CHAPTER III

METHODS OF INVESTIGATION

3.1 Data manipulation

3.1.1 Original data Well data are collected from two main sources First, the Metropolitan Water Works Authority where 3 types of data are available.

a) Electrical log data consisting of the Self Potential and the Resistivity logging. There are 18 wells where these information are completely available.

b) Lithological log data consisting of cutting samples. There are 15 wells where the data are available.

c) Groundwater Potentials data consisting of water quality from 290 wells and hydraulic character from 222 wells.

Second, the Division of Geotechnical and Transportation Engineering, Asian Institute of Technology where extensive compilation of groundwater wells in the Lower Central Plain from various agencies are systematically published. The various original data sources previously mentioned are listed in Table 9. For the benefit of simplicity, the present investigation follows the similar abbreviation code.

Table 9 : Name and abbreviation codes of source through which data was collected.

Name of the Original Source	Abbreviation Code
Department of Mineral Resources	M (or DMR)
Poblic works Department	P
Metropolitan Water Works Authority	W (MWWA)
Electricity Generating Authority of Thailand	E
Private Drilling Contractors	C

These well data are arranged into four main categories, namely, well characteristics, hydraulic characteristics, water quality and lithological characteristics. However, lithological characteristics are emplayed in this investigation only. The total number of well data utilized in this regard is 550.

3.1.2 Data refining The surface elevation and the grid reference number of each well are the essential information which are primarily collected and compiled. The grid reference number of a particuler well gives its location in the map with reference to the military grid system of 1:20,000 scale map series for sedimentary facies analysis and 1:275,000 scale map series for groundwater potential analysis. The first three digits of the number collectively give the E-W coordinate increasing in castward direction and the remaining last three digits give the N-S coordinate increasing in northward direction.

All well data can be separated into 2 main types.

a) Primary well data These are mainly used in this study and they are divided into 2 groups :

a.1) Primary reference well data. The primary reference wells have been designated to those wells where complete cutting samples and electrical log motifs are available. Altogether there are 15 lithological primary reference wells and 18 electrical primary reference wells. Data obtained from these wells are essentially served as the skeleton of the study programme.

a.2) Primary well data. The primary wells are those collected, compiled and systematically identified from various sources. The information and data regarding these wells are available from the research programme of A.I.T. which has been published in 1978. Detailed information of these primary wells is as follows :

a.2.1 Lithological data. Information regarding the depth of the well, type of sediment, grain size, colour are tabulated and graphically presented with appropriate code system for each well (Figure 11, Tables 10, 11).

a.2.2 Groundwater data. The groundwater data may be further classified into 2 categories, namely, the water quality and the hydraulic character. An attempt has been made to select only those wells which have been penetrated and withdraw the groundwater from any particalar aquifer for water quality data used. Besides, only

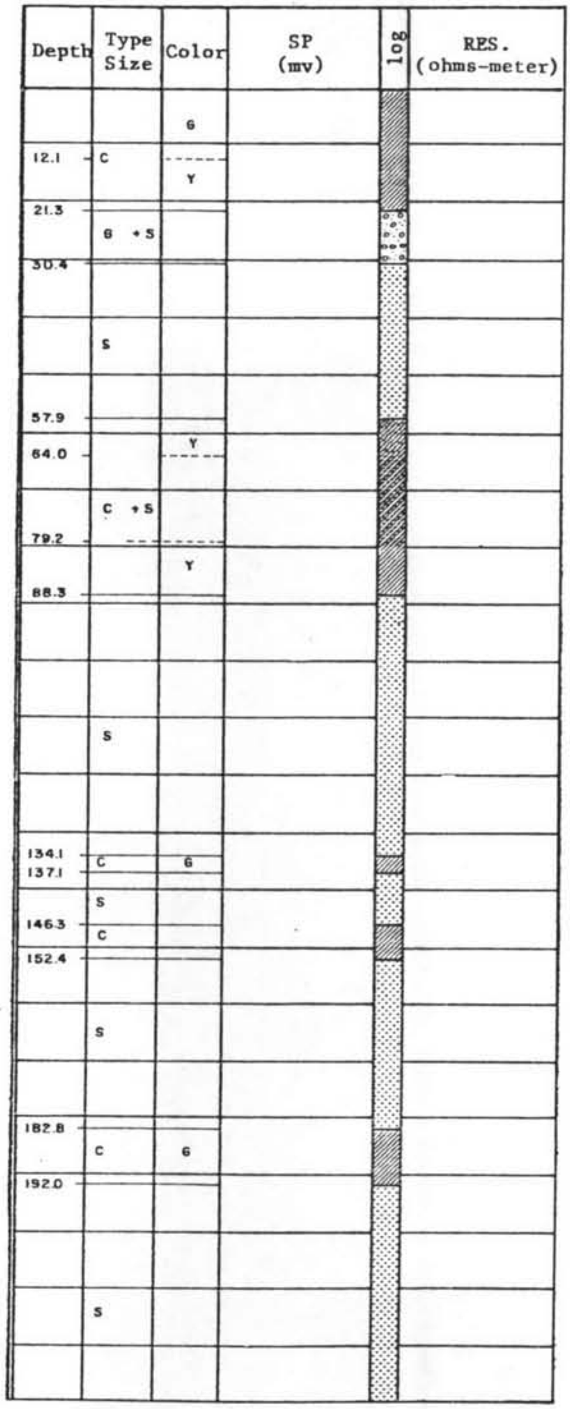
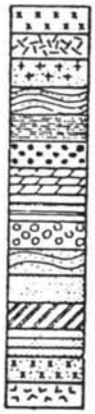


Figure 11 Well data (AIT, 1978).

Table 10 Abbreviations for Lithologic Types and Grain Sizes and Lithologic Symbols of Sediments and Rocks (AIT, 1978).

