2.6 Types of Pumps

Submersible pumps rated 5.5 to 22 kW, delivering 150 to 1,450 m^3/d, are installed in shallow and deep tubewells. Centrifugal pumps rated 5.5 to 15 kW, delivering 750 to 1,300 m^3/d, are equipped in dug wells at Kota Belud waterworks. Careful maintenance of the submersible pump is carried out due to the clogging of pump intake by cohesion of iron bacteria deposits. Some submersible pumps were dropped in the well resulting in the corrosion of the steel riser pipe. But the steel riser pipe is being replaced by stainless steel pipe. It is recommended to replace the centrifugal pumps at Kota Belud waterworks by submersible pumps which can provide the increased capacity (Ref. 18).

2.7 Pumping Test

GSD Sarawak has carried out some pumping tests on shallow tubewells in coastal alluvial aquifers with thickness of 5 to 10 m along the South China Sea, and the available pumping yield was estimated in the range of 100 to 240 m^3/d with an average of 210 m^3/d (Refs. 38 to 45). The PWD in Sabah has also performed pumping test on 16 new deep tubewells in sandstones with alternating shales in Labuan Island and the available pumping yield was estimated in the range of 140 to 600 m^3/d with an average of 390 m^3/d (Ref. 16). Productivity of existing 24 deep tubewells in sandstones with alternating shales at Sandakan area was estimated to be 240 to 1,450 m^3/d with an average of 780 m^3/d. Maximum pumping yield from each existing dug well in alluvial sediments at Kota Belud was estimated to be 700 m^3/d (Refs. 1 to 4).

Coefficient of transmissivity was estimated to be from 70 to 420 m^2/d with an average of 230 m^2/d in coastal alluvial aquifers and correspondingly 20 to 160 m^2/d with an average of 80 m^3/d in Neogene sandstones with alternating shales.

3. DEVELOPMENT POSSIBILITIES

3.1 Classification of Groundwater Potential

Aquifers are recognized mainly in sandy layers of Quaternary sediments and fissures or cracks of Neogene sandstones with alternating shales.

Quaternary sediments are composed of clays, silts, sands and some gravels. Trick layers of clay or silt are prominantly found in coastal plains along the South China Sea. The occurrence of aquifers are often limited in extent that is assumed to be less than 10% of the coastal alluvial plain. At present, it is difficult to estimate the thickness of aquifers except for the shallow part of Quaternary sediments which are less than 30 m in depth. Quaternary sediments more than 30 m in depth are not known resulting in the limited capacity of the existing drilling equipment of GSD Sarawak. A systematic exploration scheme with the acquisition of a new drilling machine is being planned by GSD Sarawak assess the maximum thickness of the Quaternary sediments which are deduced to be 90 m. Aquifer thickness of Quaternary sediments less than 30 m in depth is assumed to be 2 to 20 m for this Study (Refs. 19 to 45).

Brackish to saline groundwater is observed in the exploration holes along the coast of South China Sea. Aquifers intruded by salt water are noted in mangrove swamp areas at the coastal plains (Refs. 19 to 45). Typical hydrogeological profiles are as shown in Fig. 2.

The composition of the rocks in Sabah and Sarawak includes limestones, sandstones, conglomerates, volcanic rocks of andesite, basalt, tuff and breccia, charts shales, mudstones, granites, schists and others. The aquifers are recognized more or less in the faulting or fissured zones in all rocks. The occurrence of aquifers in hard rocks are often limited in extent.

Neogene sandstones with alternating shales make it possible to distinguish the characteristics of aquifer (Refs. 1 to 15). The maximum depth of the existing exploratory boreholes is 305 m (Refs. 11 to 14). Average depth of the existing production wells in sandstones is approximately 100 m (Refs. 1 to 15). Aquifer thickness of sandstone is estimated to be 5 to 25 m on the basis of some results of flow velocity logging (Ref. 3).

On the basis of the parameters of thickness, specific yield, pumping discharge, transmissivity coefficient and drawdown concerning the aquifer as described in the Phase II Study, the potential areas were classified by eight hydrogeological land classification classes. The range of specific yield was assumed because there was no data available.

(1) Alluvial Class I

This is the excellent aquifer with high permeability being located in the alluvial plain at Kota Belud and some coastal plains. Aquifer parameters are assumed as below:

Thickness of Aquifer	:	5 - 20 m
Specific Yield	:	15 - 20%
Pumping Discharge	:	400 - 1,000 m^3/d
Transmissivity Coefficient	:	200 - 500 m^2/d
Drawdown	:	1 - 10 m

(2) Alluvial Class II

This is the good aquifer with moderate permeability and thickness being located at the downstream areas in the Rajang river basin and some other coastal plains. Aquifer parameters are assumed as below:

Thickness of Aquifer	:	5 - 15 m
Specific Yield	:	10 - 20%
Pumping Discharge	:	200 - 400 m^3/d
Transmissivity Coefficient	:	50 - 200 m^2/d
Drawdown	:	1 - 10 m

(3) Alluvial Class III

This is the fair aquifer with moderate permeability and thickness less than alluvial Class II being located both in coastal and river alluvial plains. Aquifer parameters are assumed as below:

Thickness of Aquifer	:	2 - 8 m
Specific Yield	:	10 - 15%
Pumping Discharge	:	50 - 150 m^3/d
Transmissivity Coefficient	:	10 - 50 m^2/d
Drawdown	:	1 - 10 m

(4) Alluvial Class IV

This is the poor aquifer with medium to low permeability and very thin thickness less than 2 m being located at the foothills of the highlands or sea coast. Aquifer parameters are assumed as below:

Thickness of Aquifer	:	0 - 2 m
Specific Yield	:	5 - 15%
Pumping Discharge	:	0 - 50 m^3/d
Transmissivity Coefficient	:	0 - 10 m^2/d
Drawdown	:	1 - 10 m

(5) Alluvial Class V

This is the very poor aquifer with thickness approximately zero or intruded by sea water being located at the mangrove swamp areas. No groundwater development is expected in this class.

(6) Rock Class I

This is the excellent aquifer with large to moderate in thickness being located in the limestone of crystalline and karst type. However, the distribution of limestone is very limited. Aquifer parameters are assumed as below:

Thickness of Aquifer	:	5 - 30 m
Specific Yield	:	5 - 10%
Pumping Discharge	:	100 - 1,000 m^3/d
Transmissivity Coefficient	:	50 - 300 m^2/d
Drawdown	:	1 - 10 m

(7) Rock Class II

This is the fair to good aquifer with moderate to large thickness being located in the sandstones with intensive fissures or cracks. Occurrence of aquifers is noted in Neogene sandstone formation in Sandakan and Belait. Aquifer parameters are assumed as below:

Thickness of Aquifer	:	5 - 25 m
Specific Yield	:	2 - 8%
Pumping Discharge	:	100 - 500 m^3/d
Transmissivity Coefficient	:	20 - 100 m^2/d
Drawdown	:	5 - 20 m

(8) Rock Class III

This is the fair to poor aquifer with moderate thickness being located at mountain areas where they consist of other rocks with fissures or cracks. Aquifer parameters are assumed as below:

Thickness of Aquifer	:	1 - 15 m
Specific Yield	:	2 - 5%
Pumping Discharge	:	0 - 100 m^3/d
Transmissivity Coefficient	:	0 - 20 m^2/d
Drawdown	:	10 - 25 m

Purpose of this classification is to make a roughly figure of groundwater resources potential map. Some good shallow aquifers in sand dune or natural levees which are developed along the coastal plain of large river basins such as Limbang, Miri and Dalat will be found in alluvial Class III or IV, however, this type of aquifers which are often limited extent are not distinguished in the above classification. It is rather difficult to distinguish the exact areas of potential well field in hardrocks due to the irregular distributions of fissures or cracks. In this scene, neogen sedimentary rocks of sandstones with alternating shales such as Miri, Nyalau and Tukau formations which are widely developed in hilly or mountain areas along South China Sea are not all included in rock Class II. Further investigations will delineate the above uncounted potential well fields in alluvial Class III or IV and rock Class III.

Probability of occurrence of non-productive fields is assumed to be 10% for alluvial Class I, 30% for alluvial Class II, 50% for alluvial Class III, 80% for alluvial Class IV, 100% for alluvial Class V, 50% for rock Class I, 70% for rock Class II and 90% for rock Class III depending on some empirical probability of water well development. Hydrogeological land classification map is as shown in Figs. 3 to 5. Area of hydrogeological land by class by Basin is as shown in Tables 2 and 3.

3.2 Storage Potential

Storage potential refers to groundwater storage volume in the aquifers. A part of the storage volume could be used for mining yield in rock aquifers. The storage potential is estimated as follows:

$$SP = A \times b \times Sy \quad \ldots\ldots\ldots\ldots (1)$$

where, SP: Storage potential
A : Area
b : Thickness of aquifer
Sy: Specific yield (Effective porosity)

Assuming the average thickness and average specific yield by hydrogeological land class as shown in Table 4, the storage potential by class in the Basin was calculated as shown in Tables 5 and 6.

