for the respective geological formations are summarized as follows:

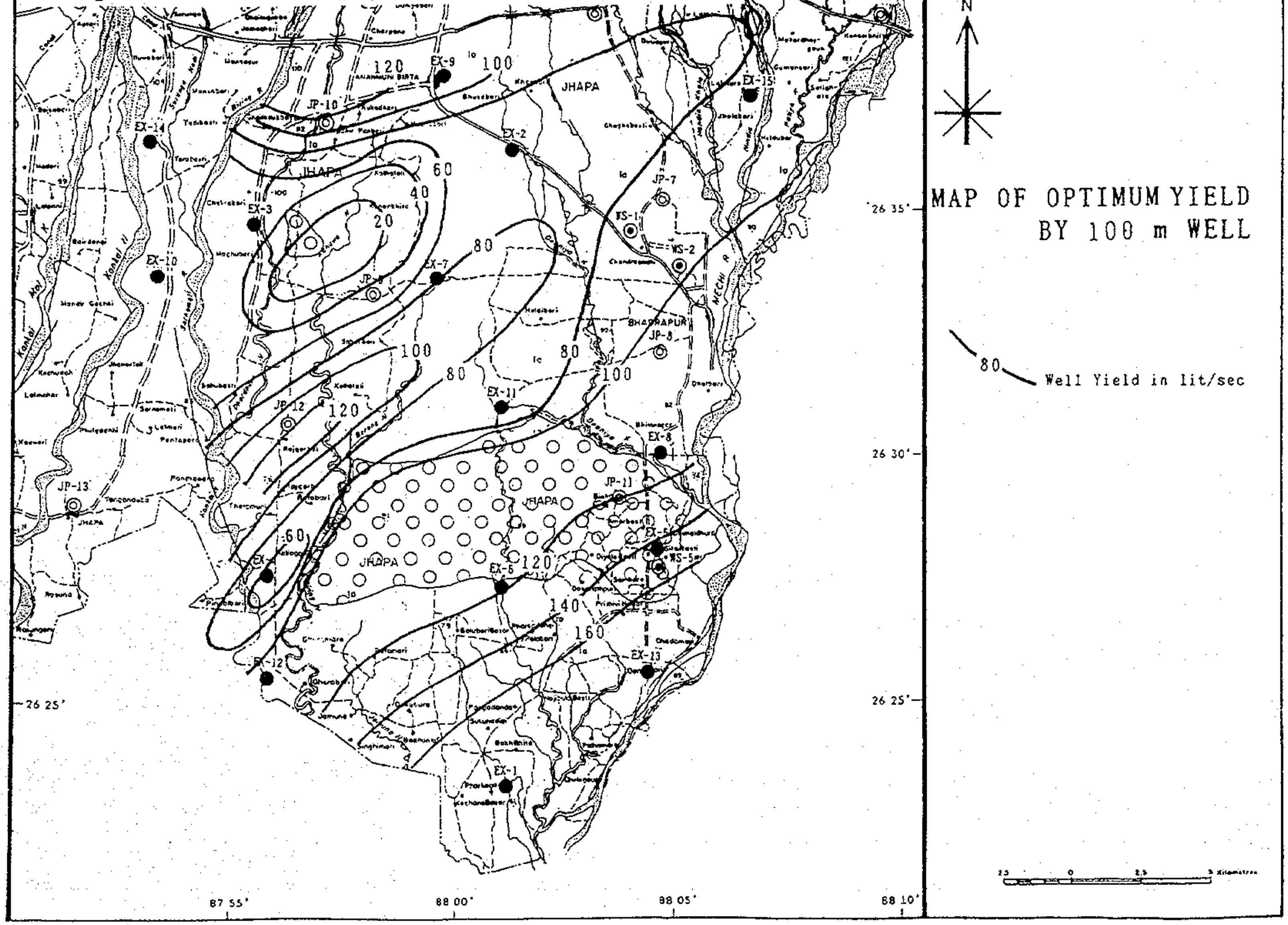
Name of formation	Transmissivity in m2/day	Name of tested wells
Gangetic Alluvium	1,240 - 2,540	EX-1, EX-12, EX-13
Kankai Alluvium	1,700 - 2,230	EX-10, EX-14
Northern Alluvium	7,10 - 1,130	EX-11, EX-15
Northern Churia	380 - 410	EX-2, EX-7, EX-9
Central Churia	520 - 730	EX-5, EX-6, EX-8
Western Churia	1,200 - 1,240	EX-3, EX-4

Table 2.5.1. Optimum Well Yield in Jhapa District

Well Name	TESTED DATA										DESIGN OF OPTIMUM WELL					
	Depth (m)	Bed Name	thick (m)	Scr'n L. (m-m) from	to	total	D/d (m)	Yield (l/s)	S.C. (l/s/m)	Y.F. (l/s/m/m)	Depth (m)	Bed Name	S.L. (m)	D/d (m)	Y.F. (l/s/m/m)	Yield (l/s)
GANGETIC ALLUVIUM																
EX-1	300	Gg11	46	248	269	21	27.59	50.2	1.82	0.06	130	g5	30	20	0.29	174
		Gg12	27	273	282	9										
EX-12	150	Gg10	9	123	129	6	13.63	50.2	3.68	0.25	120	g5, 6, 7, 8	30	20	0.25	150
		Gg11	14	136	145	9										
EX-13	100	Gg5	70	46	55	9	8.30	50.2	6.05	0.29	100	g5	30	20	0.29	173
		Gg5		60	72	12										
NORTHERN ALLUVIUM																
EX-2	300	Bg1-10	77	Not tested in this beds							120	g2, 3, 4, 5, g6	30	20	0.14	84
EX-3	300	Bg1-10	82	Not tested in this beds							150	g3, 5, 6, 7, g8, 10	30	20	0.08	50
EX-4	250	Bg1-10	127	Not tested in this beds							150	g4, 7, 9	30	20	0.12	72
EX-7	200	Bg10	5	141	146	5	29.23	9.5	0.33	0.07	150	g2, 4, 6, 7 g8, 9, 10	30	20	0.18	108
EX-9	200	Bg8	6	149	152	3	14.84	8.7	0.58	0.10	150	g2, 4, 6, 7	30	20	0.21	128
EX-11	150	Bg7	3	94	97	3	30.84	8.0	0.26	0.04	120	g2, 3, 5, 6, g7	30	20	0.12	70
		Bg8	4	99	102	3										
		Bg8		104	107	3										
EX-15	100	Bg2	9	39	42	3	11.25	34.7	3.08	0.26	100	g3, 4, 5, 7 g8	30	20	0.28	156
		Bg4	6	63	66	3										
		Bg7	9	88	94	6										
JP-2	125	Bg2	15	45	48	3	21.50	11.5	0.53	0.03	120	g2, 3, 4	30	20	0.15	90
		Bg3	28	71	77	6										
		Bg4	26	99	103	4										
		Bg5	10	110	113	3										
JP-7	148	Bg3	15	66	69	3	15.70	30.0	1.91	0.09	160	g2, 7, 8, 9	30	20	0.15	91
		Bg5	11	73	82	9										
		Bg6	3	91	97	6										
JP-8	146	Bg3	14	43	49	6	3.00	14.3	4.77	0.20	150	g3, 6, 7	30	20	0.20	120
		Bg6	12	83	92	9										
		Bg7	10	100	109	9										
JP-9	146	Bg2	25	35	50	15	5.20	10.0	1.92	0.05	150	g3, 5, 8 g10	30	20	0.06	36
		Bg4	2	69	75	6										
		Bg5	18	86	92	6										
		Bg6	4	99	108	9										
JP-10	145	Bg1	30	36	46	10	20.80	90.0	4.33	0.17	120	g2, 4	30	20	0.26	156
		Bg2	26	61	67	6										
		Bg4	5	97	106	9										
WS-1	150	Bg5	7	72	78	6	4.30	26.3	6.12	0.16	120	g5, 6, 7	30	20	0.16	96
		Bg6	16	82	93	11										
		Bg7	9	99	105	6										
		Bg8	12	116	121	5										
		Bg9	9	131	142	11										
WS-2	150	Bg5	9	88	99	11	32.20	18.0	0.56	0.01	160	g2, 4, 5, 6, g7, 8	30	20	0.08	49
		Bg7	4	108	114	6										
		Bg8	11	119	130	11										
		Bg8		136	147	11										
KANKAI ALLUVIUM																
EX-10	150	Ag7	13	100	112	12	11.91	40.0	3.36	0.19	150	g7, 8	30	20	0.19	114
		Ag8	21	128	134	6										
EX-14	100	Ag3	15	57	60	3	8.88	30.0	3.38	0.11	100	g3, 4, 5	30	20	0.11	66
		Ag4	12	64	88	24										
		Ag5	10													
		Ag6	8	92	95	3										
JP-12	168	Bg3	14	32	42	10	5.10	43.0	8.43	0.25	120	g4, 5, 6, 7	30	20	0.25	150
		Bg4	5	48	51	3										
		Bg6	7	77	80	3										
		Bg7	21	86	105	12										
		Bg8	14	117	123	6										
JP-13	150		26	33	123	26	3.10	36.7	11.84	0.46	100		30	20	0.46	276
JP-3	86	Ag2	13	33	42	9	0.70	2.5	3.57	0.40	100	g3, 4, 5, 6	30	20	0.11	66
NORTHERN CHURIA																
EX-2	300	SNg6	4	243	246	3	15.06	34.3	2.28	0.11	230	g1, 2, 3, 4	30	20	0.11	66
		SNg8	2	253	256	3										
		SNg9	8	261	267	6										
		SNg10	7	277	283	6										
		SNg11	4	290	293	3										
EX-7	200	SNg1	9	158	167	9	29.23	34.3	1.17	0.07	220	g1, 2, 3, 4	30	20	0.07	42
		SNg2	17	170	176	6										
		SNg3	3	183	186	3										
EX-9	200	SNg1	7	177	183	6	14.84	17.3	1.17	0.10	230	g1, 2, 3, 4	30	20	0.10	60
		SNg2	10	191	197	6										
EX-11	150	SNg0	5	127	130	3	30.84	4.0	0.13	0.04	220	g1, 2, 3, 4	30	20	0.07	42
CENTRAL CHURIA																
EX-5	250	STg12	41	206	224	18	19.19	40.1	2.09	0.09	120	g4, 5, 6, 7	30	20	0.09	52
		STg14	14	237	243	6										
EX-6	250	STg14	33	214	241	27	17.16	29.0	1.69	0.06	120	g4, 5	30	20	0.06	38
EX-8	200	STg10	20	167	173	6	24.10	50.2	2.08	0.10	130	g4, 5, 6, 7	30	20	0.10	60
		STg11	3	178	193	15										
WS-5	150			37	95	41	5.79	30.9	5.34	0.11	130		30	20	0.11	64
JP-11	155	STg3	6	42	48	6	7.50	39.0	5.20	0.24	120	g4, 5, 6, 7 g8	30	20	0.24	144
		STg5	8	66	69	3										
		STg8	18	107	120	13										
WESTERN CHURIA																
EX-3	300	SWg4	3	202	205	3	15.06	40.0	2.66	0.10	270	g1, 2, 3, 4 g5	30	20	0.10	60
		SWg5	13	243	252	9										
		SWg5		255	258	3										
		SWg6	15	262	271	9										
		SWg7	6	285	288	3										
EX-4	250	SWg12	7	202	208	6	16.53	44.8	2.71	0.10	260	g10, 11 12, 13, 14	30	20	0.10	60
		SWg13	11	218	227	9										
		SWg14	18	232	244	12										

Remark: D/d=Drawdown S.C.=Specific capacity Scr'n L.=Screen length Y.F.=S.C/Sc'n L.
Depth=Well depth of proosed well S.L.=Screen length Bed=Beds for screens

Figure 2.5.2. Map of Optimum Well Yield by 100 m Well



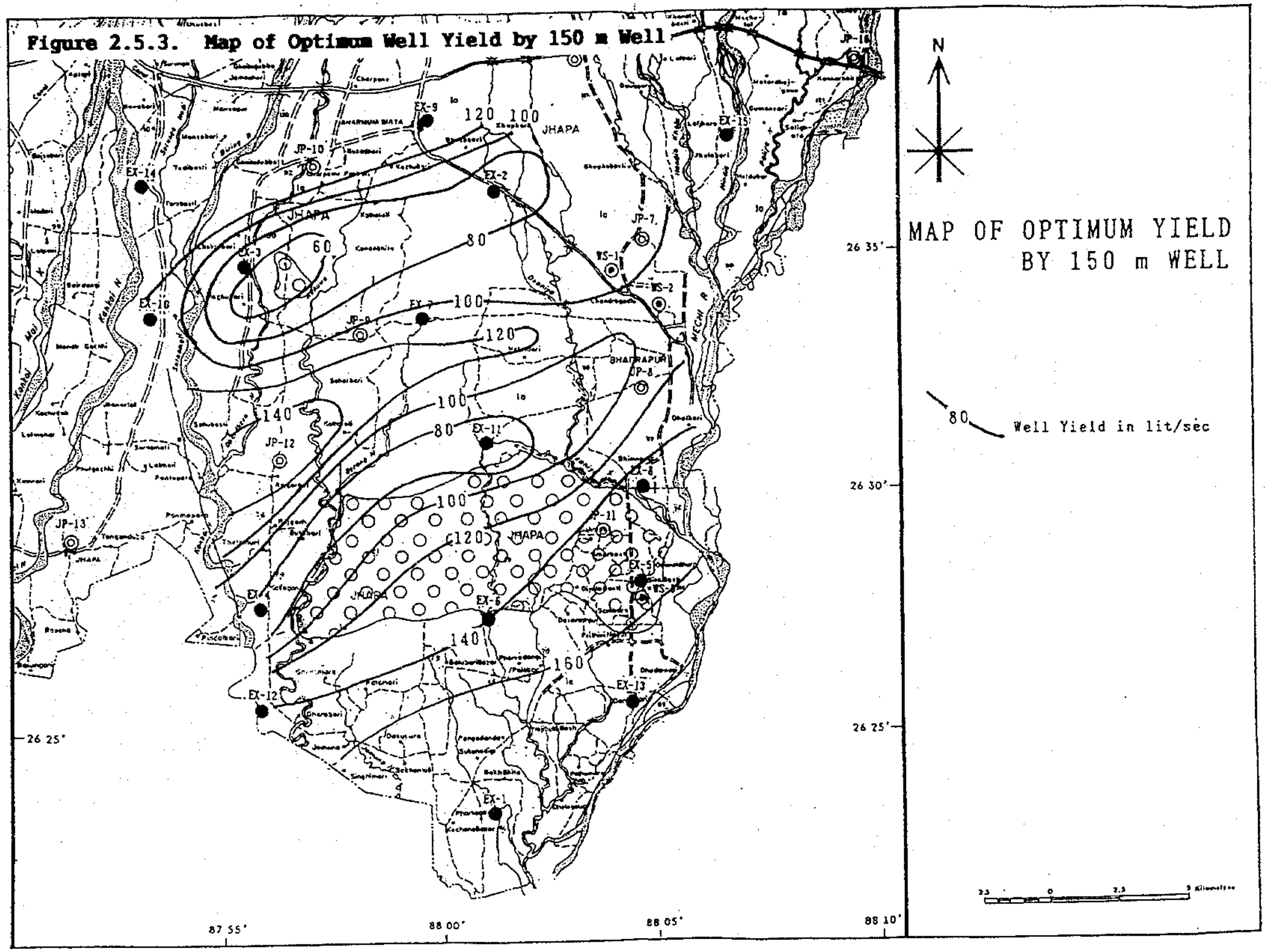


Figure 2.5.3. Map of Optimum Well Yield by 150 m Well

Gangetic and Kankai alluviums indicate excellent transmissivity where aquifers are subject to recharged by surface rivers. The Churia Formation shows comparatively low transmissivity, except in the Western Churia Formation where surface river systems are concentrated.

c) Potential of Deep Aquifer

Based on the specific capacity obtained by exploratory wells of the Project and GWRDB, optimum well yields for the respective geological formations have been assessed in Table 2.5.1. The table shows that the yield factor, the unit length of specific capacity, is applied to the calculation of the well yield. The depth of the proposed well is optimally determined based on the length of the respective permeable beds. The optimum well yield is finally calculated based on the standard well specifications - 250 mm diameter, 30 m screen, 50 m housing, and 20 m drawdown.

