CHAPTER 3

METHODOLOGY AND DATA ACQUISITION

3.1 Introduction

The main objective of this study is to assess the impact of seawater intrusion into groundwater aquifer and agricultural activities in coastal area in Carey Island. The impact of groundwater salinity towards oil palm plant is crucial for the plant's life. This chapter discussed the tools and procedure of the research methodology to achieve the objectives of this study.

The research tools used included surface study, subsurface hydrogeology study and subsurface resistivity study. The details of surface study, subsurface hydrogeology study and subsurface resistivity study are discussed in sections 3.2, 3.3 and 3.4, respectively. Summary of flowchart for the research methodology used in this study is given in Figure 3.1.

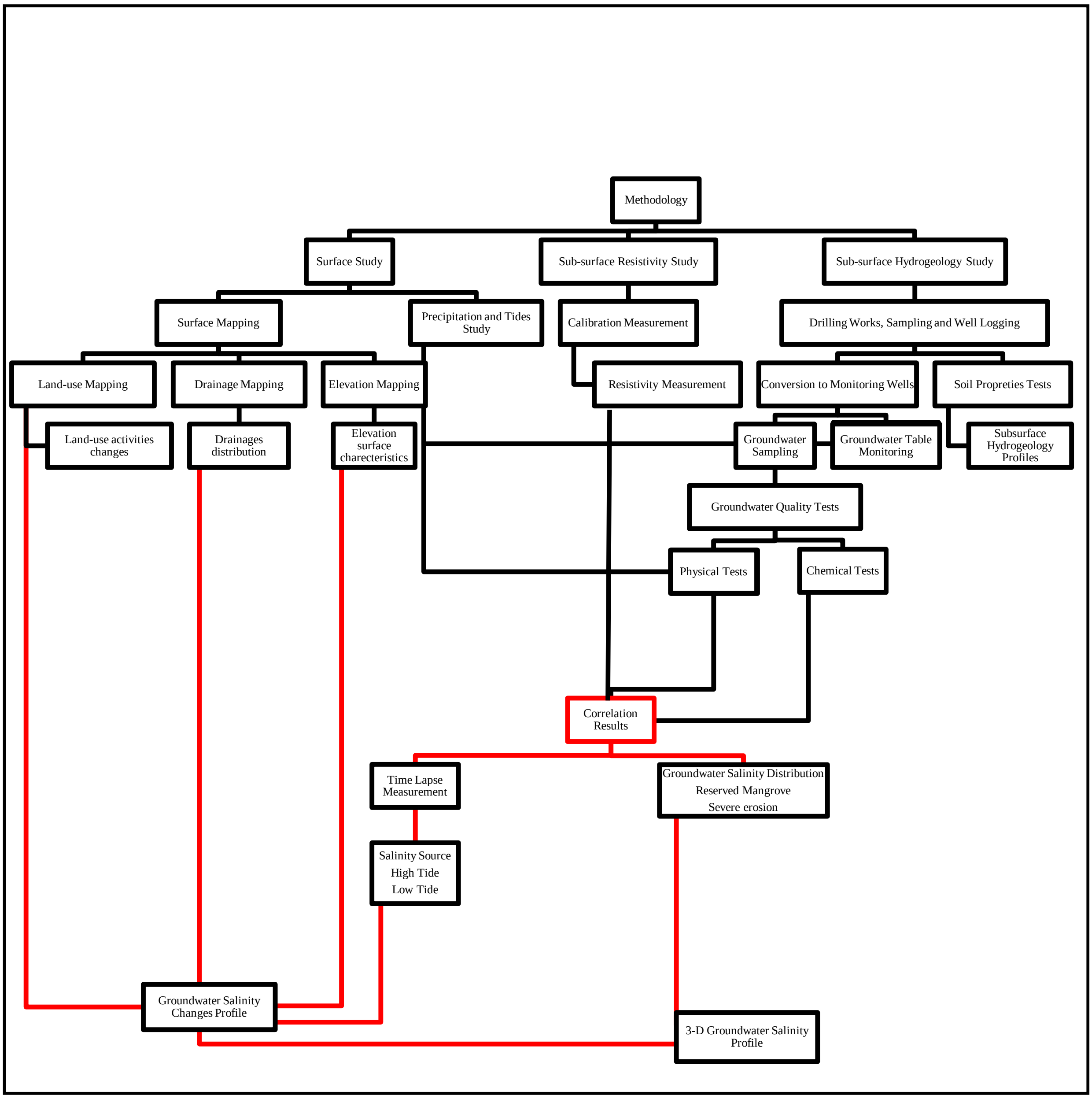


Figure 3.1: Flow chart of methodology

3.2 Surface study

Surface study is used to determine the surface characteristics of the study area. The importance of surface study is to assess the relationship between surface and subsurface hydrogeological characteristics of the study area. The study involved surface mapping, precipitation and sea tides changes.