3.3 Groundwater Recharge

Very few studies on deep percolation or groundwater recharge are recognized in the Study. According to the recent study on deep percolation in Japan, linear relation between deep percolation and precipitation is recognized by a field investigation and water balance analysis. The deep percolation in alluvial plain and hilly land is estimated to be 15 to 25% of the annual precipitation (Refs. 54 & 55). The deep percolation in mountain areas of granitic rocks is preliminarily estimated to be 3% of annual precipitation (Ref. 56). Some rates of the deep percolation are used in the previous studies to estimate the sustained yield of the well field (Refs. 1 & 38 to 45). They are assumed to be 20 to 30% of the annual precipitation in the well field of coastal alluvial plain and 15% of the annual precipitation in the well field of Sandakan sandstone formation. Based on the previous studies, annual deep percolation rates were assumed to be 22% of annual precipitation in alluvial plain, 15% of annual precipitation in the hilly lands of limestones and Neogene sandstones and 3% of annual precipitation in the mountain areas of other rocks. The deep percolation rates in the 47 Basins were calculated with the above-mentioned assumptions as shown in Table 7. Average daily groundwater recharge was estimated by hydrogeological land class by Basin as shown in Tables 8 and 9.

3.4 Preliminary Estimate of Safe Yield

Assuming the probability of occurrence of non-productive field 0.1 to 0.9 safe yield was preliminarily estimated by class in Basins and districts as shown in Tables 10 to 13, which is neither larger than the storage potential nor groundwater recharge.

3.5 Cost Analysis

The unit cost of water source was estimated so as to compare the cost of groundwater with surface water. Corresponding to hydrogeological land classification, seven cases were assumed by aquifer types, average well depth, average pumping discharge, average drawdown, well types and pump capacity as shown in Tables 14 and 15. Taking into account the water quality of high iron ion and iron bacteria in both alluvial and rock aquifers, the higher standard of well design is therefore adopted in this analysis. The construction cost of well was estimated based on some contract documents (Refs. 6 to 8 & 15).

Regarding the power source and electric supply from power system, the power generated by diesel engine is used on the basis that a very little difference of the power cost of less than 10% is recognized between diesel generator and NEB electric supply.

Economic life of the facilities are assumed as follows:

Well	:	25 years
Pump	:	8 years
Other facilities	:	50 years

Estimated cost stream for 50 years of the assumed groundwater source facilities is as shown in Table 16.

Unit cost of water source was estimated on assuming discount rates of 6 to 20% as shown in Table 17.

4. SOME COMMENTS ON GROUNDWATER DEVELOPMENT AND MANAGEMENT

Present groundwater use is rather limited compared with the use in Peninsular Malaysia resulting from the limited occurrence of potential aquifers. Groundwater use in water supply is concentrated mostly in rock aquifers of sandstones with alternating shales in Sabah, while some coastal alluvial aquifers are being used in Sarawak.

4.1 Sabah

At present, groundwater use is concentrated in the towns of Sandakan and Labuan where the pumping yield is increasing to the sustained yield or safe yield in the existing well field. Groundwater level may drop if the pumping discharge exceeds the sustained yield. Gradual drop in water level year by year is recognized in some of the existing pumping wells at Sandakan. The cause of drop in the water level is not known. It could be due to either overpumping or clogging of screen pipe. High iron ion and iron bacteria is found in deep aquifers of sandstone, which could be the cause for the clogging of screen pipe or riser pipe. Careful maintenance of production tubewell is carried out which includes development of well and periodical replacement of riser pipe or submersible pump (Ref. 5). A systematic monitoring of change in groundwater level and water quality should be executed so as to avoid the exhaustion of groundwater resources. It may be possible that withdrawal of groundwater from rock aquifers could consume a part of the mining yield. However, if the groundwater extraction exceeds the sustain yield, it is not recommended to use the mining yield until a complete monitoring system is established in the groundwater basin. Artificial recharging methods such as flooding, basin, ditch and furrow, canal and well could be used to set up the underground reservoir. Some catchment areas also include the potential site of artificial recharging, which is being reserved by the PWD.

Management of groundwater basin includes the application of not only reserving the catchment area but also implementing the alternative artificial recharging which would be taken into consideration in the further study.

Conjunctive use of groundwater and surface water is being carried out at Sandakan. Surface water of the two small river is used as supplemental source for water supply. Extensive surface water resources development is being systematically planned by PWD including the idea of conjunctive use of surface water and groundwater toward the year 2000. According to the proposed plan of the conjunctive use, groundwater could be used for flexibly supplemental water source after the completion of the intake/dam scheme (Ref. 1). An example of the conjunctive use of surface water and groundwater is as shown in Fig. 6.

A plan of the conjunctive water use is recognized at Labuan water supply as shown in Fig. 7 (Ref. 9). The maximum reliable yield of the conjunctive use of groundwater and surface water was estimated to be 31×10^3 m^3/d. The conjunctive water use could be recommended until the estimated water demand in the year 2000 exceeds the reliable yield of 31×10^3 m^3/d in Labuan Island (Ref. 10).

4.2 Sarawak

Present groundwater use is limited to very minor areas at the coastal plains along the South China Sea. Groundwater in perched or shallow aquifers in coastal areas could be used for rural water supply schemes, but it requires a careful monitoring to predict the salt water intrusion resulting in overpumping.

GSD is carrying out the preliminary monitoring of groundwater level and water quality at the four monitoring basins of Nonok, Kabong, Belawai and Kuala Lawas. Apart from groundwater exploration and development, GSD is also in charge of monitoring it. All the monitoring data including the operating record of water level, water quality and pumping discharge of PWD's waterworks would be connected by GSD and compiled into annual report of groundwater data book. A systematic groundwater exploration program which covers all the coastal areas and some mountain areas including the monitoring of representative groundwater basin is being carried out to assess the possibility of rural water supply. However the problem of shortage in manpower at the Hydrogeological Section of GSD needs urgent attention and an adequate allocation of finance which should be supported by PWD, EPU and other agencies.

Catchment areas of the recharging basin are purchased to reserve the well field of PWD. They are well fields of Belawai and Kabong. GSD is in charge of evaluating the recharging catchment area on the basis of the estimation of the sustained yield (Refs. 40 & 44). Some coordination among GSD, PWD and DID was made to reserve the catchment area of well field within the area of DID's perimeter drain at Belawai and Kabong. The controlled drainage system of the perimeter drain constructed by DID is expected to increase the potential of shallow groundwater by replacing the environment of water quality in shallow aquifers from the salt/brackish to fresh, as shown in Fig. 2.

Drought prone area is concentrated in coastal areas where almost all the rivers are subjected to the sea water intrusion. In this sense, groundwater development for rural water supply in this area is considered to be the most important alternative to solve the problems in water shortage. Some areas in sand dunes or natural levees which are composed of loose sediments of sands and some gravels are one of the potential well field to be developed in coastal area. Fresh groundwater in shallow aquifer of sands which is directly replenished by rainfall is perched on sea water. This type of small scale aquifer is limited in extent, however, it is possible to exploit them for small scale rural water supply if careful groundwater management to monitor the change in water level is carried out. Occurrence of this perched water could be distinguished in some areas in sand dune or natural levee where elevation of the land is 5 meters or more. Aerophotographic analysis to distintinguish the micro-geographical features would help the estimation of potential well field. Safe yield of optimum pumping program is to be assessed by forecasting the change in water level which does not permit the sea water intrusion into aquifer of sands depending on Gyben-Hertzberg law of elevation zero. An example of groundwater management in sand dune area which is estimated by hydrogeological tank model method is shown in Ref. 58.

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TABLES

Table 1 PRODUCTION TUBEWELLS

Location	Served Population (10^3)	Average Daily Supply ($10^3 m^3/y$)	Number of Well	Well Type	Aquifer
Sandakan/1	48.5	16.5	21	Deep tubewell	Sandstone and shale
Labuan	14.9	5.0	31	Deep tubewell	Sandstone and shale
Kota Belud	7.2	1.7	3	Dug well	Alluvial
Kuala Penyu	1.0	0.1	2	Tubewell	Sandstone and shale
Semporna/2	1.3	0.4	4	Dug well	Alluvial
Total	71.6	23.3	57	-	-

Remarks; /1: Groundwater extraction is 82% of the average daily supply by PWD's water works.