Abbreviation	Symbol	Type	Abbreviation	Symbol	Type
AN		Andesite	B		Pebble
BA		Basalt	C		Clay
DI		Diorite	G		Gravel
GN		Gneiss	CR		Granite
I		Silt	IG		Igneous rock
L		Lateritic sediments	LS		Limestone
M		Marl	MB		Marble
MD		Mudstone	O		Cobble
P		Granule	PH		Phyllite
QZ		Quartzite	RH		Rhyolite
S		Sand	SC		Schist
SH		Shale	SL		Slate
SS		Sandstone	ST		Siltstone
TR		Trachite	TS		Top soil
VO		Volcanic rock	X		Rock fragment

Explanation:

To denote a combination of two or more types of sediments, abbreviations are combined, such as

C + S = sandy clay

S + C + G = clayey gravelly sand

L + G = gravels mixed with lateritic sediments.

The same principle is used for other combinations.

Table 11 Sediment and Rock Color Codes (AIT, 1978).

Code	Color	Code	Color
B	Brown	C	Cream
D	Dark	G	Gray
K	Black	L	Light
N	Green	O	Orange
P	Pink	PP	Purple
R	Red	U	Blue
V	Violet	W	White
Y	Yellow		

Explanation:

When more than one color of sediments is given, the codes are combined as in the following examples

BK = Brownish black

B–K = Brown to black

Y–NY = Yellow to greenish yellow

YW, R = Yellowish white and red

B–PPB = Brown to purplish brown

B, K = Brown and black

Y–G–B = Yellow to gray to brown

YB–GB = Yellowish brown to grayish brown

YW, BY = Yellowish white and brownish yellow

GB–G–K = Brownish gray to gray to black

The same principle applies when other combinations of colors are used.

the latest analysis of water quality from these wells are employed in this study (Table 12). The parameters concerning water quality include, total dissolved solid, total hardness, chloride, sulphate, total alkalinity, magnesium, sodium & potassium, and iron. Regarding the hydraulic character of the well, the information is consisting of the static water level (W.L.), the yield or pumping capacity and the draw down (D.D.).

b) Secondary well data. The secondary wells referred to in this study are those wells with incomplete data previously defined. The data from there wells have been used to supplement the correlation programme whenever possible (Figure 12).

3.2 Preparation of location maps

Location maps are prepared with reference to the military grid system of 1:20,000 scale map series for sedimentary facies analysis and 1:275,000 scale map series for groundwater potentials analysis.

Primary reference wells, primary wells and secondary wells are located on the maps according to their grid references using different symbols to indicate their categories. (Plate 1-A, 1-B, and 1-C). Besides, the location map of the study area has been separately presented in 3 parts due to the limitation of materials for the map preparation in the required scale. These 3 location maps are the Plate 1-A for the northern part, Plate 1-B for the middle part, and Plate 1-C for the southern part. The administrative boundaries of Amphoe and

Table 12 Water Quality Data (Metcalf & Eddy Inc., 1977).

Date Sampled	Color	Turbidity JTu	pH	mgl														
				Tot. Alkalinity	Tot. Dis. Solid	Tot. Hardness	Cl	SO_4 as $NaSO_4$	Ammonia: Free as N	Ammonia: Albuminoid as N	NO_3 as N	NO_2 as N	Ca	Fe	F	Mn	Mg	Free CO_2
4/ 4/77	-	2.6	7.1	290	270	126	10	-	-	-	-	-	-	0.29	-	-	-	89.0
27/12/76	-	3.6	6.92	244	275	148	9	49.70	-	-	Trace	0.001	14.4	0.44	0.2	0.302	26.88	69.0
28/ 6/76	-	5.7	7.11	286	260	124	6	-	-	-	0.085	Trace	-	0.47	-	-	-	78.0
5/ 4/76	-	4.6	7.25	276	268	126	8	17.0	0.784	0.480	0.265	Trace	32.8	0.40	0.305	0.076	10.6	76.0
20/12/75	-	4.75	7.09	292	280	124	9	-	0.621	0.188	-	0.002	35.2	0.39	0.279	0.520	8.64	-
4/ 8/75	-	5.25	7.25	302	260	124	9	17.04	0.164	0.002	0.096	-	36.8	0.53	0.265	0.188	7.68	-
6/ 5/75	-	5.6	7.05	286	275	124	6.0	9.94	0.492	0.056	-	-	36.0	0.45	0.203	0.263	8.16	-
17/ 2/75	-	3.7	7.3	258	330	122	5.0	18.48	0.177	-	-	0.006	24.8	0.38	0.20	0.188	14.4	-
26/ 9/74	-	-	7.7	-	-	126	7	-	-	0.028	0.186	0.109	-	0.39	-	-	-	-
25/ 2/74	-	-	-	-	-	131	18	-	-	0.079	0.056	Trace	-	0.44	-	-	-	-
30/ 4/73	5	7.4	6.9	268	275	66	nil	nil	0.22	0.04	0.62	0.002	18.4	0.66	0.34	0.226	4.80	-
12/ 3/73	nil	6.7	6.8	264	270	98	1	5.68	0.37	0.05	Trace	nil	27.2	0.94	0.34	0.216	7.20	-

