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An Assessment of Groundwater Pollution Potential of a Proposed Petrochemical Plant Site in Ulsan, South Korea

Hydrogeologic and site characterization and groundwater pollution potential by utilizing several empirical assessment methodologies

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ABSTRACT : A tentative hydrogeologic and hydrodispersive study was carried out to evaluate the groundwater pollution potential at a selected site by utilizing empirical assessment methodologies in an advanced stage of quantitative computer aided assessment. The upper most aquifer is defind as saturated overburden and weathered zone including the upper part of highly fractured rock. Representative hydraulic conductivity and storativity of the uppermost aquifer are estimated at 2.88 E-6 m/s and 0.09, respectively. Also calculated Darcian and average linear velocity of groundwater along the major pathway are 0.011 m/d and 0.12 m/d with average hydraulic gradient of 4.6% in the site. The results of empirical assessment methodologies indicate that 1) DRASTIC depicts that the site is situated on non-sensitive and non-vulnerable area. 2) Legrand numerical rating system shows that the probability of contamination and degree of acceptability are classed to "Maybe-Improbable, and Probable Acceptable and Marginally Unacceptable" with situation grade of "B". 3) Waste soil-site interaction matrix assessment categorizes that the study site is located on "Class-8 Site".

INTRODUCTION

The study is aimed to evaluate the vulnerability of the groundwater system of the study area against accidental or unexpected spills and leaks of toxicants from storage tanks during plant operation. The study basically covers the following items : 1) to define hydrogeologic and hydrodispersive characteristics of the groundwater environment, 2) to establish a base-line of groundwater quality of the site and its environs, 3) to evaluate the groundwater pollution potential and vulnerability of hydrogeologic system against a selected toxic substance by utilizing three (3) empirical assessment methodologies, and 4) to predict and assess the contaminant migration by using computer aided assessment.

The study has been performed in 4 stages that are preliminary site definition, data generation survey, evaluating of groundwater pollution potential, and finally contaminant migration study tentatively.

In this paper, an interpreted result up to the third stage is described. Advection-dispersion studies in field and laboratory with quantitative groundwater assessment result will be described in the next paper.

Preliminary site definition study

A broad data available such as hydrometeorology, demography, land use near the site, topography and geology of the site and its environs, background qualities of the groundwater, and other related information were collected from several concerned organizations.

Data generation survey was conducted to define the surface and subsurface hydrogeology and to identify groundwater flow path and rate, and to define the hydrodispersive characteristics of the groundwater system.

The first step of the data assessment is aimed to determine the site hydrostratigraphy and the uppermost aquifer, and the second step is to evaluate the groundwater flow path.

This procedure is successively and correlatively conducted during the course of the data generation survey.

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Data genetation survey

Seventeen (17) boreholes were drilled in 1987 by Dohwa Consultant. Co.

Unfortunately, those holes could not be used for the observation of water level due that all of the boreholes were collapsed and damaged. Therefore, data generation survey was performed from the middle of July 1989 to January 1990.

Surface geologic mapping was performed in the area of one (1) kilometer radius from the study site. Detailed mapping, joint orientation survey, was carried out to identify the joint systems relating to the groundwater movement in the site.

Forty-one (41) points of the vertical electric sounding (VES) was performed to schedule the observation well location by means of outlining the relatively low resistivity area in the site. VES location was selected based on the presumed groundwarer flow path with brief geologic mapping result and groundwater table map constructed by the results of previous Dohwa investigation.

Two (2) test wells were installed. One is placed at the up-gradient location (P1) and the other is located at the down-gradient location (P2). Additionally twenty-nine observation wells were installed in the study area. Fig. 1-1 shows the location map of observation holes and test wells.

After completion of drilling, flowmeter observation and well logging were performed in the selected wells. Static groundwater level has been measured daily or periodically to obtain the data of groundwater fluctuation and to construct potentiometric surface map.

Twenty-nine (29) times of flowmeter observation were performed in the course of the installation of observation wells and testing wells. The observation includes flow direction, temperature, electric conductivity, and pH of the groundwater. Flow direction was observed with Flowmeter PZ-1005 and electric conductance was recorded with EC-meter. Portable pH-meter H18014 was used for pH measurement.

Sixteen (16) times of well logging were performed with Geologger 3030 OYO/Japan.

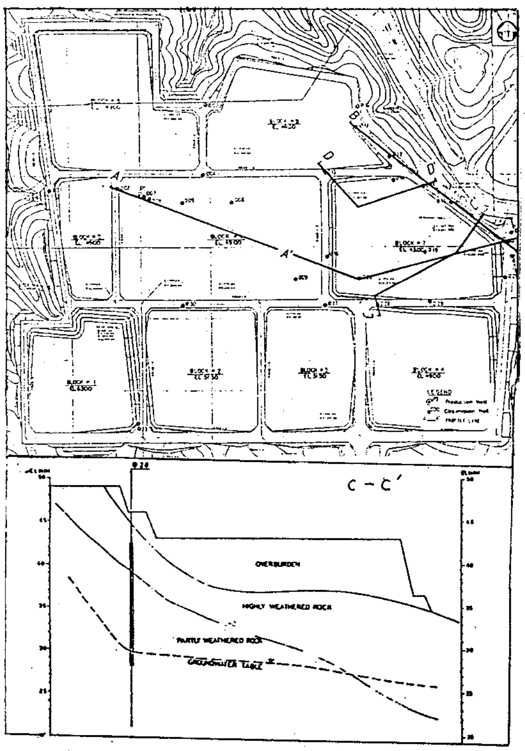

Fig. 1-1. Location map showing borehole, test well and cross section of c-c' line.

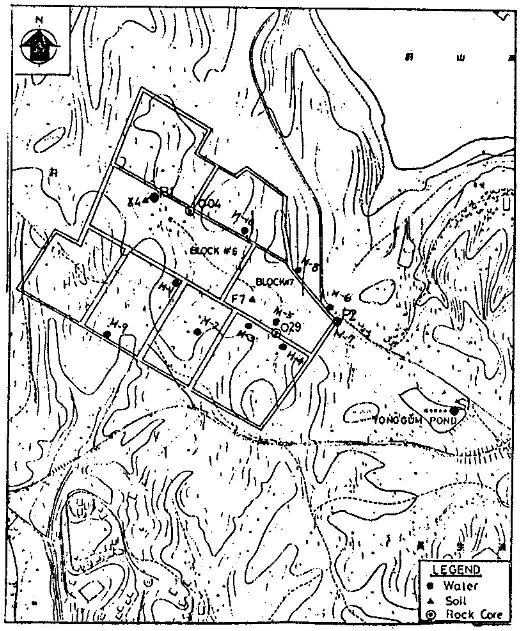

Fig. 1-2. Sampling sites of soil and rock core for column, batch test and water quality analysis.

Table 1-1. Sampling location for laboratory tests.

Item	Sample location	Depth(m)	Contents
Soil	X4 ; vicinity of ϕ02	1.5	
	F7 ; vicinity of ϕ25	2.5	column and batch test
Rock	ϕ04	11, 18	
	ϕ29	5, 15	
Surface water	Yonggum pound	surface	water analysis
Ground water	P1	17.0	〃
	P2	20.0	〃
	M1-M10		〃

Total forty-one (41) times of falling head test, slug test and water pressure test were performed to identify the local hydraulic conductivity (k value). Two (2) series of step-drawdown test and long-term aquifer test were performed in the test wells. The sampling location and the contents of laboratory test are shown in the Fig.1-2 and Table 1-1.

Four (4) sets of column and batch test in laboratory and a radial injection-withdrawal test in field at P1 test well were performed to determine hydrodispersive characteristics of the uppermost aquifer.

TOPOGRAPHY AND DESCRIPTION OF THE SITE ENVIRONMENT

Topography

The study site is located at Kosa-dong, Nam-gu, Ulsan city, and approximately 9 km to the south from the downtown and situated on the small hill which was partly filled and levelled with cutting materials. Due to the controlled nature of filling and cutting, the difference of the floor elevations is approximately EL(+) 41 to (+) 63 meter above mean sea level. The southwestern end of the site is the highest hill in the adjacent area of 1.5Km radius(Fig. 2-1).

Yonggum stream which originated from the site flows eastward into East Sea. The total length, width, gradient and watershed of the stream are about 2.5 Km, less than 2m, 1.6/100 and 1.82 Km, respectively.

Yongyon stream which runs from the site flows southward into East Sea. The total length, width, gradient and watershed of the stream are about 3.5Km, less than 2m, 1.4/100 and 2.6Km, respectively.

The drainage pattern shows a typical trellis pattern which is mearly parallel to the strike of the sedimentary bedrock and major joint systems. Most of the drainages are originated from the site and flow south to southeast direction, and finally into the East Sea. Other minor drianage system contributing the one of the site is a small gully running northward from the site through a near-by refinery to Ulsan Bay.

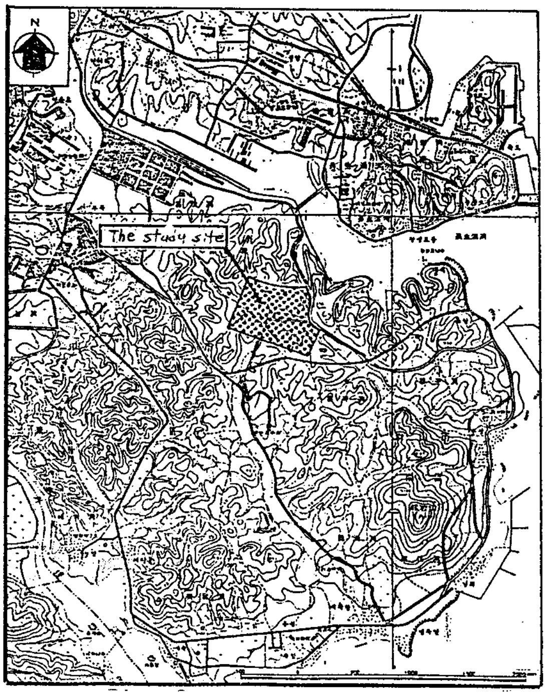

Fig. 2-1. Location map of the study site.

Description of site environment

This section presents basic available information concerning the hydrometeorological data, the physical and other related characteristics of regional and local environment that might be affected by the plant operation.

Table 2-1. Monthly temperature in the area (1968-1987 at Ulsan).

month cont.	Jan.	Feb.	Mar.	Apr.	May	Jun.	Jul.	Aug.	Sept.	Oct.	Nov.	Dec.	mean
mean	0.0	2.4	6.7	12.6	17.3	20.8	24.7	25.6	21.0	15.5	9.1	3.3	13.3
max.	13.0	15.7	20.3	26.3	30.3	31.8	35.1	34.8	31.0	27.0	22.1	17.5	25.4
min.	-9.7	-9.0	-5.1	0.8	6.3	10.8	17.0	18.0	11.5	3.8	-3.1	-7.7	2.8

Table 2-2. Monthly relative humidity in the area (1968-1987 at Ulsan).

month cont.	Jan.	Feb.	Mar.	Apr.	May	Jun.	Jul.	Aug.	Sept.	Oct.	Nov.	Dec.	mean
mean	57	60	64	68	71	79	83	81	79	73	67	61	70
min.	21	23	22	22	24	32	45	44	36	29	25	24	29

Hydro-meteorology

(1) Temperature

Situating on the southeasterm corner of Korean Peninsula, the area has an average southern character of Korean climate.

Its mean temperature is about 13.3, with the minimum mean of 0.9 in January and the maximum mean of 25.6 in August.

The monthly mean, maximum and minimum temperature in the area recorded at Ulsan station are shown in Table 2-1.

(2) Relative humidity

During the summer relative humidity is rather high because of influence of hot humid air masses predominant in the northwestern Pacific area, and on the contrary the winter humidity is considerably low. The mean and minimum relative humidities throughout the year are about 70% and 29%, respectively (see Table 2-2).

(3) Precipitation

The area has the mean annual precipitation of about 1300mm, being a little more than that of the country. The annual percipitation, however, varies considerably from year to year; about 832mm of the minimum value in 1971 to about 1936mm of the maximum in 1969 (see Table 2-3).

Table 2-3. Annual precipitation in the area (1968-1987 at Ulsan).

max. annual	min. annual	mean annual
1936.5mm	832.3mm	1300.9mm

As compared with the annual percipitation, the monthly precipitation fluctuates much more; about 26mm of the monthly precipitation during the winter (December to January), and 215mm in July, being equivalent really 8.3 times greater than the monthly precipitation. This kind of maldistribution of the precipitation is one of the remarkable characteristics of the precipitation not only in the site area but all over the country. Table 2-4 shows the monthly mean precipitation in the site and its environs.

(4) Pan evaporation

The mean annual pan evaporation in the site and its environs is 1257.9 and varies little from year to year, in the range of the maximum 1432.7 and the minimum 1079.0 (refer to Table 2-5).

(5) Wind speed

The mean instantaneous maximum wind speed in the area is 19.2m/sec recorded at Ulsan station, with the maximum mean of 22.3m/sec in

Table 2-4. Monthly precipitation in the area (1968-1987 at Ulsan).