/2: Estimated based on Ref. 57

Table 2 HYDROGEOLOGICAL LAND CLASSIFICATION IN SABAH

Unit: km^2

Basin No.	Alluvial Class				Rock Class			Total
	I	II	III	IV	I	II	III	
201	–	–	126	–	–	–	5,791	5,917
202	–	–	–	40	–	–	1,218	1,258
203	–	–	–	26	–	–	1,221	1,247
204	–	–	–	60	–	–	631	691
205	–	–	–	70	–	–	430	500
206	–	–	–	60	–	–	424	484
207	–	–	–	270	–	–	468	738
208	–	–	110	300	–	–	2,069	2,479
209	–	–	–	300	–	720	1,274	2,294
210	–	–	440	678	–	310	3,805	5,233
211	–	45	680	1,038	5	–	15,337	16,105
212	–	–	–	–	–	227	2,082	2,309
213	–	40	200	250	–	437	5,366	6,293
214	–	–	220	70	–	42	2,702	3,034
215	–	–	135	175	–	110	845	1,255
216	–	–	80	–	–	–	1,566	1,646
217	–	70	183	7	–	414	1,412	2,086
218	40	40	180	–	–	–	1,136	1,396
219	15	20	75	–	–	–	1,112	1,222
220	–	20	98	60	–	–	411	589
221	–	20	20	8	–	–	751	799
222	–	20	33	55	–	–	449	557
223	–	–	130	180	–	11	270	591
224	–	256	820	220	–	20	7,445	8,761
225	–	–	–	–	–	23	29	52
226	–	–	–	180	–	–	1,086	1,266
Total	55	531	3,530	4,047	5	2,304	58,330	68,802

Table 3 HYDROGEOLOGICAL LAND CLASSIFICATION IN SARAWAK

Unit: km^2

Basin No.	Alluvial Class I	Alluvial Class II	Alluvial Class III	Alluvial Class IV	Rock Class I	Rock Class II	Rock Class III	Total
227	-	-	-	25	-	-	975	1,000
228	-	-	-	112	-	-	2,557	2,669
229	-	-	-	425	60	-	3,390	3,875
230	-	-	2,500	160	50	-	19,570	22,280
231	-	-	-	585	-	-	203	788
232	-	-	-	214	-	-	711	925
233	-	-	-	170	-	-	1,175	1,345
234	-	-	-	162	-	-	1,240	1,402
235	-	-	-	160	-	-	1,058	1,218
236	-	-	-	120	-	-	5,827	5,947
237	-	-	-	401	-	249	4,480	5,130
238	-	-	-	1,233	-	10	1,255	2,498
239	-	-	-	1,200	-	-	1,414	2,614
240	-	-	-	800	-	-	1,185	1,985
241	-	6	4,907	-	-	-	44,740	49,653
242	-	-	24	570	-	-	981	1,575
243	-	-	-	1,004	-	-	826	1,830
244	-	-	-	2,380	-	22	4,361	6,763
245	-	-	-	1,542	50	25	2,038	3,655
246	-	5	-	655	223	251	1,573	2,707
247	-	-	-	350	-	-	1,308	1,658
Total	-	11	7,431	12,268	383	557	100,867	121,517

Table 4 THICKNESS AND SPECIFIC YIELD USED FOR POTENTIAL ANALYSIS

Aquifer Class	Average Thickness of Aquifer (m)	Average Specific Yield
Alluvial I	15	0.17
Alluvial II	10	0.15
Alluvial III	5	0.13
Alluvial IV	1	0.10
Rock I	15	0.08
Rock II	10	0.05
Rock III	5	0.03

Table 5 ESTIMATED STORAGE POTENTIAL IN SABAH

Unit: $10^6 m^3$

Basin No.	Alluvial Class I	II	III	IV	Rock Class I	II	III	Total
201	-	-	82	-	-	-	870	952
202	-	-	-	5	-	-	190	195
203	-	-	-	5	-	-	190	195
204	-	-	-	5	-	-	100	105
205	-	-	-	10	-	-	70	80
206	-	-	-	5	-	-	70	75
207	-	-	-	30	-	-	70	100
208	-	-	70	30	-	-	310	410
209	-	-	-	30	-	360	190	580
210	-	-	286	70	6	157	570	1,089
211	-	67	442	105	-	-	2,150	2,764
212	-	-	-	-	-	113	310	423
213	-	60	130	25	-	217	820	1,252
214	-	-	144	10	-	23	410	587
215	-	-	88	20	-	50	130	288
216	-	-	52	-	-	-	240	292
217	-	106	118	-	-	207	220	651
218	102	60	116	-	-	-	170	448
219	39	30	50	-	-	-	170	289
220	-	30	64	5	-	-	60	159
221	-	30	12	-	-	-	120	162
222	-	30	22	5	-	-	70	127
223	-	-	84	20	-	7	40	151
224	-	384	534	25	-	10	1,120	2,073
225	-	-	-	-	-	13	10	23
226	-	-	-	20	-	-	170	190
Total	141	797	2,294	425	6	1,157	8,840	13,660

Table 6 ESTIMATED STORAGE POTENTIAL IN SARAWAK

Unit: $10^6 m^3$

Basin No.	Alluvial Class I	Alluvial Class II	Alluvial Class III	Alluvial Class IV	Rock Class I	Rock Class II	Rock Class III	Total
227	-	-	-	5	-	-	150	155
228	-	-	-	10	-	-	390	400
229	-	-	-	45	72	-	510	627
230	-	-	1,624	15	60	-	2,940	4,639
231	-	-	-	60	-	-	30	90
232	-	-	-	25	-	-	110	135
233	-	-	-	20	-	-	180	200
234	-	-	-	15	-	-	190	205
235	-	-	-	15	-	-	160	175
236	-	-	-	15	-	-	880	895
237	-	-	-	40	-	123	670	833
238	-	-	-	125	-	7	190	322
239	-	-	-	120	-	-	210	330
240	-	-	-	80	-	-	180	260
241	-	9	3,188	-	-	-	6,710	9,907
242	-	-	16	60	-	-	150	226
243	-	-	-	100	-	-	130	230
244	-	-	-	240	-	13	660	913
245	-	-	-	155	60	13	310	538
246	-	7	-	65	268	127	240	707
247	-	-	-	35	-	-	150	185
Total	-	16	4,828	1,245	560	283	15,140	22,072

Table 7 PRECIPITATION AND ESTIMATED DEEP PERCOLATION RATE

Basin No.	Precipitation (mm/y)	Deep Percolation in Alluvial Plain Class I to IV (mm/d)	Deep Percolation in Mountain Area Class I & II (mm/d)	Deep Percolation in Mountain Area Class III (mm/d)
201	2,491	1.5	1.0	0.2
202	2,093	1.3	0.9	0.2
203	2,168	1.3	0.9	0.2
204	2,071	1.2	0.9	0.2
205	2,013	1.2	0.8	0.2
206	2,080	1.3	0.9	0.2
207	2,262	1.4	0.9	0.2
208	2,233	1.3	0.9	0.2
209	2,639	1.6	1.1	0.2
210	2,550	1.5	1.0	0.2
211	2,660	1.6	1.1	0.2
212	3,161	1.9	1.3	0.3
213	3,273	2.0	1.3	0.3
214	3,255	2.0	1.3	0.3
215	3,506	2.1	1.4	0.3
216	2,700	1.6	1.1	0.2
217	2,582	1.6	1.1	0.2
218	3,130	1.9	1.3	0.3
219	3,023	1.8	1.2	0.2
220	3,126	1.9	1.3	0.3
221	3,190	1.9	1.3	0.3
222	3,106	1.9	1.3	0.3
223	3,064	1.8	1.3	0.3
224	2,109	1.3	0.9	0.2
225	3,376	2.0	1.4	0.3
226	2,900	1.7	1.2	0.2
227	3,762	2.3	1.5	0.3
228	2,998	1.8	1.2	0.2
229	3,884	2.3	1.5	0.3
230	3,793	2.3	1.6	0.2
231	2,976	1.8	1.2	0.2
232	2,745	1.7	1.1	0.2
233	2,681	1.6	1.1	0.2
234	2,993	1.8	1.2	0.3
235	3,378	2.0	1.4	0.3
236	3,918	2.4	1.6	0.3
237	3,912	2.4	1.6	0.3
238	3,830	2.3	1.6	0.3
239	3,914	2.4	1.6	0.3
240	3,369	2.0	1.4	0.3
241	3,990	2.4	1.6	0.3
242	3,637	2.2	1.5	0.3
243	3,547	2.1	1.5	0.3
244	3,612	2.2	1.5	0.3
245	3,716	2.2	1.5	0.3
246	4,193	2.5	1.7	0.3
247	4,793	2.9	2.0	0.4

Table 8 ESTIMATED GROUNDWATER RECHARGE IN SABAH

Unit: $10^6 m^3/d$

Basin No.	Alluvial Class				Rock Class			Total
	I	II	III	IV	I	II	III	
201	-	-	0.18	-	-	-	1.20	1.38
202	-	-	-	0.05	-	-	0.30	0.35
203	-	-	-	0.05	-	-	0.30	0.35
204	-	-	-	0.10	-	-	0.20	0.30
205	-	-	-	0.10	-	-	0.10	0.20
206	-	-	-	0.10	-	-	0.10	0.20
207	-	-	-	0.40	-	-	0.10	0.50
208	-	-	0.14	0.40	-	-	0.40	0.94
209	-	-	-	0.45	-	0.87	0.30	1.62
210	-	-	0.64	1.05	-	0.33	0.80	2.82
211	-	0.07	1.12	1.55	0.08	-	2.80	5.62
212	-	-	-	-	-	0.33	0.60	0.93
213	-	0.09	0.40	0.50	-	0.63	1.60	3.22
214	-	-	0.40	0.15	-	0.07	0.80	1.42
215	-	-	0.30	0.40	-	0.13	0.30	1.13
216	-	-	0.12	-	-	-	0.30	0.42
217	-	0.11	0.30	0.05	-	0.50	0.30	1.26
218	0.07	0.07	0.32	-	-	-	0.40	0.86
219	0.02	0.04	0.14	-	-	-	0.20	0.40
220	-	0.04	0.18	0.15	-	-	0.10	0.47
221	-	0.04	0.04	0.05	-	-	0.30	0.43
222	-	0.04	0.06	0.10	-	-	0.20	0.40
223	-	-	0.24	0.35	-	0.03	0.10	0.72
224	-	0.33	1.04	0.30	-	0.03	1.50	3.20
225	-	-	-	-	-	0.03	0.10	0.13
226	-	-	-	0.35	-	-	0.20	0.55
Total	0.09	0.83	5.62	6.65	0.08	2.95	13.6	29.82

