CHAPTER 3 PROSPECTING METHOD

CHAPTER 3 PROSPECTING METHOD

3.1 Survey of Existing Wells

Existing wells in both Quetta and Kalat Areas were investigated, and data such as well structure, pumpage and amount of drawdown were collected. These basic data were used in tritium analysis to clarify the state of groundwater flow or storage, to establish detection reference of groundwater veins for the aerial gamma-ray prospecting and to obtain specific capacities from gamma-ray intensity.

The location and the measurements of existing wells where preliminary surveys were executed are summarized in FIGs 3.1 and 3.2 and TABLE 3.1. The figures in the table show that hydraulic features vary largely according to the location of the wells. The wells having good hydraulical characteristics have good correlation with the groundwater veins.

3.2 Aerial Selective Gamma-ray Prospecting

3.2.1 Flow of Aerial Prospecting

An overall work flow chart of aerial prospecting is given in FIG. 3.3. A flow chart of site aerial prospecting work is given in FIG. 3.4. The site prospecting work consists of the preliminary survey and the main survey.

The preliminary survey, which is mentioned in detail in the following section, consists of the selection of selective gamma-ray and survey of specific capacity. In the main survey, verification whether the surveyed gamma-ray values were recorded completely or not was done by printing the surveyed values immediately after prospecting each prospecting line. If any error was discovered, the line was prospected once more.

3.2.2 Selection of Selective Gamma-ray and Survey of Specific Capacity

Taking the topographical structures of this area into account, the preliminary aerial prospecting to determine the detective gamma-ray energy was executed by examining the groundwater in fissured bedrock and in the Quaternary sedimentation above the bedrock.

According, it was determined that 1 ch gamma-rays, which had a strong correlativity with the specific capacity of groundwater was very effective in the detection of gamma-rays by aerial prospecting among the gamma-rays from 150 to 3,200 KeV.