(unit : mm)

month cont.	Jan.	Feb.	Mar.	Apr.	May	Jun.	Jul.	Aug.	Sept.	Oct.	Nov.	Dec.	mean
mean	30.8	41.5	61.9	119.2	98.7	166.6	215.3	201.7	206.7	88.3	49.0	21.2	1300.9

Table 2-5. Monthly pan evaporation in the area(1968-1987 at Ulsan).

month cont.	Jan.	Feb.	Mar.	Apr.	May	Jun.	Jul.	Aug.	Sept.	Oct.	Nov.	Dec.	mean
mean	61.6	66.1	95.3	119.9	148.4	128.8	141.5	147.8	112.8	100.0	73.5	62.2	1257.9
max.	72.7	62.6	112.6	142.7	170.8	165.1	224.9	208.4	147.1	130.4	89.0	78.2	224.4
min.	43.4	52.3	73.4	101.3	130.6	106.5	71.8	70.1	88.8	79.6	57.3	52.3	43.4

Table 2-6. Monthly instrantaneous maximum wind speed in the area(1968-1987 at Ulsan).

month cont.	Jan.	Feb.	Mar.	Apr.	May	Jun.	Jul.	Aug.	Sept.	Oct.	Nov.	Dec.	mean
mean	20.6	20.2	20.1	19.5	17.5	15.1	22.3	19.8	17.4	17.6	20.0	20.1	19.2
max.	24.6	24.3	27.1	26.5	23.0	23.3	30.5	36.7	25.1	27.0	27.5	25.0	26.3
min.	16.0	16.3	15.5	15.7	13.1	12.1	11.4	11.0	12.6	12.1	13.5	14.5	13.7

Table 2-7. Monthly mean wind speed in the area(1968-1987 at Ulsan).

month cont.	Jan.	Feb.	Mar.	Apr.	May	Jun.	Jul.	Aug.	Sept.	Oct.	Nov.	Dec.	mean
mean	2.9	3.0	2.8	2.6	2.3	2.0	2.1	2.1	2.1	2.0	2.2	2.6	28.7
max.	3.8	3.9	3.7	3.5	2.6	2.5	2.8	2.9	2.5	2.0	2.8	3.2	3.9
min.	2.2	2.0	2.2	1.8	1.6	1.3	1.6	1.7	1.7	1.4	1.7	1.6	1.3

Table 2-8. Census of population of Ulsan city(1987).

cont.	population			density	increase
year	male	female	total	(person/km^2)	rate(%)
1976	135.170	130.465	269.635	1,490	6.7
1977	158.912	145.584	304.496	1,704.1	12.9
1978	194.226	170.230	364.456	2,039.1	19.7
1979	208.627	184.804	393.431	2,202.8	7.9
1980	218.341	200.074	418.450	2,325	6.3
1981	234.671	215.870	450.541	2,002	7.7
1982	247.389	228.975	476.364	2,644.9	5.7
1983	265.371	241.507	506.878	2,812.5	6.4
1984	279.175	256.011	535.186	2,968.1	5.6
1985	286.577	264.743	551.320	3,057.4	3.0
1986	289.518	267.133	556.651	3,093	0.1

July and the minimum means of 15.1m/sec in June. The monthly mean, maximum and minimum instantaneous wind speeds in the site and its emvirons are shown in Table 2-6 The annual mean wind speed in the area is 28.7m/sec, with the maximum mean of 3.0m/sec in Feburary and the minimum mean of 2.0m/sec in July and October. The monthly mean, maximum and minimum mean wind speeds recorded at Ulsan Station are as shown in Table 2-7.

Demography

The total population of concerned area is about 556,651 persons according to the census conducted in 1987 by Ulsan City Office. Table 2-8 depicts the population distributed within approximately 10Km radius of the site.

Among the totals, the most densely populated areas are the central part of Ulsan City and the Hyundai Ship Building Co. apart from 3.5 to 6 Km E from the site. The population density is 3,093 per Km^2 in 1987.

All schools within Ulsan City are reported to be 197. Among them, 119 are Kindergartens, 40 primary schools, 21 middle schools, 14 high schools, and 2 colleges.

The students and school staffs in the 197 public schools increases the overall population by 28.8% (156.406 students and 3,865 school staffs).

The workers in the industrial facilities with more than 5 employees are 87,535 (15.7% of resident population) persons during working days from 248 registered factories. Among 248 factories, 4 are textile industry, 10 petrochemical and chemical facilities, 124 machinary and 50 other factories.

The city government is planned to construct 17 parks including natural park, small size resort park, and cemitary purposes, but only one named Haksong Park is under operation now.

There are 2 intergrated hospitals (categorized 1st class), 6 general hospitals, 120 small hospitals (categorized 3rd class), 31 dental hospitals and other 51 related facilites. Total personnel to work at the hospital facilities are 224 medical doctors, 34 dentists, 36 oriental medical doctors, 320 nurses and other 238.

Land use

The nature, extent, and distribution of local land use are important for the groundwater assessment of the plant operation and expansion.

Table 2-9 shows the ratio of land use in the area and its environs(Ulsan city) and that agricultural land occupies about 22.2% of the total area($180Km^2$) and primarily in the northern and northeastern part of the city. Main products are rice and cabbages. No other important crop out live-stock production appears to occur in the area.

Table 2-9. Land use in Ulsan city(1989).

Land use	rate(%)
Paddy field	8.1
Farming upland field	14.1
Forest	45.6
Residental area	7.1
Factory site	8.8
Transpotation road	4.4
Other	11.9
Total	100.0

GENERAL AND SPECIFIC SITE HYDROGEOLOGY

General geology

The site area is consisted of sedimentary rock of Ulsan Formation of Silla Series in Cretaceous age. The rock consists of gray to grayish green siltstone and shale, purple shale, and light gray fine grained sandstone. Occassionally, thin units of tuffaceous sandstone are interbedded and felsic dykes are intruded into the aforesald rocks.

The Ulsan formation is divided into three units in view point of petrographic characteristics, that are purple siltstone, gray siltstone and meta-siltstone(see Fig. 3-1). The site is located in the area of gray siltstone. Geologic sequences in the study area are as follows ;

Quarternary [Alluvium, colluvium, talus
~ Unconformity ~

Cretaceous [Felsic dykes
— Instrusive —
Ulsan Formation] Silla Series
(Meta siltstone,
Gray siltstone, shale,
Fine sandstone,
Purple siltstone, shale

The general strikes and dips of the bedding plane are N25°- 45° E and 20°- 40° SE. Joints are frequently occured in the site. Strikes and dips of total 176 joints are measured. Fig. 3-2 depicts stereo-plot and Rose diagram of bedding plane and joint of the rocks.

According to the results plotting on the pole density stereogram, joint systems of the site can be classed into three groups as following;

Joint group	Strike	Dip
set 1	N 80W-EW	40-60 NE
set 2	N 60-70 E	60 NW
set 3	N 35-40 W	80 SW

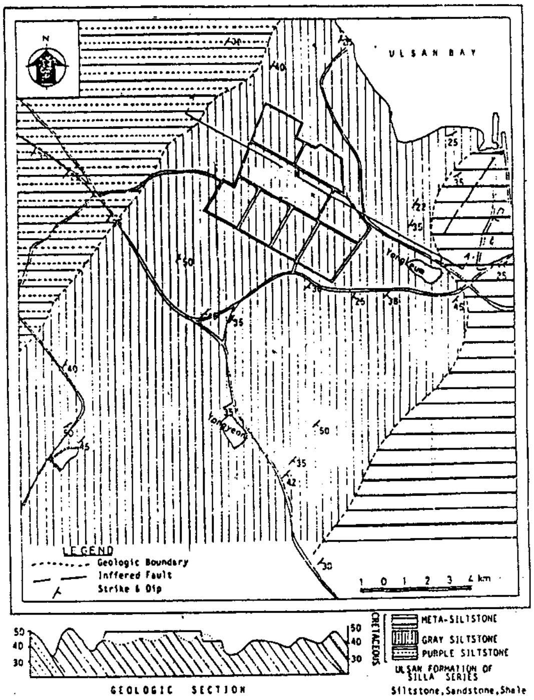

Fig. 3-1-A. Hydrogeologic map of the site and its environs.

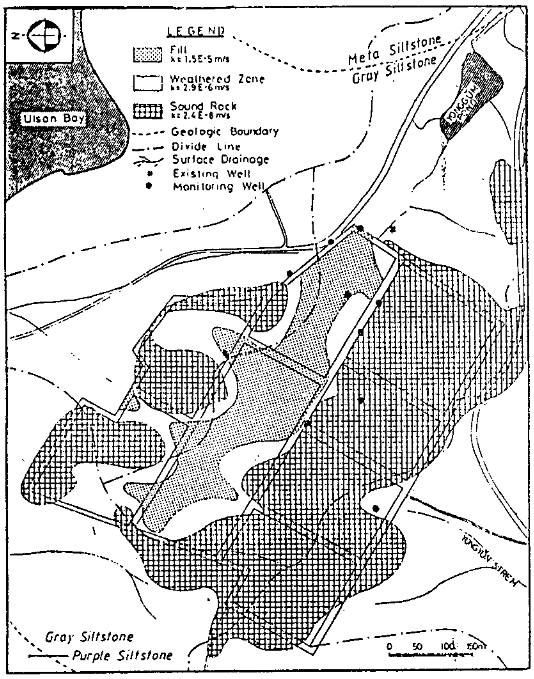

Fig. 3-1-B. Hydrogeologic map of the site.

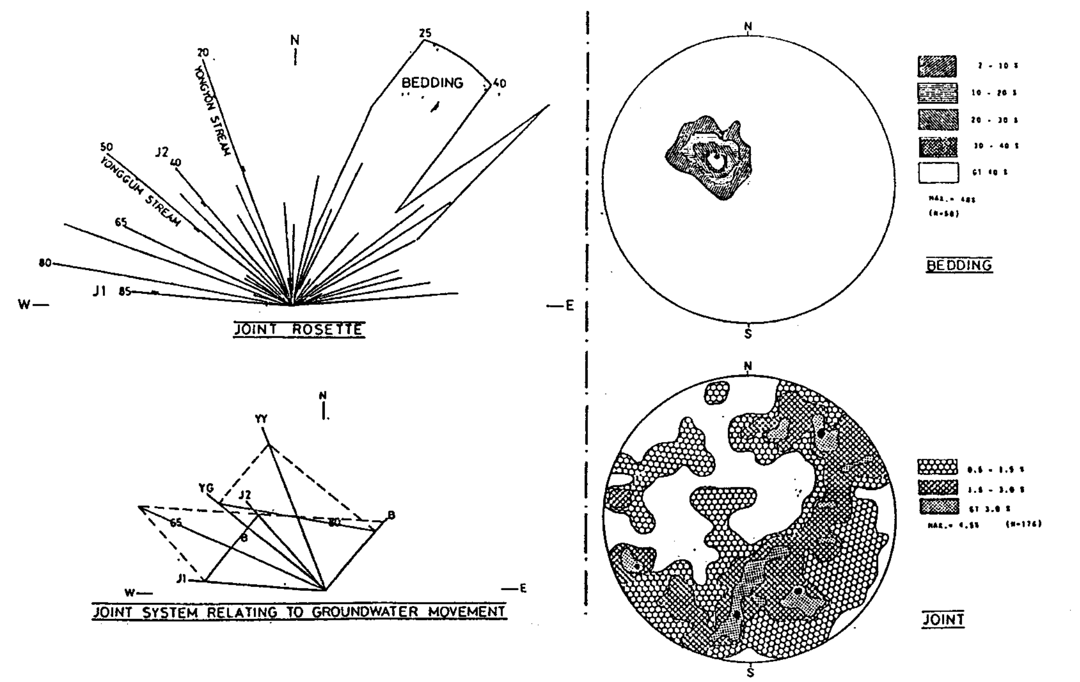

Fig. 3-2. Rose diagram and stereonets of bedding plane and joint system.

The joint systems relating to the groundwater movement are summarized as follows ;

Joint group	Strike	Dip
Bedding fracture	N 25-45 E	20-40 SE
Yongyon stream	N 20 W	NE
Yongyon stream	N 50 W	SW
J1	N 80W-EW	40-60 NE
J2	N 35-40 W	80 SW

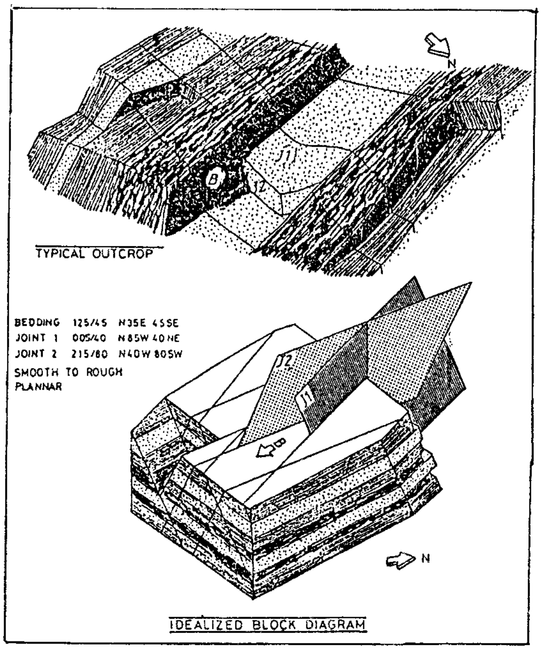

Fig. 3-3. Schematic diagram of joints and bedding planes.