Table 9 ESTIMATED GROUNDWATER RECHARGE IN SARAWAK

Unit: $10^6 m^3/d$

Basin No.	Alluvial Class				Rock Class			Total
	I	II	III	IV	I	II	III	
227	-	-	-	0.05	-	-	0.30	0.35
228	-	-	-	0.20	-	-	0.50	0.70
229	-	-	5.92	0.80	0.10	-	1.00	7.82
230	-	-	-	0.35	0.08	-	3.80	4.23
231	-	-	-	1.05	-	-	0.10	1.15
232	-	-	-	0.40	-	-	2.00	2.40
233	-	-	-	0.25	-	-	0.30	0.55
234	-	-	-	0.30	-	-	0.40	0.70
235	-	-	-	0.35	-	-	0.30	0.65
236	-	-	-	0.30	-	-	1.80	2.10
237	-	-	-	1.00	-	0.40	1.40	2.80
238	-	-	-	2.80	-	0.03	0.40	3.23
239	-	-	-	3.00	-	-	0.40	3.40
240	-	-	-	1.70	-	-	0.40	2.10
241	-	0.01	11.62	-	-	-	13.20	24.83
242	-	-	0.06	1.30	-	-	0.30	1.66
243	-	-	-	2.00	-	-	0.30	2.30
244	-	-	-	5.35	-	0.03	1.30	6.68
245	-	-	-	3.50	0.08	0.03	0.60	4.21
246	-	0.01	-	1.65	0.40	0.47	0.50	3.03
247	-	-	-	1.05	-	-	0.50	1.55
Total	-	0.02	17.60	27.4	0.66	0.96	29.8	76.44

Table 10 PRELIMINARY ESTIMATE OF SAFE YIELD BY BASIN IN SABAH

Unit: $10^6 m^3/d$

Basin No.	Alluvial Class I	Alluvial Class II	Alluvial Class III	Alluvial Class IV	Rock Class I	Rock Class II	Rock Class III	Total
201	-	-	0.09	-	-	-	0.12	0.21
202	-	-	-	0.01	-	-	0.03	0.04
203	-	-	-	0.01	-	-	0.03	0.04
204	-	-	-	0.01	-	-	0.02	0.03
205	-	-	-	0.01	-	-	0.01	0.02
206	-	-	-	0.01	-	-	0.01	0.02
207	-	-	-	0.02	-	-	0.01	0.03
208	-	-	0.07	0.02	-	-	0.04	0.13
209	-	-	-	0.02	-	0.26	0.03	0.31
210	-	-	0.32	0.04	-	0.10	0.08	0.54
211	-	0.05	0.56	0.06	0.03	-	0.29	0.99
212	-	-	-	-	-	0.10	0.06	0.16
213	-	0.06	0.20	0.02	-	0.19	0.16	0.63
214	-	-	0.20	0.01	-	0.02	0.08	0.31
215	-	-	0.15	0.01	-	0.04	0.03	0.23
216	-	-	0.06	-	-	-	0.03	0.09
217	-	0.08	0.15	0.01	-	0.15	0.03	0.42
218	0.06	0.05	0.16	-	-	-	0.04	0.31
219	0.02	0.03	0.07	-	-	-	0.02	0.14
220	-	0.03	0.09	0.01	-	-	0.01	0.14
221	-	0.03	0.02	-	-	-	0.03	0.08
222	-	0.03	0.03	0.01	-	-	0.02	0.09
223	-	-	0.12	0.01	-	0.01	0.01	0.15
224	-	0.23	0.52	0.02	-	0.01	0.15	0.93
225	-	-	-	-	-	0.01	0.01	0.02
226	-	-	-	0.01	-	-	0.02	0.03
Total	0.08	0.59	2.81	0.32	0.03	0.89	1.37	6.09

Table 11 PRELIMINARY ESTIMATE OF SAFE YIELD BY BASIN IN SARAWAK

Unit: $10^6 m^3/d$

Basin No.	Alluvial Class				Rock Class			Total
	I	II	III	IV	I	II	III	
227	-	-	-	0.01	-	-	0.03	0.04
228	-	-	-	0.01	-	-	0.05	0.06
229	-	-	-	0.01	0.05	-	0.10	0.16
230	-	-	2.22	0.01	0.04	-	0.39	2.66
231	-	-	-	0.03	-	-	0.01	0.04
232	-	-	-	0.01	-	-	0.02	0.03
233	-	-	-	0.01	-	-	0.03	0.04
234	-	-	-	0.01	-	-	0.04	0.05
235	-	-	-	0.01	-	-	0.03	0.04
236	-	-	-	0.01	-	-	0.18	0.19
237	-	-	-	0.02	-	0.12	0.14	0.28
238	-	-	-	0.07	-	0.01	0.04	0.12
239	-	-	-	0.07	-	-	0.04	0.11
240	-	-	-	0.05	-	-	0.04	0.09
241	-	0.01	4.37	-	-	-	1.34	5.72
242	-	-	0.02	0.03	-	-	0.03	0.08
243	-	-	-	0.06	-	-	0.03	0.09
244	-	-	-	0.13	-	0.01	0.13	0.27
245	-	-	-	0.09	0.04	0.01	0.06	0.20
246	-	0.01	-	0.04	0.20	0.14	0.05	0.44
247	-	-	-	0.02	-	-	0.05	0.07
Total	-	0.02	6.61	0.70	0.33	0.29	2.83	10.78

Table 12 PRELIMINARY ESTIMATE OF SAFE YIELD BY DISTRICT IN SABAH

Unit: $10^6 m^3/d$

District No.	Alluvial Class				Rock Class			Total
	I	II	III	IV	I	II	III	
201	-	-	0.12	-	-	-	0.12	0.24
202	-	-	-	0.04	-	-	0.09	0.13
203	-	-	0.01	0.01	-	-	0.01	0.03
204	-	-	0.23	0.04	-	0.27	0.11	0.65
205	-	0.05	0.75	0.06	0.01	0.16	0.33	1.36
206	-	-	-	0.01	-	0.10	0.03	0.14
207	-	-	-	0.01	-	-	0.08	0.09
208	-	0.06	0.56	0.04	-	0.24	0.17	1.07
209	-	-	0.06	-	-	-	0.03	0.09
210	-	0.08	0.15	-	-	-	0.04	0.27
211	-	-	-	-	-	0.17	0.01	0.18
212	0.06	0.05	0.16	-	-	-	0.03	0.30
213	0.02	0.03	0.06	-	-	-	0.03	0.14
214	-	-	0.06	-	-	-	0.01	0.07
215	-	0.03	0.04	-	-	-	0.01	0.08
216	-	0.05	0.05	0.01	-	-	0.03	0.14
217	-	-	0.01	-	-	-	0.03	0.04
218	-	0.21	0.25	-	-	-	0.05	0.51
219	-	0.02	0.13	0.01	-	0.01	0.04	0.21
220	-	-	0.18	0.03	-	-	0.02	0.23
221	-	-	-	0.01	-	-	-	0.01
222	-	-	-	-	-	0.01	-	0.01
223	-	-	-	0.01	-	-	0.05	0.06
Total	0.08	0.58	2.82	0.28	0.01	0.96	1.32	6.05

Table 13 PRELIMINARY ESTIMATE OF SAFE YIELD BY DISTRICT IN SARAWAK

Unit: $10^6 m^3/d$

District No.	Alluvial Class				Rock Class			Total
	I	II	III	IV	I	II	III	
224	-	-	-	0.01	-	-	0.10	0.11
225	-	-	-	0.02	0.07	-	0.11	0.20
226	-	-	2.05	0.02	0.06	-	0.61	2.74
227	-	-	0.17	0.07	-	-	0.08	0.32
228	-	-	-	0.02	-	0.09	0.36	0.47
229	-	-	-	0.12	-	0.02	0.09	0.23
230	-	-	-	0.05	-	-	0.04	0.09
231	-	-	-	-	-	-	0.64	0.64
232	-	-	-	-	-	-	0.52	0.52
233	-	-	-	-	-	-	0.14	0.14
234	-	-	0.15	-	-	-	0.08	0.23
235	-	-	2.45	-	-	-	0.01	2.46
236	-	-	1.11	-	-	-	-	1.11
237	-	-	-	-	-	-	0.09	0.09
238	-	0.01	0.55	-	-	-	0.01	0.57
239	-	0.01	0.15	-	-	-	0.03	0.19
240	-	-	-	0.03	-	-	0.03	0.06
241	-	-	-	0.04	-	-	0.03	0.07
242	-	-	-	0.01	-	0.01	0.07	0.09
243	-	-	-	0.17	-	0.01	0.04	0.22
244	-	-	-	0.06	-	0.01	0.01	0.08
245	-	-	-	0.02	0.09	0.01	0.05	0.17
246	-	-	-	0.03	0.16	0.05	0.03	0.27
247	-	-	-	-	0.09	0.03	0.03	0.15
248	-	-	-	0.03	-	-	0.05	0.08
Total	-	0.02	6.63	0.7	0.47	0.23	3.25	11.3

Table 14 PRINCIPAL FEATURE OF ASSUMED GROUNDWATER SOURCE FACILITIES

	Case						
	1	2	3	4	5	6	7
Aquifer	------ Alluvial -----				---- Rock -----		
Class	I	I	III	IV	I	II	III
Depth of Well (m)	25	25	25	15	50	120	50
Pumping Discharge (m^3/d)	600	300	120	30	660	430	70
Drawdown (m)	2	3	4	5	5	10	15
Transmissivity (m^2)	300	100	30	5	150	50	5
Well Type	--Shallow Tubewell---				-Deep Tubewell--		
Pump Capacity (PS)	10	2	2	0.5	10	25	1.5
Motor Capacity (kW)	7.5	2.2	1.5	0.4	7.5	11.0	1.1

Remarks; Radius of screen pipe is assumed to be 0.1 m.