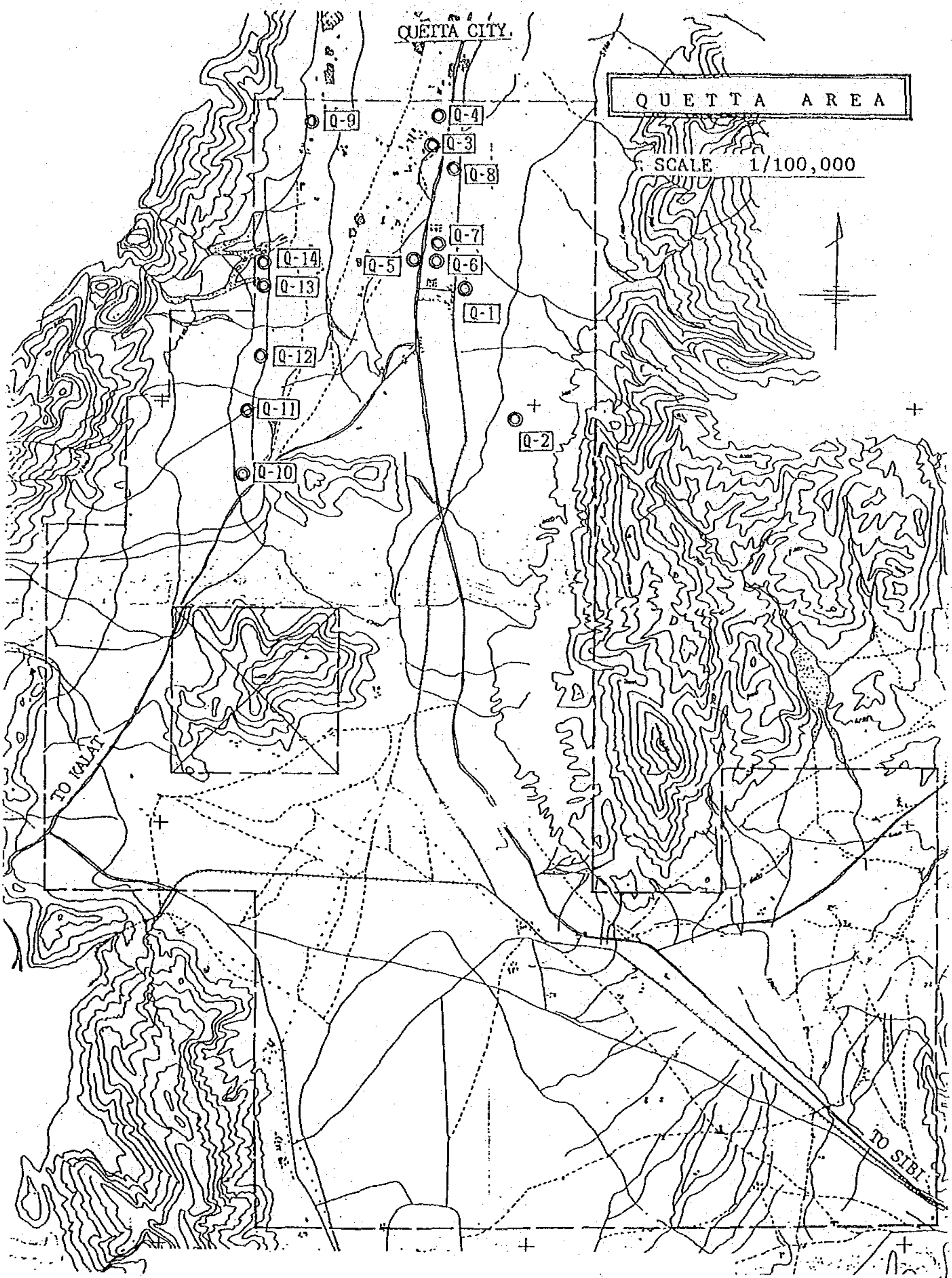


FIG. 3.1 LOCATION OF SURVEYED EXISTING WELL, QUETTA AREA

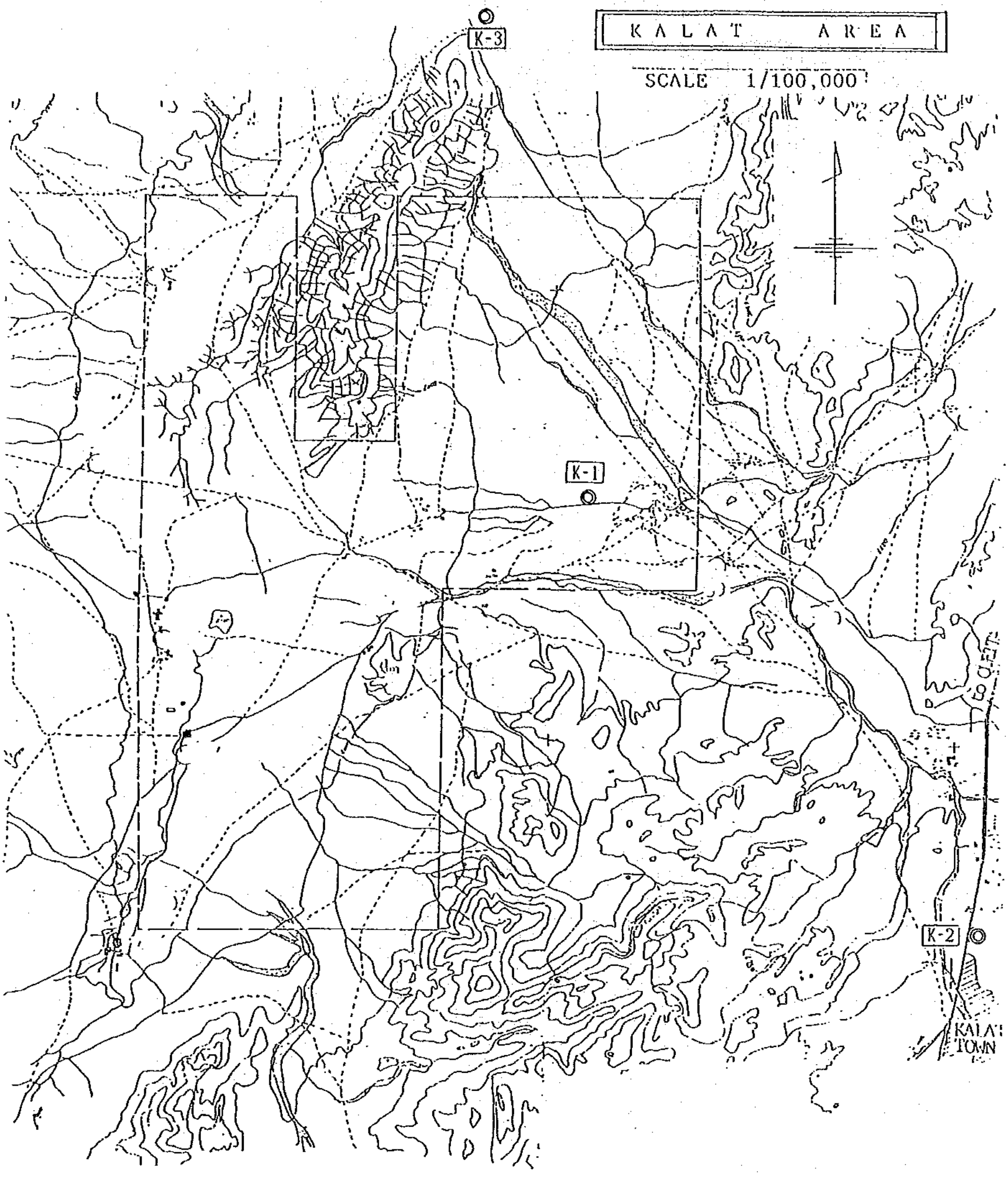


FIG. 3.2 LOCATION OF SURVEYED EXISTING WELL, KALAT AREA

TABLE 3.1 EXISTING TUBE WELLS

QUETTA AREA

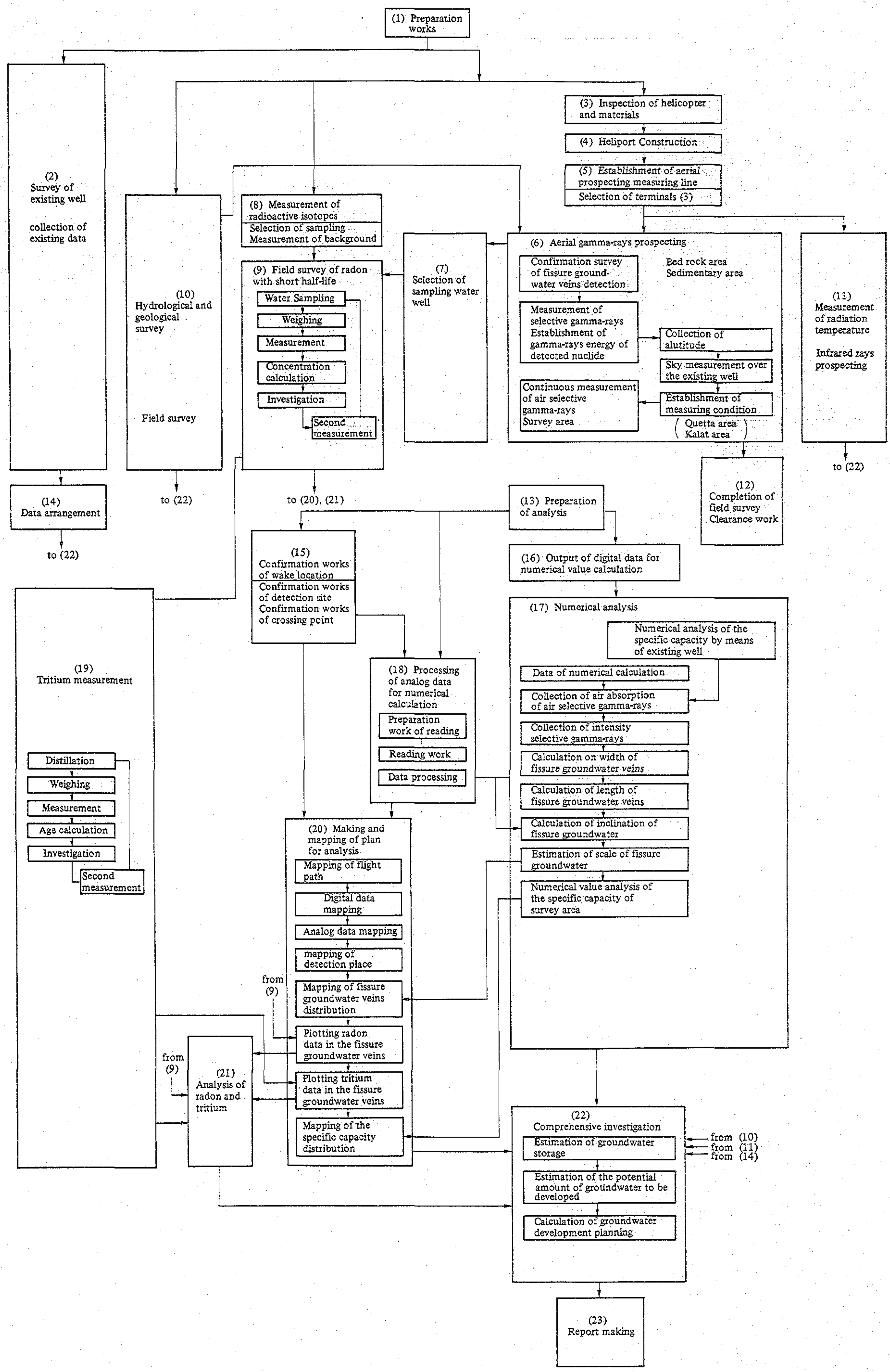
Well No.	Total Depth (m)	Dia Housing Blind (cm)	Screen Dia (cm)	Screen Setting (m)	Screen Length (m)	Static Water Level (m)	Discharge (m³/min)	Draw-down (m)
1.	2.	3.	4.	5.	6.	7.	8.	9.
MP-2- 6	95.7	25.4	25.4	50.0- 95.7	45.7	38.1	1.514	39.6
MP-2-34	297.5	25.4	25.4	135.6-145.4 239.9-249.6 259.7-291.4	51.2	38.4	0.454	62.2
QV-3- 1	144.5	20.3	20.3	77.4-144.5	67.1	21.9	0.625	29.0
QV-3-11	101.2	30.5			34.1	18.3	0.379	24.4
QV-4-64	92.4	20.3	20.3	74.1- 92.4	18.3	21.3	0.303	30.5
QV-4-103	144.2	25.4	25.4	27.4- 45.7 51.8- 71.6 88.4- 96.0 115.8-121.9 137.2-141.1	55.8	27.4	0.439	13.7
QV-4-104	95.7	25.4	25.4	27.4- 32.0	39.3	27.4	0.568	45.7
QV-4-109	–	25.4		Data not available		28.0	0.265	Data not available
CP-2- 7	103.3	25.4	20.3	42.4- 48.5 53.6- 68.9 77.1- 80.2 95.4- 98.5	27.4	13.2	0.946	20.8
CP-2-32	122.5	25.4	25.4	82.3-117.3	35.1	56.7	0.556	15.8
CP-2-34	197.2	30.5	30.5/20.3	64.9-125.0 164.0-193.9	105.8	44.5	1.931	29.9
CP-2-35	195.7	30.5	30.5/20.3	65.8-103.9 125.0-192.9	106.1	45.7	1.760	46.0
CP-2-36	193.2	30.5	20.3	110.9-128.9 133.2-157.3 158.8-190.2	73.5	65.8	1.325	49.8
CP-2-37	195.4	30.5	20.3	73.5-127.4 132.9-138.4 142.6-184.7 188.7-194.8	107.9	54.3	1.696	4.3

KALAT AREA

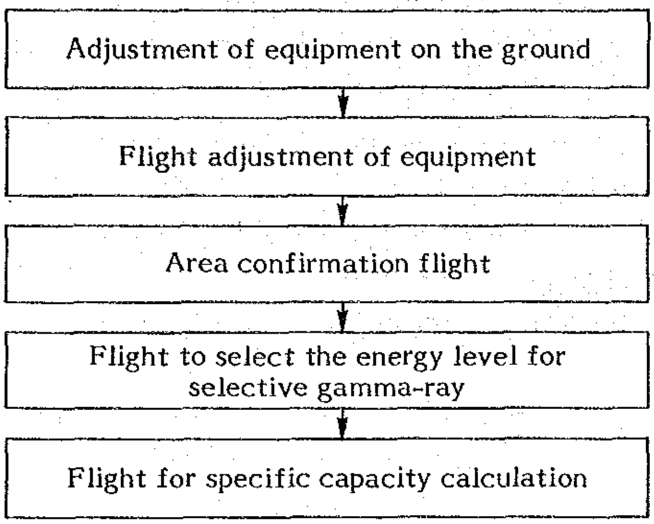
Well No.	Total Depth (m)	Dia Housing Blind (cm)	Screen Dia (cm)	Screen Setting (m)	Screen Length (m)	Static Water Level (m)	Discharge (m³/min)	Draw-down (m)
1.	2.	3.	4.	5.	6.	7.	8.	9.
UN-KL-4	205.7	20.3	20.3	115.8-103.6 140.2-152.4 161.5-185.9	15.2 12.2 24.4	54.6	0.102	9.8
UN-KL-5	116.4	20.3	20.3	27.4- 47.2 53.3- 64.0	19.8 10.7	13.8	0.379	1.5
UN-KL-3	169.8	20.3	20.3 10.2	61.0- 77.7 100.6-137.2	16.8 36.6	47.3	0.485	4.3

Source: WAPDA

FIG. 3.3 GENERAL FLOW CHART OF AERIAL GAMMA-RAY PROSPECTING



1. Preliminary Survey



2. Main Survey

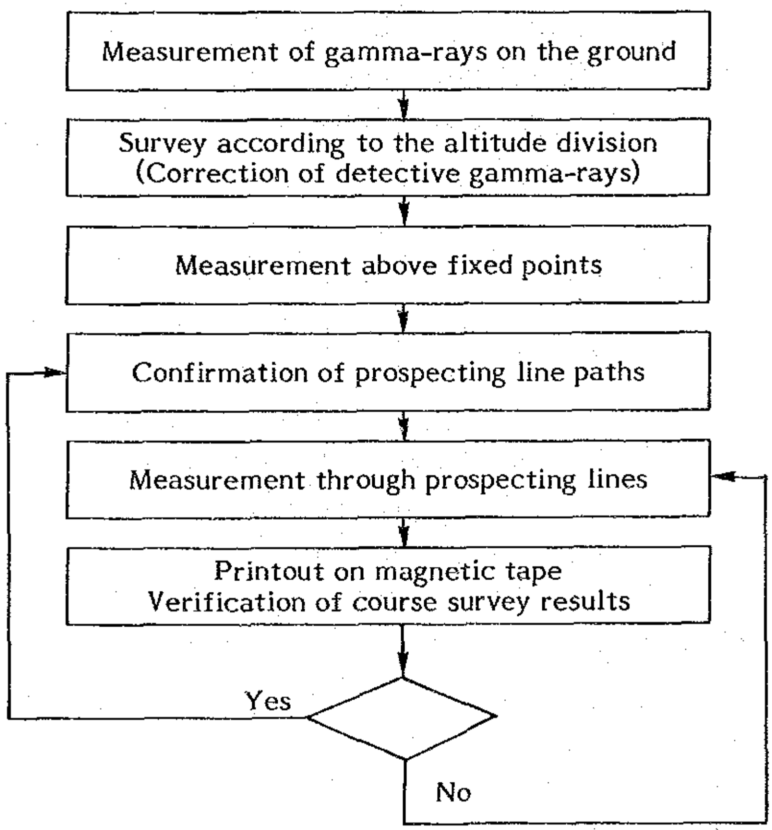


FIG. 3.4 FLOW CHART OF SITE AERIAL PROSPECTING WORK

Additionally, it became clear that gamma-rays of 2 ch and 3 ch were also useful as auxiliary rays. Thus in this survey, gamma-rays of 1 ch were primarily surveyed and 2 ch and 3 ch gamma-rays were also used as auxiliary rays.

The flight to estimate specific capacity is a basic research method designed to learn the specific capacity from aerial gamma-ray intensities. The relationship between gamma-ray intensity and specific capacity is clarified using the results of gamma-ray survey above the existing wells from where specific capacities have been obtained. The specific capacity mentioned here, whose unit is $m^3/d/m$, is a value calculated by dividing pumpage (m^3/d) by drawdown of wells (m) at a time when pumping levels are stable.

As for the relationship between gamma-ray intensity and specific capacity, the gamma-ray of 1 ch shows the highest positive correlativity (correlation coefficient in Quetta: 88%and in Kalat: 99.5%).