Fig. 3-3 depicts the schematic diagram of joints and bedding planes.

Geologic setting of the site

Evaluation of geologic setting beneath the site is focused on the hydraulic and hydrodispersive characteristics rather than lithology.

Special attention is given on the determination of types of geologic material, because the capacity of the contaminant to move through the subsurface is governed by the hydraulic conductivity and porosity of subsurface materials.

This section includes general findings obtained in the course of the vertical electric sounding well drilling, flowmeter observation, well logging, and surface geologic mapping.

Table 3-1. Geologic setting of the study site.

Unit	Description
Overburden	Fill, paddy soil, colluvium
Weathered zone	Residual soil
	Completely to highly weathered sedimentary rock.
Sound rock	Moderately weathered to fresh sedimentary rock

The subsurface material encountered in the site is classified into following three (3) units (see Table 3-1).

Table 3-2 shows the details of the subsurface geologic setting of the site obtained from test boring and well drilling.

Fig. 3-4 depicts the fence diagram of the subsurface geolofic settings and the typical geologic section of the site.

Overburden

It is the top surface layer that is artificially placed on the original ground surface during the site grading. Filling material is encountered only at the banking area where is mainly located at the central part of the site. The layer consists mainly of yellowish brown to yellowish gray mixture of clay, silt, sand and angular rock fragments derived from the original top soil and cutting of sedimentary rock in the site. It is generally classified as GM(ASTM D 2488-84).

The relative density is medium dense to very dense due to the irregular content of rock fragments.

The thickness of filled layer ranges from 0.3m to maximum of 17.0m at the observation well ϕ 18 and averages about 3.45m within the filled area (see Table 3-2). After heavy rainfall occurred at July and August 1989, infiltration of ponded rainwater could be ovserved at the site. The observation indicates that infiltraiton rate at filled area was a little rapid locally than cutted area owing to higher contents of coarser materials. Occasionally paddy soil occurs below the filling materials at the boreholes located at the center in original gully.

Weathered zone

Weathered zone includes residual soil and completely to highly weathered rock derived from sedimentary bedrock. Residual soil is decomposed and disintergrated in place and altered to perfect soillike. But completely weathered rock(CW) and highly weathered

Table 3-2. Subsurface geologic setting of the site.

Content / Well No.	Ground Elevation (m)	Over-burden (m)	Weathered Zone (m)	Sound Rock (m)	Total Depth (m)	Water Level Fluctuation Range/Change (m)	Core Recovery less than 30% section (m)	Water Level Position
○01	47.0	1.0	3.0	11.0	15.0	2.3-3.6/1.3		WR
○02	49.0	2.2	9.0	3.8	15.0	8.32-11.89/3.57	12.0-15.0	WR-B
○03	47.0	1.0	2.3	16.7	20.0	7.65-9.7/2.05	3.3-20.0/10%	B
○04	49.0	1.8	5.4	17.8	25.0	9.95-11.75/1.8	7.2-25.0/10-27%	B
○05	49.0	4.0 6.2	2.6	22.2	35.0	9.49-11.24/1.75	0.0-4.0 ; fill 4.0-10.2 ; col/21-35	B
○06	49.0	1.2	6.6	7.2	15.0	7.09-10.43/3.38		WR-B
○07	49.0	3.0	9.0	13.0	25.0	8.56-9.22/0.66		WR
○08	49.0	3.0	12.0	15.0	30.0	9.56-10.04/0.48		WR
○09	49.0	10.8	5.5	3.7	20.0	11.5-11.79/0.29	below 16.3m 25%	WR
○10	48.0	0.7	11.3	3.0	15.0	6.81-12.85/6.04	8.6-15.0	WR-B
○11	47.0	0.5	11.5	8.0	20.0	13.04-17.92/4.88	12.0-20.0	WR
○12	45.0	0.8	16.8	2.4	20.0	10.0-15.1/5.1	0.8-20.0	B
○13	49.0	8.0	0.0	10.0	18.0	8.47-9.7/1.23	8.0-16.0	WR-B
○14	43.0	0.4	9.1	5.5	15.0	8.23-14.6/6.37	1.5-15.0	WR-B
○15	40.0	0.3	9.3	5.4	15.0	0.95-13.9/12.95	5.3-15.0	WR
○16	39.0	0.6	10.4	4.0	15.0	1.75-9.38/7.63	4.0-13.0	F-WR
○17	34.0	4.0	8.4	7.6	20.0	2.89-4.62/1.73	14.0-17.0	WR
○18	49.0	17.0	6.2	11.8	35.0	17.48-18.0/0.52	paddy-soil ; 15.5-17	WR
○19	43.0	9.3	5.9	4.8	20.0	13.38-14.35/0.97	paddy-soil ; 8.5-9.3 15.2-20.0	WR
○20	34.5	5.0	1.0	14.0	20.0	5.0-5.88/0.88	paddy soil ; 4.0-5.0	WR
○21	34.5	6.0	3.0	11.0	20.0	3.78-5.67/1.94	paddy soil ; 4.5-6.0	F
○23	55.5	0.5	3.3	16.2	20.0	9.71-11.62/1.86	3.8-20.0	B
○24	35.0	1.4	6.6	6.7	14.7	0.7-2.1/1.39	below 7.5 over 50%	F
○25	43.0	0.3	11.1	3.6	15.0	12.37-13.23/0.86	11.4-15.0	B
○26	36.0	1.3	2.7	26.0	30.0	0.54-2.03/1.49	4.8-30.0	F-WR
○27	49.0	2.2	15.8	7.0	25.0	9.46-17.88/8.42	18.0-25.0	WR
○28	46.0	1.2	5.8	18.0	25.0	3.52-17.95/14.43	7.0-25.0	WR
○29	43.0	1.6	0.0	18.4	20.0	2.29-5.27/2.98	1.6-5.0	B
○30	49.0	2.7	0.0	17.3	20.0	2.57-11.8/9.23		F-B
P-1	49.0	3.0	6.0	16.0	25.0	5.34-10.81/5.47		WR-B
P-2	34.5	6.0	3.0	8.0	20.0	5.02-5.91/0.89	paddy soil ; 4.5-6.0	F
Range		0.3~ 17.0	0.0~ 16.8	3.6~ 26.0	14.7~ 35.0			
Average		3.41	0.63					

Note : F ; Fill, WR ; Weathered Rock, B ; Bedrock.

rock (HW) contains significant amount of altered rock fragments which is moderately weathered. The layer occurs in between overburden layer and sound bedrock in the filling area and crops out specially at the vicinity of cutting area. The thickness of the layer ranges from naught(ϕ 13,29,30) to maximum 16.8m at ϕ 12 well and averages about 6.7m. The layer consists mainly of sandy clay and clayey silt with broken rock fragments originated from intensive physicochemical weathering process of the sedimentary rock forming the basement of the site. The unsaturated portion of the residual and weathered soils is classified as SC to SM while the saturated portion as CL to ML. The residual soil being generally very stiff to hard with locally soft occurs at the uppermost part of the layer.

Generally speaking, the residual and weathered soil contains its original textures and structures of the parent rock, even it was highly to completely weathered, such as bedding structures and joint systems as well. Highly weathered rock still contains altered rock fragments.

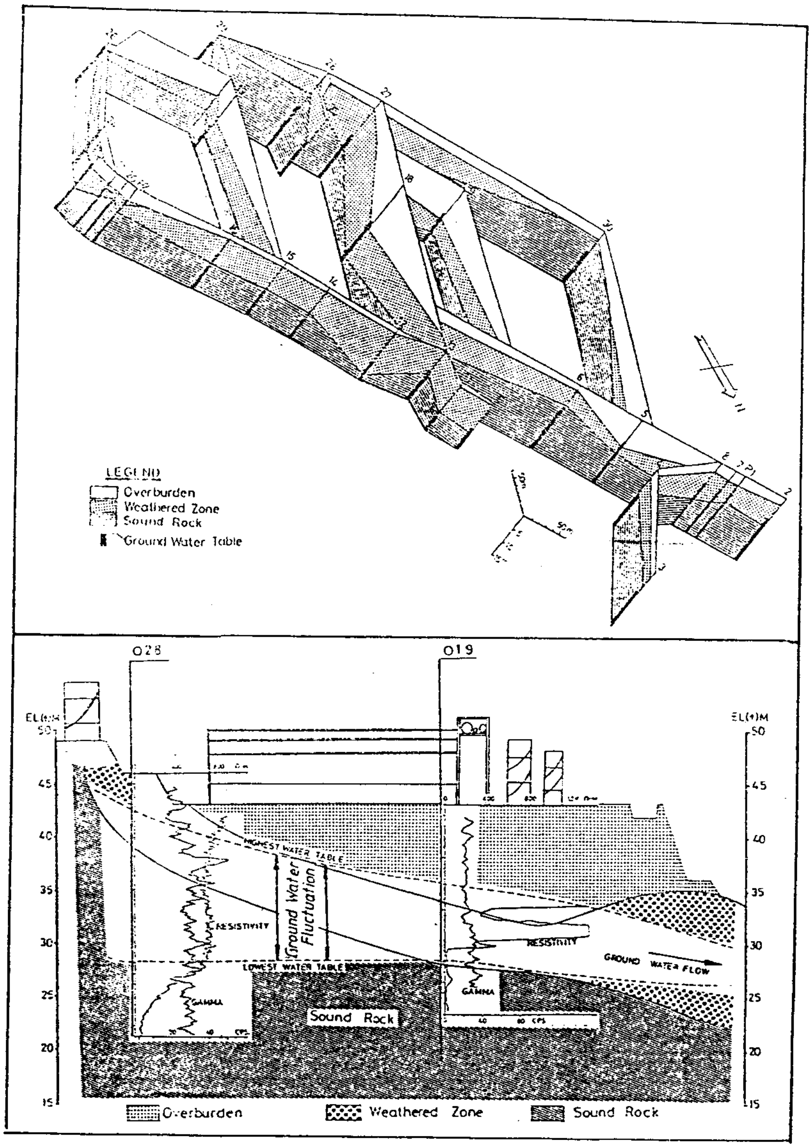

Fig. 3-4. Fence diagram and typical geologic section of the site.

Bedrock

Sound sedimentary bedrock exhibits the complex unit of stratum with an average thickmess of 20cm. Siltstone, shale and sandstone are frequently alternated. The sedimentary rock includes moderately weathered to fresh sound rock. Transition zone between highly weathered and moderately weathered section exhibits highly fractured.

In regard of groundwater movement, bedding, fractures and joint planes will act a groundwater conduit rather than the primary porosity of the sedimentary rock itself, even its hydraulic conductivity is one (1) order less than the overlain weathered zone and over-burden which will be described in detail in following section.

GROUNDWATER HYDROLOGY AND HYDROGEOLOGIC PARAMETERS OF THE SITE

Special attention was given to identify the groundwater level change, groundwater flow path, hydraulic gradient and hydraulic conductivities of the subsurface hydrogeologic system.

Groundwater level and its fluctuation

All thirty-one (31) observations and testing wells are networked for the water level measurement in the hydrogeologic regime of the site. Water level of well were measured once in a day or periodically (see Fig. 4-1).

Some of the water level of the observation wells during the investigation period fluctuates quite different pattern. The water level of ϕ24 well fluctuated from a high of 0.7m to low of 2.1m below ground surface.

It's total change of water level was recorded only 1.39m during July to end of October, while the water level of ϕ28 well fluctuated from 3.52m to 17.95m being equivalent of total decline of 14.43m from August to October. As presented in Table 4–1, observation wells whose water level change during the investigation period is more than 3.0 m(such as 02, 06, 10, 11, 12, 14, 15, 16, 27, 28, 30 and P1) are located on originally up-hillside. The water level of the most of wells in the site decline steadily across the site between August to October as shown on the hydrograph (Fig. 4-1).

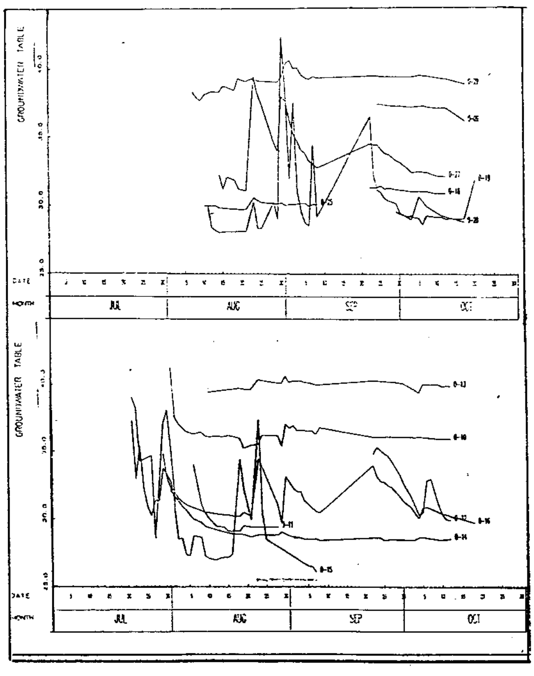

Fig. 4-1. Hydrograph of groundwater level at the site.