An influenced drawdown at a distance of 1 km is also calculated by the nonequilibrium equation using a 120 day pumping duration. Results are show in Table 2.5.2.

Table 2.5.2 Summary of the Groundwater Potential in Jhapa District

Formation	By Specific Capacity (s=20)		By Theis (r=1 km, t=120d)	
	Optimum Yield (lit/sec)	Re.Well Depth (m)	Yield (lit/sec)	Drawdown (m)
Alluvium				
Gangetic	150-173 (165)	100-130	34-198 (85)	5.81-7.02
Northern	36-156 (93)	100-160	34-198 (85)	5.47-6.50
Kankai	66-276 (134)	100-150	114-330 (223)	5.74-6.67
Churia				
Northern	42- 66 (53)	220-230	66- 71 (68)	5.24-5.29
Central	38-144 (72)	120-130	79-180 (112)	5.35-5.86
Western	60	260-270	153-158 (156)	6.09-6.11

Remark: Re=required Theis=Nonequilibrium Equation s=drawdown
r=distance from pumped well t=pumping time d=day ( )=average

The table indicates that the optimum well yield in the alluvium ranges from 93-276 l/s on average and that the wells require a maximum depth of 160 m based on the calculation of the specific capacity. Groundwater development in the Churia Formation is not feasible as wells require a depth greater than 200 m, except in the Central Formation in the terrace where average yields are 72 l/s at a depth of 130 m.

Figure 2.5.2 and Figure 2.5.3 represent maps of the optimum yield by wells of 100 m and 150 m depth, based on exploratory wells of the Project and other existing wells. The figures show that well yields of more than 80 l/s are located south of Chandragadhi and that they increase to the south.

d) Potential of Shallow Aquifer

The shallow aquifer in the Bhabar Zone consists mostly of sand and gravel, with some boulders. The aquifer in the Southern Terai Plain consists of finer-grained sand and gravel. The lithological continuity is weak in both directions, north to south and east to west. Shallow irrigation wells have been sunk at a rate of 100 to 200 per year since 1978. The total number of shallow wells has reached 2,167 in the district. The total number of wells for potable water use has reached 198 in recent years. Drilling logs provided by SAIP reveal that the composition rate of the permeable beds up to a depth of 30 m in the shallow wells ranges from 17% to 98% or from 5 m to 29 m, with an average length of 17 m. The total length of the permeable beds in the Bhabar Zone is more than 15 m, while it is less than 15 m in the Southern Terai. The area with thick beds of sand and gravel appear in the Southern Terai along the Kankai River. The aquifer test reveals that the transmissivity of shallow aquifers ranges from 180 to 1,200 m2/day, with an average of 600 m2/day. The spatial distribution of the transmissivity shows that a high value of more than 1,000 m/day is distributed in the Southern and Central to Western Terai. As well, as permeable beds are sparsely distributed, zones of low transmissivity are distributed in the east and west edges. The specific capacity of the shallow wells ranges from 0.6 to 32.8 l/s/m, with an average of 5.7 l/s/m. A higher specific capacity is distributed in the Bhabar Zone with a 5 l/s/m average.

2.5.2. Mahottari District

(1) Groundwater Potential of Shallow Aquifers

The Bhabar deposits spread out in the northern part of the area and consists mostly of sand and gravel, with some boulders. The deposit reaches a maximum thickness of approximately 20 m. The composition rate of the permeable beds ranges from 60% to 90% in the eastern part of area and decreases to 45% in the central part and even lower in the western part.

Based on the information from JADP, 671 shallow wells have been sunk in the district since 1981, and 584 of these wells which yield 3 l/s are under operation. The depth of wells ranges from 15 m to 25 m. SAIP provided 15 shallow wells with a depth of 40 m in the Gangetic Alluvium.

The transmissivity ranges from 265 to 330 m2/day, and a higher value is distributed in the southern to eastern-central part of the area. For the deep aquifer, a high value is distributed in the southern part.

The specific capacity of the shallow wells ranges from 0.4 to 3.3 l/s/m, and a higher value is distributed in the south-eastern part of the area.

The potential area for shallow groundwater development is distributed in the eastern-south and eastern-central parts of the district.

(2) Groundwater Potential of Deep Aquifers

The major deep aquifers of the area are located in the Upper Churia Formation in the Bhabar zone and the Gangetic Alluvium in southern part of Terai. The former shows the highest potential and the latter in the most southerly part of the Terai Plain shows the second highest potential. The potential in the western edge of area is the lowest, as shown in Table 2.5.3.

Based on the data from 45 exploratory wells drilled by GWRDB, the specific capacity of the Upper Churia Formation ranges from 0.4-29 l/s/m, with an average of 13 l/s/m; while it reaches a maximum of 5 l/s/m in the Gangetic Alluvium. In the west edge of the area, the specific capacity is only 0.2 l/s/m on average.

In general the value of transmissivity is consistent with the specific capacity in the area. The average transmissivity in the Upper Churia Formation is 4,800 m2/day. It varies in the Gangetic Alluvium to 490 m2/day in the South and 250 m2/day in the Central, and 410 m2/day on average. In the western edge of the area, transmissivity is 25 m2/day on average (see Figure 2.3.3 Hydrogeological Map of Mahottari).

Table 2.5.3. Summary of Groundwater Potential in Mahottari District

Formation	Well Depth (m)	Rate of Per. Bed (%)	Tested Data		Standard Well Yield (l/s)
			T (m2/day)	S.C. (l/s/m)	
Churia For.					
North	125	61	5,970	14.9	447
South	146	58	1,310	3.0	90
Gangetic Alv.					
Center	150	53	290	1.7	51
South	170	48	500	3.3	99
West	130	54	17	0.2	6

Remarks: Per=permeable T=transmissivity S.C.=specific capacity

The aquifer potential is calculated based on the standard well design as represented by 150 m well depth, 250 mm diameter, 30 m screen length, and 20 m drawdown. Results are shown in Table 2.5.3. The possible yield of a standard well in the Bhabar zone is calculated at more than 120 l/s, with average of 97 l/s. This area forms an alluvial fan and is covered by thick forest. Direct infiltration by rivers through flood deposits in the broadly extended river beds contributes to the recharge of the Bhabar Deposits and the Gangetic Alluvium.

The second highest potential area is distributed in the southern part of the Terai. The calculated well yield is 51 l/s in the Central, 99 l/s in the South, and 6 l/s in the West.

2.5.3. Banke District

(1) Groundwater Potential of Shallow Aquifers

Shallow aquifers up to 30 m depth are distributed in the Bhabar Zone, especially in the western edge and along the river courses of the Rapti and Babai. Only small-scale shallow aquifers underlie along the Indian border where there are no large surface rivers. The composition rate of the permeable beds is more than 30% in the Bhabar Zone and along the river courses of the Rapti and Babai; in other locations the composition rate is at its lowest. The transmissivity of the shallow aquifers ranges from 250 to 1,040 m2/day, with an average of 690 m2/day. Transmissivity is more than 800 m2/day in the Bhabar Zone and along the river courses of the Rapti and Babai. A higher specific capacity for shallow wells more than 2 l/s/m is also distributed in the above areas.

The potential area for shallow groundwater development is distributed in the Bhabar Zone and along the river courses of the Rapti and Babai.

(2) Groundwater Potential of Deep Aquifers

Three major aquifers underlie the area: Northern Alluvium, Central Churia Formation, and Gangetic Alluvium. The first one shows high artesian pressure in the east while the other two have low pressure, especially in the Churia Formation where it is more than 10 mbgs.

Table 2.5.4 shows that the highest potential area is located in the Southern Terai along the Indian border. The transmissivity of the Gangetic Alluvium in this area ranges from 510 to 1,640 m2/day, with an average of 1,100 m2/day, and the average specific capacity is 3.8 l/s/m. The estimated possible yield from standard wells ranges from 89 to 120 l/s, with an average of 110 l/s.

The second highest potential area is distributed in the Bhabar Zone. The transmissivity of the Northern Alluvium in the Bhabar Zone ranges from 230 to 3,050 m2/day, with an average of 700 m2/day, and the average specific capacity is 3.6 l/s/m. The calculated possible well yield from standard wells ranges from 63 to 120 l/s, with an average of 92 l/s.

The groundwater potential of the Central Churia Formation underlying Central Alluvial Plain is quite low compared with the other formations due to the low composition rate of the permeable beds. The average transmissivity and possible well yield are 210 m2/day and 28 l/s, respectively.

The groundwater potential in the Gangetic Alluvium in the Southern Terai and the Northern Alluvium in the Bhabar Zone seems to be suitable for the deep groundwater development for irrigation use (see Figure 2.3.7 Hydrogeological Map of Banke). The assessed groundwater potential for the respective hydrogeological units is summarized in Table 2.5.4.

Table 2.5.4 Summary of Groundwater Potential in Banke District

Formation	Well Depth (m)	Rate of Per. Bed (%)	Tested Data T (m2/day)	Tested Data S.C. (l/s/m)	Standard Well Yield (l/s)
Churia For.					
Central	240	21	170	0.79	24
Alluvium					
Rapti	120	47	900	3.86	116
North	180	21	390	2.62	79
Gangetic	150	32	750	3.28	98

Remarks: Per=permeable T=transmissivity S.C.=specific capacity

2.6. Groundwater Utilization

2.6.1. Jhapa District

(1) Water Use

An investigation of water utilization has been conducted in the Study Area covering 15 village development boards, as shown in Figure 2.6.1, and the results are summarized in Table 2.6.1. The total number of households investigated is 405 out of a population of 7,793.

The table shows that 90% of the households utilize groundwater for drinking, cattle breeding, farming, and irrigation. Shallow wells with hand pumps are dominant, while some are equipped with rubber pumps. Tubewells, both shallow and deep, are a minor water source used commonly by villagers.

Consumption of water by a household is estimated at 495 l/d, which is large if only utilized for drinking purposes.

(2) Drinking Water Supply

Two drinking water supply projects, urban and rural, are programmed in Jhapa District. The urban projects in Chandragadhi, Bhadrapur, Prithivinagar, Birtamod, Sanischare, Kakarbitta, and Dhulabari are on-going with deep tubewells providing the water source, except in Dhulabari where surface water is available (see Table 2.6.2).

The rural water supply project is covered by UNICEF. Shallow tubewells with hand pumps provide the major source of water. The project expects to serve 67% of total population until 1994.

2.6.2. Mahottari District

(1) Drinking Water Supply

A pipe water supply system equipped with individual taps is provided only in Jaleswar. Deep tubewells serve as the water source and service 10,000 people out of a total of 18,000. Another deep well water supply is located in Rajkhola but is equipped with only communal taps.

The major sources of rural water are shallow tubewells with hand pumps and dug wells with buckets. A single source can supply about 15 to 20 households. Several villages along the highway are provided with water by surface rivers.

2.6.3. Banke District

(1) Water Supply

A pipe water supply system is provided only in Nepalganj. The system was constructed in 1966, and it has been improved by three deep wells.
The major source of rural water depends on shallow tubewells with hand pumps, while several dug wells are also being utilizing by the villagers.