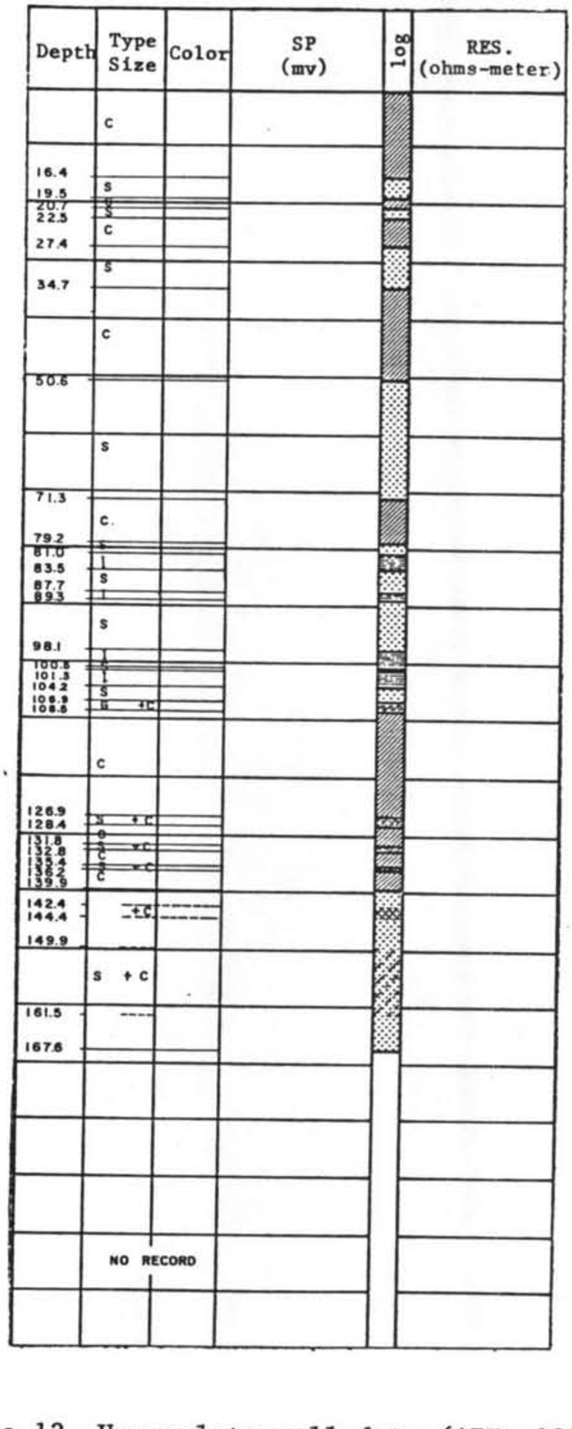


Figure 12 Uncomplete well data (AIT, 1978).

Changwat are also indicated in the maps using the reference code numbering system developed by the A.I.T. (Table 13).

In addition, the grid reference number of groundwater wells for the groundwater potential analysis has also been degignated as another running number series. (Appendix 2, Figure 26).

3.3 Sedimentary facies analysis.

3.3.1 Interpretation of depositional environment.

The interpretation of depositional environment is carried out on the basis of sedimentary facies concept. In this regard, the spontaneous potential logs (S.P. logs) are essentially employed to determine the facies. Besides, data on the actual grain size characteristics obtained from the cutting study have been partially used to supplement the cross-checking mechanism. The sedimentary environment of deposition of sediments concerned is therefore deduced by means of the comparison method with appropriate vertical grain size profile and S.P. log models.

Generally, there are 3 main facies models characterized the unconsolidated sediments in the study area.

a) Shelf mud facies. The sediments of shelf mud facies are principally made up of salty silt and clay. The characteristic fatures of shelf mud facies are curves of the spontaneous potential swinging further to the left hand side of the normal shale line and appear in a box-like manner. This is primarily due to the current in the bore

Table 13 : Changwat and Amphoe Codes for the study area.
(AIT, 1978)

Changwat Name	Code	Amphoe Name	Code	Amphoe Name	Code
Bangkok	17	Bang Kapi	171	Bang Khen	172
		Bang Khun Thian	173	Bangkok Noi	174
		Bangkok Yai	175	Bang Rak	176
		Dusit	177	Huai Khwang	178
		Klong San	179	Lat Krabang	180
		Min Buri	181	Nong Chok	182
		Nong Khaem	183	Pathum Wan	184
		Phasi Charoen	185	Phra Khanong	186
		Phra Nakhon	187	Phaya Thai	188
		Pom Prap	189	Rat Burana	190
		Samphanthawong	191	Taling Chan	192
		Thonburi	193	Yan Nawa	194
Nonthaburi	25	Bang Bua Thong	261	Bang Kruai	262
		Bang Yai	263	Muang Nonthaburi	264
		Pak Kret	265	Sai Noi	266
Samut Prakan	30	Bang Bo	321	Bang Phli	322
		Muang Samut Prakan	323	Phra Pradaeng	324

hole moves in the reverse direction and gives the negative value if the clay has a high salinity content. Besides, the increase in salinity content of the shelf mud facies gives the increase in conduetivity and so concurrently decrease in the resistivity. As a result the resistivity curve shows a low ohms-meter value and swing to the left. The pattern of S.P. logs and resistivity curves of the salty shelf mud facies are so distinctive as compared with those of the normal clay. (Figure 13 A).

b) Deltaic plain facies. The facies are mainly consisting of distributary channel sands, and a variety of interdistributary or non-channel deposits which are principally muds and thin muddy sands (Figure 13 B). Within the depth range of 0 to 250 meters of subsurface sediments of the study area, 2 deltaic plain facies have been recognized. First, the deltaic plain facies which is developed as the lowest facies underlying the delta front facies. Second, the deltaic plain facies which is developed higher in the sequence underlying the shelf mud facies. The deltaic plain facies in the study area can be categorized into 2 major types as follows :

(b.1) The deltaic plain aggradational channel fill which is characterized by the abrupt lower and upper boundaries with internally uniform channel sands (Box-like S.P. curve). The pattern is alternating with the non-channel pattern (low S.P. curve) of thin and poorly developed sands of crevasse splay and levee origins, muds of interdistributary bays and floodplain origins (Figure 13 B.a).

(b.2) The deltaic plain aggradational channel fill which is characterized by an abrupt crosional base and fining upward sequence. In addition, the resistivity curve of the sequence indicate the fresh-water nature of the interstitial pore fluid. (Figures 13.B.b & 13.B.c).