But the water levels in the end of August to early September respond to precipitation occurred at the time and then steadily recessed. From Table 4-1, wells drilled in a thicker weawthered zone show generally larger fluctuation of groundwater level. The water level of wells except locating at lower elevation(such as, ϕ 21,24,26,17 and P2) stands at the portion of weathered zone or the uppermost part of fractured rock.

Groundwater flow net of the Site

Groundwater flow direction

One potentiometric surface map (I) before site grading (October, 1987) was drawn up by the data obtained from Dowha who carried out foundation survey at the site. Other potentiometric surface map (II) is drawn up by using the data of water levels measured at Oct. 12, 1989 (see Fig. 4-2). Fig. 4-3 depicts the groundwater level change map between Oct. 1987 and Oct. 1989.

The groundwater level had been declined almost 4 m at the northeastern discharge area and 4 to 6 m at the western hillside of the site due to the topography change by grading work. The general groundwater flow pattern was not much changed except slight shift in the discharge area at northeastern corner of the site. Fig. 4-2 (II) also shows groundwater flow directions measured from the observation holes by using the flowmeter PZ–1005.

The flow directions measured by flowmeter and predicted from the delineated potentiometric surface map of 1989 are very coincide with. The potentiometric surface map(Fig. 4-2 "II") reveals two distinguishable divide lines in the hydrogeologic regime.

One divide is running west to east direction along the southern part of Block #6. The divide turns to southeast at the northeastern corner of Block #6. After passing the middle part of Block #7, it turns to the northeast at the center of Block #7.

And then, it leaves the site passing through the northeastern part of Block #7. A basin occupying the eastern part of Block #6 and the southern part of Block #7 is formed in this hydrogeologic regime (say "A" zone). The other divide is located at the southern border of the site separating the hydrogeologic regimes as in-

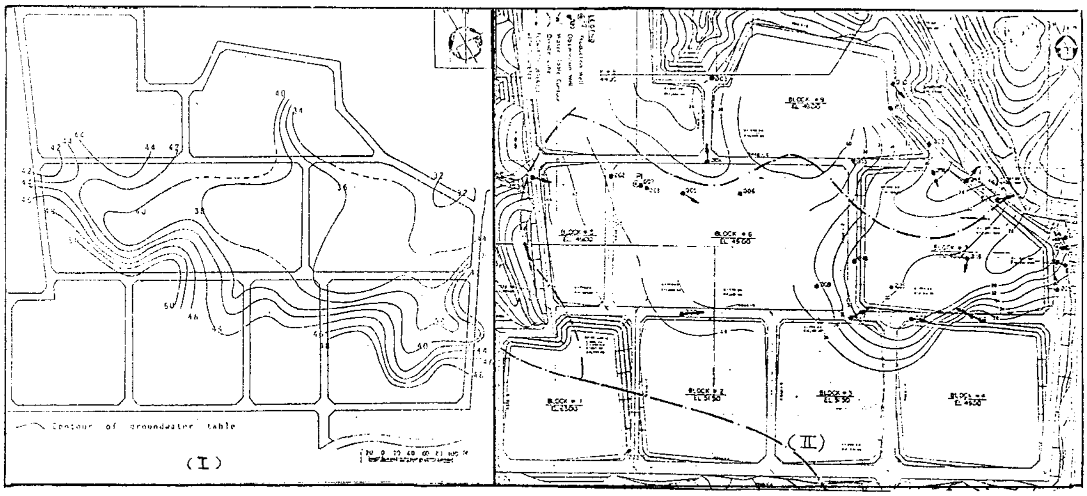

Fig. 4-2. Potentiometric surface map of Oct. 1987 (I) and Oct. 1989 (II).

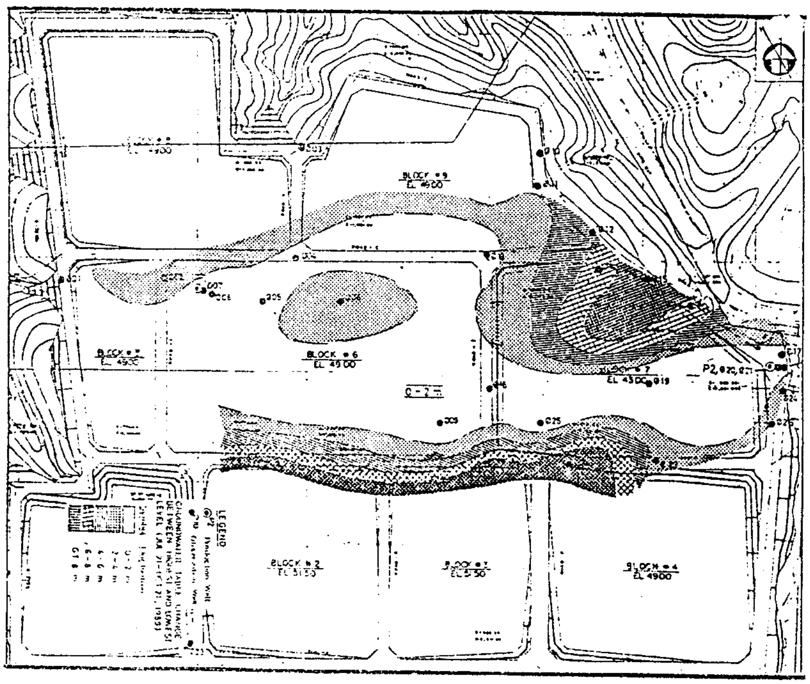

Fig. 4-3. Map showing groundwater level change (Oct. /1987-Oct. /1989).

Table 4-1. Highest and lowest groundwater level measured during the study period.

Hole No.	Ground Elevation (ML)	Highest			Lowest			Water Level Change (m)
		Date	Water Level	Saturated Zone	Date	Water Level	Saturated Zone	
○01	47.0	10.12.	44.70	Weathered Rock	9.8.	43.40	Weathered Rock	1.30
○02	49.0	8.28.	40.68	〃	10.11.	37.11	〃 Sh/Ss	3.57
○03	47.0	8.23.	39.35	〃 Sh/Ss	10.11.	37.29	〃	2.05
○04	40.0	9.24.	30.05	〃	8.24.	37.25	〃	1.80
○05	49.0	9.27.	39.51	Soil	10.21.	37.76	〃	1.75
○06	49.0	8.31.	41.91	Wearthered Rock	10.12.	38.57	〃 Sh/Ss	3.38
○07	49.0	10.18.	40.44	Soil	10.12.	39.78	〃	0.66
○08	49:0	10.18.	39.44	Wearthered Rock	10.21.	38.96	〃	0.48
○09	49.0	9.24.	37.50	〃	10.9.	37.21	〃	0.29
○10	48.0	7.31.	41.19	〃	8.19.	35.15	〃 Sh/Ss	6.04
○11	47.0	8.6.	33.00	〃 Sh/Ss	8.16.	29.90	〃	4.88
○12	45.0	9.24.	35.00	〃	10.12.	29.90	〃 Sh/Ss	5.10
○13	49.0	8.30.	40.53	Weathered Rock Sh/Ss	10.4.	39.30	Weathered Rock	1.23
○14	43.0	7.29.	34.77	〃	9.8.	28.40	〃	6.37
○15	40.0	7.21.	39.05	〃	9.7.	26.10	〃	12.95
○16	39.0	7.21.	37.25	〃	8.29.	29.62	〃	7.63
○17	34.0	10.5.	31.11	Soil	9.30.	29.38	〃	1.73
○18	49.0	9.25.	31.52	〃	10.10.	31.00	Soil	0.52
○19	43.0	9.26.	29.82	Weathered Rock	10.6.	28.65	Weathered Rock	0.97
○20	34.5	10.6.	29.50	〃	10.17.	28.62	〃	0.88
○21	34.5	10.10.	30.77	Soil	10.17.	28.83	Soil	1.94
○23	55.5	10.2.	45.74	Weathered Rock Sh/Ss	10.12.	43.83	Weathered Rock Sh/Ss	1.56
○24	35.0	9.22.	34.30	Soil	10.16.	32.91	Weathered Rock	1.39
○25	43.0	8.23.	30.63	Weathered Rock Sh/Ss	8.21.	29.77	〃 Sh/Ss	0.86
○26	36.0	9.25.	35.46	Soil	10.17.	33.97	〃	1.49
○27	49.0	8.23.	39.54	〃	8.21.	31.12	〃	8.42
○28	40.0	8.30.	42.48	Weathered Rock	8.14.	28.05	〃 Sh/Ss	14.43
○29	43.01	9.1.	40.71	〃 Sh/Ss	8.9.	37.73	〃	2.98
○30	49.0	8.31.	46.43	Soil	8.21.	37.20	〃	9.23
P-1	49.0	10.12.	43.66	Wearthered Rock	10.21.	38.19	〃	5.47
P-2	34.5	10.8.	29.48	Soil	10.17.	28.59	Soil	0.89

and out part of the plant site. Hydrogeologic regime of the study site is noted as "A" and "B" zone as shown is Fig. 4–4.

Major flow path in "A" zone is from southwest (Block #3) to northeast direction which is compatible with the strike direction of J1 point. The down-gradient flow path is in the northeastern corner of Block #7. Minor flow path originated from Block #6 runs to southeast direction and join to aforesaid main flow path at southwestern corner of Block #7.

Main flow path in "B" zone runs along the former divide line forming an arc. It starts from the southeastern part of Block #9 toward southeast direction which is compatible with the strike of J2 joint. And then it turns to northeast direction, which is quite coincided with the strike of J1 point, at northern part of Block # 7.

Hydraulic gradient and main pathway

As far as a study on accidental leak and spill are concerned, potential impact of contaminants to the hydrogeologic regime of the site shall be concentrated to main storage tank and plant unit area are belonged to "A" zone. Major

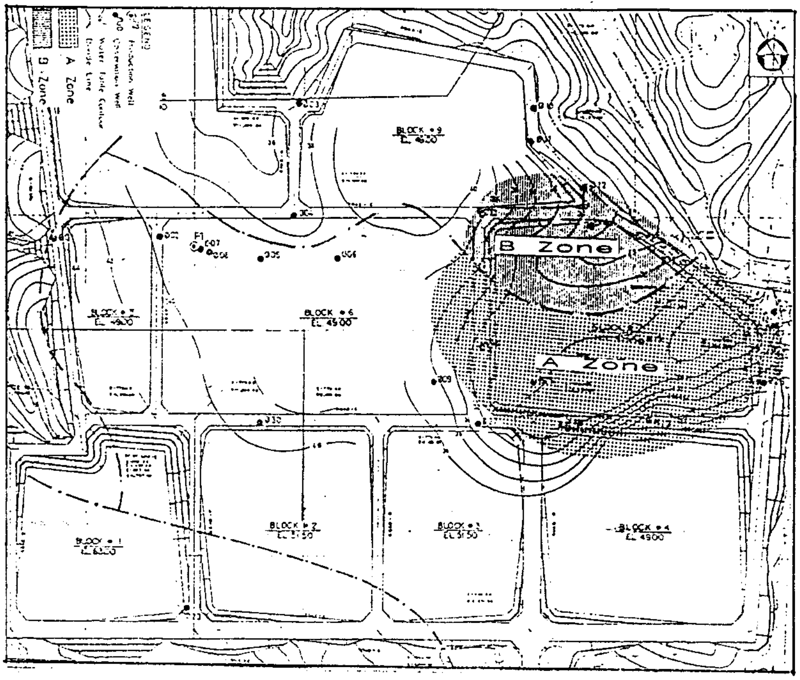

Fig. 4-4. Hydrogeologic regimes in the study area.

pathway of groundwater of "A" zone is about N 80°W-EW which is quite parallel to major joint system (J1) in the area (see Fig. 4-5). The hydraulic gradient of major and minor pathways in "A" zone of the site are presented in Table 4-2.

Hydrogeologic Parameters

To determine hydrogeologic parameters, such as hydraulic conductivity, transmissivity and storativity of the satruated zone, slug and falling head tests were conducted in the field.

The hydraulic conductivity of overburden ranges from 1.9 E-7 to 1.5 E-5 m/sec and harmonic mean of the value is about 3.7 E-7m/sec. The one of weathered zone ranges 2.5 E-4 m/sec and average about 8.1 E-7 m/sec (harmonic mean). But the hydraulic conductivity of bed rock mainly composed of siltstone, shale and sandstone ranges from 2.4 E-7 to 1.5 m/sec and harmonic mean of the hydraulic conductivity is about 5.3 E-7 m/sec.

Fig. 4-6 represents the frequency diagram of hydraulic conductivities. The summary of hydraulic conductivities of each layer calculated from the falling head and slug tests is shown in Table 4-3.

Table 4-4 is the summary of aquifer test results of P1 and P2 test well calculated by computer programs of Automated derivation of pa-

Table 4-2. Hydraulic gradients of the major and minor pathways of groundwater at "A" zone.

	Pathway	Hydraulic gradient	Distance(m)
Major	a-d-h-f-b	4.6/100	210
Minor	c-d	22.0/100	45
	e-f	14.0/100	49
	g-h	6.5/100	112
Average		13.0/100	

Table 4-3. Summary of K value at the study site.