3.3 Measurement of Radioisotope

To clarify groundwater flow and the possible yield of groundwater development, the concentration of radon (^{222}Rn) with a short half-life and tritium (^{3}H) with a middle half-life contained in the groundwater was measured.

3.3.1 Radon

The water samples for measurement were collected from both inside and outside the survey areas. In the Quetta Area, water samples were obtained from 37 places in total, which include 14 open wells, 21 tube wells, one spring and one flat pond temporarily formed due to heavy rainfall in August 1986. In the Kalat Area, on the other hand, since there were fewer practical wells, water samples were obtained from 15 places in total, including 12 open wells, one tube well and 2 springs.

From the fact that the half-life of radon is as short as 3.825 days and that its configuration is gaseous, chemical treatment was performed in the field and the radon was sealed in a 25 ml glass vial for quick measurement in a heli-pad laboratory. For the measurement, a portable liquid scintillation counter (S-1287B) was used, and a 10-minute and 2-line repeated measurement was adopted.

The locations of water sampling in both areas are shown in FIGs 3.5 and 3.6.

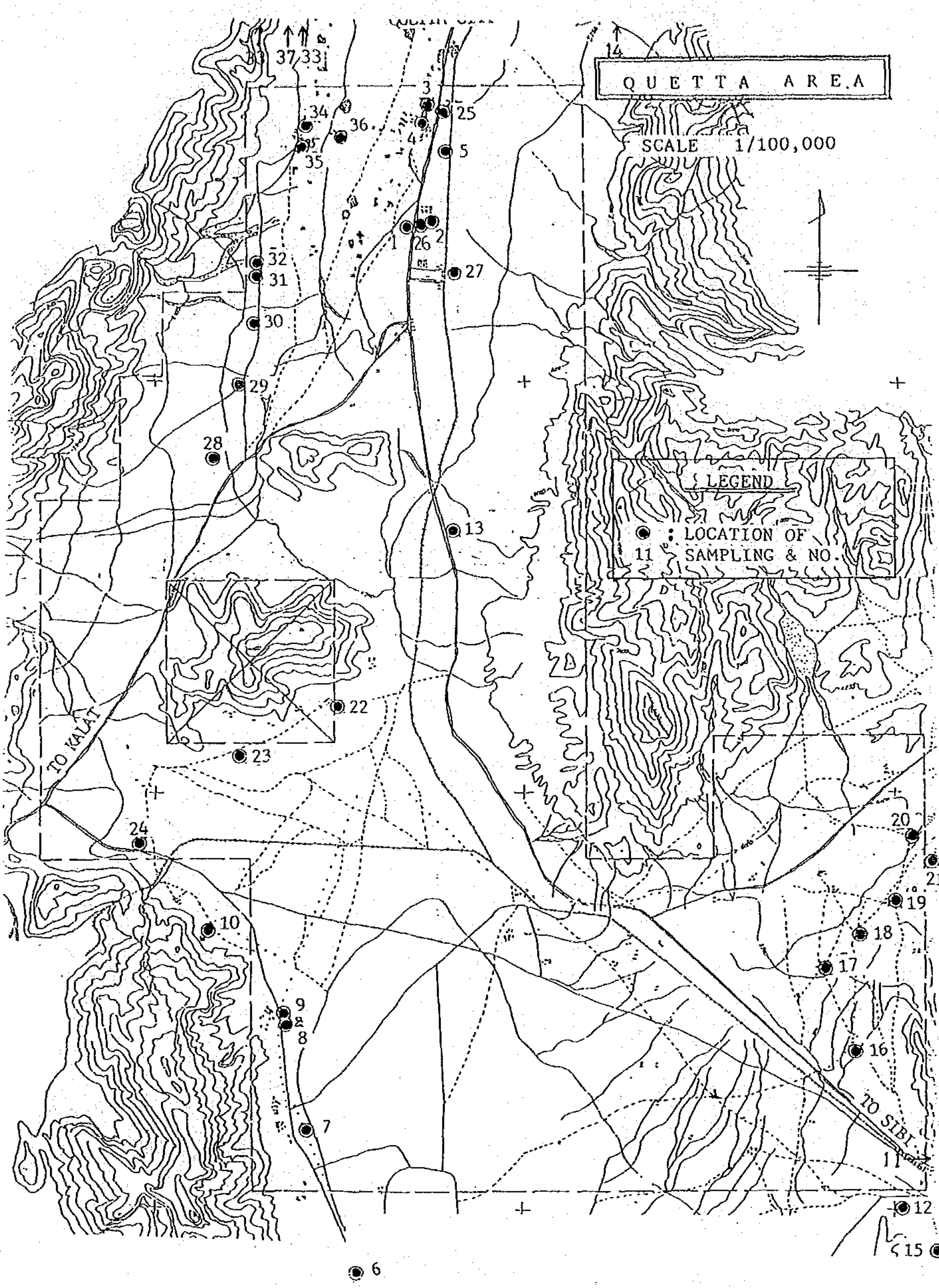


FIG. 3.5 LOCATION OF WATER SAMPLING, QUETTA AREA

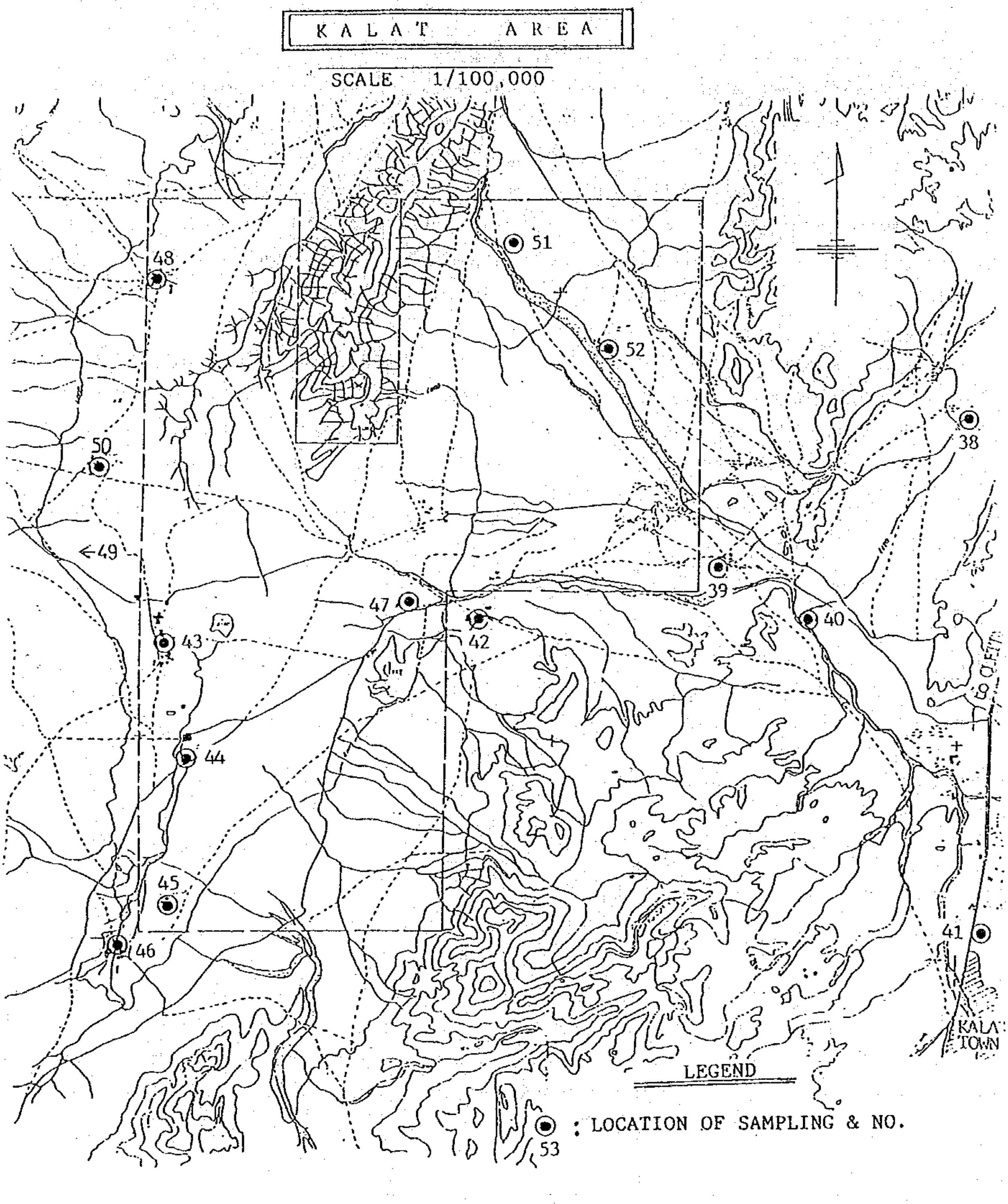


FIG. 3.6 LOCATION OF WATER SAMPLING, KALAT AREA

3.3.2 Tritium

The locations of water sampling for tritium measurement are the same as for radon measurement in both areas; that is, the water samples were collected from 37 places in the Quetta Area and 15 places in the Kalat Area. These water samples were collected simultaneously with the radon water samples; 500 ml of water was sampled, sealed and stored in a polyethylene vial.

Since the half-life of tritium is as long as 12.262 years, measurement was conducted after the samples were brought to Japan. For this measurement, firstly, in order to remove impurities, the total amount (500 ml) of water collected was distilled in a glass distiller. Next, 40 ml of the distilied sample was accurately weighed, then mixed with 60 ml of AQUASOL-II which is a scintillator.*1 The sample was left to stand in a dark place for 24 hours, and then measured using a liquid scintillation counter. This measurement was repeated for 100 minutes in order to obtain more accurate data.

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*1 H. Kawasaki and S. Kimura: "Yatabe precipitation tritium content", Technical report of National Research Institute of Agricultural Engineering, Japan, No. 24, 1981

CHAPTER 4 ANALYTICAL METHOD

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4.1 Aerial Selective Gamma-ray Prospecting

4.1.1 Numerical Analysis

Prior to numerical analysis, the intensity of measured aerial gamma-rays was corrected in order to correspond to that of 100m above the ground. One example of the original intensity of gamma-rays is shown in TABLE 4.1. When geometrical relief caused the standard height to be adjusted, the gamma-ray count was corrected using a radar altimeter to determine the height above the ground. For the correction factor, the values measured for the different heights were employed.