C) Delta front facies. The facies is further subdivided into 2 sub-facies, namely, delta front & sheet sand subfacies and distributary mouth bar sub-facies. Within the study area the delta front facies is developed between the 2 cycles of deltaic plain facies previously mentioned. The characteristic feqtures of these 2 sub-facies are as follows :

(C.1) Delta front & Sheet sand subfacies which is characterized by the abrupt lower boundary and coarsening upward sequence. Ideally the subfacies might appear in 3 different patterns, namely, slope, distal and marginal (Figures 5-4). However, within the study area these 3 patterns do not distinctively develop (Figure 13.C.a).

(C.2) Distributary mouth bar sub-facies which is characterized by an inverted Christmass Tree pattern of the S.P. curve. Furthermore, the lower part of the sequence is consisting of many small layers of distal sands and silts of delta front. The whole sequence is grading upward to thicker sands of the upper part of distributary mouth bars (Figures 13.C.b, 13.C.c, and 13.C.d).

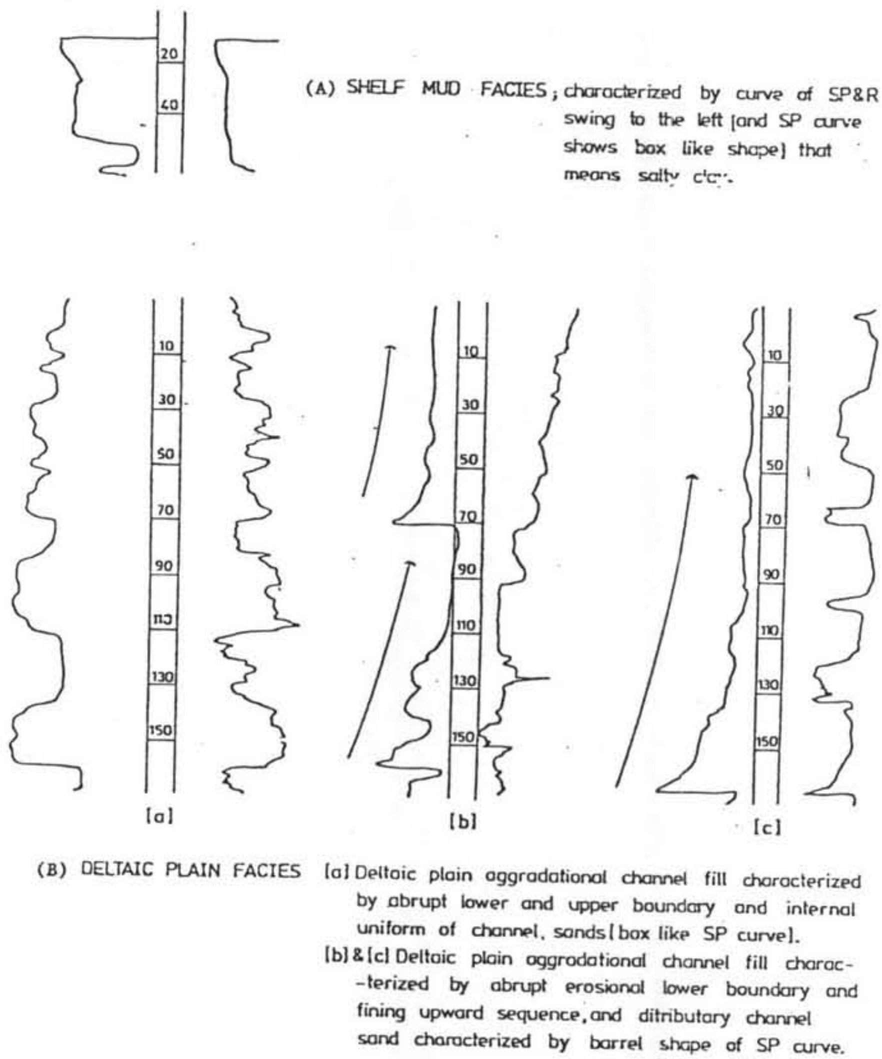
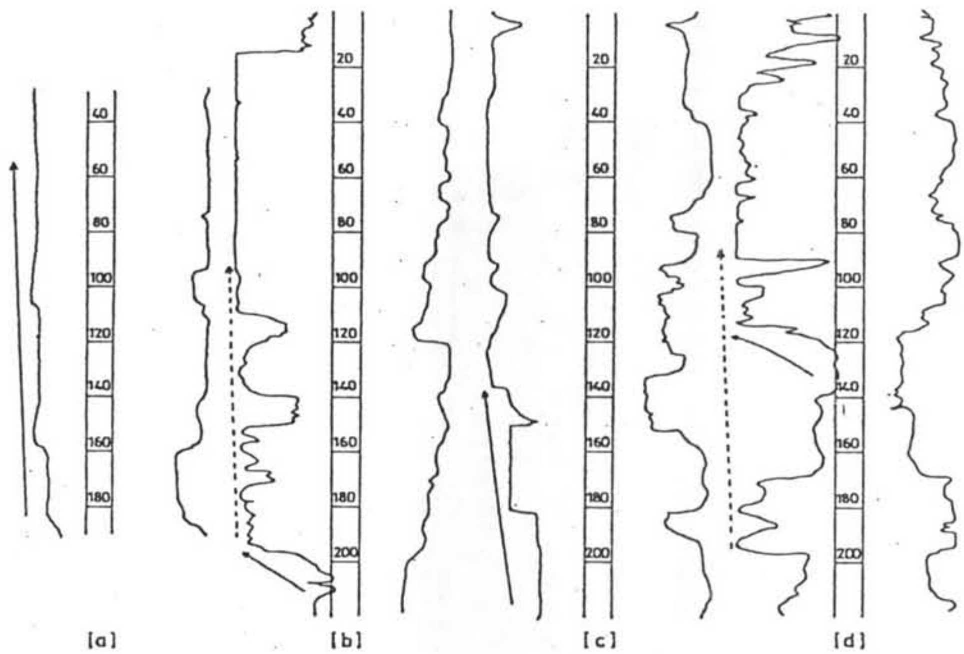


Figure 13 Representative E-log patterns, Bangkok Area.