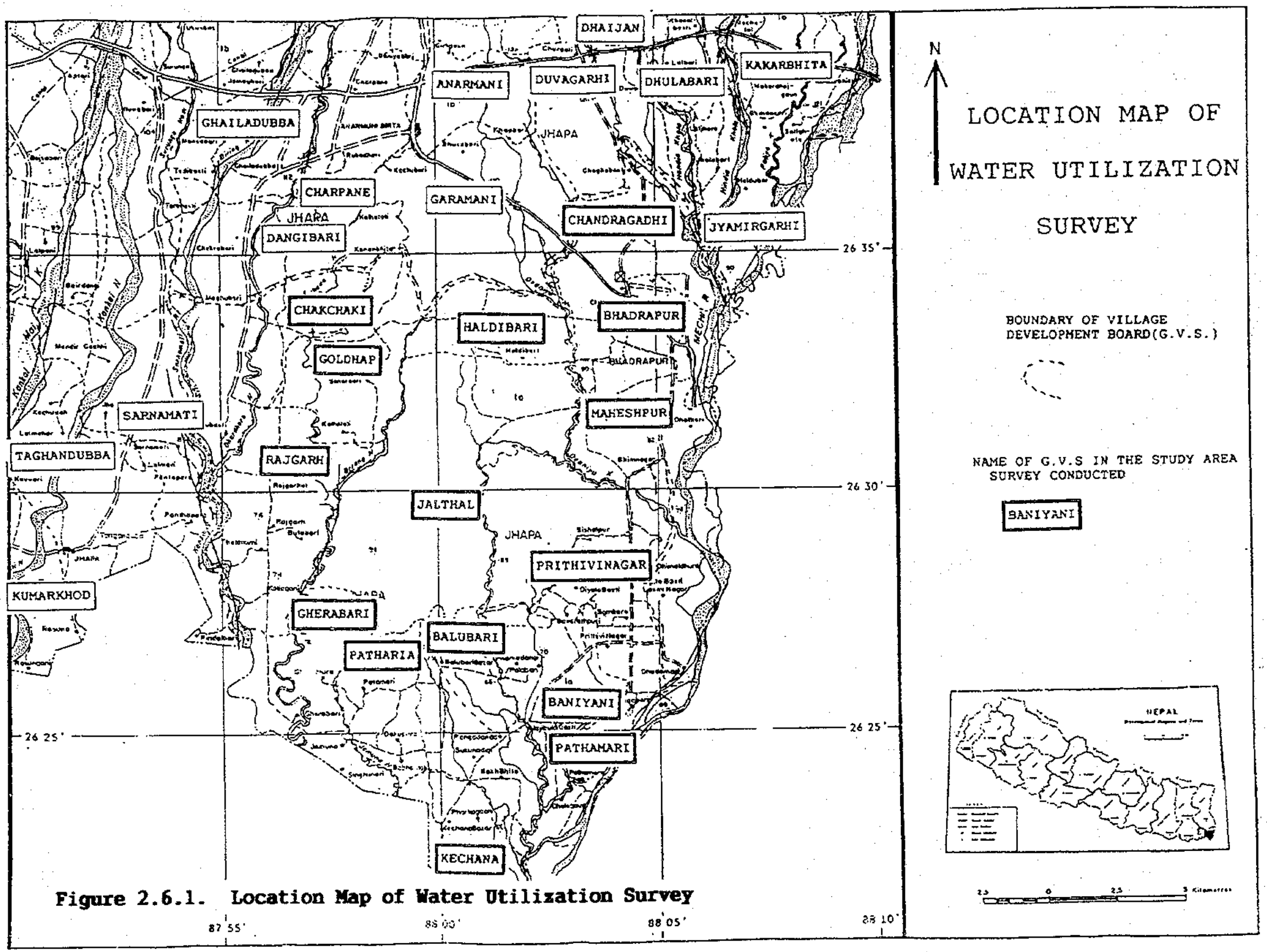


Figure 2.6.1. Location Map of Water Utilization Survey

Table 2.6.1. Summary of Water Utilization in Jhapa District

Total House Nos.: 7,793

Name of VDB	Type of Pump					Depth	SWL	Consum.	Purpose					House Nos.
	H.P.	R.P.	STW	DTW	Other	(m)	(m)	(l/d)	Dri	Irr	Far	Cat	Oth	
Bhadrapur	75	2	9	0	88	9.5	2.1	58,990	163	8	0	54	2	174
Balubari	101	10	5	6	170	9.8	1.9	144,424	267	6	20	236	9	292
Baniyani	140	31	4	0	161	9.7	1.8	110,812	330	7	0	46	0	334
Chakchaki	476	17	89	0	291	6.7	3.8	299,912	713	41	76	230	2	871
Chandragadhi	174	58	22	270	130	8.6	2.1	324,050	582	28	49	325	2	642
Gherabari	156	18	0	0	106	9.8	2.5	290,240	249	0	10	71	3	280
Goldhap	43	9	1	328	83	5.4	1.9	216,660	419	0	8	251	3	465
Halidibari	82	72	19	201	102	8.5	2.2	203,275	419	14	119	232	17	476
Jalthal	91	12	23	0	724	6.7	2.6	250,834	806	8	36	716	28	850
Kechana	78	1	25	2	115	13.0	3.6	64,660	172	3	55	123	11	221
Maheshpur	169	24	31	0	273	11.3	2.4	814,048	465	28	3	242	6	497
Pathamari	58	0	4	0	60	11.3		86,560	91	2	13	17	1	122
Pathariya	72	78	68	1	248	10.3	3.3	175,141	380	13	60	353	50	467
Prithivinagar	132	536	76	3	314	11.5	3.3	370,055	963	65	44	383	43	1,061
Rajgad	696	7	102	0	249	8.9	3.9	451,196	868	101	90	333	5	1,041
Total	2,543	875	478	811	3,114	9.5	2.7	3,860,859	6,887	344	583	3,612	182	7,793

Remark:H.P.=Hand Pump R.P.=Rubber Pump STW=Shallow Tube Well DTW=Deep Tube Well
Consum.=Consumption of Water Dri=Drinking Irr=Irrigation Cat=Cattle

Table 2.6.2. Water Supply Project in Jhapa District

A)UNDER THE VILLAGE DRINKING WATER PROJECT (HMG & UNICEF)

S. N.	PROJECT NAME	V. D. B.	WARD NO.	DESIGN POPU.	COMPLTED YEAR	TYPE
1	HOKSE-BUDHBARE	BUDHBARE	1, 2, 3, 4	5, 147	1983	INTAKE CNSTRU-
2	CHARMAIYA -SHANTNAGER	SANTINAGER	2, 8, 9	2, 080	1983	CTED AND WATER SUPPLY IS DONE
3	SHANTINAGER	SHANTINAGER	4, 5	1, 452	1981	UNDER GRAVITY
4	TELPANI	BAHUNDANGI	5	1, 552	1984	FLOW.
5	KHUDUNABARI	KHUDUNABARI	4, 5, 6, 9	1, 966	1985	
6	DUDHESATASI	SATASI	6, 7, 8, 9	2, 065	1985	
7	BARSESUNMAI	SHANTINAGER	1, 6	2, 353	1985	
8	GOBINDPUR	BAHUNDANGI	5	1, 847	1986	
9	PATAPUR	BAHUNDANGI	9	210	1986	
10	SURUNGA	SURUNGA	8	503	1988	
11	TIRING	BAHUNDANGI	9	1, 000	1980	
	TOTAL			20, 175		

B)UNDER THE TERAI TUBEWELL PROGRAMME (H. M. G. & UNICEF)

S. N.	PROJECT NAME	V. D. B.	WARD No	DESIGN POPU.	COMPLTED YEAR	TW. No.	TYPE
1	KECHNA	KECHNA	ALL	4, 725	1985/86	63	1.5 INCH
2	KOROBARI	KOROBARI	ALL	4, 800	1985/86	64	HAND
3	BAIGUNDHURA	BAIGUNDHURA	ALL	4, 725	1985/86	63	-PUMP
4	MAHABHARA	MAHABHARA	ALL	5, 025	1986/87	67	
5	SIVAGANJ	SIVAGANJ	5	1, 425	1986/87	19	
	TOTAL			20, 700		276	

NOTE:ACTUAL POPULATION IS 67% OF THE PROJECT DESIGNED POPULATION.

C)HANDPUMP DRINKING WATER SUPPLY PROJECT-JHAPA

S. N.	PROJECT NAME	V. D. B.	WARD NO.	DESIGN POPU.	COMPLTED YEAR	TW. No.	TYPE
1	CHERABARI	CHERABARI	ALL	5, 400	1986/87	62	1.5 INCH
2	DHARAMPUR	DHARAMPUR	ALL	11, 400	1988/89	152	HAND
3	PANCHGACHI	PANCHGACHI	ALL	7, 200	1988/89	96	-PUMP
4	KHAJURGACHI	KHAJURGACHI	ALL	4, 950	1988/89	66	
5	JAMIRGARHI	JAMIRGARHI	ALL	5, 700	1987/88	76	
6	PATHAMARI	PATHAMARI	ALL	3, 525	1988/89	47	
7	KUMARKHOD	KUMARKHOD	ALL	7, 350	1989/90	98	
8	KOHBARA	KOHBARA	ALL	11, 250	1990/91	150	
9	BANIYANI	BANIYANI	ALL	6, 900	1991/92	92	
10	BALUBADI	BALUBADI	ALL	8, 615	1992/93	111	
11	LAKHANPUR	LAKHANPUR	ALL	4, 895	1993/94	50	
12	SARNAMATI	SARNAMATI	ALL	5, 537	1993/94	50	
13	PATHARIA	PATHARIA	ALL	5, 896	1993/94	50	
14	DUAGADI	DUAGADI	ALL	2, 292	1993/94	32	
15	CHANDRAGARHI	CHANDRAGAR.	GHORA-MARA	669	1993/94	8	
	TOTAL			91, 579		1, 140	

NOTE:ACTUAL POPULATION IS 67% OF THE PROJECT DESIGNED POPU.
:BENEFITTED POPULATION BY TERAI TUBE WELL PROGRAMME 75, 227
:BENEFITTED POPULATION BY VILLAGE DRINKING WATER PROJECT 13, 526
:TOTAL BENIFITTED POPULATION BY BOTH PROGRAMMES 88, 753

2-1-1994

D)DEEP TUBE WELL DRINKING WATER SUPPLY PROJECT IN JHAPA DISTRICT

S. N.	TOWN/ V. D. B.	TOTAL(IN 1988)		SUP. SERVICE		SUPPLY(M3/DAY)		NOS. OF FOUCETS		REMARKS
		POPU.	H. HOLD	POPU.	H. HOLD	RAIN.	DRY.	COMMU.	PRIVA.	
1	CHANDRAGARHI	10, 100	920	5, 476	693	1, 160	1, 160	25	693	COMPLETED
2	BHADRAPUR	16, 155	536	4, 928	616	1, 100	1, 100	40	616	COMPLETED
3	PRITHVINAGER	15, 779	830	19, 000	1, 001	1, 073	1, 073	50		UNDER CONST.
4	BIRTAMODE			28, 743	2, 118	2, 090	2, 090	47		UNDER CONST.
5	SANISHCHARE	13, 959	1, 202							BRITISH PROJECT
6	KAKERBHITTA	17, 178	1, 028							JUST STARTED
7	DHULABARI	16, 676	787	34, 797	2, 103	2, 207	2, 207	64		GRAVITY FLOW UNDER CONSTRUC.
	TOTAL	89, 847	5, 303	92, 944	6, 531	7, 630	7, 630	226	1, 309	

CHAPTER THREE

EVALUATION AND DEVELOPMENT OF GROUNDWATER RESOURCES

CHAPTER-THREE: EVALUATION AND DEVELOPMENT OF GROUNDWATER RESOURCES

3.1. Outline

Called the "Aqua-Planet," the earth's surface is covered by a huge amount of water, estimated at approximately 1.4 billion cubic kilometers. Nevertheless, almost all of this volume, approximately 97%, is ocean water, with only the remaining three percent being fresh water on the ground. Furthermore, nearly 70% of the fresh water is fixed as polar icecaps or permanent snow, with only 0.8% of the total water volume on the earth being cycled fresh water. A figure as low as 0.8% of the earth's total water supports and nurses all life on the planet, including human beings. Although fresh water is precious to the earth, water is not only a basic human necessity but is indispensable as one of the most basic and important natural resources which supports many kinds of productive human activities.

Historically, techniques to utilize groundwater have been developed, urged on by the acceleration of human activities. A well-known example is the "Qanat," which was developed in ancient times and is still used today in the arid regions of Southwest Asia and North Africa. Groundwater development techniques in Southeast Asia began with traditional hand-dug wells and have advanced to modern drilling, draft, and management technology through driven wells, bored wells, jetting wells, and so on. The modern rotary drilling method for tubewells has also progressed as a part of the comprehensive oil resource development technology which accelerated after the World War II. While modern drilling techniques and associated groundwater investigations or exploration techniques have realized huge amounts of groundwater draft and consumption, they have also created groundwater disruptions such as land subsidence, the decline of groundwater levels, and the salinization of groundwater, among others. On the other hand, the drastic development of heavy industries and the over-concentration of city populations have caused serious groundwater pollution in some regions. Therefore, the promotion of groundwater development projects should be carefully planned based on prudent evaluations of the groundwater potential, as well as a review of past activities of water resource development in a region.

The fundamental concept in formulating a groundwater development project is to treat the target as a groundwater basin and to grasp the groundwater extensively and dynamically. For this purpose, the following three perspectives are essential for recent groundwater analysis:

a) Understanding groundwater, including aquifers and aquicludes as a member of Quaternary geology.
b) Computer simulations of groundwater movement or balance.
c) Providing a proper groundwater monitoring system.

This chapter focusses on the latter two points introduced in the Project, as the first point has been outlined in the previous chapter. Groundwater resources of the project area shall be evaluated, and a development plan shall be formulated along with a monitoring scheme.

3.2. Introduction of Groundwater Simulation

3.2.1. General

Along with the development of modern irrigation, especially groundwater irrigation, several types of water balance studies have been created to evaluate the groundwater potential and to obtain a reasonable limit for groundwater utilization.

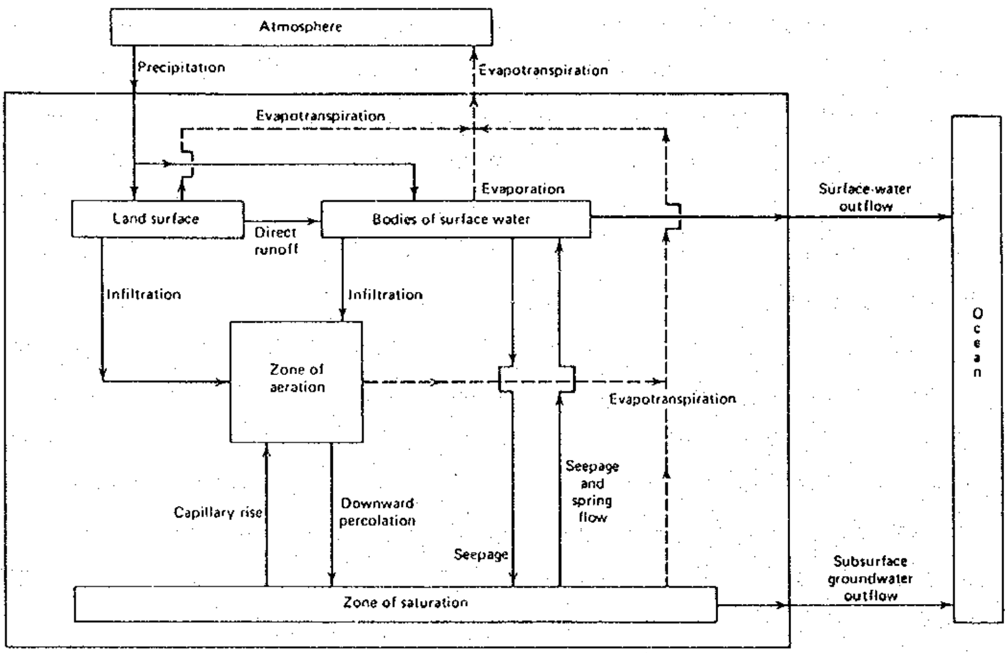


Figure 3.2.1 Global Water Balance

As the global water balance, natural conditions are summarized in Figure 3.2.1, shown above. Based on these conditions, an equation consisting of rainfall, surface runoff, evapotranspiration, drafting, inflow and outflow of groundwater, and so forth, is com-

monly applied.
The concept is very simple in that a balance must exist between the quantity of water supplied to the basin and the amount leaving the basin. The equation can give the static water balance at a certain period very easily, but not the dynamic balance.

$$\begin{bmatrix} \text{surface inflow + subsurface inflow + precipitation} \\ \text{+ imported water + decrease in surface storage} \\ \text{+ decrease in groundwater storage} \end{bmatrix}$$
$$= \begin{bmatrix} \text{surface outflow + subsurface outflow + consumptive use} \\ \text{+ exported water + increase in surface storage} \\ \text{+ increase in groundwater storage} \end{bmatrix}$$

Water balance simulations to analyze the balance under dynamic conditions, or used for forecasting purposes, have been rapidly developed recently, based on hardware and software innovations in computer technology. For the digital simulation, several kinds of methodology and related algorism have been proposed, such as FEM, FDM, and so on. In the Study, the so-called synthetic storage model has been applied to the study of the water balance.