4.1.2 Detection of Groundwater Vein/Zone and Evaluation of Its Scale

After the flight route was checked using the prospecting line video and the intensity of selective gamma-rays was corrected, the following numerical analysis was conducted to detect the groundwater veins/zones.

Since the scale of groundwater veins/zones is large and the intensity of detected gamma-rays increases proportionally as the specific capacity becomes larger,[*1] the distribution curve of 3 detected gamma-rays was extracted. Using a computer, the peak intensity from which surrounding gamma-rays were eliminated, the photoelectric area, detection width, detection position and the intensity distribution ratio of 3 types of gamma-rays were calculated. Finally, an evaluation of the scale of the groundwater veins/zones was comprehensively made. The overall evaluation was classified into 4 rank, A, B, C and D, in the order of a large scale groundwater veins/zones.

One example of this evaluation result is shown in TABLE 4.2 The last symbol in the table indicates the overall evaluation. When the overall evaluation corresponds to Ranks A and B, the size of the groundwater vein/zone and its specific capacity is great. Therefore, a large scale groundwater development is regarded as being feasible. In contrast to the above, when it falls within Ranks C and D, it follows that the size of the groundwater vein/zone is small and consequently, the specific capacity is also small. The limited utilization of groundwater should be considered.

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*1 T. Ochiai: "R.I. utilization method", Groundwater handbook, Building industry survey committee, P1163, 1979

TABLE 4.1 AERIAL SELECTIVE GAMMA-RAY MEASUREMENT VALUE (EXAMPLE)

Area :QUETTA-A EW-1 Date :1/10/86

Course No.	Time (sec.)	1ch (cps)	2ch (cps)	3ch (cps)	Cch (cps)	Altitude (ft)
2	1	194	38	23	298	484.6
2	2	214	51	14	278	504.2
2	3	218	63	19	275	505.0
2	4	180	50	31	290	492.2
2	5	201	42	23	279	474.0
2	6	187	48	27	284	427.3
2	7	201	50	30	296	358.9
2	8	188	59	31	285	312.3
2	9	187	54	22	299	301.8
2	10	184	65	25	277	322.8
2	11	191	48	29	279	347.2
2	12	195	43	26	275	328.6
2	13	205	71	33	280	326.7
2	14	221	46	17	267	325.9
2	15	221	52	15	288	322.1
2	16	215	46	21	291	312.1
2	17	232	61	32	306	305.0
2	18	212	47	26	315	297.4
2	19	206	57	27	324	292.2
2	20	189	82	25	286	286.5
2	21	210	50	33	333	281.8
2	22	207	69	28	288	278.3
2	23	206	75	34	307	273.9
2	24	212	69	25	291	272.7
2	25	217	61	26	291	274.5
2	26	225	73	27	287	276.3
2	27	204	66	25	307	280.1
2	28	226	73	29	282	253.0
2	29	232	82	25	328	211.7
2	30	276	66	30	269	253.8
2	31	262	83	26	304	300.4
2	32	274	79	28	328	304.7
2	33	252	92	24	312	309.7
2	34	279	79	22	311	315.0
2	35	271	86	34	314	320.8
2	36	263	81	22	311	323.1
2	37	278	79	28	325	327.7
2	38	273	90	38	320	326.6
2	39	298	82	26	333	325.0
2	40	267	99	35	327	327.4
2	41	220	69	28	281	327.6
2	42	264	93	20	294	282.0
2	43	254	97	27	296	272.8
2	44	252	86	33	339	304.5
2	45	277	90	37	336	334.0
2	46	265	91	28	292	342.4
2	47	258	85	36	317	344.1
2	48	277	88	32	302	341.3
2	49	249	68	26	333	343.6
2	50	283	92	29	321	343.2
2	51	281	83	27	324	339.8
2	52	281	94	30	300	332.7
2	53	268	71	31	318	326.1
2	54	292	68	30	331	315.6
2	55	268	75	21	291	308.2

TABLE 4.2 AERIAL SELECTIVE GAMMA-RAY PROSPECTING EVALUATION (EXAMPLE)

Quetta - A area

Course	NO	Time	1CH P	R	P1	Pkm	P2	W	R	S	R	B.G	2CH P	R	S	B.G	3CH P	S	B.G	A/B	A/C	TR
EW-1	1	33	280	C	0.83	0.83	0.85	0.03	D	280	D	276	80	C	80	91	22	22	33	3.50	12.73	D
	2	36	280	C	0.90	0.90	0.93	0.03	D	280	D	276	81	C	81	91	28	28	33	3.46	10.00	D
	3	38	300	B	0.95	0.95	0.98	0.03	D	300	D	276	84	C	84	91	26	26	33	3.57	11.54	D
	4	44	279	C	1.10	1.10	1.13	0.03	D	279	D	276	93	C	93	91	37	37	33	3.00	7.54	D
	5	47	280	C	1.18	1.18	1.20	0.03	D	280	D	276	91	C	91	91	32	32	33	3.08	8.75	D
	6	49	286	C	1.23	1.28	1.30	0.08	B	853	B	276	96	B	277	91	30	86	33	3.08	9.92	B
	7	53	293	C	1.33	1.33	1.35	0.03	D	293	D	276	68	C	68	91	30	30	33	4.31	9.77	D
	8	55	298	B	1.38	1.38	1.43	0.05	C	586	C	276	101	B	190	91	35	64	33	3.08	9.16	C
	9	58	290	C	1.45	1.45	1.48	0.03	D	290	D	276	74	C	74	91	22	22	33	3.92	13.18	D
	10	61	281	C	1.53	1.53	1.55	0.03	D	281	D	276	86	C	86	91	30	30	33	3.27	9.37	D
	11	66	294	B	1.65	1.65	1.68	0.03	D	294	D	276	100	B	100	91	31	31	33	2.94	9.48	C
	12	69	293	C	1.73	1.73	1.75	0.03	D	293	D	276	100	B	100	91	32	32	33	2.93	9.16	D
	13	73	302	B	1.83	1.83	1.88	0.05	C	585	C	276	104	B	201	91	33	70	33	2.91	8.36	C
	14	76	294	B	1.90	1.90	1.95	0.05	C	586	C	276	92	C	183	91	40	62	33	3.20	9.45	C
	15	79	303	B	1.98	1.98	2.00	0.03	D	303	D	276	100	B	100	91	33	33	33	3.03	9.18	C
	16	81	306	B	2.03	2.03	2.05	0.03	D	306	D	276	88	C	88	91	24	24	33	3.48	12.75	D
	17	84	287	C	2.10	2.13	2.15	0.05	C	576	C	276	88	C	176	91	28	53	33	3.27	10.87	C
	18	87	309	B	2.18	2.18	2.20	0.03	D	309	D	276	93	C	93	91	31	31	33	3.32	9.97	D
	19	91	276	B	2.28	2.28	2.33	0.05	C	584	C	276	86	C	169	91	36	57	33	3.46	10.25	C
	20	101	299	B	2.53	2.53	2.58	0.05	C	592	C	276	110	B	191	91	36	63	33	3.10	9.40	C
	21	113	301	B	2.83	2.85	2.75	0.13	A	1439	A	276	87	C	426	91	37	142	33	3.38	10.13	B
	22	119	277	C	2.98	2.98	3.00	0.03	D	277	D	276	102	B	102	91	28	28	33	2.72	9.89	D
	23	121	299	B	3.03	3.03	3.13	0.10	A	1158	A	276	99	B	368	91	31	116	33	3.15	9.98	A
	24	126	323	B	3.15	3.20	3.23	0.08	B	897	B	276	109	B	274	91	36	87	33	3.27	10.31	B
	25	130	288	C	3.25	3.30	3.33	0.08	B	848	B	276	92	C	266	91	37	104	33	3.19	8.15	C
	26	135	290	C	3.38	3.40	3.43	0.05	C	570	C	276	97	B	175	91	32	62	33	3.26	9.19	C
	27	141	301	B	3.53	3.58	3.60	0.08	B	877	B	276	100	B	272	91	33	90	33	3.22	9.74	B
	28	145	278	C	3.63	3.63	3.65	0.03	D	278	D	276	76	C	76	91	31	31	33	3.66	8.97	D
	29	147	287	C	3.68	3.70	3.73	0.05	C	573	C	276	89	C	160	91	31	60	33	3.58	9.55	C
	30	153	283	C	3.83	3.83	3.85	0.03	D	283	D	276	103	B	103	91	26	26	33	2.75	10.88	D
	31	155	286	C	3.88	3.88	3.93	0.05	C	571	C	276	103	B	202	91	33	56	33	2.83	10.20	C
	32	158	295	B	3.95	4.00	4.03	0.08	B	861	B	276	99	B	248	91	33	86	33	3.47	10.01	B
	33	162	294	B	4.05	4.10	4.15	0.10	A	1149	A	276	89	C	334	91	35	119	33	3.44	9.66	B
	34	167	300	B	4.18	4.18	4.33	0.15	A	1725	A	276	101	B	549	91	34	173	33	3.16	10.03	A
	35	175	276	B	4.38	4.38	4.45	0.08	B	863	B	276	104	B	288	91	33	82	33	3.00	10.52	B
	36	179	301	B	4.48	4.48	4.50	0.03	D	301	D	276	96	B	96	91	34	34	33	3.14	8.85	C
	37	181	306	B	4.53	4.58	4.78	0.25	A	2904	A	276	105	B	883	91	39	311	33	3.29	9.34	A
	38	193	299	B	4.83	4.85	4.88	0.05	C	576	C	276	89	C	178	91	29	48	33	3.24	12.00	C
	39	196	303	B	4.90	4.98	5.05	0.15	A	1738	A	276	96	B	489	91	33	167	33	3.55	10.41	A
	40	203	293	C	5.08	5.08	5.10	0.03	D	293	D	276	95	B	95	91	37	37	33	3.08	7.92	D

The results of overall evaluation for these detected points are plotted on a 1/50,000 topographic map in order to find a continuous groundwater vein. The detected blocklike vein which is limited to a given range is here defined as the stagnant groundwater zone.