(C) DELTA FRONT FACIES [a] Delta front and sheet sand characterized by abrupt lower boundary and coarsening upward sequence.

[b]&[c]&[d] Distributary mouth bar characterized by an inverted christmas tree of SP curve and the lower part of the sequence consisting of more distal sands and silts of delta front, grading upward to thicker sands of the upper part of the distributary mouth bar.

Figure 13 (cont.)

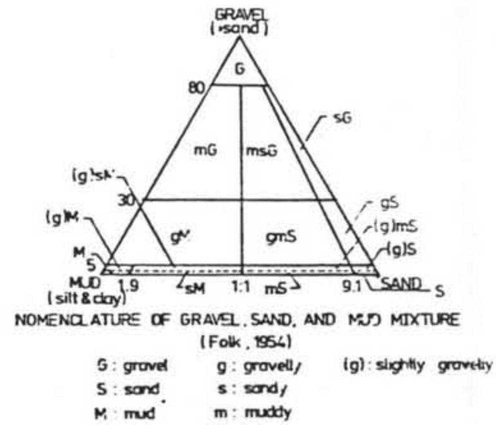
3.3.2 Identification of physical properties of sediments

Physical properties of sediments are identified from cutting samples by binocular microscope (Appendix 1-A). The properties are as follows :

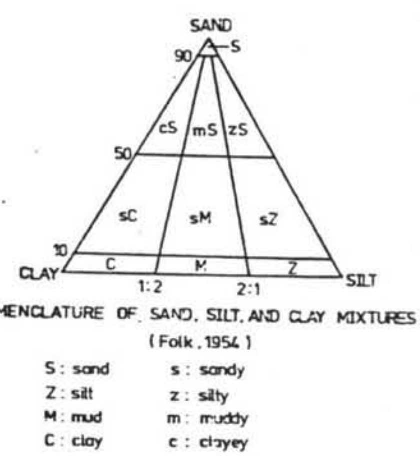
a) Lithology. The classification and nomenclature of sediments in the present investigation follow the system developed by Folk (1954). This system is consisting of 2 end-member schemes. First, the coarse-grained sediments which utilize the gravel, sand and mud as end-members. Second, the medium-grained sediments which utilize the sand, silt and clay as end-members. (Figure 14)

b) Grain size. The identification of grain size of sediments is generally referred to Wentworth grade scale (1922). However, a slight modification is made particularly with respect to the nomenclature of mud and gravel (Figure 15).

c) Color. The color of sediment is identified on the basis of color comparison of the cutting samples with the standard rock color chart of the Geological Society of America (1975). It is remarkable, however, to note that the color of sediment described in this study might be different from the original color in some cases. The color variation in this particular case might be due to the exposure of sediment to the earth's atmosphere long enough after the drilling to the time of study. The reference code numbers and appropriate color descriptions concerned are summarized and presented in Table 14.



A : For gravel, sand and mud mixtures



B : For sand, silt and clay mixtures

Figure 14 Classification and nomenclatures of sediments.
(Folk, 1954)

Scale (mm.)	WENTWORTH (1922)		Modified WENTWORTH	
	Boulder			
256				
	Cobble			
64				
	Pebble		Gravel	
4				
	Granule			
2				
	Sand	VC	Sand	VC
1				
		C		C
0.5				
		M		M
0.25				
		F		F
C.125				
		VF		VF
0.062				
	Silt		Silt	Mud
0.004				
	Clay		Clay	

Figure 15 Grain size scale : Wentworth (1922) and modified wentworth.

Table 14 Some standard code no. and appropriate color of Rock Color Chart (G.S.A., 1975).

Code No.	Color	Code No.	Color
5R 6/2	Pale red	5YR 5/6	Light brown
5Y 2/1	Olive black	5YR 6/4	Light brown
5Y 4/1	Olive gray	5YR 7/2	Grayish orange pink
5Y 6/1	Light olive gray	5YR 8/4	Moderate orange pink
5Y 7/2	Yellowish gray	10R 6/2	Pale red
5Y 8/1	Yellowish gray	10R 6/6	Moderate reddish orange
5Y 8/4	Grayish yellow	10R 8/2	Grayish orange pink
5Y 2/1	Brownish black	10YR 2/2	Desky yellowish brown
5YR 2/2	Dysky brown	10YR 4/2	Dark yellowish brown
5YR 3/2	Grayish brown	10YR 6/2	Pale yellowish brown
5YR 3/4	Moderate brown	10YR 6/6	Dark yellowish orange
5YR 4/1	Brownish gray	10YR 7/4	Grayish orange
5YR 4/4	Moderate brown	10YR 8/2	Very pale orange
5YR 5/2	Pale brown	10YR 8/6	Pale yellowish orange
N4	Medium dark gray	N7	Light gray
N5	Medium gray	N8	Very light gray
N6	Medium light gray		

d) Roundness and sphericity. The roundness and sphericity of sediments, particularly the sand fraction, have been extensively studied using the visual comparison method. The standard visual comparator developed by Power (1953) is employed in this investigation.

e) Sorting. The uniformity of grain size of the sediment is determined an reported in terms of Trask's sorting coefficient (1932), So.

$$So = \sqrt{Q_1/Q_3}$$

Where Q1 is the first quatile, and

Q3 is the third quatile of the grain size in millimeters.

The Trask's sorting coefficient obtained is then expressed in equivalent verbal scale (Table 15).

Table 15 Trask's sorting coefficient (1932).