(unit : m/sec)

Unit \ K	Range Maximum	Range Minimum	Harmonic Mean
Overburden	1.5E-5	1.9E-7	3.7E-7
Weathered zone	1.5E-4	2.5E-7	8.1E-7
Bed rock	1.5E-6	2.4E-7	5.3E-7

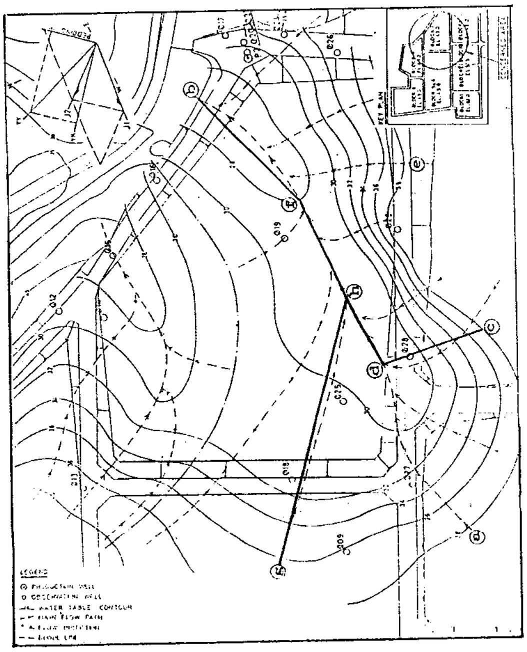

Fig. 4-5. Main-pathway of groundwater at "A" zone.

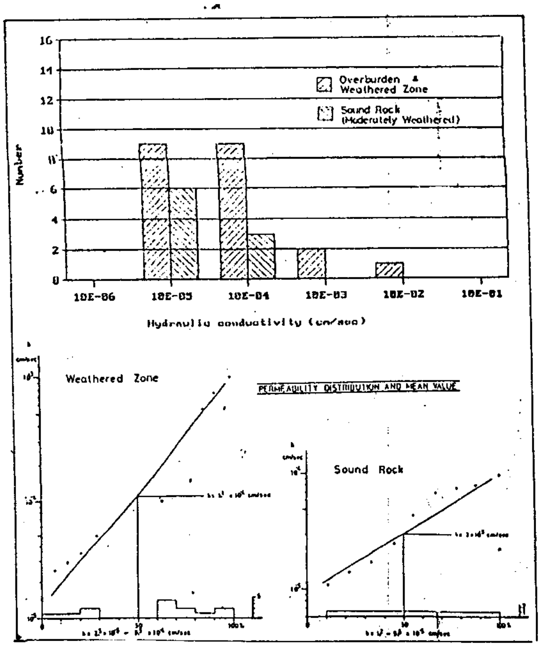

Fig. 4-6. Frequency diagram of K at the site.

Table 4-4. Hydrogeologic parameters of saturated zone.

Item	Depth (m)	Dia. (in)	S.W.L. (m)	D.W.L. (m)	T (m^2/sec)	S	Q (m^3/min)	K (m/sec)
Pl (bed rock)	25	8"	10.23	19.23	3.5E-7	0.023	1E-3	2.4E-8
					3.5E-7	0.021	1E-3	2.4E-8
P2 (weathered rock)	20	8"	5.67	8.64	7.1E-5	0.097	2E-2	5.0E-6
					7.5E-5	0.079	2E-2	5.2E-6

The hydraulic parameters presented in Table 4-5 are eatimated by using Walton's GWGRAP/BASIC program. Those values obtained by using different computer programs are nearly same.

The hydraulic conductivities (K) obtained from slug (including falling head) and in-situ aquifer tests show almost one (1) order difference between weathered zone and sound rock. In general, the value of K determined from slug test is representative of the formation only in the immediate vicinity of small diameter observation hole. On the other hand, the K value determined from longterm aquifer test is representative of full thickness of formation in drilled well.

Because the difference of average K values estimated from slug (including falling head) and in-situ aquifer test is only one order, it might be rationale that the representative value of hydraulic conductivity of each layer in the site shall be an average of those two test results as following Table 4-6.

Estimated Darcian velocity, in other word, specific discharge and average liner velocity of the major and minor pathway at "A" zone are presented in Table 4-7.

Table 4-5. Hydraulic parameters calculated by GWGRAF -program.

Pumping Test (p-1)

P-1 PUMPING – TEST

TRIAL RUN NO = 1 (UNIT: CGS)

SHIFT NO X-AXIS = .2691E+03 SHIFT NO Y-AXIS = .5302E+00
TRANSMISSIVITY = .3517E-06m^2/sec STORAGE = .2271E-01

DISCHARGE(m^3/min) = .001 DIST. OF OBS. WELL FROMPUMPING WELL (m) = .100

TIME(min)	DRAWDOWN (m)	W1	WUC	PDEV(%)
3.000	.470	.2492E+00	.2615E+00	.4712E+01
5.000	.910	.4825E+00	.5159E+00	.6468E+01
8.000	1.270	.6734E+00	.8224E+00	.1812E+02
10.000	1.510	.8006E+00	.9875E+00	.1892E+02
15.000	1.920	.1018E+01	.1313E+01	.2244E+02
20.000	2.360	.1251E+01	.1559E+01	.1972E+02
25.000	2.660	.1410E+01	.1756E+01	.1970E+02
30.000	3.020	.1601E+01	.1922E+01	.1668E+02
36.000	3.380	.1792E+01	.2090E+01	.1424E+02
40.000	3.750	.1988E+01	.2188E+01	.9120E+01
50.000	4.080	.2163E+01	.2398E+01	.9785E+01
60.000	4.480	.2375E+01	.2572E+01	.7627E+01
90.000	5.390	.2858E+01	.2962E+01	.3525E+01
120.000	5.730	.3038E+01	.3243E+01	.6305E+01
150.000	5.920	.3139E+01	.3461E+01	.9317E+01
180.000	6.330	.3356E+01	.3641E+01	.7812E+01
240.000	7.320	.3881E+01	.3925E+01	.1107E+01
270.000	8.410	.4459E+01	.4041E+01	.1034E+02
300.000	9.000	.4772E+01	.4146E+01	.1511E+02

AVERAGE DEVIATION FROM TYPE CURVE = .1312E+00 (%)
AVERAGE ABSOLUTE DEVIATION FROM TYPE CURVE = .2411E+00

OVERALL RELATIVE DEVIATION IN THE MATCH POSITION = .1046E+00 (%)

Pumping Test (p-2)

P-2 PUMPING – TEST

TRIAL RUN NO = 1 (UNIT: CGS)

SHIFT NO X-AXIS = .5678E+01 SHIFT NO Y-AXIS = .2675E+01
TRANSMISSIVITY = .7096E-04m^2/sec STORAGE . = .9669E-01

DISCHARGE(m^3/min) = .020 DIST. OF OBS. WELL FROMPUMPING WELL (m) = .100

TIME(min)	DRAWDOWN (m)	W1	WUC	PDEV(%)
3.000	1.000	.2675E+01	.3409E+01	.2154E+02
6.000	1.540	.4119E+01	.4093E+01	.6409E+00
8.000	1.680	.4493E+01	.4378E+01	.2635E+01
10.000	1.780	.4761E+01	.4600E+01	.3502E+01
15.000	2.000	.5349E+01	.5003E+01	.6914E+01
20.000	2.120	.5670E+01	.5290E+01	.7186E+01
25.000	2.200	.5884E+01	.5513E+01	.6740E+01
30.000	2.240	.5991E+01	.5694E+01	.5208E+01
35.000	2.280	.6098E+01	.5848E+01	.4269E+01
40.000	2.300	.6152E+01	.5982E+01	.2839E+01
50.000	2.310	.6178E+01	.6205E+01	.4236E+00
60.000	2.330	.6232E+01	.6387E+01	.2426E+01
90.000	2.470	.6606E+01	.6792E+01	.2733E+01
120.000	2.570	.6874E+01	.7079E+01	.2906E+01
150.000	2.660	.7114E+01	.7302E+01	.2575E+01
190.000	2.780	.7435E+01	.7539E+01	.1371E+01
210.000	2.790	.7462E+01	.7639E+01	.2313E+01
240.000	2.850	.7623E+01	.7772E+01	.1926E+01
270.000	2.890	.7730E+01	.7890E+01	.2034E+01
300.000	2.970	.7944E+01	.7995E+01	.6487E+00

AVERAGE DEVIATION FROM TYPE CURVE = .1038E-02 (%)
AVERAGE ABSOLUTE DEVIATION FROM TYPE CURVE = .2127E+00

OVERALL RELATIVE DEVIATION IN THE MATCH POSITION = .3475E-01 (%)

Table 4-6. Representative K and S values.

Geology	K(m/s)	Storativity	Remarks
Weathered zone	2.88E-6	0.09	(8.1+5.3+50+52)E -7/4=2.88E-6
Bed rock	2.40E-8	0.02	

Table 4-7. Darcian velocity and average linear velocity at "A" zone.

Content / Pathway	Pathway	Hydraulic Gradient	K (m/s)	V (m/d)	$\bar{V}$ (m/d)
Major	a-d-b-f-b	4.6/100	2.88×10^{-6}	0.011	0.12
Minor		22.0/100 14.0/100 6.5/100		0.055 0.035 0.016	0.61 0.39 0.18

Note : $\bar{V}$; Average linear velocity, V ; Darcian.

Table 4-8. Saturated thickness of fill at highest and lowest water level.

Well	Thickness fill & soil (m)	Water Level (m)		Max. Saturation	
		Highest	Lowest	Highest	Lowest
O 17	4.0	2.89	4.62	1.11	–
O 21	6.0	3.78	5.67	2.22	0.33
O 23	1.4	0.70	2.10	0.70	–
O 26	1.3	0.54	2.03	0.76	–
O 30	2.7	2.57	11.80	0.13	–
P-2	6.0	5.02	5.90	0.98	0.10

The properties of the upermost aquifer

For the purpose of predicting the migration of contaminants due to the accidental leaks and/or spill, the identification of following site specific hydrogeologic characteristics is essential, that are defining of the uppermost aquifer, subsurface geology relating to the uppermost aquifer, the vertical and horizontal components of flow in the uppermost aquifer and the vertical extent of the uppermost aquifer.

The properties of the uppermost aquifer comprising weathered zone (GW to HW) obtained from total 6 test borings and 7 test pits are available in the site, which were carried out before site grading phase.

The available data are sampling depths, natural moisture contents, and specific gravity and bulk density for each layer. The laboratory tests are conducted in general accordance with the ASTM and KSF procedures on the representative samples. The results of identification test are presented on the Table 4-10 and 4-11 respectivity.

Definition of the uppermost aquifer

To immediate detect accidental release, the proper characterization of the uppermost aquifer is essential for the establishment of a compliant groundwater monitoring system. The uppermost aquifer is defined the aquifer nearest to the ground surface and is capable of yielding a significant amount of groundwater to wells or springs (according to CFR s 260-10). But the significant yield must be made on a case by case basis. Sometimes, proper definition of the uppermost aquifer should rest on any hydraulic communication between different formations.

According to the aquifer test of P1 and P2 well, all the observation wells respond abstraction effect by the pumping well. Even through the average hydraulic conductivity is one (1) order difference between each layer, the aquifer test result represents the hydraulic interconnection between filled and weathered zone and beneath sedimentary rock which is highly fractured.

Among 31 wells drilled in the study site, only

Table 4-9. The upper most aquifer and its saturated thickness at the site.

Cont. / No.	Drilled Depth (m)	Thickness of the Uppermost Aquifer(m)				Highest water Level below Ground Level (m)	Saturated Thickness (m)	Maximun Water Level Change (m)
		Over-burden	weathered Zone	Sound Rock	Total			
1	15	1.0	3.0	3.0	7.0	2.30	4.70	1.30
2	15	2.2	9.0	0.8	12.0	8.32	3.68	3.57
3	20	1.0	2.3	16.7	20.0	7.65	12.35	2.05
4	25	1.8	5.4	2.6	10.0	9.95	0.05	1.80
5	35	10.2/6.2	2.6	8.2	21.0	9.49	11.51	1.75
6	15	1.2	6.6	2.2	10.0	7.09	2.91	3.38
7	25	3.0	9.0	NR	–	8.56	–	0.66
8	30	3.0	12.0	NR	–	9.56	–	0.48
9	20	10.8	5.5	3.7	20.0	11.50	8.50	0.29
10	15	0.7	11.3	3.0	15.0	6.81	8.19	6.04
11	20	0.5	11.5	8.0	20.0	13.04	6.96	4.88
12	20	0.8	16.8	2.4	20.0	10.00	10.00	5.10
13	18	8.0	0.0	3.3	11.3	8.47	2.83	1.23
14	15	0.4	9.1	5.5	15.0	8.23	6.77	0.37
15	15	0.3	9.3	5.4	15.0	0.95	14.05	12.95
16	15	0.6	10.4	2.0	13.0	1.75	11.25	7.63
17	20	4.0	8.4	2.6	15.0	2.89	12.11	1.73
18	35	17/1.5	6.2	6.8	30.0	17.48	12.52	0.52
19	20	9.3/0.8	5.9	4.8	20.0	13.38	6.62	0.97
20	20	5.0/1.0	1.0	NR	–	5.0	–	0.88
21	20	6.0/1.5	3.0	NR	–	3.73	–	1.94
23	20	0.5	3.3	1.2	5.0	9.76	–	1.86
24	14.7	1.4	6.6	1.0	9.0	0.70	8.30	1.36
25	15	0.3	11.1	1.6	13.0	12.37	0.63	0.86
26	30	1.3	2.7	3.0	7.6	0.54	6.46	1.49
27	25	2.2	15.8	3.0	21.0	9.46	11.54	8.42
28	25	1.2	5.8	6.0	13.0	3.52	9.48	14.43
29	20	1.6	0.0	7.4	9.0	2.29	6.71	2.98
30	20	2.7	0.0	7.2	7.0	2.57	4.43	9.23
P-1	25	3.0	6.0	1.81	10.81	5.34	5.47	5.47
P-2	20	6.0/1.5	3.0	NR	–	5.02	–	0.89
Range	14.7~35.0	0.3~17.0	0.0~16.8	0.8~16.7	5.0~30.0	0.54 ~17.48	0.05~14.05	0.29~14.34
Mean	20.89	3.45	6.53	4.36	14.20	7.02	7.52	3.63

Table 4-10. Properties of Weathered Zone.