4.1.3 Calculation of Specific Capacity

The values of the specific capacity of the respective groundwater veins/zones are calculated on the basis of the intensity of selective aerial gamma-rays, using the method described in para. 3.2.2 as follows:

$$S.C. = 232.1\ N - 214.1 \text{ (for Quetta Area)}$$

$$S.C. = 849.1\ N - 852.6 \text{ (for Kalat Area)}$$

where, S.C.: Specific capacity ($m^3/d/m$ in case of ϕ250mm well);

N: Intensity of selective gamma-ray/intensity of basic gamma-ray

One example of calculation of S.C. is shown in TABLE 4.3. In the determination of constants of the above equation, the values of S.C. of existing wells listed in TABLE 3.1 were applied as the basic data after confirming enough reliability of data through investigation of the mechanism of and relationship between pumpage and drawdown about the accuracy of the estimated S.C. in the case of the deep wells.

4.1.4 Groundwater Vein Dip

For some continuous veins with an almost constant width, the groundwater vein dip is calculated. These groundwater veins are assumed to be veins which are related with fractured zones.

In the analysis of the groundwater vein dip, the gamma-ray intensity distribution curve is used, and a statistical technique is applied for its computer analysis. The diagram for judging the groundwater vein dip is shown in FIG. 4.1. When the groundwater vein dips on the forward side in the flight direction, a rightward inclined gamma-ray intensity distribution is produced; while in the reverse dip, a leftward inclined gamma-ray intensity distribution is produced.

TABLE 4.3 SPECIFIC CAPACITY CALCULATION (EXAMPLE)

```
**  ﾁｸﾒｲ*1  **  QUETTA-A
   ------------------------
------------------------------

Nﾉﾍｲｷﾝ*2 =  *3 1.11825
S. Cﾉﾍｲｷﾝ=  45.39
ｶﾞﾝﾏ*4 = .879769

 ｿｸｾﾝ*5 No.EW-1
 -------------------

  1  N= 1.01449  S. C= 21.312
  2  N= 1.01449  S. C= 21.312
  3  N= 1.08696  S. C= 38.128
  4  N= 1.01087  S. C= 20.4712
  5  N= 1.01449  S. C= 21.312
  6  N= 1.03623  S. C= 26.3568
  7  N= 1.06159  S. C= 32.2424
  8  N= 1.07971  S. C= 36.4464
  9  N= 1.05072  S. C= 29.72
 10  N= 1.01812  S. C= 22.1528
 11  N= 1.06522  S. C= 33.0832
 12  N= 1.06159  S. C= 32.2424
 13  N= 1.0942   S. C= 39.8096
 14  N= 1.06522  S. C= 33.0832
 15  N= 1.09783  S. C= 40.6504
 16  N= 1.1087   S. C= 43.1728
 17  N= 1.0471   S. C= 28.8792
 18  N= 1.11957  S. C= 45.6952
 19  N= 1.07246  S. C= 34.7648
 20  N= 1.08333  S. C= 37.2872
 21  N= 1.09058  S. C= 38.9688
 22  N= 1.00362  S. C= 18.7896
 23  N= 1.08333  S. C= 37.2872
 24  N= 1.17029  S. C= 57.4664
 25  N= 1.04348  S. C= 28.0384
 26  N= 1.05072  S. C= 29.72
 27  N= 1.09058  S. C= 38.9688
 28  N= 1.00725  S. C= 19.6304
 29  N= 1.03986  S. C= 27.1976
 30  N= 1.02536  S. C= 23.8344
 31  N= 1.03623  S. C= 26.3568
 32  N= 1.06884  S. C= 33.924
 33  N= 1.06522  S. C= 33.0832
 34  N= 1.08696  S. C= 38.128
 35  N= 1.07246  S. C= 34.7648
 36  N= 1.09058  S. C= 38.9688
 37  N= 1.1087   S. C= 43.1728
 38  N= 1.08333  S. C= 37.2872
 39  N= 1.11594  S. C= 44.8544
 40  N= 1.06159  S. C= 32.2424
```

NOTE: *1 BLOCK NAME
*2 MEAN VALUE OF NAME N
*3 MEAN VALUE OF SPECIFIC CAPACITY
*4 CORRELATION COEFFICIENT
*5 PROSPECTING LINE

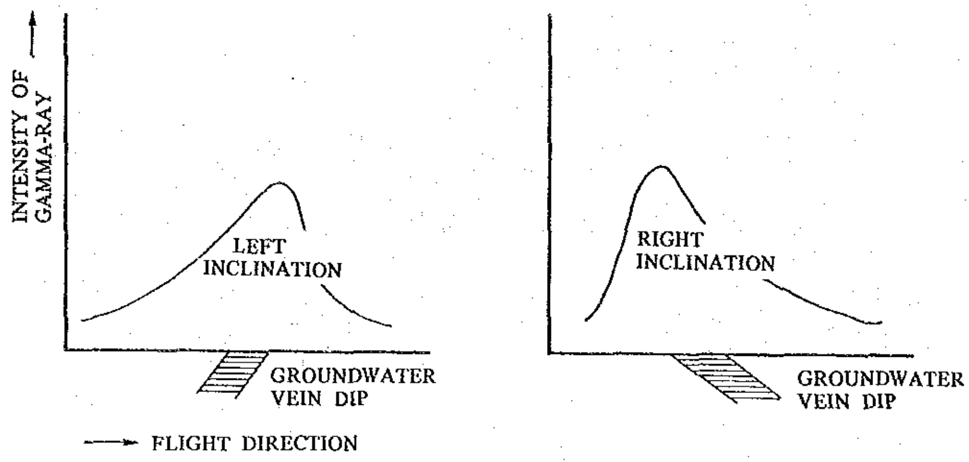

FIG. 4.1 GROUNDWATER VEIN DIP JUDGING DIAGRAM

4.2 Radioisotope

4.2.1 Radon

Since its half-life is as short as 3.825 days, Radon is an effective tracer for a hydrologic water cycle of approx. one day to one month. Due to its short half-life, the decay time between water sampling and measurement time was corrected to produce a true value. The measured value is expressed in terms of a ratio to N (background count). Samples No. 15 (Quetta) and Nos 44 and 45 (Kalat) contained a lot of suspended organic matter and silt particles; thereby obstructing luminance of scintillater and making it impossible to obtain accurate data of radon.

4.2.2 Tritium

Tritium concentration is assessed based on the start of nuclear tests in 1954 when the tritium concentration in the air increased abnormally. Therefore, the age of groundwater before 1954 is indicated as O (an old type of groundwater); while its age after 1954 is indicated as N (a new type of groundwater).

CHAPTER 5 RESULTS OF ANALYSIS

CHAPTER 5 RESULTS OF ANALYSIS

5.1 Aerial Selective Gamma-ray Prospecting

5.1.1 Distribution of Groundwater Vein/Zone

5.1.1.1 Quetta Area

(1) Moving groundwater

FIG. 5.1 shows the distribution of the groundwater veins/zones prepared as the result of analysis.

The moving groundwater vein detected in the Quetta Area are four (4), A, B, C and E as shown in TABLE 5.1.

TABLE 5.1 MOVING GROUNDWATER VEIN, QUETTA AREA

No.	Vein Name	Vein Length in Area (km)	Vein Width (m)	Average Specific Capacity ($m^3/d/m$)
1	A	11.5	500 - 700	51
2	B	9.0	500 - 1,400	43
3	C	6.0	500 - 800	37
4	E	6.5	400 - 550	74

Since the groundwaters in veins A and B have a high concentration of tritium, these groundwaters are assumed to belong to those of recent age and are regarded as moving groundwater. As is apparent from the groundwater vein map(FIG. 5.1), it is of high possibility that both these veins, form major groundwater veins flowing in a western direction of Quetta City. Groundwater vein C performs the function of reinforcing groundwater vein A. The above stated veins belong to the groundwater system in the northern side of Mt. Landi.

Groundwater vein E belongs to the groundwater system in the southern side of Mt. Landi. Vein E, distributed along Zarkhu Nala, in the southeastern part of the Quetta Area, is a newly-found vein. This basin is not related to the groundwater vein in the direction of Quetta City. The recharging area of this vein is quite large and this vein is judged to be a fissured groundwater vein. Also, at its periphery, the groundwater zone extends, and vein E shows the largest specific capacity value in the Study Area. It can thus be evaluated as a particularly significant vein.

In the case of necessity of reinforcing the groundwater in the downstream area by means of artificial recharging, the efficiency of groundwater utilization in the downstream area will significantly increase by utilizing this detected groundwater vein system, and constructing the recharging basin in the upstream area of the vein. Particularly in the Quetta Area, this groundwater recharging effect can be expected.

(2) Stagnant groundwater

Besides the above stated moving groundwater vein, ten (10) groundwater, zones D and from F to N, are detected as shown in FIG. 5.1. The specific capacity of these zones is less than that of the above stated moving groundwater veins, and these zones are judged to be stagnant groundwater zones. It is presumed that the development of groundwater in accordance with the storage capacity is possible.

5.1.1.2 Kalat Area

(1) Moving groundwater

FIG. 5.2 shows the vein map in the Kalat Area. The moving groundwater veins detected in the Kalat Area are three (3), A to C. Referring to the results of tritium analysis, the groundwater in these veins can be regarded as moving groundwater.

TABLE 5.2 MOVING GROUNDWATER VEIN, KALAT AREA

No.	Vein Name	Vein Length in Area (km)	Vein Width (m)	Average Specific Capacity ($m^3/d/m$)
1	A	17.5	700 - 1,300	141
2	B	6.0	750 - 1,000	132
3	C	7.0	600 - 1,100	150

Vein A and B, as shown in FIG. 5.2, join in the northern part of the Kalat Area, to produce the same water system. It is estimated that vein A is a fissured groundwater vein in partial contact with the fracture zone.

Vein C, distributed in the western side of Mt. Chappai, is a large-scaled newly-found vein. This vein is independent of the water systems A and B, and shows the greatest specific capacity value in the Kalat Area. It can be thus evaluated as a significant vein.

(2) Stagnant groundwater

In addition to the above groundwater veins, groundwater zones D and E are detected around the conference of vines A and B. These zones appear to be stagnant groundwater zone and the specific capacity of these zones is less than that of moving groundwater veins A, B and C. The groundwater of these zones, however, can be developed with some limitation.

5.1.2 Conformity between Aerial Selective Gamma-ray Prospecting and Seismic Prospecting

Seismic prospecting was conducted on some part of the groundwater veins detected by aerial gamma-ray prospecting. The following are the conformity between both prospectings:

(1) Quetta area

The seismic prospecting was performed on the groundwater zone D and vein E, detected by aerial gamma-ray prospecting, from which the bedrock depth is presumed. For the groundwater zone D, the maximum and minimum bedrock depths are 250m and 200m, respectively. The bedrock is presumed to be Chiltan limestone of the Mesozoic era. These facts justify the analytical results that this zone is lacking in continuity and is a limited reservoir.