So (mm.)	Verbal Scale
less than 2.5	well sorted
about 3.0	moderate sorted
greater than 4.5	poor sorted

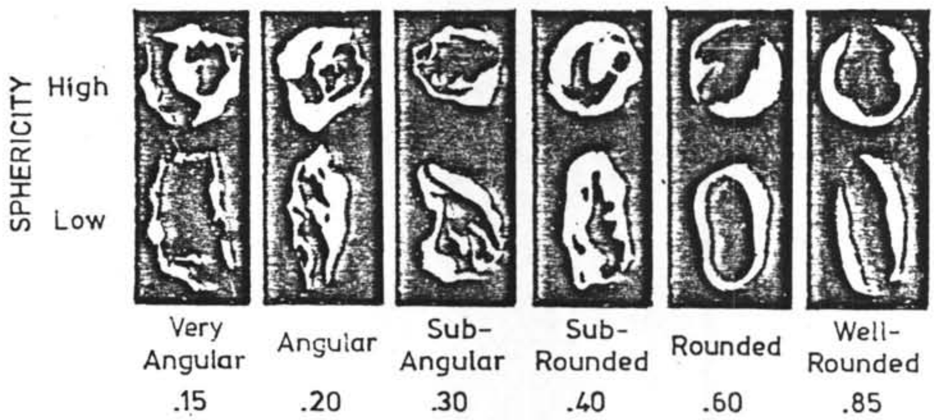


Figure 16 Visual comparator for estimating two-dimensional roundness of sand grains. (Power, 1953)

3.3.3 Stratigraphic correlation. Then

A) Depositional environment The interpretation of depositional environment of each primary reference well is delineated first on the basis of vertical grain size profile. Then the information from electrical logs of primary reference wells in the adjoining are principally used in the correlation of the depositional environment of a larger area. The data are synthesized and presented in terms of close system fence diagram (Plate 2). The 3 main criteria employed in the determination of depositional environment are the type of depositional environment, the depth and the standard deltaic models.

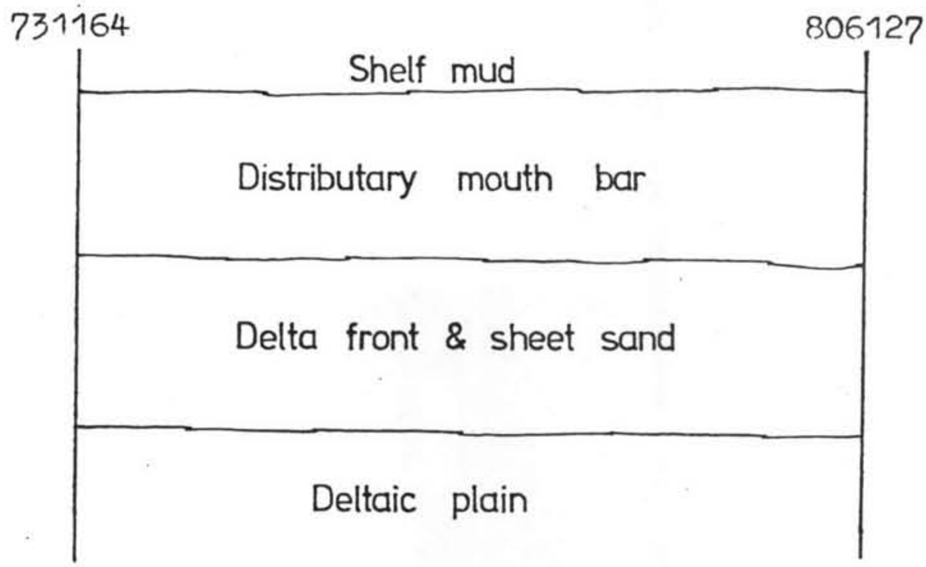
On the basis previously described method, there appears to be 2 possibilities for correlation. They are :

Case I : The same depositional environment exists at the same depth in the adjoining wells. In this case the correlation can be simply interpolated (Figure 17).

Case II : If various types of depositional environment are revealed at different depth levels in the afjoining wells, then the standard depositional environment models (Reineck, 1973) are served for the correlation. (Figures 17, 18)

B) Stratigraphy The stratigraphic correlation referred to in this study is the lithostratigraphy. In order to achieve the most beneficial and accurate correlation, 2 technical procedures are employed as follows :

Case I : The same type of depositional environment at the same depth can be correlated.



Case II : Different type of depositional environment at the same depth can be correlated by reference to the standard model, (Reineck, 1973).