Table 15 COST ESTIMATE OF ASSUMED GROUNDWATER SOURCE FACILITIES

Unit: M$10^3

	Case 1	2	3	4	5	6	7
Investment Cost							
1. Well Construction	40	40	40	30	120	300	120
2. Submersible Pump /1	20	14	10	8	20	20	10
3. Diesel Generator Set /2	15	8	7	7	15	20	7
4. Building /2	12	12	12	12	12	12	12
5. Quarter /2	10	10	10	10	10	10	10
6. Land Acquisition /2	10	10	10	10	10	10	10
7. Engineering /2	4	4	4	4	4	4	4
8. Physical Contingency /3	11	10	9	8	19	38	17
Total	122	108	102	89	210	414	190
O&M Cost							
1. Power Generation /4	6.6	1.9	1.3	0.4	6.6	9.6	0.9
2. Chemicals /5	11.0	5.5	2.2	0.5	12.0	7.8	1.3
3. Well Cleaning	2.0	2.0	2.0	2.0	2.0	2.0	2.0
4. Other Cost	2.0	2.0	2.0	2.0	2.0	2.0	2.0
Total	21.6	11.4	7.5	4.9	22.6	21.4	6.2

Remarks; All the costs are at price level of 1980.

/1: This item includes a stand by unit
/2: See Ref. 57
/3: Assumed to be 10% of total cost from 1 to 7
/4: Electric charge (M$/y) = M$0.15 x kW x 16 hours per day x 365
/5: Unit cost is assumed to be M$0.05/m3

Table 16 ESTIMATED COST STREAM OF ASSUMED GROUNDWATER SOURCE FACILITIES

Unit: M$10³

Year	Capital Cost Case 1	2	3	4	5	6	7	O&M Cost Case 1	2	3	4	5	6	7
1	122	108	102	89	210	414	190	21.6	11.4	7.5	4.9	22.6	21.4	6.2
2-7	-	-	-	-	-	-	-	21.6	11.4	7.5	4.9	22.6	21.4	6.2
8	35	22	17	15	35	40	17	21.6	11.4	7.5	4.9	22.6	21.4	6.2
9-15	-	-	-	-	-	-	-	21.6	11.4	7.5	4.9	22.6	21.4	6.2
16	35	22	17	15	35	40	17	21.6	11.4	7.5	4.9	22.6	21.4	6.2
17-23	-	-	-	-	-	-	-	21.6	11.4	7.5	4.9	22.6	21.4	6.2
24	35	22	17	15	35	40	17	21.6	11.4	7.5	4.9	22.6	21.4	6.2
25	40	40	40	30	120	300	120	21.6	11.4	7.5	4.9	22.6	21.4	6.2
26-31	-	-	-	-	-	-	-	21.6	11.4	7.5	4.9	22.6	21.4	6.2
32	35	32	17	15	35	40	17	21.6	11.4	7.5	4.9	22.6	21.4	6.2
33-39	-	-	-	-	-	-	-	21.6	11.4	7.5	4.9	22.6	21.4	6.2
40	35	22	17	15	35	40	17	21.6	11.4	7.5	4.9	22.6	21.4	6.2
41-47	-	-	-	-	-	-	-	21.6	11.4	7.5	4.9	22.6	21.4	6.2
48	35	22	17	15	35	40	17	21.6	11.4	7.5	4.9	22.6	21.4	6.2
49-50	-	-	-	-	-	-	-	21.6	11.4	7.5	4.9	22.6	21.4	6.2

Table 17 ESTIMATED UNIT COST OF WATER SOURCE

Unit: M$10³

Discount Rate (%)	Case 1	2	3	4	5	6	7
6	0.15	0.19	0.36	1.11	0.17	0.35	0.81
8	0.16	0.20	0.39	1.21	0.18	0.38	0.91
10	0.17	0.21	0.43	1.34	0.19	0.41	1.01
12	0.17	0.23	0.46	1.44	0.20	0.45	1.11
14	0.18	0.24	0.49	1.56	0.22	0.49	1.22
16	0.19	0.26	0.52	1.65	0.23	0.53	1.32
18	0.19	0.27	0.55	1.75	0.24	0.56	1.41
20	0.20	0.28	0.57	1.86	0.25	0.60	1.50