In vein E, based on seismic waves, the bedrock depth reaches 150m and low wave speed values of 2.1 and 2.8 km/sec are found in the bedrock whose nomal speed is 4.8 km/sec. This shows the high possibility of existence of a fissured zone in the bedrock. The result of aerial prospecting that the gamma-ray intensity continues in the form of a belt and that the existence of a fissured vein is acknowledged coincides with seismic prospecting. For reference, infrared rays (8 - 13 μm) were measured on some parts of the prospecting lines. They have, however, no relation with the existence of the groundwater vein/zone.

(2) Kalat area

In vein A, detected by aerial gamma-ray prospecting, seismic prospecting was conducted. From seismic prospecting, the bedrock depth is rather shallow, reaching in deep section. The wave speed in the bedrock is relatively low, showing 2 to 3.5 km/sec, and it is presumed that a fissured zone exists in the low speed area.

5.1.3 Distribution of Specific Capacity

FIGs 5.3 and 5.4 show the specific capacity distribution of each groundwater vein/zone, calculated from aerial prospecting. The average specific capacity of the veins is 37 - 74 $m^3/d/m$ in the Quetta Area, and 132 - 150 $m^3/d/m$ in the Kalat Area. In the Kalat Area, a larger specific capacity is generally found. It appears that this is due to the good hydrogeological characteristics of existing test wells in this area.

5.1.4 Fissured Groundwater Vein Dip

The groundwater vein dip is estimated for vein E in the Quetta Area and veins A, B and C in the Kalat Area. Vein E in the Quetta Area dips downwards to the northwest direction. The angle of dip is unknown. Veins A and B in the Kalat Area, dip downwards to the northwest direction, but vein C dips downwards to the southeast direction.

5.2 Radioisotope

5.2.1 Radon

Radon contents in the Quetta and Kalat Areas are shown in TABLEs 5.3 and 5.4, respectively. In the Quetta Area, the maximum and minimum radon contents are 2.96N and 1.03N. The average is 1.84N. In the Kalat Area, the radon content ranges from 4.65N (Max.) to 1.07N (Min.), and the average proves to be 2.45N, which is on the whole a large value. It seems that this is self-explanatory from the conditions described below.

During August 1986, in the vicinity of the Quetta Area, substantial precipitation was recorded. Since then, there was no rainfall for about 2 months, no recharging to the groundwater. From the fact that half-life of radon is as short as 3.825 days and that the radon content of precipitation is as a rule zero, it follows that approximately 90% of radium contained in a stratum reaches radioactive equilibrium in about one month, if not replenished by new precipitation. Therefore, the radon content of the samples collected from the end of September through to mid October 1986 seems to have been significantly reflected by radium content in the stratum. Consequently, due to the weather conditions that there was no rainfall for the last 2 months, the use of radon as a tracer proves to have been useless.

TABLE 5.3 RADON-TRITIUM CONTENT MEASUREMENT RESULTS, QUETTA AREA

(Page 1)

No.	Sampling Data and Time		Location	Rn *1	3H *2
1	9/27	14:15	QV-4/64	2.96	N
2	9/27	14:40	QV-4/104	2.16	N
3	9/27	15:20	QV-3/11	2.44	N
4	9/27	15:55	QV-3/1	2.63	N
5	9/29	14:50	QV-3/103	2.51	N
6	9/29	10:40	Sikazi	2.22	N
7	9/29	11:05	Fauj Ali	1.92	N
8	9/29	11:30	Gausodo Tube Well	2.01	N
9	9/29	11:35	Gausodo Tube Well	1.65	N
10	9/29	12:10	Shah Beg Gubti	1.31	N
11	9/30	13:40	Abdul Khan	1.37	N
12	9/30	14:15	Cement Factory	2.19	N
13	10/1	11:40	QDA Heli Pad	1.14	N
14	10/1	12:50	N.Lourdes Hotel	1.13	N
15	10/1	11:30	Gwandne	–	N
16	10/1	12:20	Jamalan	1.76	N
17	10/1	13:00	Abdullah	1.58	O
18	10/1	14:00	Muhammad Qasim	1.68	O
19	10/1	14:00	Faiz Muhammad	1.49	O
20	10/1	14:20	Rasul Bakhsh	1.52	O
21	10/2	15:00	Karim Bakhsh	1.49	N
22	10/2	14:10	Hasani	1.77	N
23	10/2	14:45	Lashkar Khan Kili	2.13	N

(To be continued)

TABLE 5.3 RADON-TRITIUM CONTENT MEASUREMENT RESULTS, QUETTA AREA

(Continued) (Page 2)

No.	Sampling Data and Time	Location	Rn *1	^3H *2
24	10/2 15:20		1.64	O
25	10/8 11:20	QV-3/39	2.32	N
26	10/8 11:40	QV-4/103	2.52	N
27	10/8 12:19	MP-2/6	1.97	N
28	10/8 13:06	CP-2/32	2.33	O
29	10/9 12:45	CP-2/34	1.16	O
30	10/9 13:15	CP-2/35	1.57	O
31	10/9 13:46	CP-2/36	1.03	O
32	10/9 14:35	CP-2/37	1.40	O
33	10/9 15:30	Quetta Airport	2.43	N
34	10/11 15:45	CP-2/7	2.48	N
35	10/11 16:25	Dilder Open Well	1.28	O
36	10/11 17:03	Barazai Open Well	1.46	O
37	10/11 16:00	Springs	1.49	O

Note: *1 This is expressed in terms of the ratio to radon content N (background count).

*2 Tritium content is based on 1954 measurement; the groundwater before 1954 is expressed as O (Old) and that after 1954 as N (New).

TABLE 5.4 RADON-TRITIUM CONTENT MEASUREMENT RESULTS, KALAT AREA

No.	Sampling Data and Time	Location	Rn *1	^{3}H *2
38	10/14 15:43	S 1 Springs	1.78	N
39	10/14 16:19	OW 1 Open Well	2.55	N
40	10/14 17:00	OW 2 Open Well	1.48	N
41	10/14 17:27	KL-5 Tube Well	3.22	O
42	10/15 11:28	OW 3 Open Well	1.55	N
43	10/15 11:51	OW 4 Open Well	–	N
44	10/15 12:21	OW 5 Open Well	–	N
45	10/15 13:00	OW 6 Open Well	4.55	N
46	10/15 13:27	OW 7 Open Well	3.75	N
47	10/15 14:20	OW 8 Open Well	1.33	N
48	10/16 09:53	OW 9 Open Well	2.34	N
49	10/16 10:45	S 2 Springs	1.68	N
50	10/16 11:28	OW 10 Open Well	4.65	O
51	10/16 11:40	OW 11 Open Well	1.07	N
52	10/16 13:35	OW 12 Open Well	1.85	N

Note: *1 This is expressed in terms of the ratio to radon content N (background count).

*2 Tritium content is based on 1954 measurement; the groundwater before 1954 is expressed as O (Old) and that after 1954 as N (New).

5.2.2 Tritium

The tritium measurement results for the Quetta and Kalat Areas are shown in TABLEs 5.3 and 5.4, respectively. In the Quetta Area, among 37 samples, 14 samples indicate old typed groundwater prior to 1954, and 23 samples are of new type after 1954. It is cleared that the well group in the western side of block A and the well group distributed in the eastern side of block I belong to old typed groundwater. However, these old typed well groups do not coincide with the groundwater vein detected through aerial selective gamma-ray prospecting. Because, both groups exist on the mountain side out of the detected vein areas.

In contrast, the well group which exists in the western side of block F, with the same topography, also indicates new typed groundwater. Both well groups are of quite difference. This fact may be explained as follows: The slope of the ground surface where the old typed groundwater well groups are located is gentle, presenting a partial debris fan. Therefore, the rainfall may be stored temporarily in the debris fan due to its topographical and geological-strucutral conditions, and reach the fan edge slowly. On the contrary, the topography at the back of the place where the new typed groundwater well groups are located is similar to talus. Therefore, the rainfall may recharge the groundwater directly.

In the Kalat Area, it is cleared that among 15 samples, 13 samples show new typed groundwater and only 2 samples indicate of old type. This shows that groundwater in the Kalat Area, unlike that in the Quetta Area, is mainly of new type. This also coincides with the results of the seismic prospecting that the bedrock depth is approximately 30 to 100m. Besides the above, the spring waters of Nos. 38 and 49, which are not included in the Study Area are new typed groundwater, indicating that the recharging speed is great.

CHAPTER 6 GROUNDWATER CAPACITY

CHAPTER 6 GROUNDWATER CAPACITY

6.1 General

The groundwater is divided into two groups; moving groundwater and stagnant groundwater.

(1) Moving groundwater

The flow capacities of the moving groundwater for respective veins are calculated using the Darcy's law as follows:

$$Q = T \times I \times W$$

where, Q: Groundwater flow capacity (m^3/d)
T : Transmissibility coefficient (m^2/d)
I : Hydraulic gradient of groundwater
W: Width of vein (m)

The section where the flow capacity (Q) is estimated is the one that crosses the groundwater vein at its downstream portion with the right angle to the moving direction of groundwater.

The transmissibility coefficient (T) is obtained in the following method:

a) To estimate the specific capacity (S.C.) for the whole vein with the method described in 4.1.3, Chapter 4;

b) To convert S.C. into T with the following formula*1:

$T = \xi \times S.C. + \eta$ (and = constant)

Here, and are the optimum values obtained with the least square method

For Quetta Area: $\xi = 9.329$, $\eta = 26.087$

For Kalat Area: $\xi = 5.431$, $\eta = 16.066$

c) Then to obtain the mean value of T to be used in the calculation.

The hydraulic gradient (I) of groundwater veins is estimated based one the groundwater contour maps prepared by WAPDA and UNDP*2. For the Quetta Area, the contour map covering the whole Study Area surveyed by the WAPDA in 1971 is used (FIG 5.1). Although the measurement of groundwater contour line was

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*1 Logan, J.: "Estimating transmissibility from routine production tests of winter wells", Groundwater, Vol. 2, No. 2, 1964

*2 United Nation/WAPDA, "Groundwater studies in selected area of Baluchistan", Technical report No. 4, 1982 carried out by the UNDP in 1978, the data is lacking around vein E. The tendency of groundwater drawdown resembles through macro-view, though the groundwater drawdown was observed during the period between 1971 and 1978. Therefore, it is judged that the data of 1971 are appricable for the estimation. For the Kalat Area, the contour map surveyed by the UNDP in 1978 is used (FIG. 5.2).