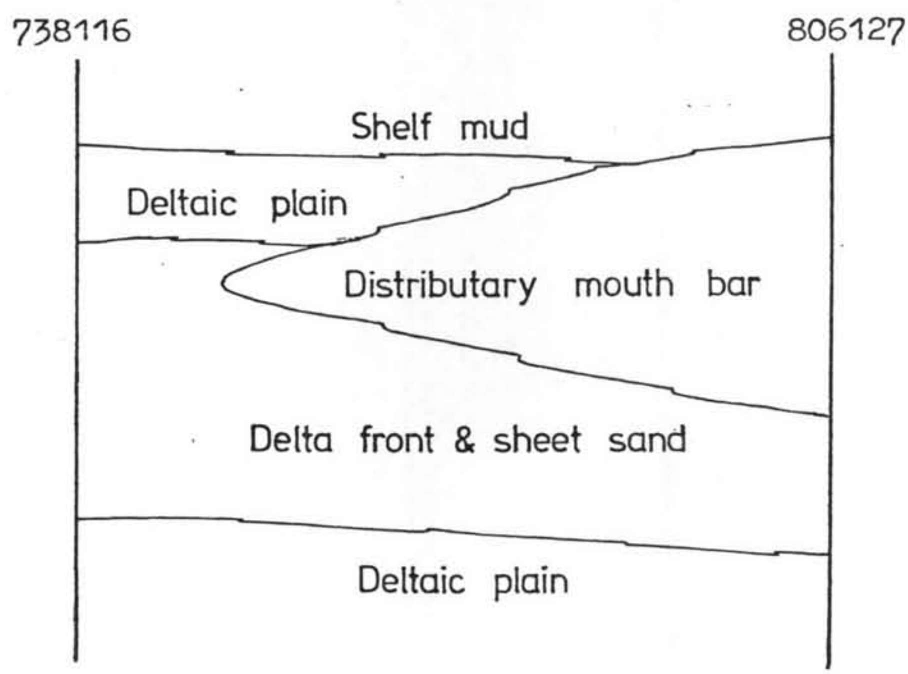
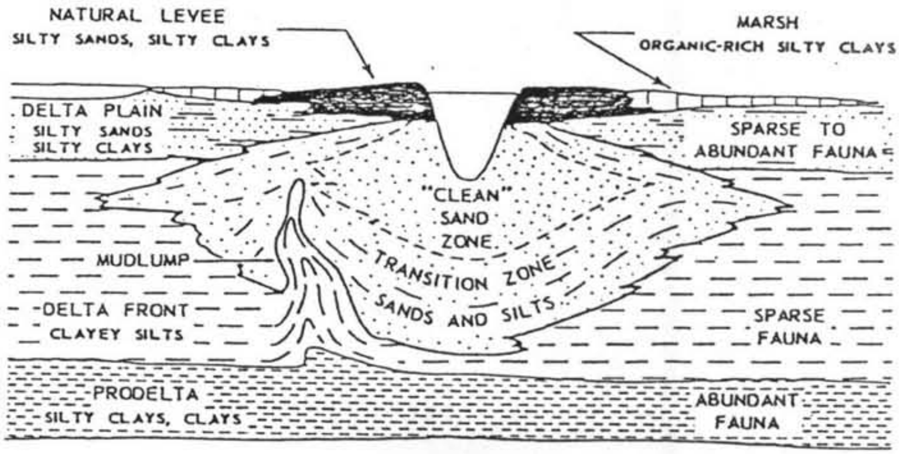
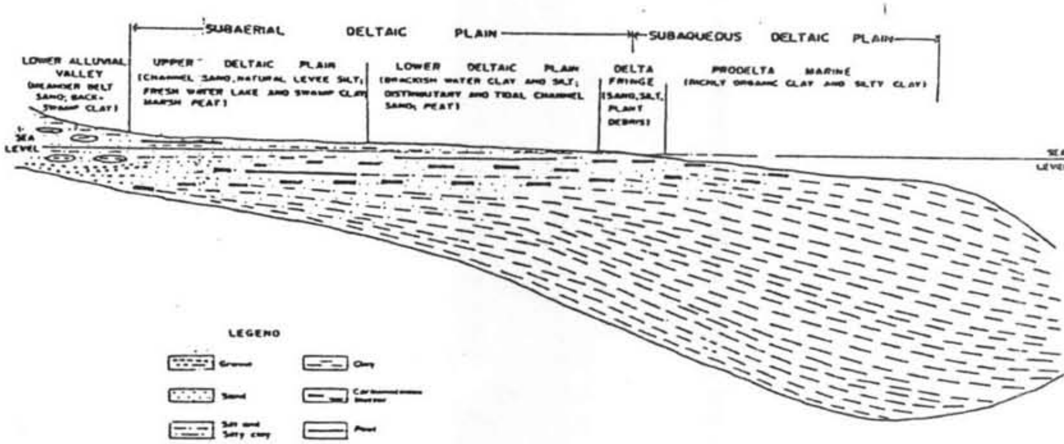


Figure 17 Correlation on the basis of simple interpolation of adjoining wells.



(A) Cross-section of a distributary channel. (Fisk, 1961)



(B) Schematic longitudinal section of delta progration.

(Rainwater, 1966)

Figure 18 Standard deltaic models. (Fisk, 1961 and Rainwater, 1966)

B.1) The lithological characteristics of all primary reference wells as determined from the cutting samples are used in the large scale correlation of the subsurface geology of the study area. The information, particularly regarding the geometry of permeable and impermeable sediments, and synthesized and presented in terms of the fence diagram (Plate 3). As a result, the three-dimentional lithostratigraphic model of the subsurface geology (0-250 meter depth) within an area of approximately 700 square kilometers is established.

B.2) Additional information from the primary wells concerned, especially the lithological characteristics, have been used to supplement the correlation between adjoining primary reference wells. The procedures is apparently proved to be very beneficial in constructing altogether 12 cross-sectional profiles. These cross-sectional profiles are then further employed as a cross-checking mechanism of the lithostratigraphic fence diagram previously prepared.

As a result of the lithostratigraphic correlation, 4 permeable units at different depth levels interbedded with impermeable units are defined in terms of their aerial extent, thicknesses, and their stratigraphic positions. The nomenclature of 4 permeable lithostratigraphic units are equivalent to those aquifers previously studied by the DMR, namely, Bangkok, Phra Pradaeng, Nakhon Luang and Nonthaburi aquifers irrespect to the increasing depth level.

The conceptual framework of lithostratigraphic correlation between 2 adjacent wells are illustrated in terms of every possible working procedures in Figure 19.