FIGURES

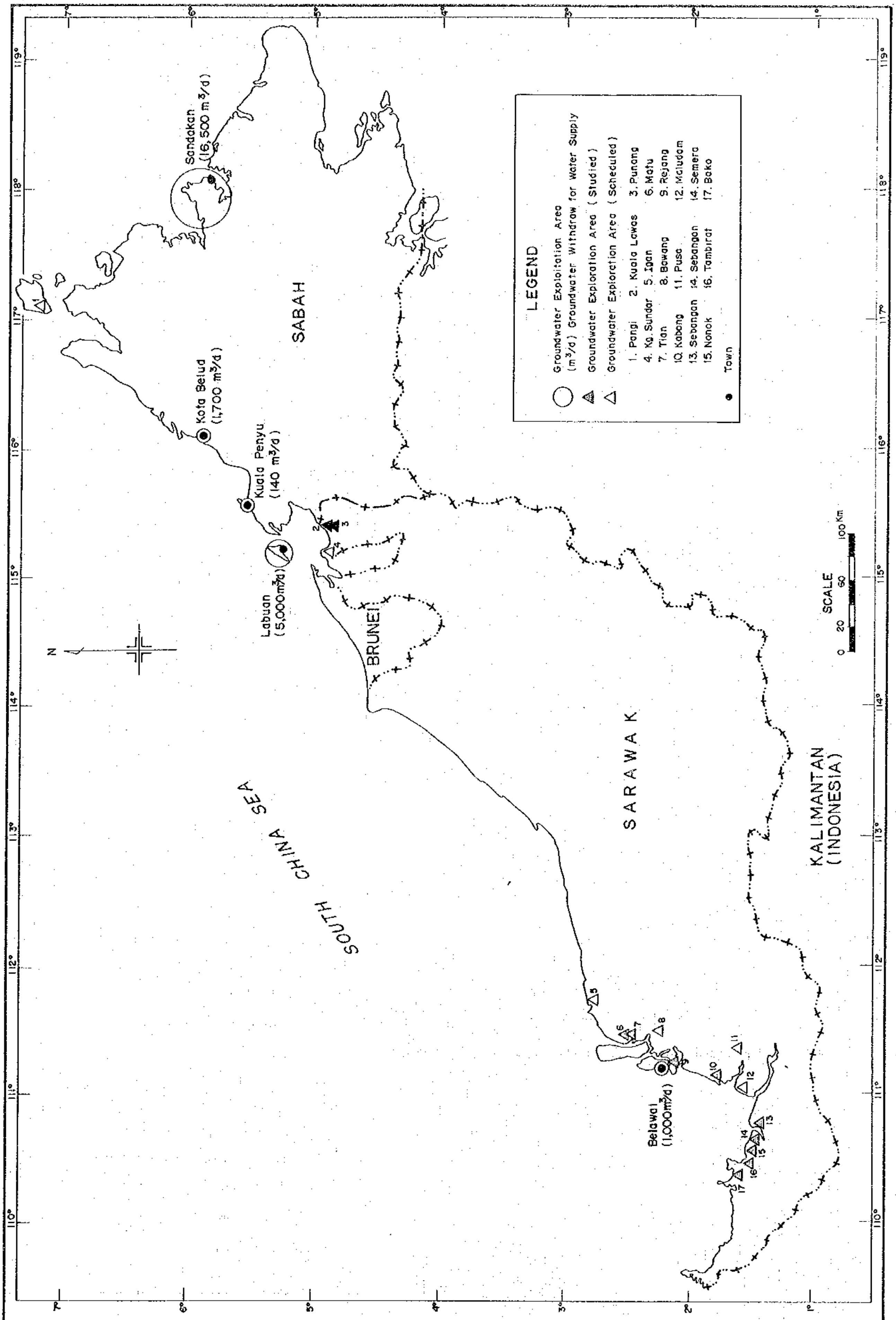

Fig.1 Groundwater Exploitation /Exploration Area

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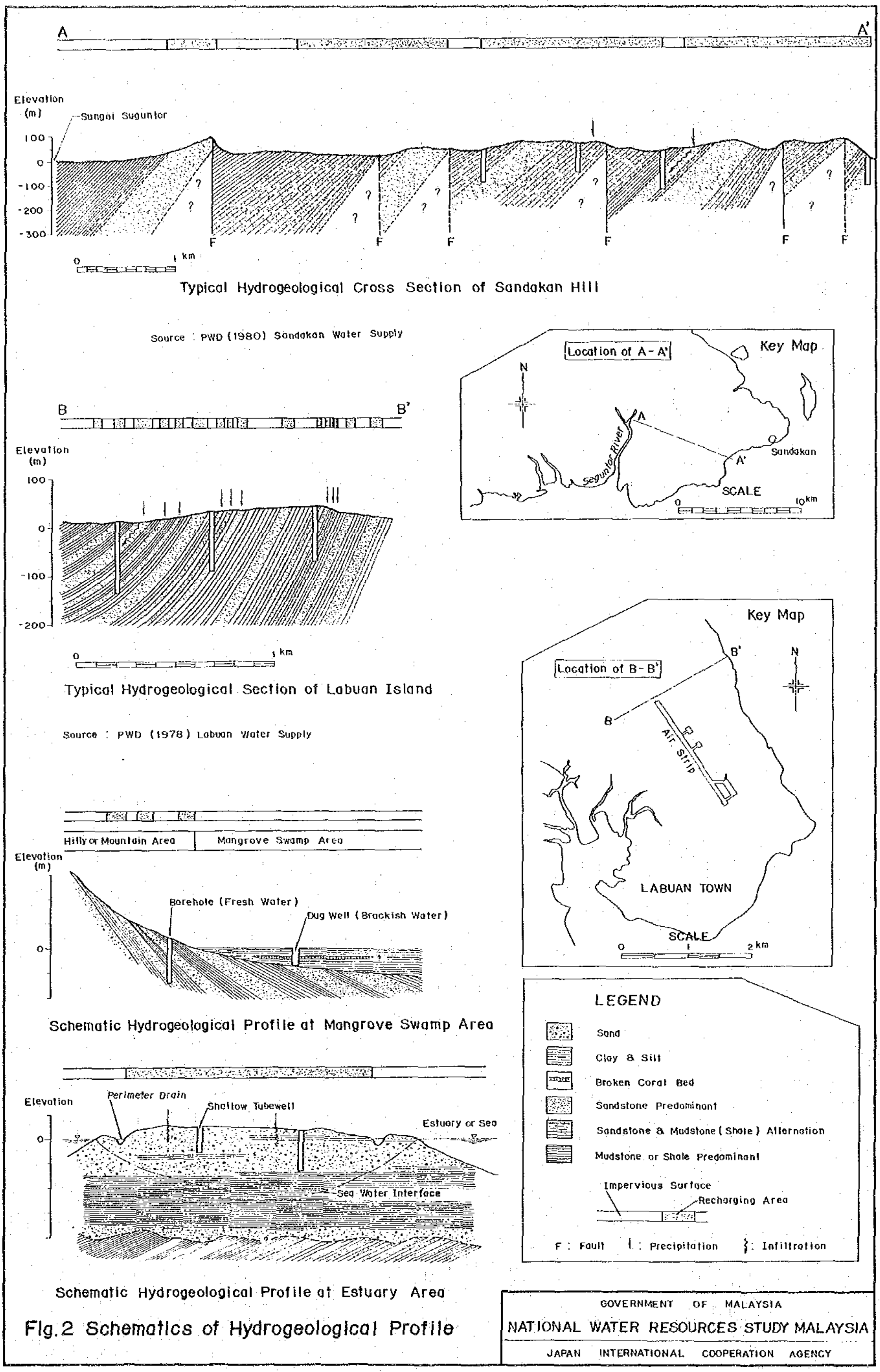

Fig.2 Schematics of Hydrogeological Profile

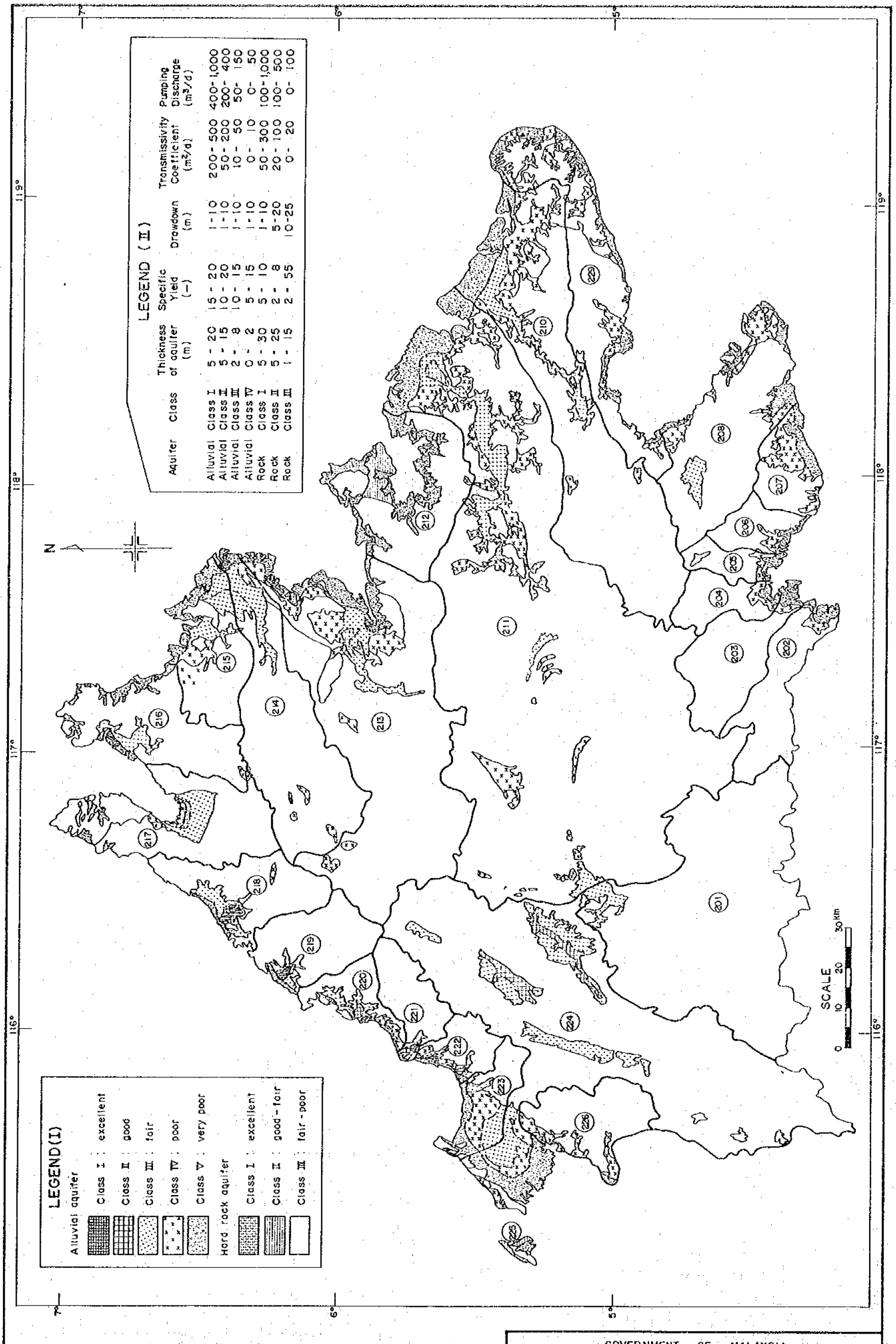

Fig. 3 Hydrogeological Land Classification Map (1/3)