As the width of vein (W), the width of vein at its downstream section is adopted.

(2) Stagnant groundwater

Since the storage capacity of the stagnant groundwater differs in the hydrologic characteristics from the flow capacity of the moving groundwater, the calculation method applied for the moving groundwater cannot be applied to the calculation of the storage capacity of the stagnant groundwater. Therefore, the possible yield from the stagnant groundwater zone is estimated using the specific capacity and permissible critical groundwater drawdown not based on the storage capacity.

6.2 Quetta Area

6.2.1 Moving Groundwater

The estimated flow capacity of veins A, B, C and E is shown in TABLE 6.1.

TABLE 6.1 MOVING GROUNDWATER FLOW CAPACITY, QUETTA AREA

Vein Name	Transmissibility Coefficient T (m^2/d)	Hydrauric Gradient (1971) I	Vein Width: W (m)	Groundwater Flow Capacity Q (m^3/d)
A	582	1/ 66	610	5,380
B	486	1/265	1,350	2,480
C	396	1/ 46	772	6,650
E	707	1/ 46	498	7,650
Total				22,160

In vein A, the groundwater flow capacity amounts to about 5,380 m^3/d. In vein B, it is estimated to be 2,480 m^3/d. In the mid and downstream sections of veins A and B, both open and deep wells are excavated in order to utilize the groundwater.

Vein C crosses the debris fan and the groundwater flow capacity is large compared with the scale of the vein. Since groundwater development in this periphery area has not yet been promoted, it is judged that this vein is promising for the future development of moving groundwater. Consequently, it is judged that vein C is a favorable one for test boring and verification.

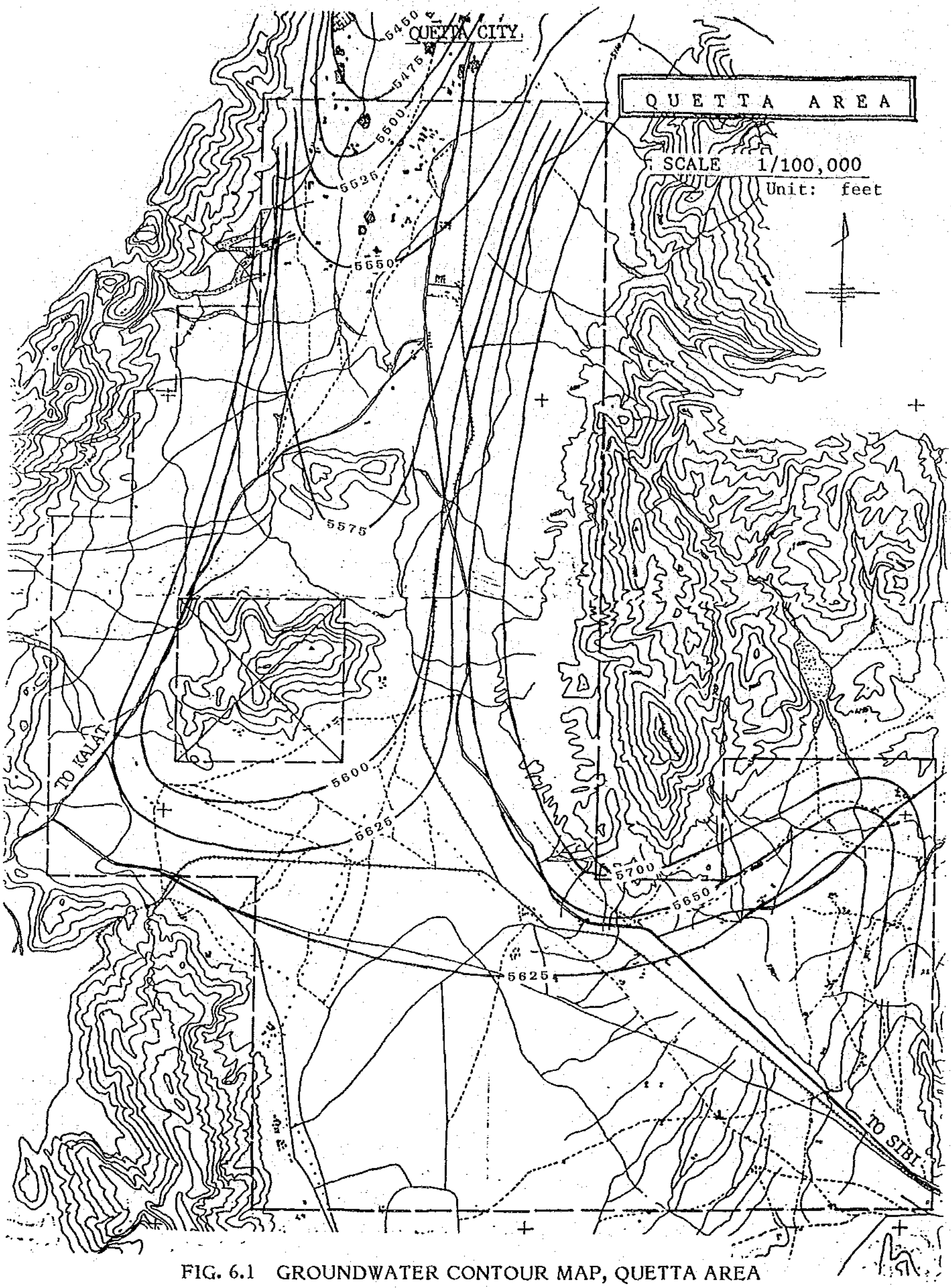

FIG. 6.1 GROUNDWATER CONTOUR MAP, QUETTA AREA

Source: WAPDA 1971

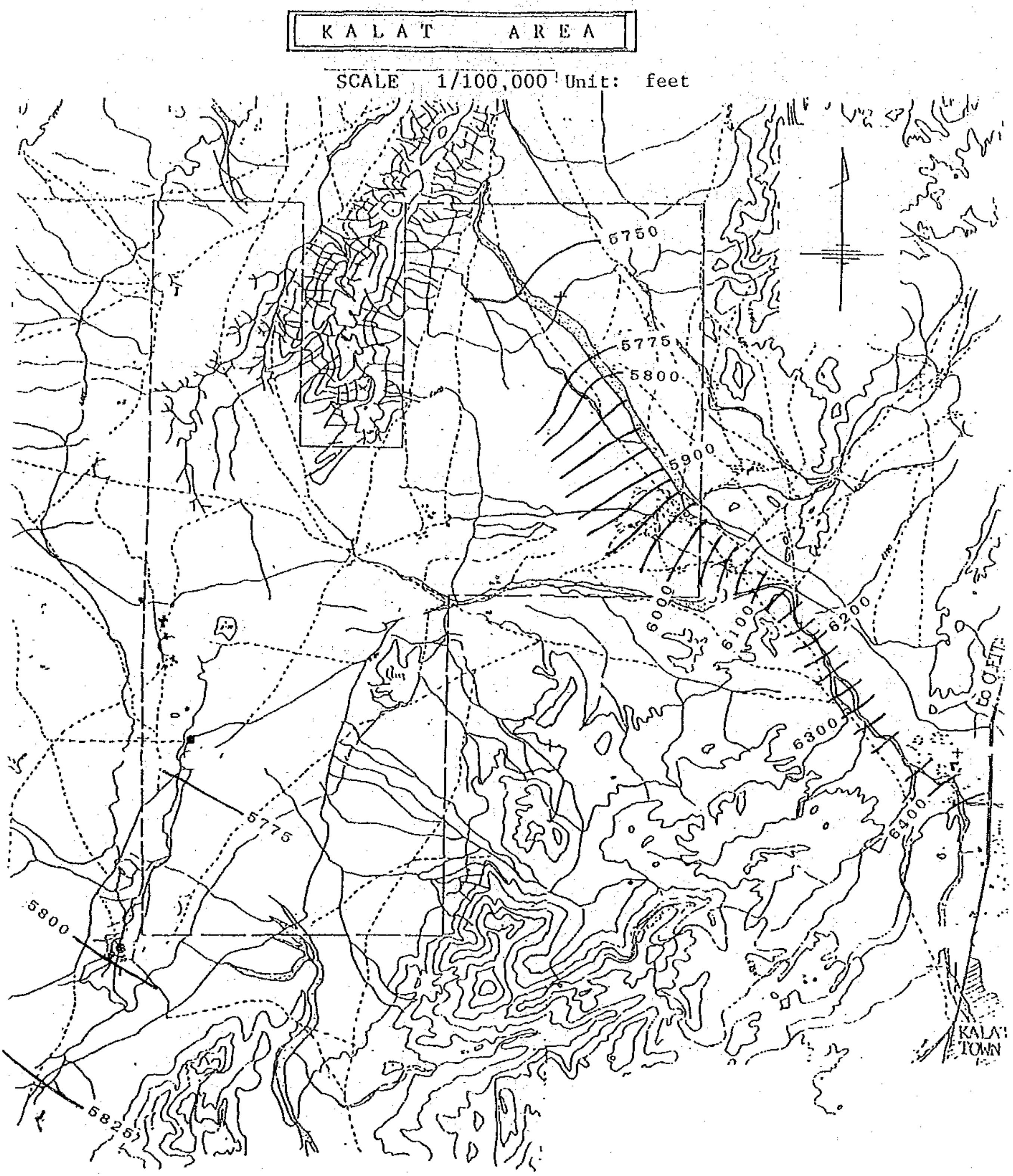

FIG. 6.2 GROUNDWATER CONTOUR MAP, KALAT AREA

Source: UNDP 1978

Vein E has a different water system from veins A, B and C, and the groundwater flow capacity is calculated at 7,650 m^3/d. This shows a large flow capacity compared with the vein scale. It is judged that this vein is a fissured groundwater one connected with the fracture zone. Consequently, not only development of the groundwater in the Quarternary stratum, but also development of the fissured groundwater vein will be possible. The results of the seismic prospecting show that bedrock exists 150m below the ground surface. This means that the fissured vein will exist in the section 150m below the ground surface or lower. Vein E has not yet been developed and is considered to be most suitable for future groundwater development. It is advised that the depth of the test borings be planned to excavate the bedrock by 100m beyond the location where the test borings attain the bedrock.