The synthetic storage model has been developed to make simulations possible on a practical-use basis. The model is a mathematical model and deals with a basin-wide hydrological balance analysis for both surface and subsurface systems simultaneously in an unsteady, quasi-three dimensional state, in addition to the water balance and hydraulic analyses of multi-aquifer systems including aquicludes, Therefore, the model can be applied to solve phenomena such as multi-phase density flow, underground dams, land subsidence, substance balance, and so forth.

3.2.2. The Synthetic Storage Model (STML)

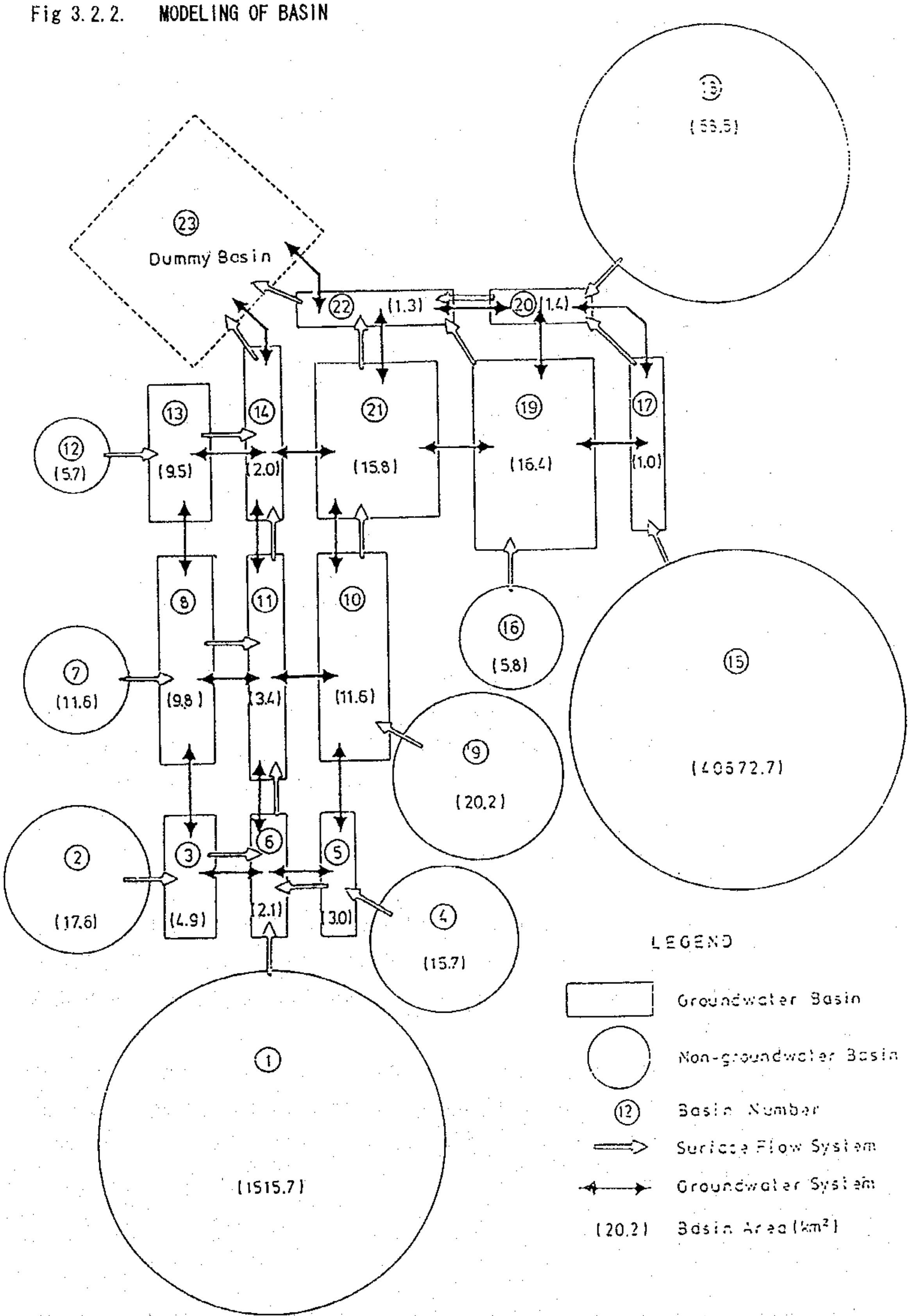
(1) Modeling of Basin, Aquifer, and Aquiclude

The basin to be analyzed is divided into arbitrary, rectangular sub-basins, according to the characteristics of the topography, drainage system, hydrogeology, water and land uses, and so on. The upstream and downstream relations with the neighboring sub-basins are previously defined (refer to Figure 3.2.2).
In regard to the groundwater system, the aquifers and aquicludes are grouped based on the conditions of hydrogeology and water drafts from aquifers at different depths. The aquifer groups in the same horizon in the neighboring sub-basins are also previously defined (refer to Figure 3.2.3).

(2) Structure of Model for Surface Systems

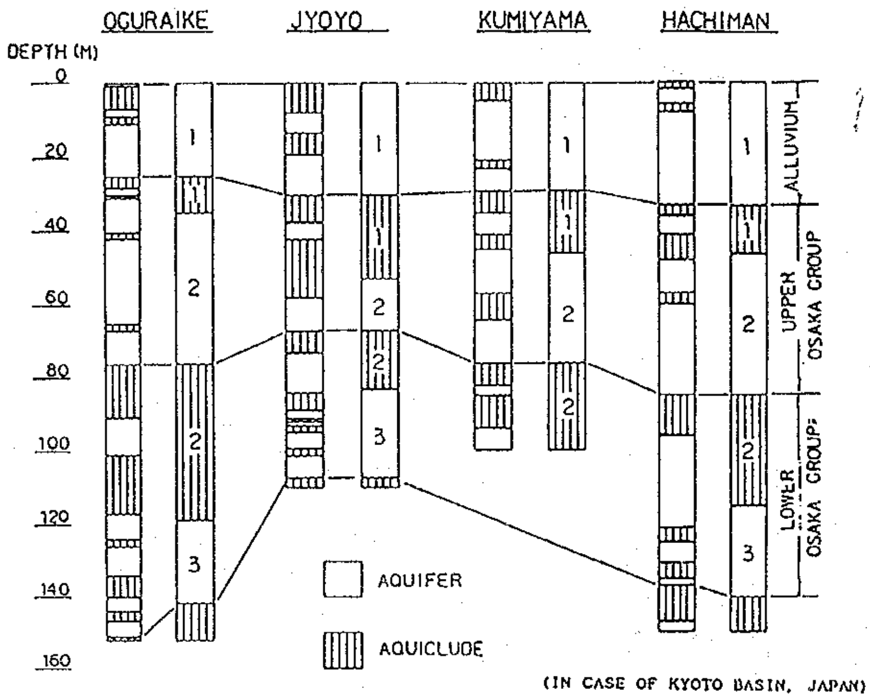
The surface system is an exponential serial depletion model and is well known as the "tank model," which can be explained in terms of inflow, storage, and outflow of water in a container (tank) with orifices. The lowest orifice at the lowest tank plays the role of groundwater recharge (RE), as shown in Figure 3.2.4 Concept of the Storage Model.

Fig 3.2.2. MODELING OF BASIN



(IN CASE OF KYOTO BASIN, JAPAN)

Fig 3.2.3. MODELING OF AQUIFERS AND AQUICLUDES



(3) Structure of Model for Groundwater System

Groundwater storage takes place in the uppermost unconfined and confined aquifers, separated by leaky aquicludes (refer to Figure 3.2.4).
In the hydraulic analysis, which applies potential solution methods, such as FEM and FDM, the water head is initially solved and the water storage is then secondarily defined. This model initially solves the change of storage (balance) of an aquifer in a basin, and water head is derived through the relationship between the storage and the head which are previously defined (refer to Figure 3.2.5). The methodology is the most particular part of the model and is the origin of model's name.

The balance of storage in an aquifer of a sub-basin is the sum of the recharge from the surface system (RE), the leakance through the neighboring aquiclude(s), inflow (GI) and outflow (GF) from/to the aquifers in the same horizon of the neighboring sub-basin(s), and the draft (DF).
The components, except RE and DF, are estimated by "Darcy's Principle," i.e., the product of the permeability of aquifer or aquiclude concerned, the seepage area, and the hydraulic gradient. The product of permeability and the seepage area in the model can be expressed as runoff coefficients, α, α' and α'', as shown in Figure 3.2.6.

(4) Identification of Model

The constructed model is identified through trial runs to meet the actual hydrological

Fig 3.2.4. CONCEPT OF STORAGE MODEL

LEGEND

RF; Rainfall
ET; Evapotranspilation
SI; Surface Inflow
SF; Surface Runoff
SR; Soil Retention
PC; Percolation
RE; Recharge
GI; Groundwater Inflow
GR; Groundwater Runoff
DF; Groundwater Draft
LR; Leaky Recharge
H; Groundwater Head
SY; Specific Yield
A; Runoff Coefficient for Surface System
GA; Runoff Coefficient for Groundwater System
L; Leakance
B; Aquiclude Thickness

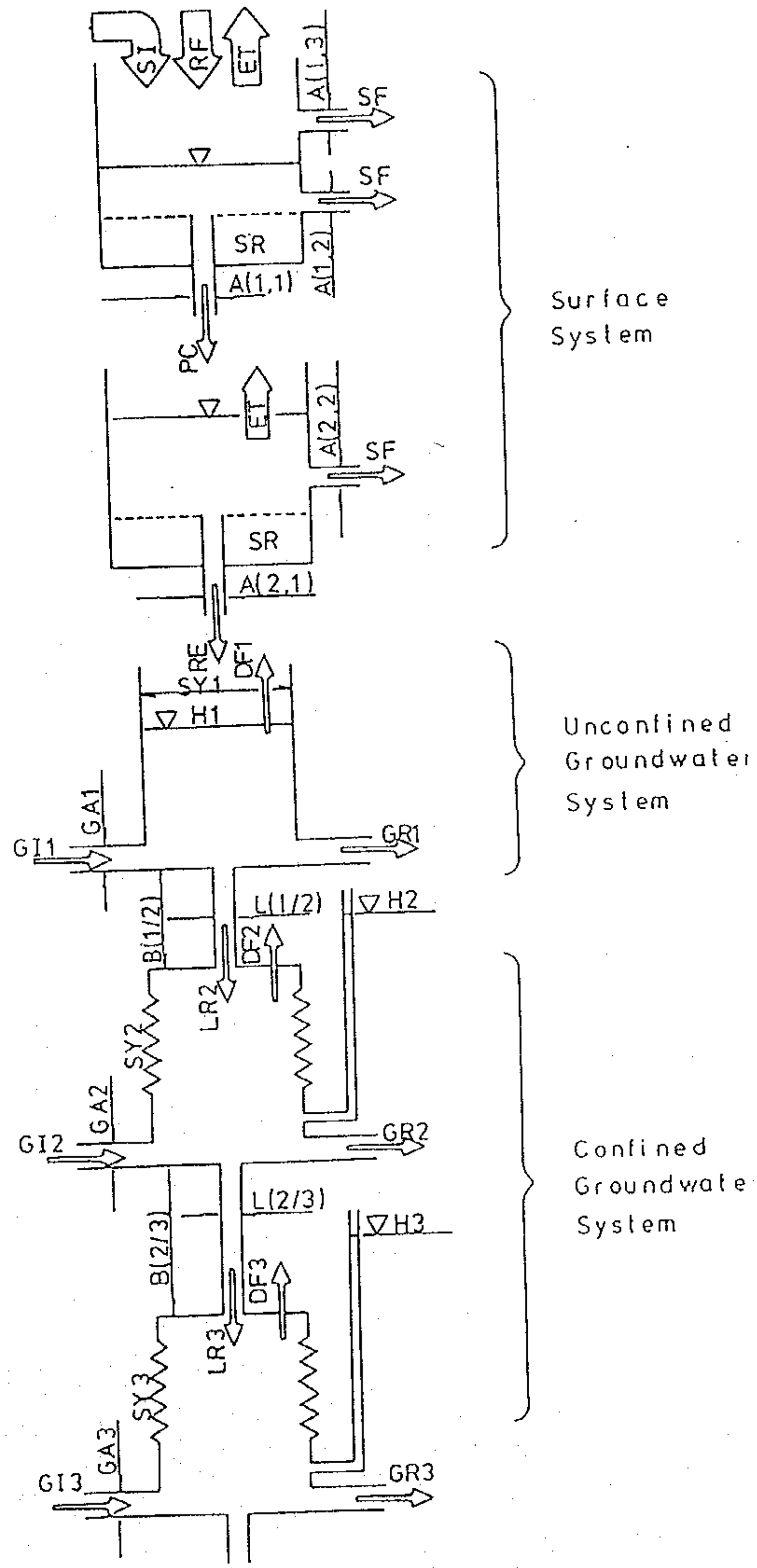
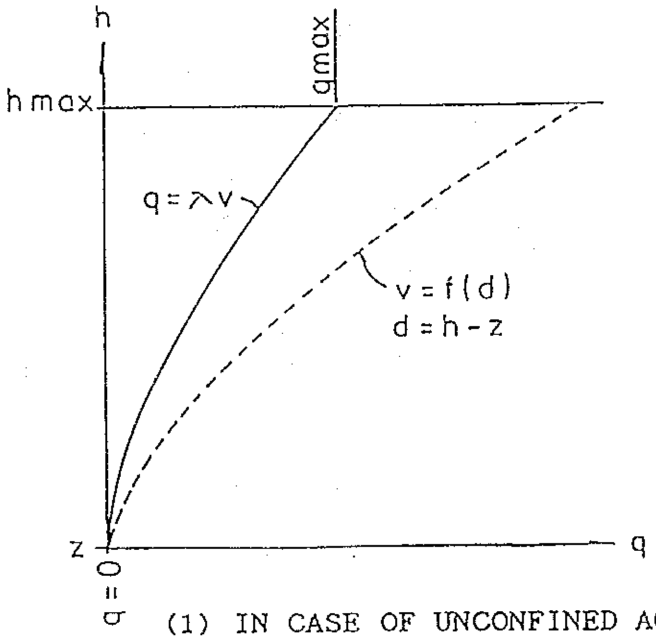
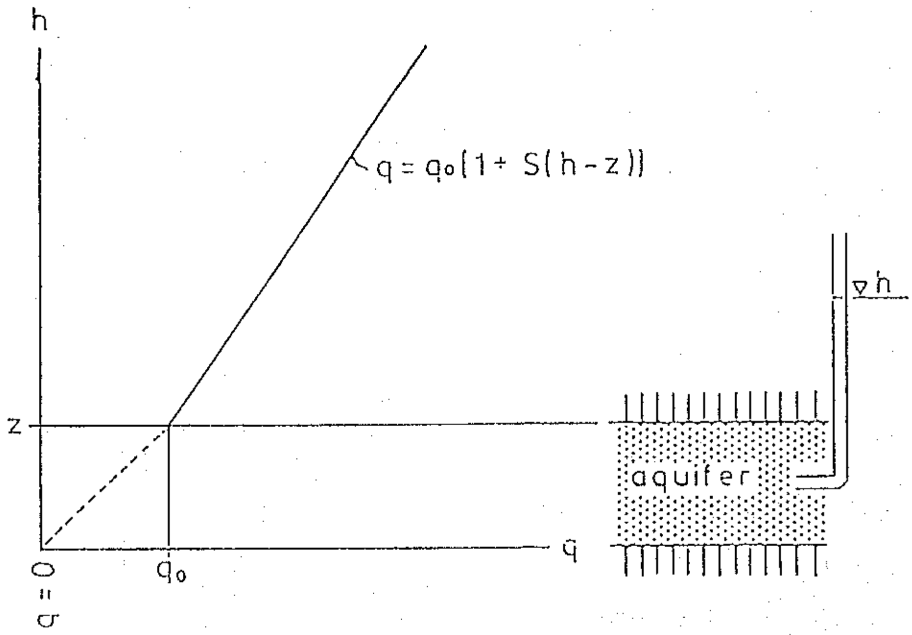