Item / Hole No.	Depth (m)	M C (percent)	G S	n (percent)	rd (g/cm^3)
B-74	0.8	21.0	2.7	35.8	1.69
B-82	0.3	24.9	2.66	42.8	1.52
B-85	1.0	22.5	2.68	36.8	1.69
B-16	1.5	25.4	2.72	41.3	1.6
B-90	0.5	29.3	2.65	42.9	1.51
Range	0.3-1.5	21.0-29.3	2.65-2.72	35.8-42.9	1.51-1.69
Representative value 4.6			2.68	39.9	1.6

Note : MC ; Moisture content, GS ; Specific gravity, n ; Porosity, rd ; Bulk density.

6 wells encountered groundwater level at the portion of fill at the time of highest water level but the thickness of saturated portion was only 0.14 up to 2.22m.

At the period of water level decline, in other word, lowest water level period, only two (2) among 31 wells show very thin saturated portion of fill material (0.1-0.33 meter) (see Table 4-8).

So the uppermost aquifer in the study site can be defined to be overburden and weathered zone including upper part of the highly fractured sedimentary rock which are hydraulically interconnected.

The overburden in general, might be treated as vadose zone in the site because of the above mentioned reasons.

Thickness of the uppermost aquifer

As showm in Tables 4-1 and 4-9, the properties of the slightly weathered rock and fresh stained sedimentary rock are clearly different from those of highly weathered rock. Therefore, the bottom of the uppermost aquifer should be defined down to the bottom layer of moderately weathered zone. The estimated thickness of the uppermost aquifer in the site hydrogeologic regime ranges from 5 up to 21m and average about 14.4m (Table 4-9)

Overburden and completely weathered zone

The sampling depth ranges from 0.3 to 1.5m below the original land surface. The natural water content of completely weathered zone varies between 21 and 29.3% at the field with average 24.6%. The specific gravity is determined as 2.68 and the bulk density ranges from 1.51 to 1.69 g/cm^3. The total porosity varies between 35.8 and 45.9% and average about 39.3% (Table 4-10).

Highly to moderately weathered zone

Table 4-11 represents the properties of underneath HW to MW siltstone and shale. The samples were taken from 0.8 to 2.0 m below the original land surface. The natural water content of the zone ranges from 11.1 to 27.7% and average about 17.58%. The specific gravity was determined in average of 2.68 which is the same with the upper zone. The dry density varies between 1.62 and 1.87 g/cm in average of 1.78g/cm.

BACKGROUND QUALITY OF GROUNDWATER

Present status of groundwater quality of the site hydrogeologic system is very important to evaluate the future contamination during the plant operation. The main characteristics of the site includes the present quality of the groundwater and surface water. Liquid and gaseous effluents to be generated during the plant operation would be also a factor to the groundwater contamination besides of accidental leak and spill of hazardous raw material from storage tanks.

This section describes the background characteristics of groundwater quality that will be continually monitored during the life time of plant operation for the detection of the unexpected accidental spill and leakage of hazardous substances.

Potential source of contaminants of the site

Monitoring of groundwater quality of the study site aims to detect hazardous materials dealing with the plant operation. The meterials to be handled at the site are summarized in Table 5-1.

Table 4-11. Properties of HW to MW sedimentary rock.

Item / Pit No.	Depth (m)	M C (percent)	G S	rd (g/cm)
TP-1	1.2	14.2	2.66	1.77
TP-2	1.0	17.4	2.66	1.79
TP-3	0.8	15.5	2.7	1.872
TP-4	2.0	27.7	2.63	1.62
TP-5	0.8	16.8	2.69	1.785
TP-6	1.0	11.1	2.69	1.785
TP-10	1.0	18.4	2.65	1.822
Range	0.8-2.0	11.1-27.7	2.63-2.7	1.62-1.872
Representative value		17.58	2.68	1.78

Table 5-1. The list of end products and intermediate and raw materials.

END PRODUCTS	
Propylene oxide	Styrene monomer
Etyl-benzene	Propylene glycol
Dipropylene glycol	Tripropylene glycol
INTERMEDIATE MATERIAL	
Ethyl benzyl hydroperoxide	
Methly benzly alchohol	
Acetophenone	
RAW MATERIAL	
Benzene	Phosphoric acid
Ethylene	Ammonia (Aqu. 25%)
Prophyene	H_2SO_4 (98%)
Glycerine	$Al_2(SO_4)_3$ $18H_20$
NaOH (50%)	NaCIO
Octanoid Acid	IPC-1700
Octane	P-TSA
KOH(45%)	P-TBC
Phonotiazime	

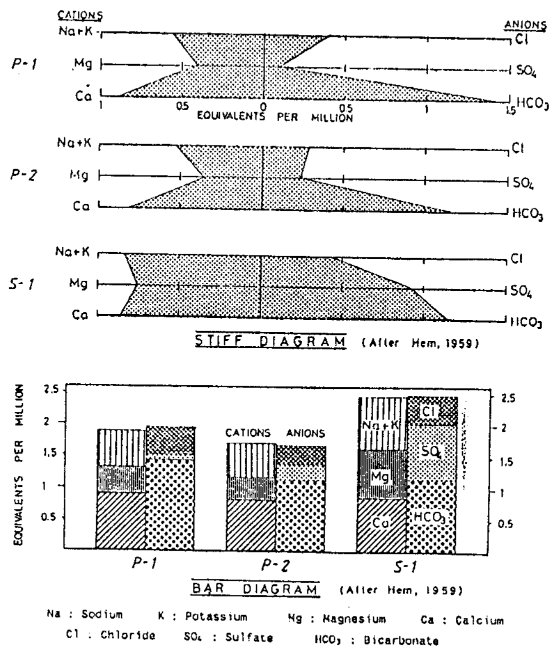

Fig. 5-1-A. Background qualities of groundwater and surface water at and near the site.

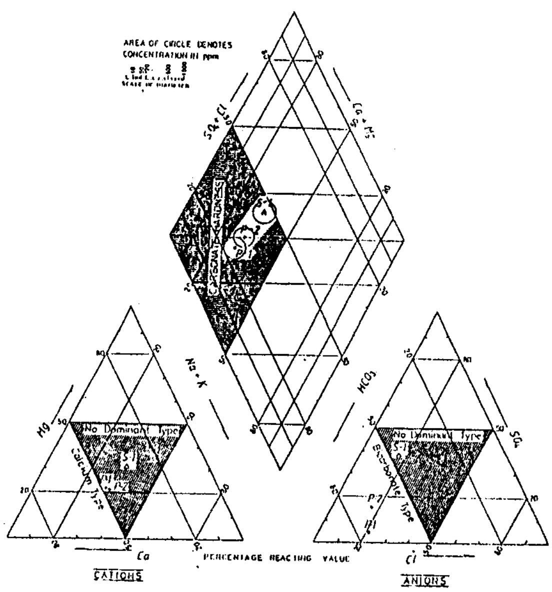

Fig. 5-1-B Trilinear diagram (P-1, P-2 and S-1 water).

Background characteristics of groundwater and surface water quality in and near-site.

Several data are available to review the quality of groundwater. However, the data obtained from the previous 'Environmental Assessment Report' prepared by SKEC exhibit lack of information. For determination of the background characteristics of the study site, two stages of

Table 5-2. Summary of water quality analysis results.

sample / stage / Content	Unit	1987.10	Previous work					First stage(1990)			Second stage(1990.5.10)					Base-line quality	
		Before SiteGrading(G.W.)	G-1(1989.6)		G-2(1989.6)		G-3 (1987.7)	P-1	P-2(M-7)	S-1	M-1	M-2	M-3	M-6	M-7	Remarks	Surface water
Ph		5.7-6.1	6.47	7.18	7.51	7.51	5.4				7.12	7.7	6.34	5.51	5.53		
$KMnO_4$	ppm		0.8	1.0	2.1	0.6											
M-Alkalinity	〃		28.0	28.0	19.8	19.4											
T-Hardness	〃		23.0	36.0	259.0	42.0											
Cl^-	〃	7.5-23.4	14.2	19.17	33.4	31.95		14.5	10.2	15.0	20.2	23.7	16.9	15.3	15.3		
NH_3-N	〃		ND	ND	ND	ND	ND										
NO_2-N	〃		ND	ND	ND	ND	3.0										
NO_3-N	〃		1.79	1.93	3.32	4.47		2.1	4.5	2.1	16.3	18.4	15.8	17.8	17.34		
CN^-	〃		ND	ND	ND	ND	ND										
Pb	〃		ND	ND	ND	ND	ND										
Cd	〃		ND	ND	ND	ND	ND	-0.01	-0.01	-0.01	0.01이하	-0.01	-0.01	-0.01	-0.01	0.01이하	
As	〃			ND	ND	ND	ND	-0.01	-0.01	-0.01	-0.01	-0.01	-0.01	-0.01	-0.01	0.01"	
Hg^{2+}	〃		ND	ND	ND	ND	ND	-0.001	-0.001	-0.001	-0.001	-0.001	-0.001	-0.001	-0.001	0.001"	
G-Bacteria	〃		32.0	29.0	37.0	43.0	21,000										
Ca-iform	〃																
(MPN/100**m)			ND	ND	ND	ND	79.0										
T.S	〃		139.0	156.0	227.0	225.0											
Colority	Deg.		0.8	1.0	1.0	1.0	1.0										
Turbidity	〃		1.0	0.8	1.0	1.0											
SO_4^{2-}	ppm	10.3-54.3					61.7	4.31	11.5	44.5	99.7	118.4	74.4	56.3	55.8		
Residual	〃						108.0										
Cu^{2+}	〃						ND										
Organic Phosphate	〃						ND										
F^-	〃						0.02	0.32	0.15	0.38	0.5이하	-0.5	-0.5	-0.5	-0.5	0.005	
Phenol	〃							-0.05	-0.05	-0.05	-0.005	-0.005	-0.005	-0.005	-0.005		
Fe^{2+}	〃						0.04	0.2	0.5	0.7	11.7	3.05	11.7	0.14	0.09		
Mn^{2+}	〃						0.01	0.11	0.009	0.089	0.35	0.096	0.41	0.004	0.065		
Mg^{2+}	〃	3.3-8.1						5.0	4.4	9.2	10.0	10.6	9.6	9.0	8.8		
NH_4	〃	0.1-0.8															
HCO_3^-	〃							87.8	69.5	69.5	105	113	73.8	28.1	25.6		
CO_3^{2-}	〃							0.3	0.3	0.3	0.5이하	0.5이하	0.5이하	0.5이하	0.5이하		
Na^+	〃							12.2	11.8	18.0	25.6	27.8	21.2	19.4	19.2		
K^+	〃							1.23	0.68	2.21	3.6	3.35	3.5	1.38	1.40		
Ca^{2+}	〃							18.2	16.2	17.4	56.0	59.0	35.0	10.8	11.2		
Ba^{2+}	〃							ND	ND	ND	0.094	0.047	0.096	0.050	0.049		
Cr^{6+}	〃							-0.05	-0.05	-0.05	0.049	0.03이하	0.055	0.03이하	0.03이하		
Se	〃							-0.01	-0.01	-0.01	-0.1	-0.1	-0.1	-0.1	-0.1		
Ag	〃							-0.01	-0.01	-0.01	-0.01	-0.01	-0.01	-0.01	-0.01		
Al	〃							0.20	0.96	-	11.2	2.7	11.7	0.2	0.2		
Endrin	〃							-0.05	-0.05	-0.05							
Lindane	〃							-0.05	-0.05	-0.05						0.005	
Silvex	〃							-1.0	-1.0	-1.0							
Toxaphene	〃							-1.0	-1.0	-1.0							
Styrene	ppb							-40	-40	-	40이하	-40	-40	-40	-40		
Toluene	〃							-50	-50	-	-40	-40	-40	-40	-40		
Xylene	〃							-50	-50	-40	-40	-40	-40	-40	-40		
Benzene	〃							-40	-40	-40	-40	-40	-40	-40	-40		
Ethyl benzene	〃										-40	-40	-40	-40	-40		
Total Org.Carbon	〃							840	840	4,100	4,500	6,900	3,500	2,000	1,800		
Trichloro Etylene	〃							-1.0	-1.0	-							
Tetrachloro Etylene	〃							-3.0	-3.0	-							
Prophylene Glycol	〃										5,000이하	-5,000	-5,000	-5,000	-5,000		

(–) means below detection limit.
ND : Not detected under laboratory scale.

water quality analysis were performed. The first stage of sampling and water quality analysis had been performed at the time of data generation survey. Three (3) water samples were collected such as groundwater from P1 and P2 test wells and surface water at Younggum pond(S-1) (refer to Fig. 1-2). Other 5 wells drilled at the site were sampled and analyzed at the second stage. Those samples were analyzed by KIST laboratory. The result of water quality analysis comprising previous, 1st and 2nd stages are summarized in Table 5-2.