6.2.2 Stagnant Groundwater

In the Quetta Area, groundwater zone D is the largest stagnant groundwater zone. By verifying with a test borning the stagnant groundwater in zone D where the bedrock depth has been estimated by seismic prospecting, the groundwater storage conditions and bedrock characteristics will be made more clear. Since the groundwater zone D is wide in its distribution range and both the scale of the zone and the specific capacity are greater than those of other stagnant groundwater zones, it is intended for future development in preference to other stagnant groundwater zones. However, since it is a closed groundwater zone in a dry area, attention should be paid to its sustainability[*1].

As the existence of groundwater after 1954 is confirmed by tritium analysis in the outer area of the central northwestern part of this groundwater zone, induction of supplemental recharge by pumping may be expected from the peripheral area. In addition to the above, the stagnant groundwater zone is distributed in nine locations F to N as shown in FIG. 5.1

*1 S. Yamamoto: "Groundwater prospecting method", Chikyu Publishing Co., P22, 1973

6.3 Kalat Area

6.3.1 Moving Groundwater

The estimated flow capacity of veins A, B and C of the Kalat Area is shown in TABLE 6.2.

TABLE 6.2 MOVING GROUNDWATER FLOW CAPACITY, KALAT AREA

Vein Name	Transmissibility Coefficient T (m^2/d)	Hydrauric Gradient (1978) I	Vein Width: W (m)	Groundwater Flow Capacity Q (m^3/d)
A	700	1/372	1,290	2,430
B	610	1/ 53	805	9,260
C	678	1/106*1	805	5,150
Total				16,840

The groundwater flow capacity in the downstream section of vein A is 2,430 m^3/d. The flow capacity in vein B is greater than that in vein A, 9,260 m^3/d. The groundwater flow capacity in vein C is estimated to be 5,150 m^3/d. Since the periphery of vein C is an undeveloped area, it is regarded as promissing groundwater development area.

6.3.2 Stagnant Groundwater

The stagnant groundwater zones D and E exist near the junction of veins A and B. Since both these zones are in contact with veins A and B, there will be a possibility that supplemental recharge is induced by pumping in veins A and B.

*1 This value is estimated taking into account the surrounding geography and moving groundwater veins. It is, therefore, necessary to confirm this by performing test borings.

CHAPTER 7 POSSIBLE YIELD FROM GROUNDWATER DEVELOPMENT

CHAPTER 7 POSSIBLE YIELD FROM GROUNDWATER DEVELOPMENT

7.1 General

The possible yield from groundwater development was calculated for both moving and stagnant groundwaters.

In developing groundwater, it is necessary to introduce the concept of safe yield that water can be collected from the groundwater veins/zones without incurring unfavorable results. According to radioisotope analysis, it is confirmed that moving groundwater is hydrologic cycle water. The possible yield from moving groundwater development is set at 80%*1 of the groundwater flow capacity. The stagnant groundwater differs from moving groundwater in the above definition. The possible yield from stagnant groundwater development is estimated using the specific capacity on the basis of the permissible critical groundwater drawdown of 10m in consideration of prevension of an unfavorable influence caused by pumping*2. In the case of development of groundwater of this type, care should be given to the change of dinamic water level.

7.2 Possible Yield from Moving Groundwater Development

The possible yield from moving groundwater development is estimated in both the Quetta and Kalat Areas and summarized in TABLE 7.1. In the detected moving groundwater veins, both Quaternary stratum groundwater and fissured groundwater in the bedrock are considered to be developed and utilized. In particularly, since the fissured groundwater system develops many fissures at its periphery, groundwater recharge is extensive and groundwater utilization with deep wells looks promising.

Using the aforementioned method to introduce the concept of safe yield, the possible yield from moving groundwater development is estimated as 17,730 m^3/d in the Quetta Area and 13,470 m^3/d in the Kalat Area.

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*1 MITI Sendai Bureau: "Survey report for optimum groundwater utilization in the western area of the Yamagata Basin", Industrial Water, No. 317, P. 35, 1985

*2 Water balance research group: "Groundwater resources", Kyoritsu publishing Co.; P. 330, 1973

TABLE 7.1 POSSIBLE YIELD IN MOVING GROUNDWATER VEIN

Quetta Area

Vein Name	Section of Estimation	Possible Yield from Groundwater Development (m^3/d)
A	downstream	4,310
B	"	1,980
C	"	5,320
E	"	6,120
Total		17,730

Kalat Area

Vein Name	Section of Estimation	Possible Yield from Groundwater Development (m^3/d)
A	downstream	1,940
B	"	7,410
C	"	4,120
Total		13,470

7.3 Possible Yield from Stagnant Groundwater Development

The possible yield in the Quetta Area is estimated as 7,880 m^3/d in total as shown in TABLE 7.2. Of the stagnant groundwater zones, zone D represents a significantly larger groundwater zone compared with other groundwater zones.

If groundwater in Zone D is developed by controlling the groundwater level with supplemental recharge from peripheral areas, the utilization of groundwater for a relatively long period will be possible.

The stagnant groundwater zone in the Kalat Area is estimated to exist at 2 locations D and E around the junction area of the moving groundwater veins A and B. The specific capacity in these groundwater zones is relatively large at 47 to 51 $m^3/d/m$ as shown in TABLE 7.2. The total possible yield from stagnant groundwater development is estimated to be to 3,880 m^3/d. Since these groundwater zones are adjacent to the moving groundwater veins A and B, these zones appear to have the function to recharge both veins A and B even with very slow speed. Consequently, if the groundwater level is lowered by developing veins A and B, supplemental recharge from groundwater zones D and E will be accelerated, thereby producing the effect of increasing the groundwater flow amount in both veins A and B.

TABLE 7.2 POSSIBLE YIELD IN STAGNANT GROUNDWATER ZONE

Quetta Area

Zone Name	Area (km^2)	Average Specific Capacity ($m^3/d/m$)	Number of Pumping Point	Total Specific Yield ($m^3/d/m$)	Possible Yield from Groundwater Development*1 (m^3/d)
D	5.6	69	6	414	4,140
F	2.0	35	2	70	700
G	1.1	33	1	33	330
H	0.9	35	1	35	350
I	1.9	29	2	58	580
J	1.2	23	1	23	230
K	0.4	33	1	33	330
L	0.4	34	1	34	340
M	1.5	30	2	60	600
N	0.8	28	1	28	280
Total					7,880

Kalat Area

Zone Name	Area (km^2)	Average Specific Capacity ($m^3/d/m$)	Number of Pumping Point	Total Specific Yield ($m^3/d/m$)	Possible Yield from Groundwater Development*1 (m^3/d)
D	3.1	51	3	153	1,530
E	4.7	47	5	235	2,350
Total					3,880

Note: *1 The permissible critical groundwater drawdown of 10 m is adopted in the estimation.

CHAPTER 8 COMMENTS ON WELL TESTS

CHAPTER 8 COMMENTS ON WELL TESTS

8.1 General

The test wells, three (3) in the Kalat Area and four (4) in the Quetta Area (excl. one (1) outside the Quetta Area), have been drilled in the groundwater veins/zone which were detected by the aerial gamma-ray spectro prospecting. However, the pumping test, which is the standard testing method, has only been conducted for some of these test wells, although the water sampling test was carried out for all the test wells. These test wells are located in the upstream section of the respective veins and the number for each vein is only one. Therefore, the detailed assessment of the results of the aerial gamma-ray spectro prospecting in comparison with the well tests is premature. The following are the tentative comments on the well tests conducted up to the present:

8.2 Quetta Area

The limestone in the bedrock is well-developed around the test well site of Vein A. The remarkable discharge was measured through the water sampling test. However, the further development of groundwater of Vein A should be restrained, in due consideration of over-extraction of groundwater in the northern part of the Quetta Area. In case of developing groundwater of this vein, careful attention should be paid to the change of groundwater level in the downstream section of the vein.

In Vein B, the drilling was stopped at the point of 300m deep from the ground surface before reaching the bedrock due to the limited capacity of the existing drilling machine. The fact that the bedrock of this site is very deep compared with the surrounding areas may show that this site is located within the tectonic zone. Judging from the above, there is possibility that the fissured groundwater vein may exist at the section deeper than 300m from the ground surface.

The test results in Zone D shows that the aerial gamma-ray spectro prospecting was effective to detect the fissured groundwater zone under the thick alluvial layer, even thick clay layer. The development of groundwater of this zone should carefully be made, even though the test discharge is hopeful, in consideration of the groundwater in this zone being stagnant.

The past well test records show that the ratio between the discharge by water sampling and that by pumping-up differs greatly in case of the groundwater level being deep. And it becomes very hard to assume the value of discharge by pumping-up based on the results of water sampling test. Therefore, it is definitely necessary to conduct the pumping test in Vein E in order to collect the accurate discharge value.

8.3 Kalat Area

The discharges in Veins A and B collected through the water sampling test differ greatly from the amounts estimated based on the aerial gamma-ray spectro prospecting. The reasons may be the following:

(1) The shale layers are more predominant than the estimation based on the previous geological data, especially in the case of Vein A.

(2) There is a case that even the shale layer becomes good aquifer. However, the fissure of Vein A might have been collapsed by the earth pressure during drilling operation because of the shale layer of this vein being not so hard. This consideration is supported by the results of the electric logging test conducted.

However, the existence of the fissures groundwater vein is still expected in the deeper section where the limestone layer may be developed.

8.4 Conclusion

The specific capacities of the veins in the Quetta Area obtained by the well test generally coincide with the estimated ones. However, those of the Kalat Area differ each other greatly. The reason of the difference is as follows:

(1) The data regarding groundwater in the Kalat Area are very few.

(2) Those of the existing wells located outside the Area were inevitably used as the basic data for the analysis.

In the Quetta Area, the existence of groundwater in the fissured veins of limestone layer is confirmed. The groundwater in these fissured veins will have great value at the places where the groundwater cannot be collected from the Quarternary Formation.

At present, the conditions of groundwater movement are still not clear due to the limited test wells. In order to analyze the groundwater movement and its potential in detail, it is recommended that the number of test wells be increased and that the drilling of test wells in the mid-stream and downstream sections of the respective veins be included in addition to those in the upstream section.