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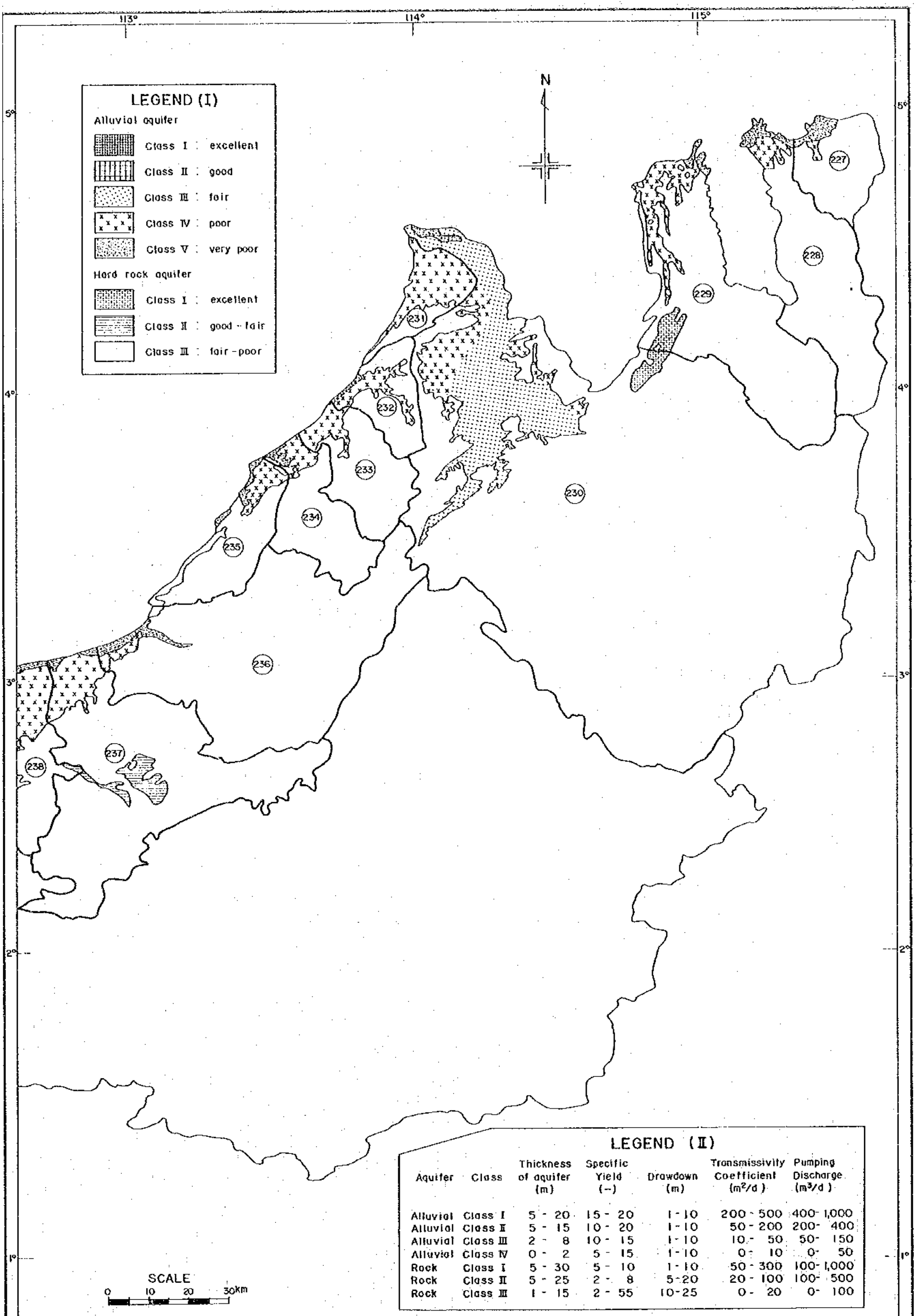

LEGEND (II)

Aquifer	Class	Thickness of aquifer (m)	Specific Yield (−)	Drawdown (m)	Transmissivity Coefficient (m²/d)	Pumping Discharge (m³/d)
Alluvial	Class I	5 - 20	15 - 20	1 - 10	200 - 500	400 - 1,000
Alluvial	Class II	5 - 15	10 - 20	1 - 10	50 - 200	200 - 400
Alluvial	Class III	2 - 8	10 - 15	1 - 10	10 - 50	50 - 150
Alluvial	Class IV	0 - 2	5 - 15	1 - 10	0 - 10	0 - 50
Rock	Class I	5 - 30	5 - 10	1 - 10	50 - 300	100 - 1,000
Rock	Class II	5 - 25	2 - 8	5 - 20	20 - 100	100 - 500
Rock	Class III	1 - 15	2 - 55	10 - 25	0 - 20	0 - 100

Fig. 4 Hydrogeological Land Classification Map (2/3)

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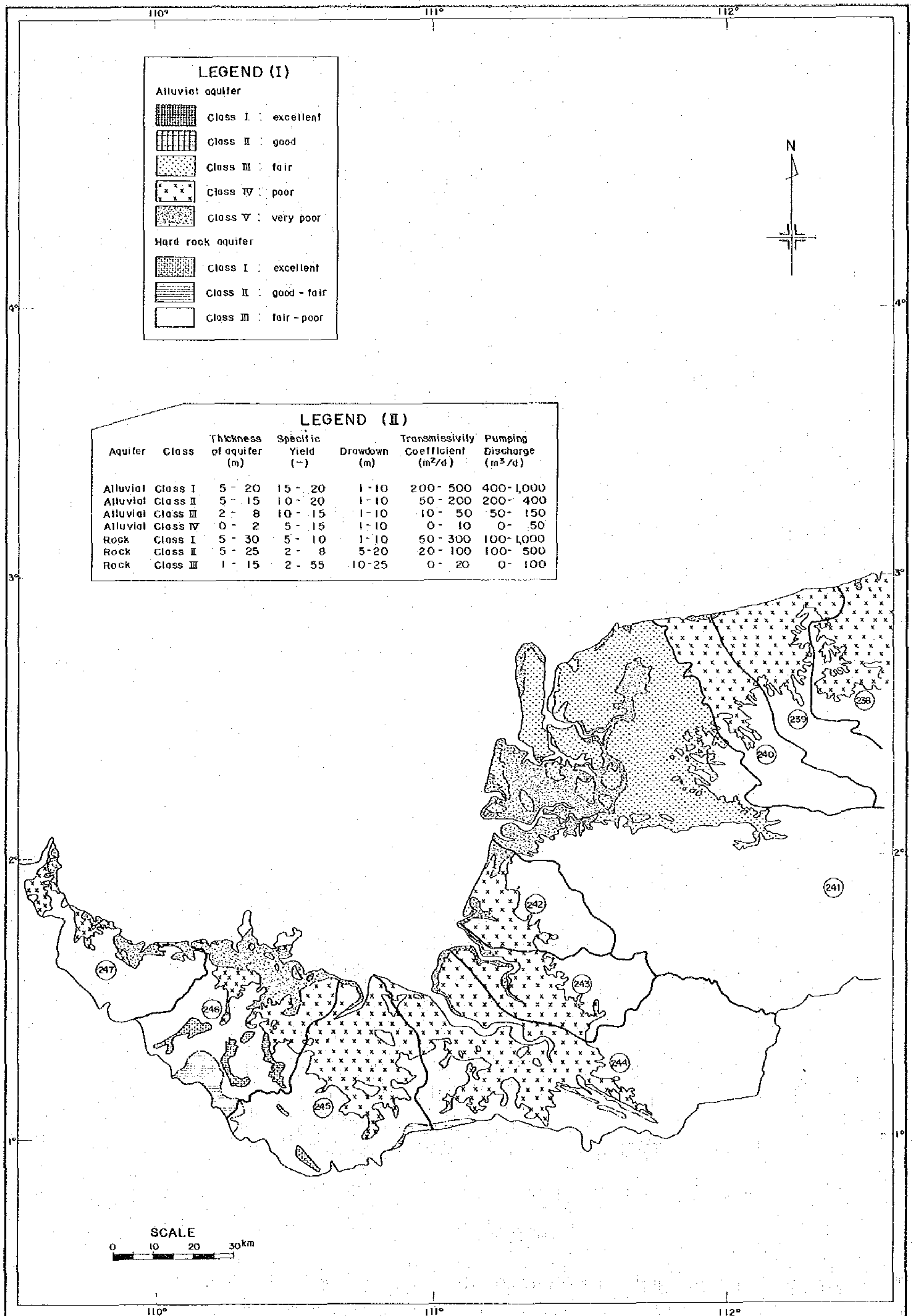

LEGEND (II)

Aquifer	Class	Thickness of aquifer (m)	Specific Yield (–)	Drawdown (m)	Transmissivity Coefficient (m^2/d)	Pumping Discharge (m^3/d)
Alluvial	Class I	5 - 20	15 - 20	1 - 10	200 - 500	400 - 1,000
Alluvial	Class II	5 - 15	10 - 20	1 - 10	50 - 200	200 - 400
Alluvial	Class III	2 - 8	10 - 15	1 - 10	10 - 50	50 - 150
Alluvial	Class IV	0 - 2	5 - 15	1 - 10	0 - 10	0 - 50
Rock	Class I	5 - 30	5 - 10	1 - 10	50 - 300	100 - 1,000
Rock	Class II	5 - 25	2 - 8	5 - 20	20 - 100	100 - 500
Rock	Class III	1 - 15	2 - 55	10 - 25	0 - 20	0 - 100

Fig. 5 Hydrogeological Land Classification Map (3/3)