Fig. 5-1 shows stiff, bar and trilinear diagrams (After Hem, 1959) for chemical composition of groundwater and surface water. Sandstone layer being the main aquifer, stiff diagram exhibits $CaHCO_3$ type water which is a typical water type stored in the Ulsan Formation. For the surface water (S-1), high sulfate and high total organic carbon contents are noted.

The trilinear diagram exhibits no dominant pattern, however, the water quality is in the category of carbornate hardness with secondary alkaline. Pesticides and other hydrocarbons are not detected.

GROUNDWATER POLLUTION POTENTIAL OF THE SUTDY SITE

There are several technical methodologies for evaluating the groundwater pollution potential.

Technical methodologies for estimating and evaluating the groundwater pollution potential by unexpected leaks and spills of toxic substances include empirical assessment approaches, groundwater flow models, solute transport models, and specific predictive equation's. Among those, the empirical assessment methodologies refer to simple approach for development of numerical indices of groundwater pollution potential.

The methodologies typically focus on a numerical index, in which larger numbers are used to denote greater groundwater pollution potential. However, some methodogies encourage the grouping or ranking of pollution potential without extensive usage of numerical indicators.

Since the empirical assessment methodologies should be utilized for the relative evalution of groundwater pollution, considerable professional judgement is highly needed for the interpretation of results.

However, they do represent the approaches based on such minimal data input as a structured procedure for preliminary source evaluation, site selection, prioritization, and monitoring planning.

In this section, a description of three selected empirical assessment methodologies, that are, Standardized system for evaluating waste disposal site(Legrand, 1983), DRASTIC index method, and Waste Soil Site Interaction Matrix-(Phillips, 1977) are used to evaluate the groundwater pollution potential of the proposed site before starting a tentative quantitative hydrodispersive study.

Those methodologies can also evaluate groundwater pollution potential of radioactive wastes as a standardized evaluation system for site selection, prioritization and soon.

DRASTIC indices

DRASTIC is used as a screening tool or hydrogeologic zoning map to ascertain whether a concerned facility is situated in an area vulnerable to the release of contaminants at the surface.

In this method, high DRASTIC score would indicate that the site is located in a generally sensitive or vulnerable area against groundwater pollution potential.

DRASTIC may also be used for preventive purposes through the prioritization of areas where groundwater protection is critical.

By utilizing the hydrogeologic and hydrologic data obtained in the stage of preliminary and data generation, DRASTIC index values were calculated as shown in Table 6-1.

Fig. 6-1 depicts a general pollution potential map constructed by the calculated DRASTIC index values.

Computation of the DRASTIC index and identification of hydrogeologic setting relied on detailed information of seven DRASTIC parameters at the site and its environs. DRASTIC values were computed from minimum 116 points to maximum 157 points (see Table 6-1).

The DRASTIC map of the site indicates that the proposed plant site is located at a quite favorable area whose DRASTIC values are mostly smaller than 140 points.

In other word, the proposed storage tank and proposed main plant site are located in a generally non-sensitive and non-vulnerable area against groundwater pollution potential.

Legrand numerical rating system

A numercial rating system is described for evaluating the potential of groundwater contamination. The numerical rating system is devided into 10-steps within four stages. Stage

Table 6-1. Groundwater pollution potential (DRASTIC).

Hole No.	Depth to water table (5)		Recharge (4)	Aquitfer (3)	Soil (2)	Topography (4)		Vadose Zone(5)	K		total point
	below G.L.(m)	Dr	Rr	Ar	Sr	gradient (%)	Tr	Ir	cm/s	Kr	
P1	5.34	35	32	18	12	2.3	9	25.6	$2.^{40}\times10^{-8}$		134.6
P2	5.02	35	32	12	12	3	9	28.44	5×10^{-6}	3	131.44
01	2.3	45	32	18	10.2	1	10	24.3	4.3×10^{-5}	3	142.9
02	8.3	25	32	18	12	2.62	9	22.6	4.6×10^{-5}	3	121.6
03	7.65	35	32	12	12	2.7	9	21.3	〃	3	124.3
04	9.95	25	32	18	12	3.32	9	21.8	7.1×10^{-5}	3	120.8
05	9.49	25	32	18	12	3.17	9	24.6	1.1×10^{-4}	3	123.6
06	7.09	35	32	18	10.7	3.73	9	21.7	7.8×10^{-5}	3	129.4
07	8.56	35	32	18	12	2.27	9	23.5	1×10^{-4}	3	132.5
08	9.56	25	32	18	12	2.2	9	23.13	9.5×10^{-5}	3	122.13
09	11.5	25	32	18	12	4.8	9	29.39	7.6×10^{-5}	3	128.39
10	6.81	35	32	18	9.5	4.8	9	21.02	5×10^{-5}	3	127.52
11	13.04	25	32	18	9.1	4.73	9	20.38	6×10^{-5}	3	116.48
12	10.0	25	32	18	9.8	5.2	9	20.8	2.6×10^{-5}	3	117.6
13	8.47	35	32	18	12	5.4	9	29.44	6.2×10^{-5}	3	138.44
14	8.23	35	32	18	8.9	4.85	9	20.48	-	3	126.38
15	0.95	50	32	18	9.3	4.0	9	23.16	4.1×10^{-4}	3	144.46
16	1.75	45	32	18	8.9	4.93	9	23.4	7.5×10^{-4}	3	139.3
17	2.89	45	32	15	12	3.5	9	30.0	3.5×10^{-4}	3	146
18	17.48	15	32	18	12	5.59	9	28.4	-	3	117.4
19	13.38	25	32	18	12	7.7	5	26.0	1.5×10^{-4}	3	121
20	5.0	35	32	18	12	4.2	9	27.0	5.5×10^{-4}	3	136
21	3.73	45	32	15	12	4.2	9	30.0	1.9×10^{-5}	3	146
22	-	-	32	-	-						
23	9.76	25	32	18	9.1	3.64	9	20.5	2.7×10^{-5}	3	116.6
24	0.7	50	32	18	12	2.1	9	30.0	1.5×10^{-2}	6	157
25	12.37	25	32	18	8.7	4.1	9	20.24	-	3	115.94
26	0.54	50	32	18	12	2.0	10	30.0	1.5×10^{-3}	6	158
27	9.46	25	32	18	12	5.5	9	22.3	-	3	121.3
28	3.52	45	32	18	10.7	5.8	9	23.4	3.5×10^{-5}	3	141
29	2.3	45	32	18	11.5	6.5	5	25.2	1.5×10^{-4}	3	139.7
30	2.57	45	32	18	12	3.2	9	30.0	1.1×10^{-4}	3	149

Aquifer rating ; Fill(8+2)/2=5, bedded siltstone, sh, SS = 6, massive shale and paddy clay = 2, Soil(top 1.8m) ; Fill (10 + 3 + 4)/3 = 6, colluvium (3 + 4 + 5)/3 = 4, bedded siltstone, sh, SS = 4, Vadose zone ; Fill = 6, colluvium = 5, bedded sh, SS = 4, paddy clay = 3.

1 (seven steps) provides a standard hydrogeologic description of a site focusing on the weighted hydrogeologic characteristics. Stage 2(eighth step) indicates the degree of seriousness of the hazard potential in a matrix by identifying the degree of sensitivity and the degree of contaminant severity. Stage 3(nineth and tenth steps) describes the relative probability of contamination by comparing the site numerical value with a standard value that is derived from an integration of aquifer sensitivity and contaminant severity. Stage 4 reassesses the site with consideration given to engineering modification by utilizing PAR(protection of aquifer rating) matrix.

Stage 1

The result of a standard hydrogeologic description of a proposed storage tank and plant site is summarized in Table 6-2.

Completions of site numerical description of both proposed sites are represented "14-3452DASP" which means that a generalized site grade based on key hydrogeologic parameters only is categorized to good site in terms of site evaluation.

Stage 2 : Degree of seriousness

In this matrix a situation is considered, including both the seriousness and likelihood of contamination. The hazard potential matrix inte-

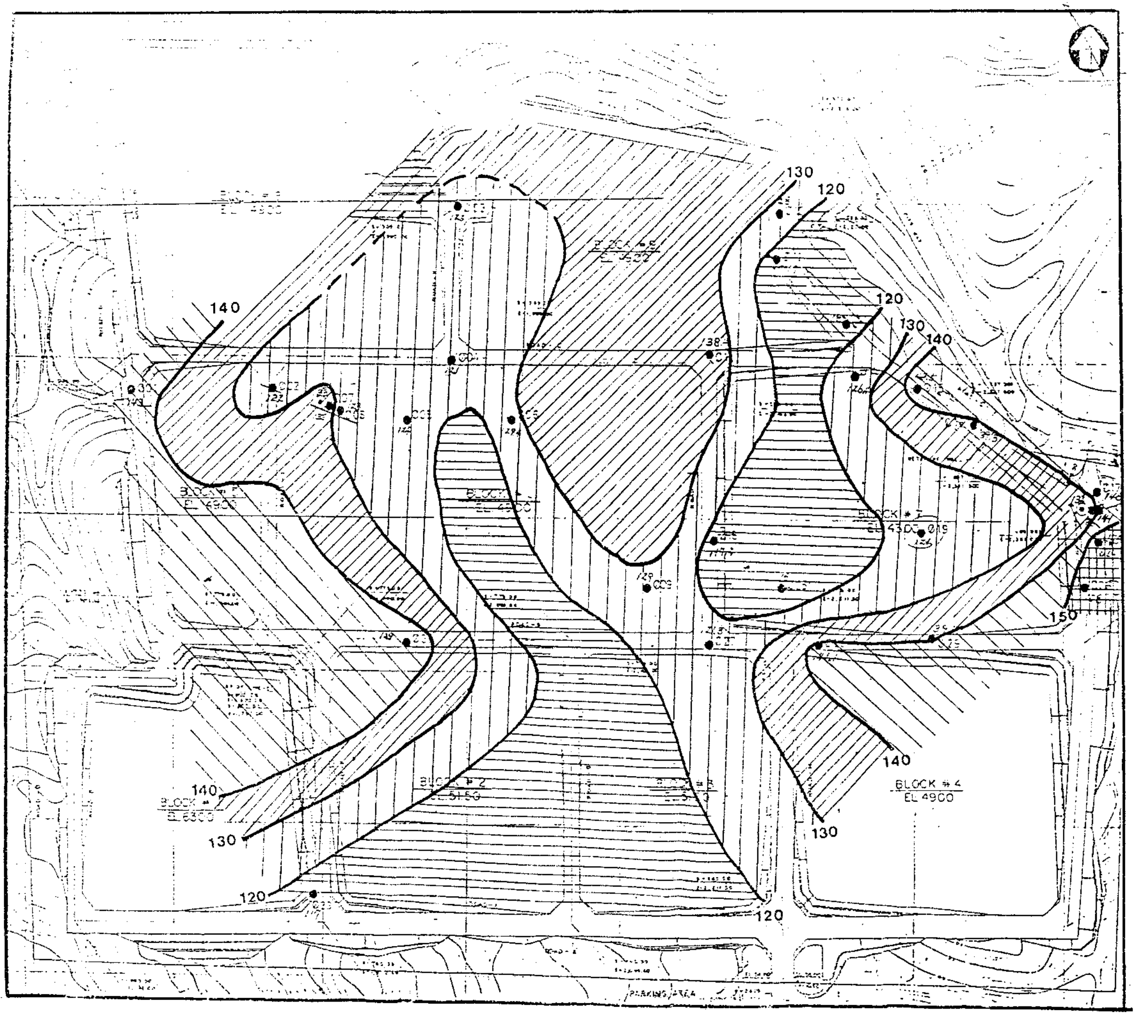

Fig. 6-1.Groundwater pollution potential map (DRASTIC).

grates contaminant severity with aquifer severity. In stage 2, the focus is on seriousness of contamination and in stage 3 the focus is on the likelihood of contamination. The degree of seriousness is indicated by the 9 squares of the matrix. Thick weathered clay material overlying fractured shale and siltstone beds results in a poor yielding aquifer, which is not much sensitive to wide spread contamination. Hence the tank and plant locaion in matrix belongs to "moderately high degree of seriousness"

Stage 3 : Grading and evaluating hazard potential probability of contamination, and degree of acceptance (for natural site).