Fig 3.2.5. RELATIONSHIP BETWEEN AQUIFER STORAGE AND WATER-HEAD

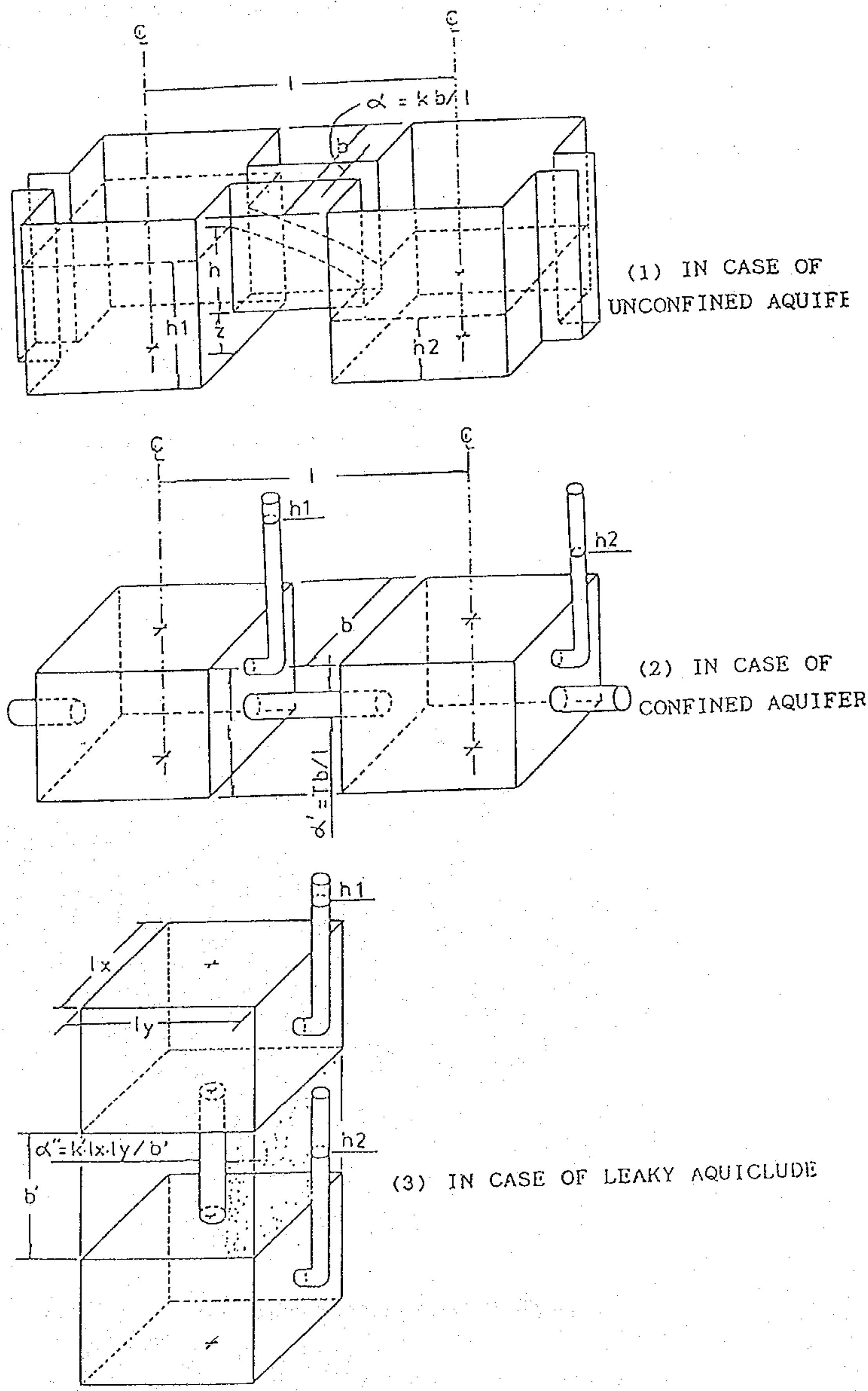


(1) IN CASE OF UNCONFINED AQUIFER



(2) IN CASE OF CONFINED AQUIFER

Fig 3.2.6.   CONCEPT OF RUNOFF COEFFICIENT



behavior observed by time-series hydrographs of the surface runoff of the surface system and the groundwater heads at each aquifer in the groundwater system. Needless to say, the artificial drafts from each aquifer must be known as precisely as possible to identify the model.

3.3. Construction of Storage Model

3.3.1. Area

(1) Overview

The study basin for the hydrologic balance overlaps the Study Area and extends upstream, therefore it inevitably involves the surface water balance. The major Study Area, the eastern half of Jhapa District, is part of the Terai Plain, as has been mentioned repeatedly. High in the northwest corner, the surface configuration inclines gently to the south; however, it includes a notable highland area near the southeast end. Figure 3.3.1 shows an overview of the major Study Area, together with the location of the EX. wells.

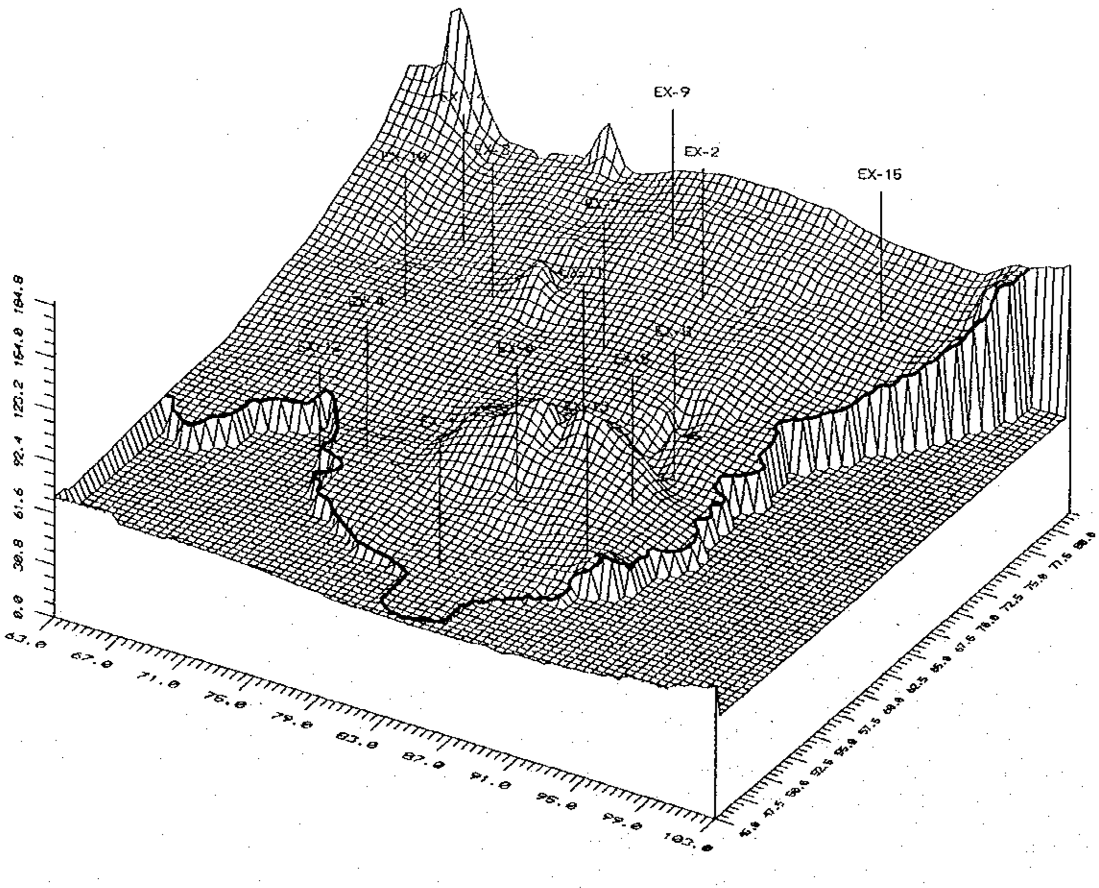


Figure 3.3.1 Overview of the Project Area

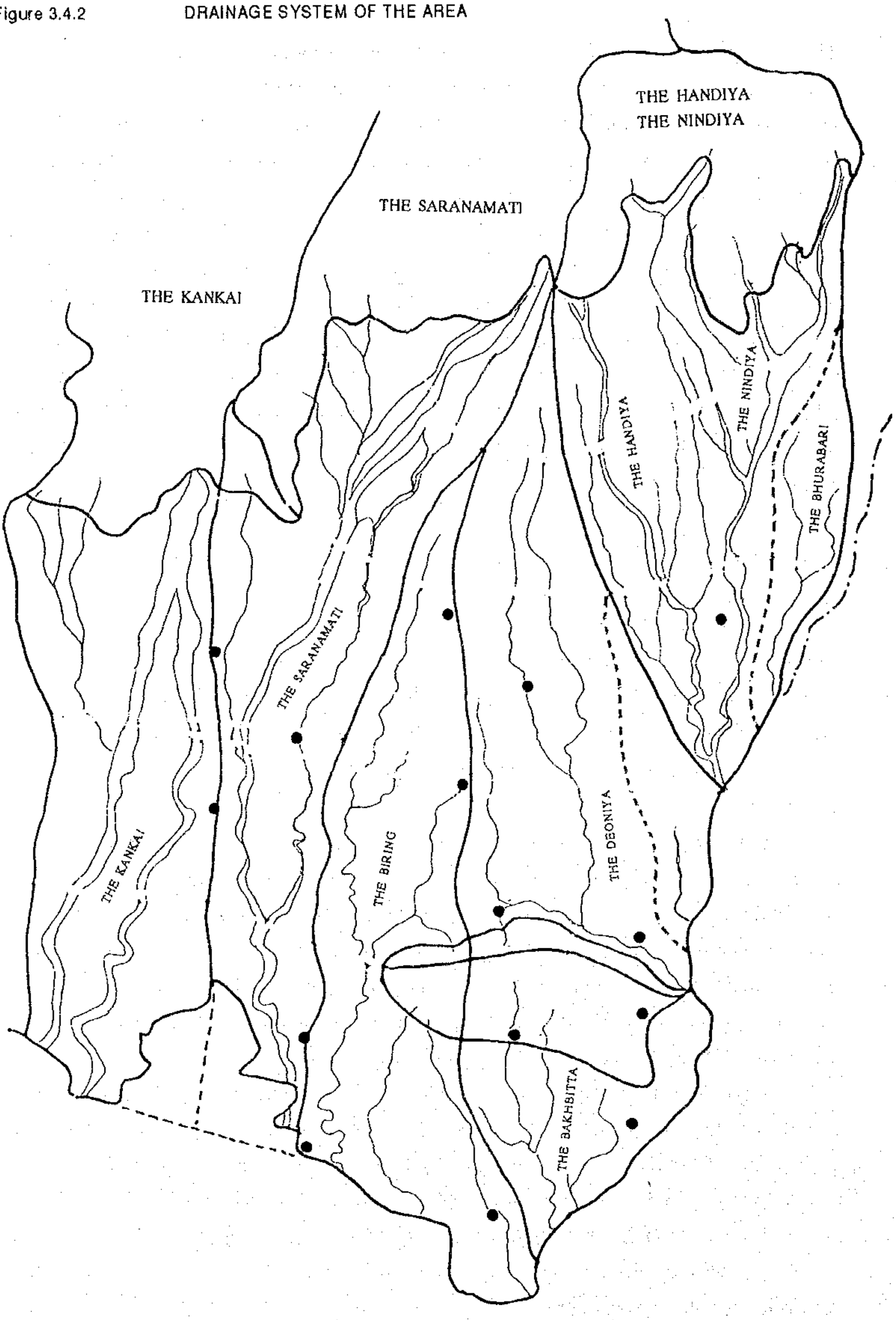
(2) Geological Situation

The geological situation of the area has already been explained in the previous chapter and is summarized below. The basement area is the Churia Formation, and the Middle Churia is believed to be the impervious basement for the Study. Covering this basement layer is a zone of thick, unconsolidated sand and gravel belonging to Upper Churia, which underlies the entire Terai Plain, and locally protrudes above the current ground surface, similar to the previously mentioned highlands. Thick alluvium also covers the Churia but the components slightly change from the upper Bhabar Zone to the lower southern lowlands. Only in the highlands do Terrace deposits cap the Churia Formation. A total of 15 exploratory wells have been drilled in the Study Area by the Study Team; 10 deep wells have been drilled by DOI, and three water supply wells (newly drilled) are in existence. Besides these deep wells, several shallow wells have also been drilled by DOI, and a number of these have been integrated into the groundwater monitoring system by DOI and the Study Team.