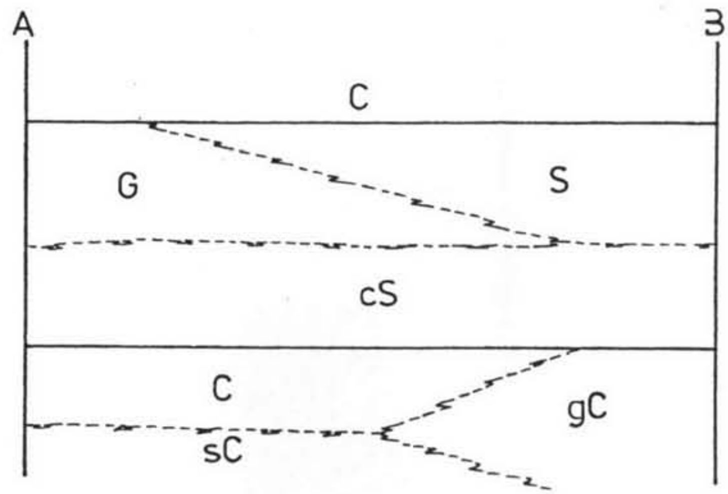
3.4 Groundwater potential analysis.

The analysis of groundwater potential in this study has focussed the attention on 2 different aspects, namely, the water quality and the hydraulic character.

3.4.1 Water quality. The quality of groundwaters in various aquifers have been extensively studied and the analyses are expressed in 2 different schemes as follows :

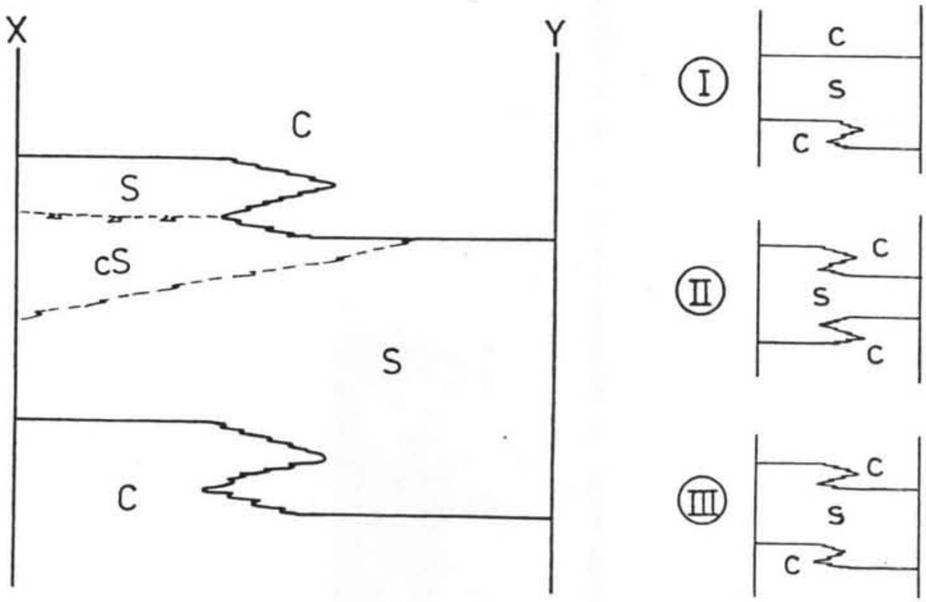
(a) Hydrochemical facies. The quantity and quality of anions, notably, chlorine, sulphate and carbonate & sulphate and of the cations, notebly, calcium, magnesium, potassium & sodium including the relationships between cations and anions are presented in the Piper's trilinear diagram (Figure 25). Within this trilinear diagram, 4 different hydrochemical facies are used in considering the groundwater quality. Analytical data from 4 different aquifers are separately determined in terms of hydrochemical facies (Figure 26).

Piper's trilinear diagram. The water quality data as obtained from standard analyticalprocedures for anions and cations with expressed in milligram per liters (mg/l) are further converted into the equivalent part per million unit (epm.) using the following formula



19-1 Illustrating how different sediment types of the same category of permeability which appear at the same depth level of two adjacent wells are correlated.

Figure 19 Possibilities of lithostratigraphic correlation between two adjacent wells of different characteristics. The heavy line indicates the boundary between permeable and impermeable units, wheras dotted line indicates boundary between different sediment types.



19-2 Illustrating how different sediment types of the same category of permeability which appear at different depth level of two adjacent wells are correlated. Additional possibilities for correlation of units with different thickness are also presented.

Figure 19 (cont.)

$$epm. = \frac{ppm.\ of\ ion \times valency\ of\ ion}{molecular\ weight}$$

The summation of epm. of all cations (Mg, Ca, Na + K) is expressed in 100 percents. In the same manner, the summation of epm. of all anions (Cl, SO_4, CO_3 + HCO_3) is expressed in 100 percents. The percentage of individual cation and anion is eventually caculated. These values are finally plotted in the triangular diagram (Appendix 2-A).

epm. calculation

$$Cl = \frac{ppm.\ of\ Cl \times 1}{35.0}\ epm.$$

$$SO_4 = \frac{ppm.\ of\ Na_2SO_4 \times 0.67 \times 2}{96.0}\ epm.$$

$$CO_3 + HCO_3 = \frac{ppm.\ of\ total\ alkalinity \times 2}{100}\ epm.$$

Cation |Ca, Mg, Na + K|

$$Ca = \frac{ppm.\ of\ Ca \times 2}{40.0}\ epm.$$

$$Mg = \frac{ppm.\ of\ Mg \times 2}{24.0}\ epm.$$

$$Na + K = \Sigma\ epm.\ of\ anion - \Sigma\ epm.\ of\ cation\ epm.$$

(b) Distribution of some chemical components of groundwater. Some chemical components of water quality are selected for special study, namely, Chloride, Iron, Total Hardness and Total dissolved solids. It is important to note that these 4 chemical components are significant to health as stated by the World Health organization. Therefore the study on the concentration level and the distribution of these components is considered necessary in this study.

The distribution patterns of four components are shows as contour lines of equal concentration (ppm.) in each aquifer using water quality data listed in Appendix 2-B.

3.4.2 Hydraulic charecter. The parameters included under the hydraulic character of each aquifers are static water level, yield, drawdown and specific capacity. The analysis of these existing data enable parameters this study to predict the tendency of these either increasing or decreasing in the future.