In this stage, a described site is compared with the standard situation or "PAR(Protection of Aquifer Rating)" along isometric lines. The standard situation rating is the approximate numerical maximum which a site's description should not exceed to prevent serious contamination of groundwater. The "PAR" along the isometric line may be considered as only a

Table 6-2. A standardized system for evaluating site (Legrand Method).
Stage-1

Step	Item to be evaluated	Storge		Plant	
		Description	Rating & Identifier	Description	Rating & Identifier
1	Distance (spring)	215m	3	210+(α)	3
2	Depth to water table	10.5m	4	11.5m	4
3	Gradient	13%	5	4.6%	5
4	K and Sorption	clay/50/S 〈0.5m	2D	11.5m	2D
5	Confidence	-	A	-	A
6	User's identifier	Spring	S	Spring	S
	—		P	〃	P
7	Completion of site numerical description	14-3452DASP		14-3452DASP	

Table 6-3. The result of legrand assessment methodology.

Situation rating combined value	Probability of contamination	Degree of acceptability	Situation Grad
-7 to -4	May be-improable	Probably acceptable or marginally unacceptable	"B"

guide-line and not necessarily as a rigid acceptance or rejection level of a site. The values obtained through stage 1 and 2 are overlapped to the matrix chart of stage-3 developed by Legrand.

The combined value of situation rating calculated from site numerical description rating after subtracting the PAR rating was (-4) ; that are

	site numerical rating	14 ··········· 2	
—)	PAR	16 ··········· 4	
		-2 ··········· -2	(-4)

Therefore, the probability of contamination, the degree of acceptability and situation grade of the site is classed to "Maybe-Improbable"in account of probability of contamination and "Probably acceptable or Marginally unacceptable" in a view point of the degree of acceptability with situation grade of "B" as shown in Table 6-3.

Waste-soil site interaction Matrix Assessment

The waste-soil site interaction matrix was developed for assessing industrial solid or liquid waste disposal on land (Phillips etal, 1977).

Accidental leak is discharged to soil through the soil adsorption/biodegradation system, hence this matrix is considered to be potentially applicable to the evaluation of unexpected leak and spill area of toxic substance.

The method involves summation of the substances of various waste-soil site consideration, with the resultant numerical values ranging from 45 to 4,830. The methodology includes ten factors related to contaminants and seven factors associated with the site of potential waste application.

Table 6-4 displays the matrix results for the study site area. Based on normal usage of the waste-soil site interaction, both class 9 and 10 would be unacceptable as waste site.

Table 6-4. Waste soil site interaction matrix assessment of the site.

Waste \ Soil		Soil group: Perme. Np (5)	Soil group: Sorption Na (5)	Hydrology group: G.W. table NWT(5.45)	Hydrology group: Gradi-ent NG(8.75)	Hydrology group: Infil. NI(3)	Site group: Distance ND(2.9)	Site group: Thickness NT(7)	Total
Effect group	Hy. Tox. Ht (6.7)	33.5	33.5	36.5	58.6	20.1	19.4	46.9	248.5
	Gr.Tox. Gt(10)	50	50	54.5	87.5	30	29	70	371
	Disease Tr. Dp(0)	-	-	-	-	-	-	-	
Behavior performance	Chen.Per. Cp(1)	5	5	5.4	8.7	3	2.9	7	37
	Biol.Per. Bp(1)	5	5	5.4	8.7	3	2.9	7	37
	Sorption So(1)	5	5	5.4	8.7	3	2.9	7	37
Behavior Properties	Viacosity Vi (2)	10	10	10.9	17.0	6	5.8	14	73.4
	Solubility Sy(4.6)	23	23	20	40.2	13.8	13.3	32.2	165.5
	Acid/Basic Ab(0)	-	-	-	-	-	-	-	
Capacity rate	Waste Appli,rate Ar(4.8)	24	24	26.1	42	14.4	13.9	33.6	178
Total		155.5	155.5	164.2	271.4	93.3	90.1	217.7	1147

Table 6-5. The method for calculating each pertinent factor for the site is based on the matrix formular and addressed value.

Waste

$Ht = \frac{10}{3} x\ 2 = 6.7$ $Gt(benzene) = 10,\ Dp = 0$

$Cp = 5 \cdot 0.1/1 = 0.5 = 1$ $Bp = 4(1\text{-}BOD/COD) = 4(1\text{-}1) = 0$

$So = 11 - Co/g = 11\text{-}1/0.1 = 4$ $Vi = 5 - \log = 2$

$Sy = 3+0.5 \log 1780 = 4.6$ $PH = 0$

$Ar = 4.5 \log(\sqrt{Rg \cdot Co} \cdot Ns) + 1$

$Rf = 0.11g/H^2/D\text{-}2$ $Co = 5+1.25 \log C$

$C < 10^{-4} \quad Co = 1$

$Ns = \frac{7}{10}(7\text{-}3.5) = 5$

$Ar = 4.5 \log(\sqrt{2.1}\ x\ 5) + 1 = 4.8$

Soil

$Np = \frac{10}{4}(4\text{-}2) = 5$ $S = \frac{10}{7}(7\text{-}3.5) = 5$

$NWT = \frac{10}{11}(11\text{-}5) = 5.45$ (WT:5 point)

$NG = \frac{10}{8}(8\text{-}1) = 8.75$ (I: 13%)

$NL = 3$ $ND = \frac{10}{12}(12\text{-}8.5) = 2.9$ $(D = 215m\text{-}8.5)$

$NT = \frac{10}{7}(7\text{-}2) = 7$

Table 6-5 shows calculated values of each pertinent factors for the site based on the matrix formula and addressed value for waste-soil site interaction matrix assessment.
The resultant numerical value obtained is classed as 8 in accordance with the classification of the matrix.

CONCLUSION

Subsurface lithology encountered in the study area is classified into three units ; overburben comprising fill, paddy soil and colluvium, weathered zone(CW-HW), and sound sedimentary rocks of shale and siltstone intercalated with sandstone.

The uppermost aquifer in the site is defined as saturated over-burden and weathered zone including upper part of moderately weathered sedimentary rock which are hydraulically interconnected.

The thickness of the uppermost aquifer ranges from 5 to maximum 21m and average about 14.4m.

Flow direction observed with flowmeter is compatible with that of the potentiometric surface map. Shale and siltstone exhibit the pH value of 5 to 7 and that of sandstone is 7 to 8.

Fluctuation of groundwater level exhibits more than 4m at the border of cutting area and almost less than 2m at the central part of the filling area. The water level is generally situated at the portion of weathered zone or upper part of fractured rock. Hydrogeologic regime in the site is divided into "A" and "B" zones.
A small catchement area occupying eastern part of Block #6 and southern part of Block #7 is defined as "A" zone. Major pathway in "A" zone is from southwest to northest which is compatible with the strike of J1 joint. Main pathway in "B" zone starts from southeastern part of Block #9 toward southeast direction which is compatible with the strike of J2. And then it turns to northest direction, which is coincide with the strike of J1 point, at northern part of Block #7.

Representative hydraulic conductivity and storativity of weathered zone and sedimentary rock are estimated as 2.88 x 10E - 06 m/s and 0.09. and 2.4×10 E-08 m/s and 0.02, separately. And also calculated Darician velocity and averge linear velocity of groundwater along major pathway of "A" zone are 0.011 m/day and 0.12m/day with average hydraulic gradient of 4.6/100.

Background of groundwater quality of the site and its environs are determined that no observable level of hydrocarbon substance were detected.

According to the results of utilized several empirical assessment methodologies to evaluate the groundwater pollution potential,
1) DRASTIC map depicts that the study site is located non-sensitive and non-vulnerable area.
2) Legrand numerical rating system indicates that probability of contamination and degree of acceptability are categorized "may be improbable to contamination" and "probable acceptable and marginally unacceptable" with situation grade of "B"
3) Waste-soil site interaction matrix assessment shows that the site is belong to class-8.

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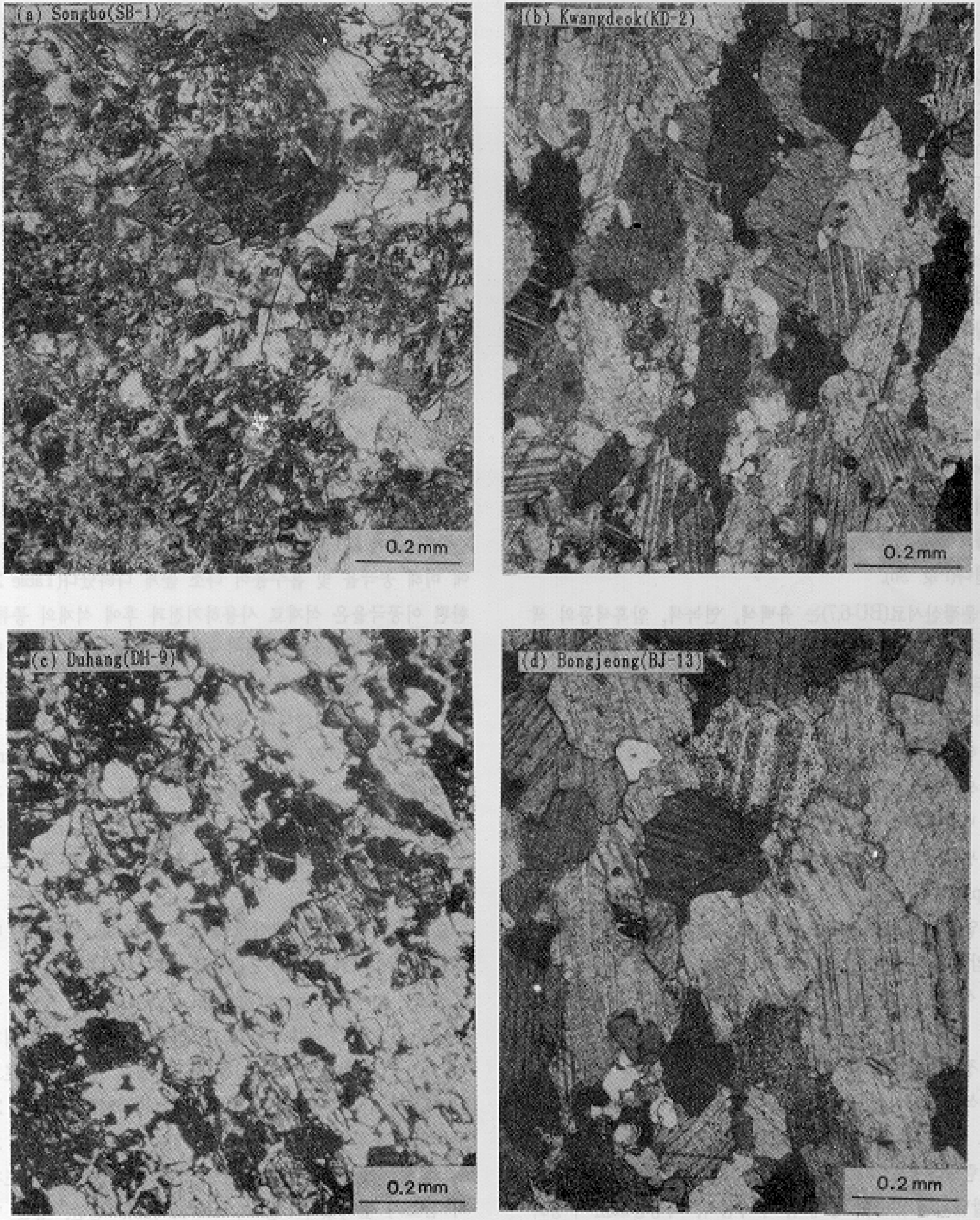
지하수 오염 가능성 평가

—수리지질 및 부지특성 조사와 경험적 평가 방법을 이용한 지하수 요염 가능성—

한 정 상 · 한 규 상 · 이 영 동 · 유 대 호

요약 : 지하수 환경의 오염 가능성에 대한 정량적인 전산분석을 실시하기 이전 단계로 경험적인 평가방법을 이용하여 조사대상 지역 지하수환경의 오염 가능성을 광범위한 수리지질 및 수리분산 실험을 실시하여 평가하였다. 그 결과 최상위 대수층은 포화 비고결 퇴적물과 풍화대 및 수리적으로 연결성이 양호한 상부 파쇄암으로 구성되어 있다. 최상위 대수층의 대표적인 수리전도도는 2.88×10^{-6}m/s, 저유계수(비산출률)은 0.09, 지하수의 주흐름 경로에서 다시 안 유속은 0.011m/d, 비반응 오염 용질의 공극유속은 0.12m/d, 지하수의 동수구배는 4.6%이다. 취득한 제반 수리지질 자료를 이용하여 조사대상 지역의 자하수환경 오염 가능성을 경험적인 평가법으로 평가한 바, 1) DRASTIC 분석 결과에 의하면, 본 지역은 "지하수 오염 가능성에 취약성이 희박하거나, 오염에 민감하지 않은 지역"으로 나타났으며, 2) Legrand 수치법 분석법을 이용하여 입지 적합성과 오염 가능성을 평가한 바, 본 지역은 "B" grade에 해당하는 "오염 가능성이 없기 때문에 대체적으로 입지로 적합하나, 부분적으로 적합지 않을 수도 있는 지역"으로 분류되었고, 3) 폐기물—토양 입지 연관성 행열 평가법에 의하면, 본 부지는 8군에 속하는 것으로 평가되었다.


(a) Songbo(SB-1)
0.2 mm
(b) Kwangdeok(KD-2)
0.2 mm
(c) Duhang(DH-9)
0.2 mm
(d) Bongjeong(BJ-13)
0.2 mm