(3) Surface System

Hydrogeologically, the study area can be simply divided into two zones: a surface water catchment and a groundwater basin directly connected to the former.
The whole catchment basin is a steep, rugged mountain area composed of the Middle to Lower Churia formations, which is part of the Churia Mountains (or Churia Hills). The groundwater basin gently slopes toward the Terai Plain and is composed of gravel, sand, silt, and clay.
The catchment basin is sub-divided into three major drainage systems: Kankai, Saranamati, and Handiya/Nindiya. The Kankai system is overwhelmingly the largest area. In the groundwater basin, the drainage system is further divided into total seven sub-basins including the above drainage areas. Besides the major drainage systems, minor systems include Biring, Deoniya, Bakbitta, and Bhurabari river basins (see Figure 3.3.2). As shown in the figure, the four minor basins have no obvious catchment area; nevertheless, most of the minor basins have a perennial river flow.
The hydrogeological conditions in the groundwater basin have a very close relationship with the natural geological classifications. As geologically classified, the alluvial deposits are separated from the Upper Churia, although the difference between them is substantial from a hydrogeological point of view. The upper limit of the Middle Churia is the most essential separator in the area because it can be regarded as an impervious basement. The correlation between the geological strata and the hydrogeological classification is discussed in the following paragraph.

Figure 3.4.2 DRAINAGE SYSTEM OF THE AREA



3.3.2. The Groundwater System

(1) Groundwater

Generally speaking, Terai is said to be groundwater-rich plain, and indeed, numerous dug wells or shallow wells have been dug successfully throughout the area. Furthermore, groundwater flows naturally from many of the wells, therefore groundwater has been utilized for a long period of time by the people living in the Terai.

The occurrence of groundwater is due to rainwater. Abundant precipitation falls in the mountainous areas, which occupy more than 80% of the country, and flows quickly down the steep slopes, recharging the groundwater at the foot of mountains, which is the high end of Terai. Groundwater is recharged not only from the rivers which originate in the mountains but also from rainfall in upper part of the Terai. A portion of the Bhabar Zone consists of heavy gravel deposits which allows rainwater to percolate into the ground.

(2) Groundwater Quality

Groundwater quality in the Study Area has been analyzed by the Study Team (refer to paragraph 2.4.1). According to their results, the water quality of the area is generally good, causing no problems for domestic and irrigation uses. One of the analysis charts (Trilinear Diagram) is shown below (Figure 3.3.3), and as shown in the figure, the water qualities of the EX wells can be clearly divided into four groups and arranged along a "water quality evolution curve." Furthermore, the water quality evolution system can be subdivided into two systems based on the cation diagram (right low diagram). Among the quality groups, Group IV consists of data indicating Gangetic groundwater, and Group III suggests Upper Churia groundwater, based on the location and depth of each water sample.

(3) Groundwater Hydrograph

Depending upon manually monitored hydrographs, the groundwater head is generally shallow at less than 1.0 m below the ground surface during the rainy season and less than 3.0 m during the dry season. The fluctuation of the groundwater head is from 1.0 m to 3.0 m in a year (a special case is beyond 6.0 m). The average groundwater fluctuation for a shallow aquifer (ST-Wells) is 2.06 m; 1.69 for a middle aquifer (JP-wells); and 1.30 m for a deep aquifer (EX-wells). There is a clear tendency for the annual groundwater fluctuation to become low and lower towards the deeper aquifer. In the case of a very deep aquifer, the water head ranges from 105 m to 104 m at EX-2, and from 78 m to 79 m at

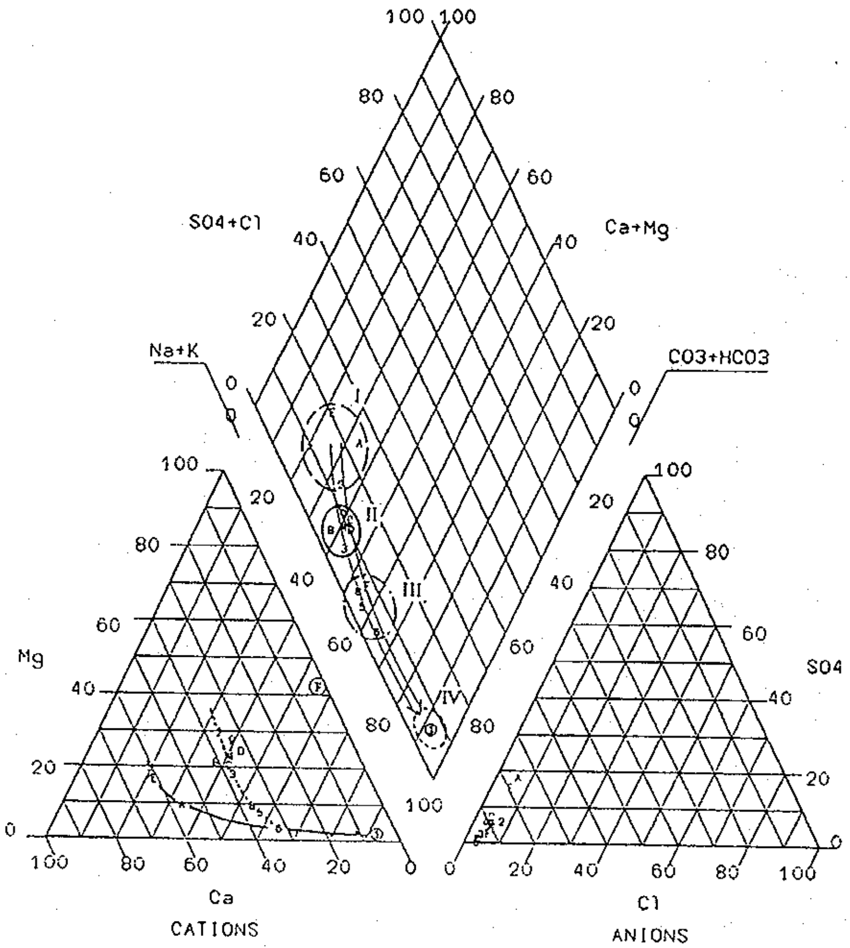


Figure 3.3.3 Groundwater Quality

EX-3, both of which are the deepest wells. This means that the groundwater head for deep aquifers fluctuates less than 1.0 m throughout the year. The groundwater head in shallow aquifers lies a few meters below the ground level as explained above, while the groundwater head of deep aquifers varies from more than 18 m below ground level (EX-3) to more than 8 m above ground level (EX-8) even during the dry season. Figure 3.3.4 shows the isobath maps of groundwater table (a) and deep aquifer water head (b), both during the early dry season. In Figure (a) three of groundwater ridges and two groundwater valleys are distinct, which is suggestive of hydrogeological discontinuities.

(4) Aquifer Classification

As previously discussed, the geology of the area is classified into three major units: Alluvial deposits, Terrace deposits, and Churia Formation. Among these units, the target aquifers for the Study are located in the former two and only in the upper part of the Churia Formation.

Alluvial deposits in the area are some of the most excellent aquifers because of their rich gravel and sand component. From a geological point of view, the deposits are further

Fig 3.3.4. (a) THE GROUNDWATER TABLE (Shallow aquifer)

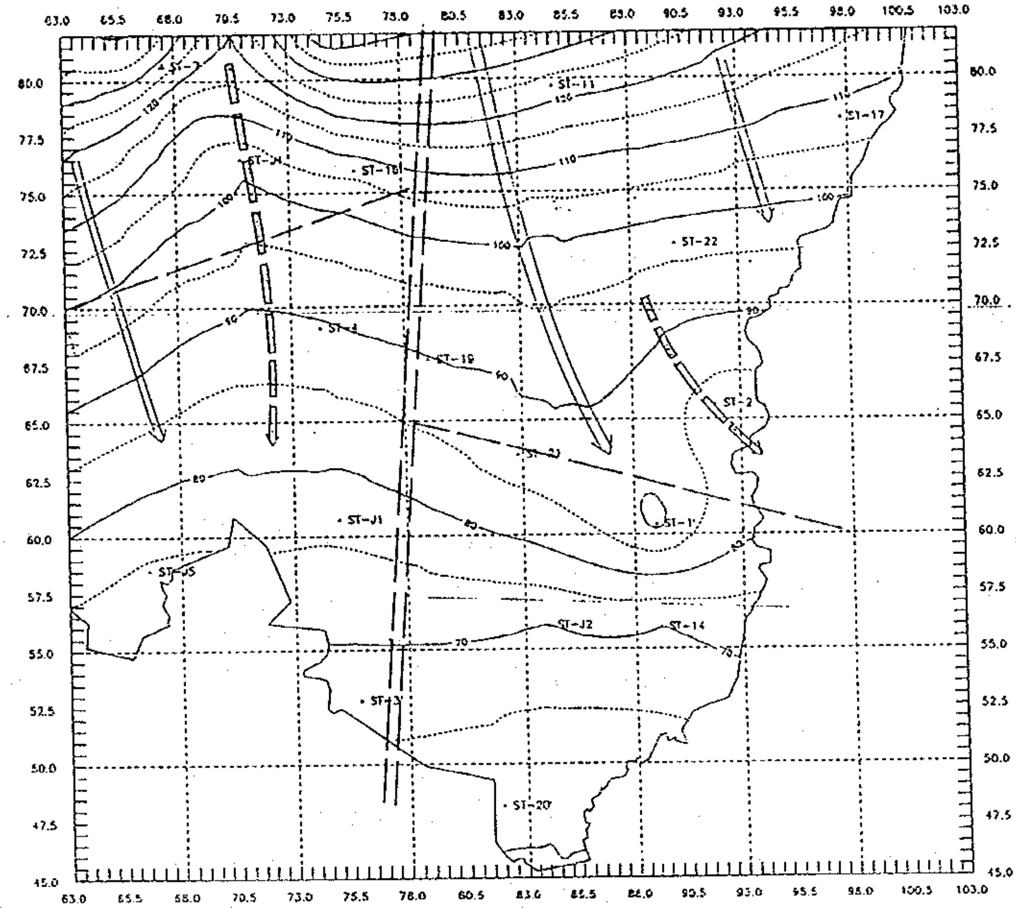
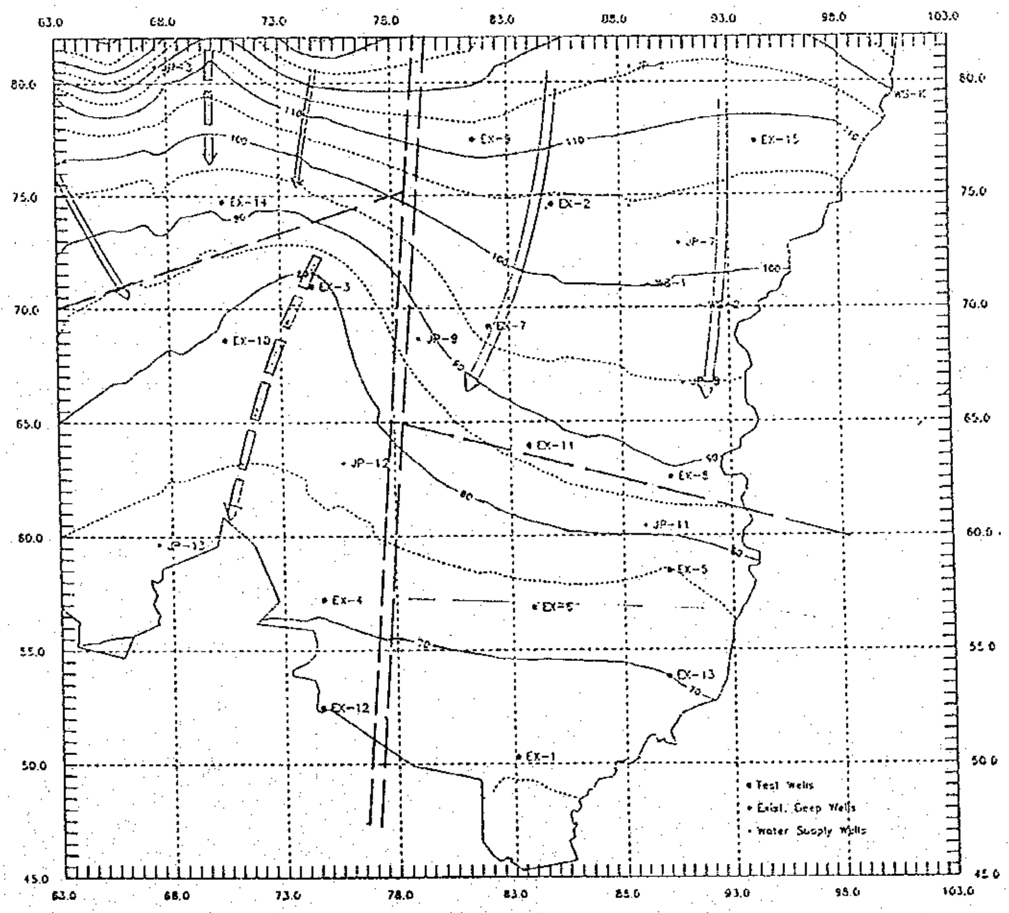


Fig 3.3.4. (b) THE GROUNDWATER HEAD (Middle aquifer)



classified into several gravel layers and almost the same numbers of clay layers. Simply speaking, the sand and gravel layers are regarded as aquifers and the clay layers are aquicludes. However, the circumstances of deposition are not simple or homogeneous, therefore the continuity of the stratum is usually heterogeneous, especially for thin or weak stratum. As shown in the geological cross-section (Figure 2.2.1), a layer zone such as gravel-rich and clay-rich zones are steadily traced from the upper to the lower reaches; and the groundwater movement seems to follow the comprehensive hydrogeological structure. Therefore, the geological strata are reclassified into aquifer and aquiclude groups from a hydrogeological point of view.

Figure 3.3.5 shows several typical lithological logs obtained from EX- wells. Although many layers are distinguished from the figure, especially at the upper 100 m to 120 m in the log, gravel-rich zones and clay-rich zones can be located with a careful examination in terms of resistivity and gamma-ray logs. Under a 100 m or 120 m depth in the log, a thick, firm low-resistivity/high-density zone is detected. This zone should be the upper diluvium in the upper end of the Churia Formation.