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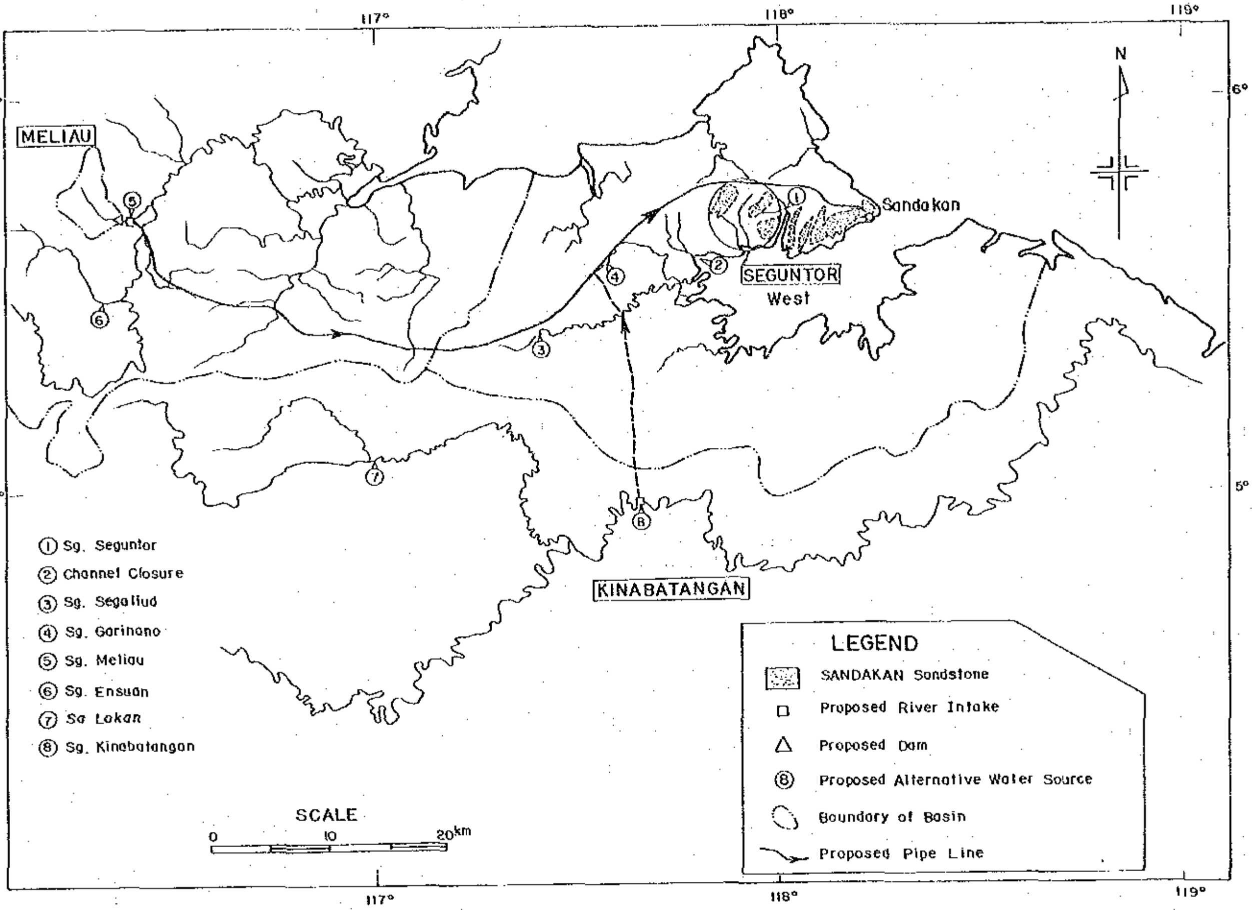

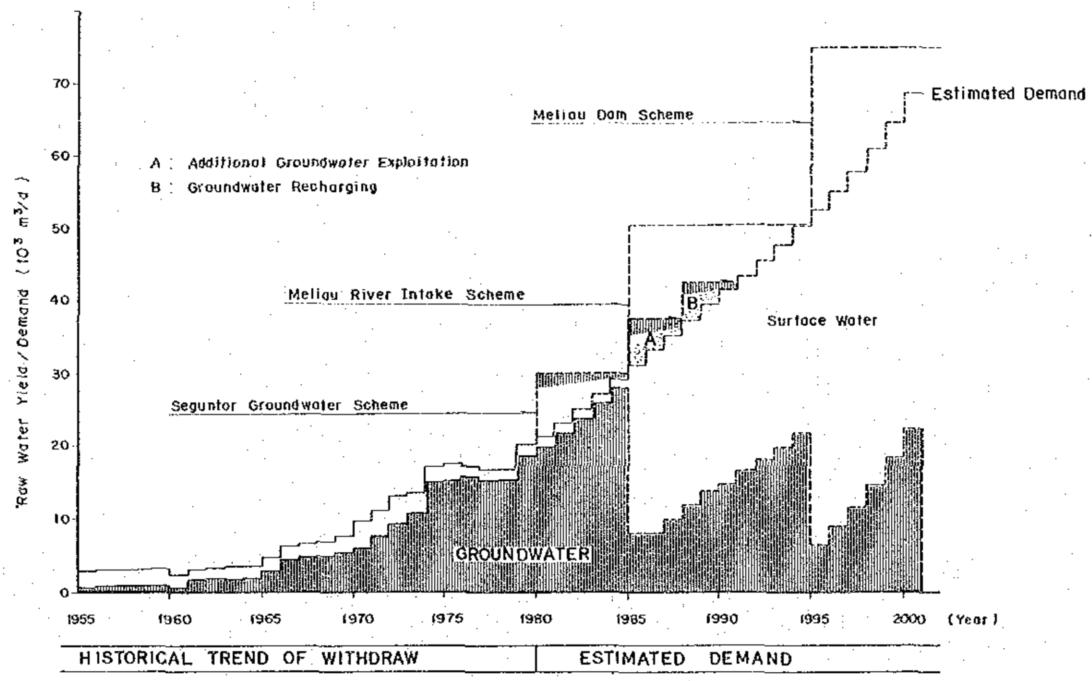

Fig. 6 An Example of Proposed Conjunctive Use in Sandakan

Source : PWD (1980) Sandakan Water Supply Extention Scheme Vol. II

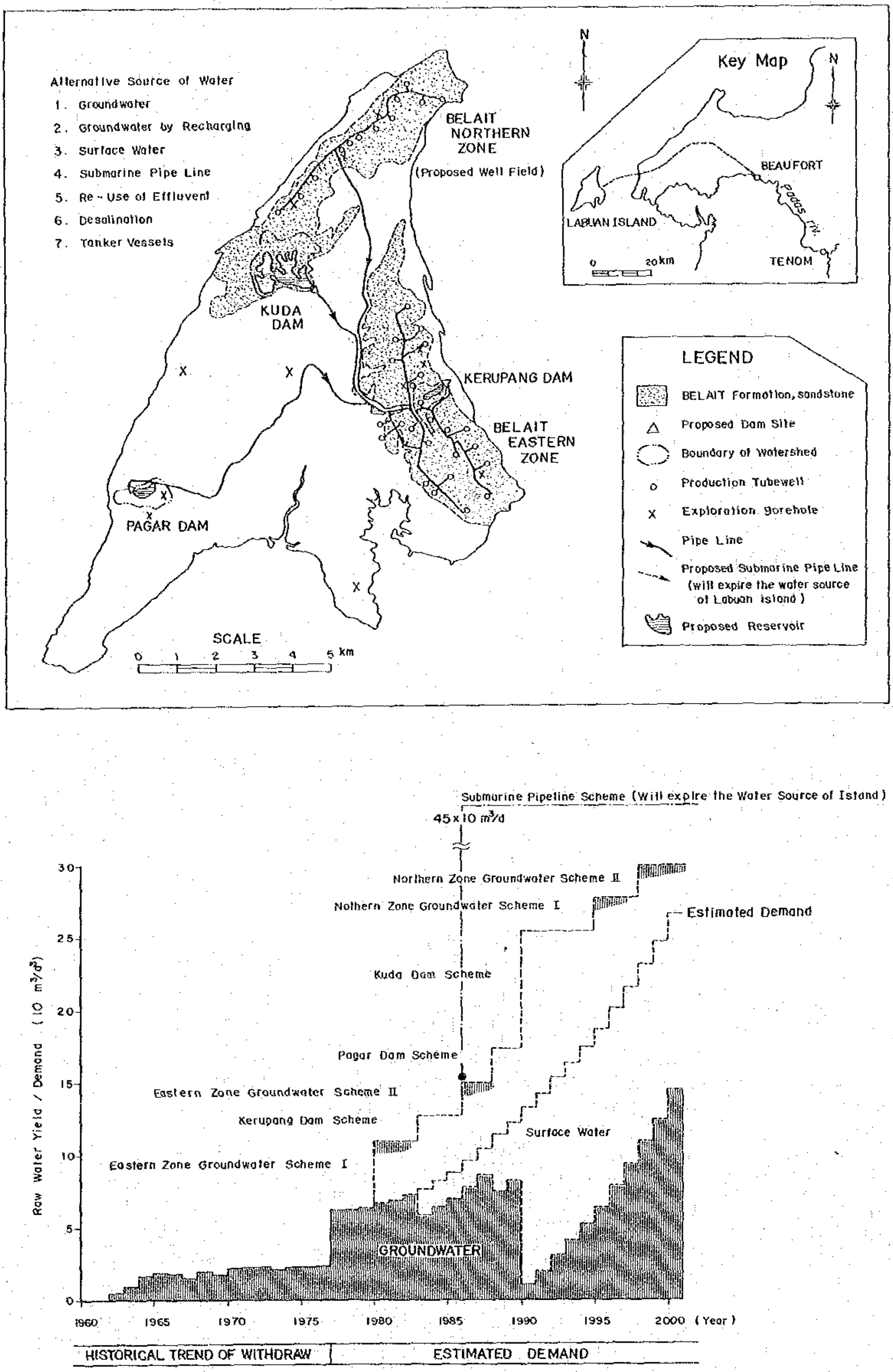

Fig. 7 An Example Proposed Conjunctive Use in Labuan

Source : PWD (1978) Labuan Water Supply Vol. I

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