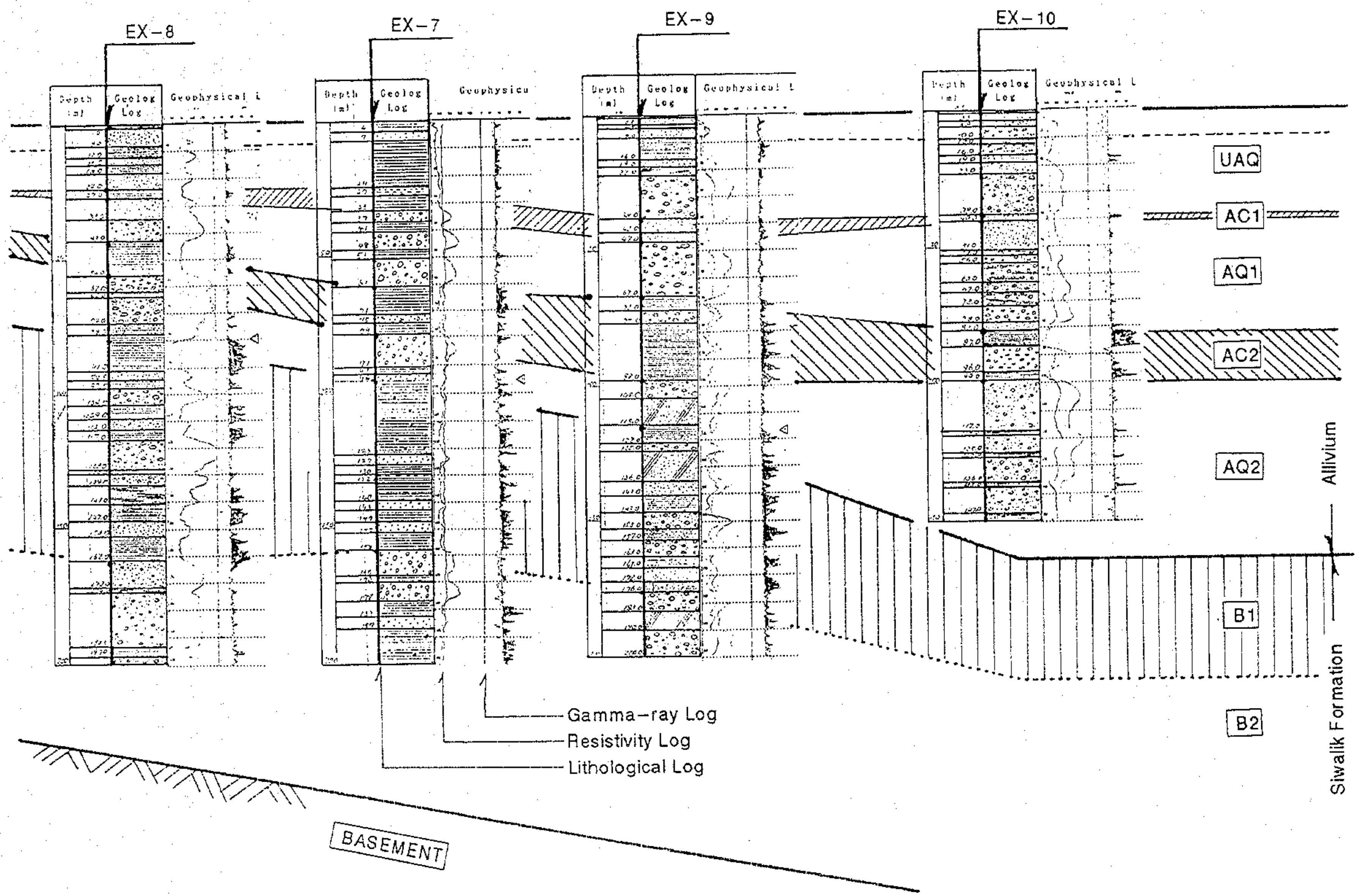
The upper part overlaying the Churia Formation consists of alluvial deposits, which can be divided into three aquifers and two aquicludes, as shown by the figures UAQ, AQ1, AQ2, and AC1, AC2. Another high resistivity zone appears below the top of the Churia Formation. Therefore, the Churia is divided into two aquifers as B1 and B2; the former is less productive but the latter is another excellent aquifer in the area. The status of such aquifer groups, represented from the results of pumping tests, logging data, water quality tests, and so on, are summarized in Table 3.3.1.

As easily distinguished from the table, the best aquifer in the area is B2, followed by AQ2, while the tightest aquiclude is AC2. Besides the main story, the unconfined aquifer UA1 is further subdivided into upper and lower zones. The upper part of the aquifer is unconfined but the lower part is considered to be a slightly confined or semi-confined aquifer. Although this part behaves as an unconfined aquifer in general, it is on occasion locally affected by an artesian head.

Table 3.3.1 Status of Aquifer Groups

Unit	Status	Transmissivity (m2/d)	Storage Co. --	Permeability (m/d)	Specific Cap. (m3/d/m)	Leakance (vertical P.)
UAQ	Unconfined	1,500.	0.08	50.	200.	
AC1	Aquiclude					0.25
AQ1	Confined	800.	2.0E-04	25.	100.	
AC2	Aquiclude					0.12
AQ2	Confined	3,000.	5.0E-04	100.	300.	
B1	Confined	500.	2.0E-05	10.	60.	1.00
B2	Confined	1,500.	1.0E-04	50.	250.	

Fig 3.3.5. AQUIFER CLASSIFICATION



3.3.3. Construction of Simulation Model

(1) Sub-basin Division

The sub-basin classification for the drainage system was referred to in the previous section. The sub-basin division for the storage model follows the division as a rule, since the model simulation includes an analysis of both surface and groundwater systems. However, the drainage sub-basins are sub-divided into smaller divisions in order to provide a more accurate analysis for each spot within the Study Area. To create these sub-division, simple rectangular shapes are taken into consideration, while the minor drainage systems are neglected to make the model as simple as possible.

The surface sub-division for the model is shown in Figure 3.3.6. The area is sub-divided into 32 sub-basins, with an additional four sub-basins on the western side beyond the Kankai River, which plays the role as a mirror domain, and a dummy basin at the lower end of the model area. The Study Area as a whole is subdivided into 37 sub-basins.

(2) Aquifer Modeling

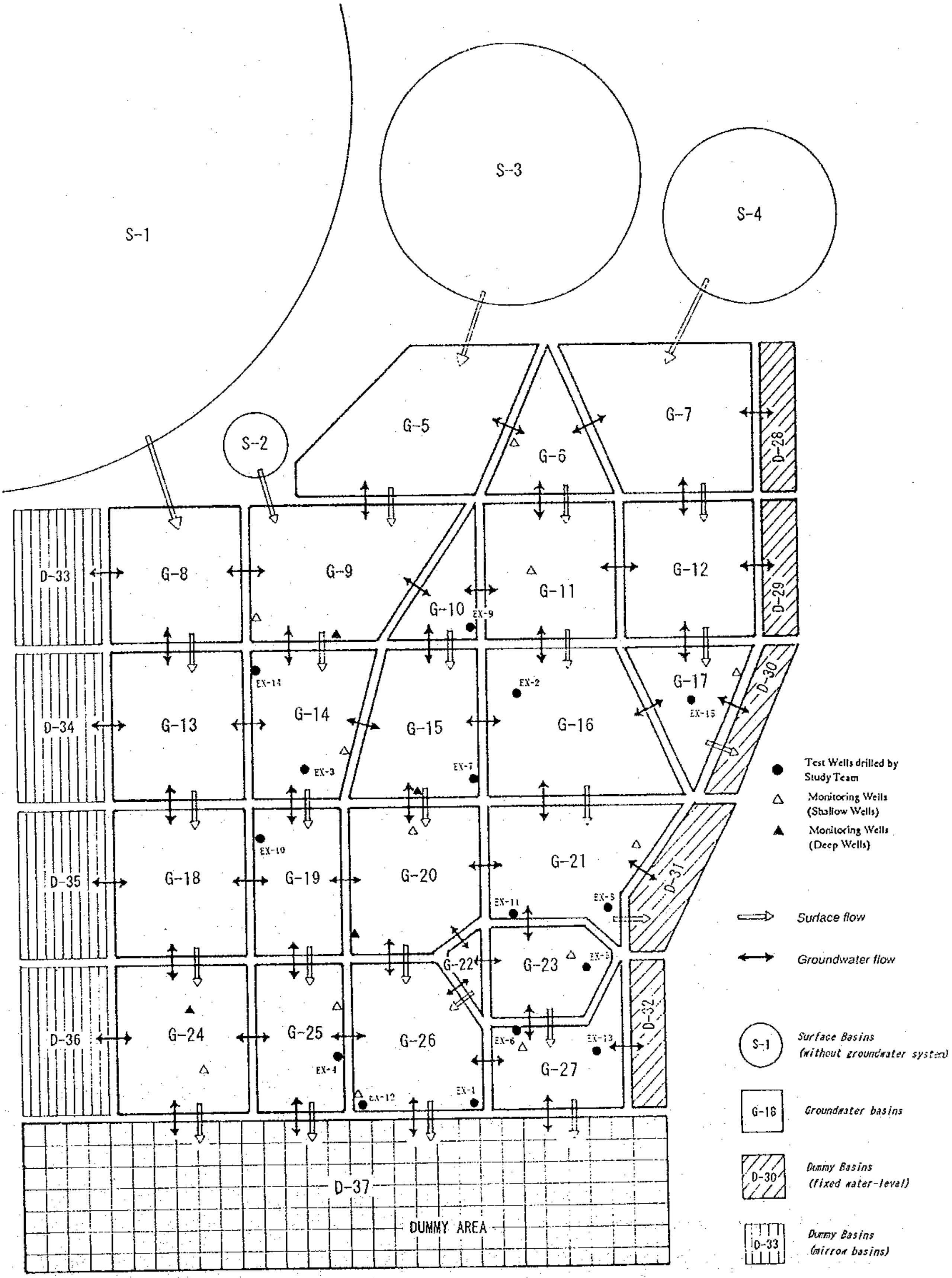
Alluvial deposits in the area can be classified into three aquifers and two aquicludes, as discussed in the previous paragraph, and the Upper Churia is also divided into two aquifers. The same concept is used for the storage model construction as used for the aquifer model as a rule.

In the course of constructing the aquifer model, further detailed considerations must be given to water quality, especially water quality evolution. For example, the groundwater taken from EX-8, EX-5, and EX-6 could be related to each other, but flows down in this order (refer to Figure 3.4.3). The two major groundwater flow systems are as follows:

```
R1.  EX9/EX2 -  EX3 - EX4/EX12 ->
                \ EX11 ->
R2.  EX14 - EX10 ->
```

Among the above, series "R1" can be shifted to "R2" series but this is not reversible because the cations, such as Ca and Mg, contained in the groundwater are reduced by the ion-exchange with clay minerals, except in the case where a special hydrogeological event occurs.

Fig 3.3.6. SUB-BASIN MODEL OF THE AREA



The unconfined aquifer (UAQ in Figure 3.4.6) is sub-divided into two parts, but it is treated as only one aquifer. Two of the confined aquifers (AQ1 and AQ2) have clear confining layers, although AC1 disappears on occasion. In the case of the diluvial aquifers, both B1 and B2 have no obvious confining layers; however, the thick B1 aquifer behaves as a type of confining layer for B2 because the average permeability of B1 is very low. Therefore, B2 is treated as a thick confining layer for B2 in this model, although it consists of some aquifers and aquicludes. Figure 3.3.7 illustrates the construction of a typical cross-section and profile; the entire set of cross-sections and profiles are presented in Appendix 2.

(3) Sub-basin Structures

The aquifer and aquiclude constants given in the simulation program are assumed from the comprehensive study on the results of drilling, pumping tests, groundwater hydrographs, water quality tests, and so forth.
Furthermore, several components of the sub-basin structure, such as the representative surface elevation, thickness and elevation of the aquifers or aquicludes, permeability groups, orifice height, outlet structure and their height, and so on, must be decided for each sub-basin. The initial water head for each aquifer must also must be given to the program. The final sub-basin structures built up through the Study are summarized in Table 3.3.2, although they are revised through the course of the trial runs until the model is identified by the verification data.

(4) Input and Verification Data

The following five inputs and verification data are required for model identification:

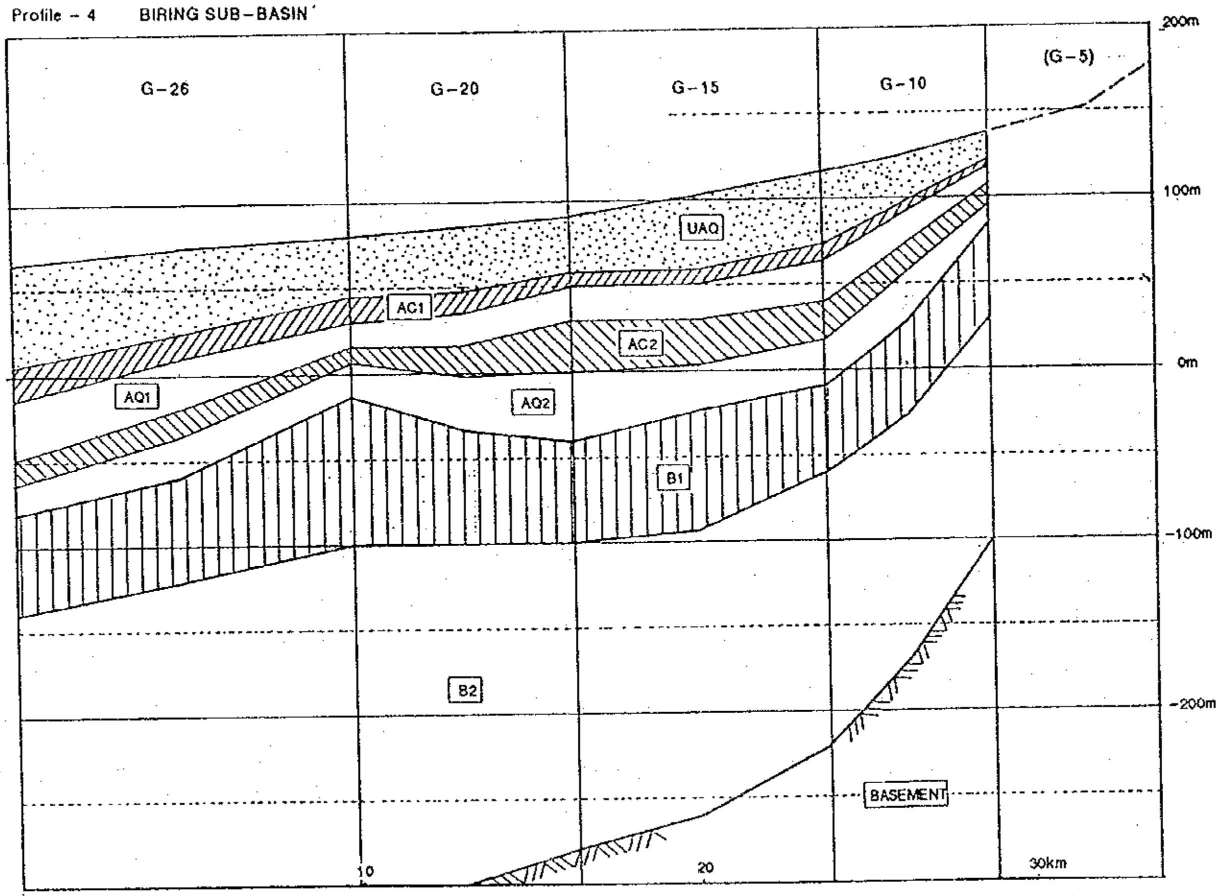
a) input data
- rainfall (daily basis, as long as possible)
- evapotranspiration (mean monthly basis)
- groundwater draft (monthly basis, for each aquifer)

b) verification data
- groundwater hydrograph (daily basis, for each aquifer if available, as long as possible)
- river runoff (daily basis, for each drainage system if available)

In regard to rainfall, annual rainfall data is available for more than 20 years, and daily rainfall data is available for a 14 year period, from 1980 to 1993. For the potential of evapotranspiration, pan evaporation is measured in Tarahara, near the Study Area, and the

Fig 3.3.7. TYPICAL SUB-BASIN STRUCTURE

Profile - 4 BIRING SUB-BASIN



Cross Section - 3 MID - ALLUVIAL ZONE

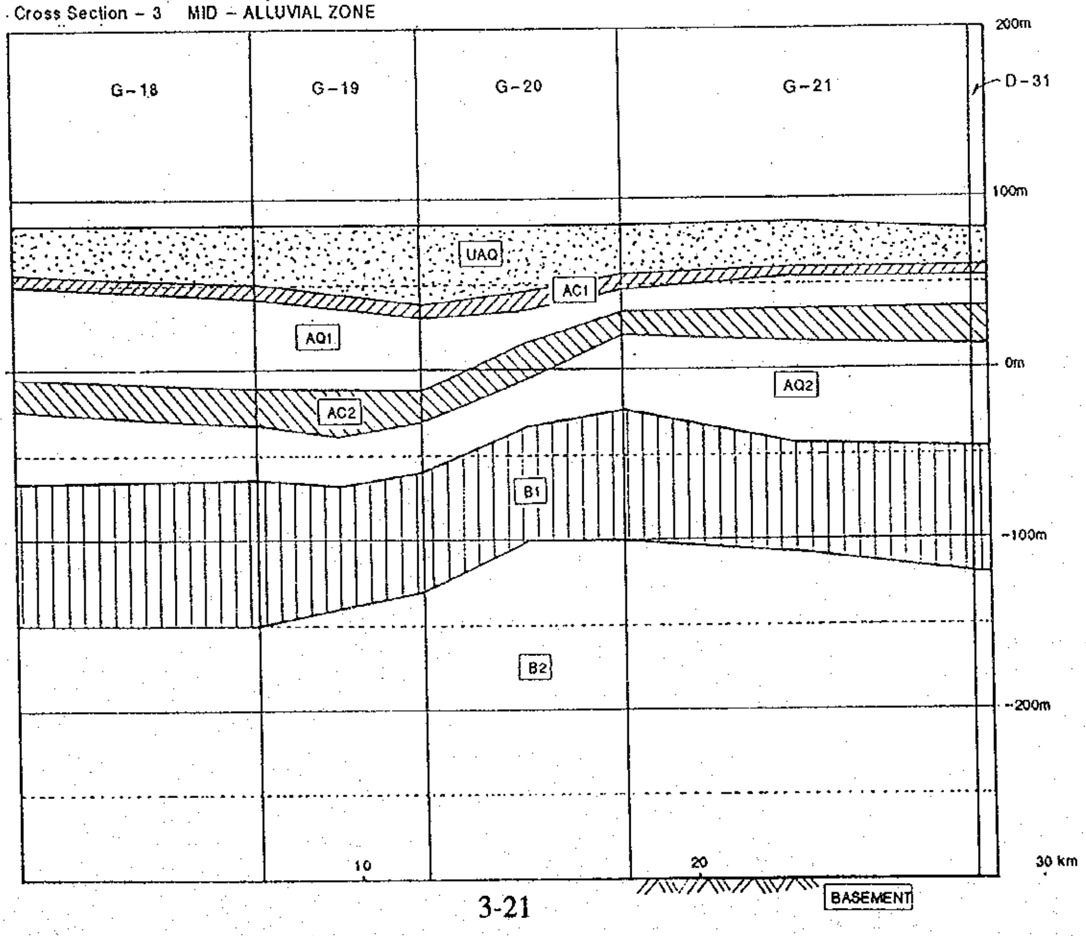


Table 3. 3. 2.　SUB-BASIN STRUCTURES　(Initial Setting)

	Item	S-1	S-2	S-3	S-4	G-5	G-6	G-7	G-8	G-9
	system	Surface	Surface	Surface	Surface	G.water	G.water	G.water	G.water	G.water
	Area	1,180.59	5.22	160.26	66.48	58.98	20.14	111.10	48.36	56.51
	X leng.	r=9.39	r=1.29	r=7.14	r=4.60	8.25	3.50	12.75	8.00	8.63
	Y leng.					7.15	5.75	8.71	6.05	6.55
	surface	750	250	750	750	152	165	183	115	115
	UAQ	–	–	–	–	130	136	156	85	93
e	AC1	–	–	–	–	–	–	156	–	90
l	AQ1	–	–	–	–	–	–	136	–	60
e	AC2	–	–	–	–	84	136	136	84	45
v	AQ2	–	–	–	–	55	115	100	55	20
	B1	–	–	–	–	0	50	45	0	–60
	B2	750	250	750	750	–20	0	0	–20	–150
c	Sur. cont.	G-8	G-9	G-5	G-7	G-9	G-11	G-12	G-13	G-14
o	G.W cont.	–	–	–	–	9,*,6,*	11,*,7,5	12,*,28,6	13,*,9,33	14,5,10,8
	UAQ(h)	–	–	–	–	50	50	50	50	50
P	–"– (v)	–	–	–	–	0.12	0.12	0.12	0.12	0.25
e	AQ1	–	–	–	–	–	–	–	–	25
r	–"– (v)	–	–	–	–	–	–	–	–	0.12
m	AQ2	–	–	–	–	100	100	100	100	100
e	–"– (v)	–	–	–	–	1	1	1	1	1
a	B1	–	–	–	–	10	10	10	10	10
b	–"– (v)	–	–	–	–	5	5	5	5	5
i	B2	–	–	–	–	50	50	50	50	50
	–"– (v)	–	–	–	–	0	0	0	0	0
s	UAQ	–	–	–	–	–	0.08	0.08	0.08	0.08
t	AQ1	–	–	–	–	–	0.0002	0.0002	0.0002	0.0002
o	AQ2	–	–	–	–	–	0.0005	0.0005	0.0005	0.0005
r	B1	–	–	–	–	–	0.00002	0.00002	0.00002	0.00002
e	B2	–	–	–	–	–	0.0001	0.0001	0.0001	0.0001

	Item	G-10	G-11	G-12	G-13	G-14	G-15	G-16	G-17	G-18
	system	G.water	G.water	G.water	G.water	G.water	G.water	G.water	G.water	G.water
	Area	11.32	28.75	48.81	41.30	37.80	37.41	66.74	51.77	44.65
	X leng.	2.25	6.13	11.25	7.00	6.13	5.00	8.00	7.50	7.19
	Y leng.	5.03	4.69	4.43	5.90	6.17	7.48	8.34	6.90	6.21
	surface	125	126	130	98	100	102	100	106	85
	UAQ	98	96	100	68	59	59	71	77	53
e	AC1	92	92	95	62	52	51	60	69	46
l	AQ1	73	73	78	30	25	30	50	60	–7
e	AC2	42	50	58	12	1	3	28	42	–25
v	AQ2	25	36	41	–25	–30	–23	2	15	–60
	B1	–27	–18	–16	–100	–105	–93	–70	–64	–150
	B2	–170	–158	–150	–200	–248	–200	–243	–228	–300
c	Sur. cont.	G-15	G-16	G-17	G-18	G-19	G-20	G-21	D-30	G-24
o	G.W cont.	15,*,11,9	16,6,12,10	17,7,29,11	18,8,14,34	19,9,15,13	20,10,16,14	21,11,17,15	*,12,30,16	24,13,19,35
	UAQ(h)	50	50	50	50	50	50	50	50	50
P	–"– (v)	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25
e	AQ1	25	25	25	25	25	25	25	25	25
r	–"– (v)	0.12	0.12	0.12	0.12	0.12	0.12	0.12	0.12	0.12
m	AQ2	100	100	100	100	100	100	100	100	100
e	–"– (v)	1	1	1	1	1	1	1	1	1
a	B1	10	10	10	10	10	10	10	10	10
b	–"– (v)	5	5	5	5	5	5	5	5	5
i	B2	50	50	50	50	50	50	50	50	50
	–"– (v)	0	0	0	0	0	0	0	0	0
s	UAQ	0.08	0.08	0.08	0.08	0.08	0.07	0.07	0.05	0.05
t	AQ1	0.0002	0.0002	0.0002	0.0002	0.0002	0.0002	0.0002	0.0002	0.0002
o	AQ2	0.0005	0.0005	0.0005	0.0005	0.0005	0.0005	0.0005	0.0005	0.0005
r	B1	0.00002	0.00002	0.00002	0.00002	0.00002	0.00002	0.00002	0.00002	0.00002
e	B2	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001

	Item	G-19	G-20	G-21	G-22	G-23	G-24	G-25	G-26	G-27
	system	G.water	G.water	G.water	G.water	G.water	G.water	G.water	G.water	G.water
	Area	28.09	38.75	59.65	16.94	40.31	55.30	39.30	72.15	54.65
	X leng.	4.88	6.00	10.19	3.75	8.00	7.50	4.69	7.25	8.75
	Y leng.	5.76	6.46	5.85	4.96	5.04	7.37	8.38	9.95	6.25
	surface	85	85	86	100	100	75	75	73	69
	UAQ	44	47	56	36	26	44	34	24	5
e	AC1	36	35	48	22	14	26	18	10	–8
l	AQ1	–11	16	35	–	–	–24	–23	–21	–30
e	AC2	–36	–2	17	–	–	–45	–44	–36	–36
v	AQ2	–68	–34	–44	–40	–50	–92	–78	–60	–70
	B1	–140	–100	–108	–100	–105	–170	–155	–132	–134
	B2	–300	–300	–300	–300	–300	–300	–300	–300	–300
c	Sur. cont.	G-25	G-26	D-31	G-28	G-27	D-37	D-37	D-37	D-37
o	G.W cont.	25,14,20,18	26,15,21,19	23,16,31,20	20,26,23,*	21,27,*,22	37,18,25,36	37,19,26,24	37,20,27,25	37,32,23,2
	UAQ(h)	50	50	50	30	30	50	50	50	50
P	–"– (v)	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25
e	AQ1	25	25	25	25	25	25	25	25	25
r	–"– (v)	0.12	0.12	0.12	0.12	0.12	0.12	0.12	0.12	0.12
m	AQ2	100	100	100	–	–	100	100	100	100
e	–"– (v)	1	1	1	–	–	1	1	1	1
a	B1	10	10	10	10	10	10	10	10	10
b	–"– (v)	5	5	5	5	5	5	5	5	5
i	B2	50	50	50	50	50	50	50	50	50
	–"– (v)	0	0	0	0	0	0	0	0	0
s	UAQ	0.05	0.05	0.05	0.02	0.02	0.05	0.05	0.05	0.05
t	AQ1	0.0002	0.0002	0.0002	0.0002	0.0002	0.0002	0.0002	0.0002	0.0002
o	AQ2	0.0005	0.0005	0.0005	–	–	0.0005	0.0005	0.0005	0.0005
r	B1	0.00002	0.00002	0.00002	0.00002	0.00002	0.00002	0.00002	0.00002	0.00002
e	B2	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001

	Item	D-28	G-29	D-30	D-31	D-32	D-33	D-34	D-35	D-36	D-37
	system	Dummy	Dummy	Dummy	Dummy	Dummy	Dummy	Dummy	Dummy	Dummy	Dummy
	Area	33.60	4.69	9.37	4.82	13.21	56.51	41.30	44.65	55.30	99,999.99
	X leng.	3.56	1.06	1.13	0.50	1.62	8.63	7.00	7.19	7.50	25.00
	Y leng.	9.44	4.43	8.29	9.64	8.16	6.55	5.90	6.21	7.37	99,999.99
	surface	183	129	103	82	65	115	98	85	75	60
	UAQ	156	106	78	60	–8	93	68	53	44	–
e	AC1	156	100	76	54	–16	90	62	46	26	–
l	AQ1	136	84	60	36	–40	60	30	–7	–24	–
e	AC2	125	70	44	14	–41	45	12	–25	–45	–
v	AQ2	100	48	16	–46	–100	20	–25	–60	–92	–
	B1	50	–16	–64	–120	–150	–60	–100	–150	–170	–
	B2	–20	–150	–220	–300	–300	–150	–200	–300	–300	–
c	Sur. cont.	–	–	–	–	–	–	–	–	–	–
o	G.W cont.	*,*,*,7	*,*,*,12	*,*,*,17	*,*,*,21	*,*,*,27	*,*,8,*	*,*,13,*	*,*,18,*	*,*,24,*	–
	UAQ(h)	–	–	–	–	–	50	50	50	50	
	–"– (v)	–	–	–	–	–	0.12	0.25	0.25	0.25	
	AQ1	–	–	–	–	–	–	25	25	25	
	–"– (v)	–	–	–	–	–	–	0.12	0.12	0.12	
	AQ2	–	–	–	–	–	100	100	100	100	
	–"– (v)	–	–	–	–	–	1	1	1	1	
	B1	–	–	–	–	–	10	10	10	10	
	–"– (v)	–	–	–	–	–	5	5	5	5	
	B2	–	–	–	–	–	50	50	50	50	
	–"– (v)	Fixed water level		–	–	–	0	0	0	0	
s	UAQ	180	125	100	77	63	0.08	0.08	0.05	0.05	
t	AQ1	156	110	90	80	63	0.0002	0.0002	0.0002	0.0002	
o	AQ2	156	110	85	80	65	0.0005	0.0005	0.0005	0.0005	
r	B1	136	110	80	75	70	0.00002	0.00002	0.00002	0.00002	
e	B2	136	110	90	80	70	0.0001	0.0001	0.0001	0.0001	