3.2.1 Surface mapping

Surface mapping is required as to assess land surface characteristics that can influence the distribution of seawater intrusion into groundwater aquifer in the study area. The mapping consists of land-use changes pattern, drainage distribution and surface elevation. These mappings provide information of land-use changes activities, drainage distribution and surface elevation characteristics. The following section discussed data acquisition, processing, analysis and interpretation for the surface mapping.

3.2.1.1 Land-use and drainage

Land-use mapping is useful for assessing the past and present land-use activities change in Carey Island. The past land-use map was obtained from topography map in the year 1974 published by The Department of Survey and Mapping Malaysia (DSMM). Scale of the topography map ratio is 1:63360 which covered the whole of Carey Island. As for the present land-use map, it is obtained from a modified land-use map with ground mapping in the year 2010.

The topography map (1974) and modified land-use map with ground mapping (2010) are combined through a digitized process by using AutoCAD software version 2009. The superimposed maps are used to interpret the land-use activities change from the year 1974 to 2010. The 30 years of land-use activities change are estimated in unit m^2.

Drainage map is used for evaluating drainage systems and distributions in study area. Drainage mapping used modified drainage map with ground mapping in the year 2010. The land-use activities change and drainage distributions in Carey Island were discussed in Chapter 4.

3.2.1.2 Surface elevation

Surface elevation study involves elevation and coordinates of routes surveys to the monitoring wells (MW) point. The purpose of surface elevation study is to obtain topography information of the study area. The precision of total station equipment, model GPT-3100N Series Top Con were used for data acquisition of elevation for the fourteen (14) monitoring wells. The location of monitoring wells was shown in Figure 3.2. The reference datum was benchmarked to station BM No. 3082 obtained from DSMM (Figures 3.2 and 3.3). The elevation of benchmarked station was 3.0458 m from mean sea level (m.msl).

The target prism was set to a fixed height of 1.44 m for all measurements. The procedure of the reduced level measurements is illustrated in Figure 3.4. The calculation for the obtained next elevation for point number 2 was used Equation (3.1).

$$\text{Elevation No. 2} = \text{VD front} - \text{VD back} + \text{Elevation No. 1} \tag{3.1}$$

where, VD is the vertical distance

The survey was conducted to calculate the reference datum to mean sea level (m.s.l). Several of the temporary bench marks (TBM) were placed at permanent hydraulic structures (e.g culvert and bridge) during the surveys. This was to ensure the elevation point survey was placed on a firm structure to avoid the loss of survey point's data. A survey elevation began at a particular bench mark (BM) or TBM and ended at the same starting point. This procedure is called a closed loop elevation. Closed loop elevation surveys were carried out, after all measurements of elevation for the boreholes have been done. Twelve closed loops were used in this study (Figure 3.5). This procedure was done to ensure the elevations of the monitoring wells were obtained in an allowable error manner. The subsurface hydrogeology profile diagram and groundwater tables data collected were referred to the accurate elevation. The permissible error of closure in accuracy levelling was expressed in terms of a coefficient and the square root of the horizontal length of the actual route over which the levelling was done.

The allowable error was as follows:

$$= \pm 20\sqrt{\mathrm{K}}, \text{ unit mm} \qquad (3.2)$$

where, K is the horizontal length (unit in kilometre) of the actual route over which the levelling is done.

The coordinates of points during elevation survey (BM, MW and TBM) were measured using Global Positioning System (GPS) by using Garmin Oregon 300 Model. The exact locations, namely longitude and latitude of the transverse survey points were determined in the field. The horizontal accuracy of GPS was nearly 8 to 15 m when strong satellite signals were detected.

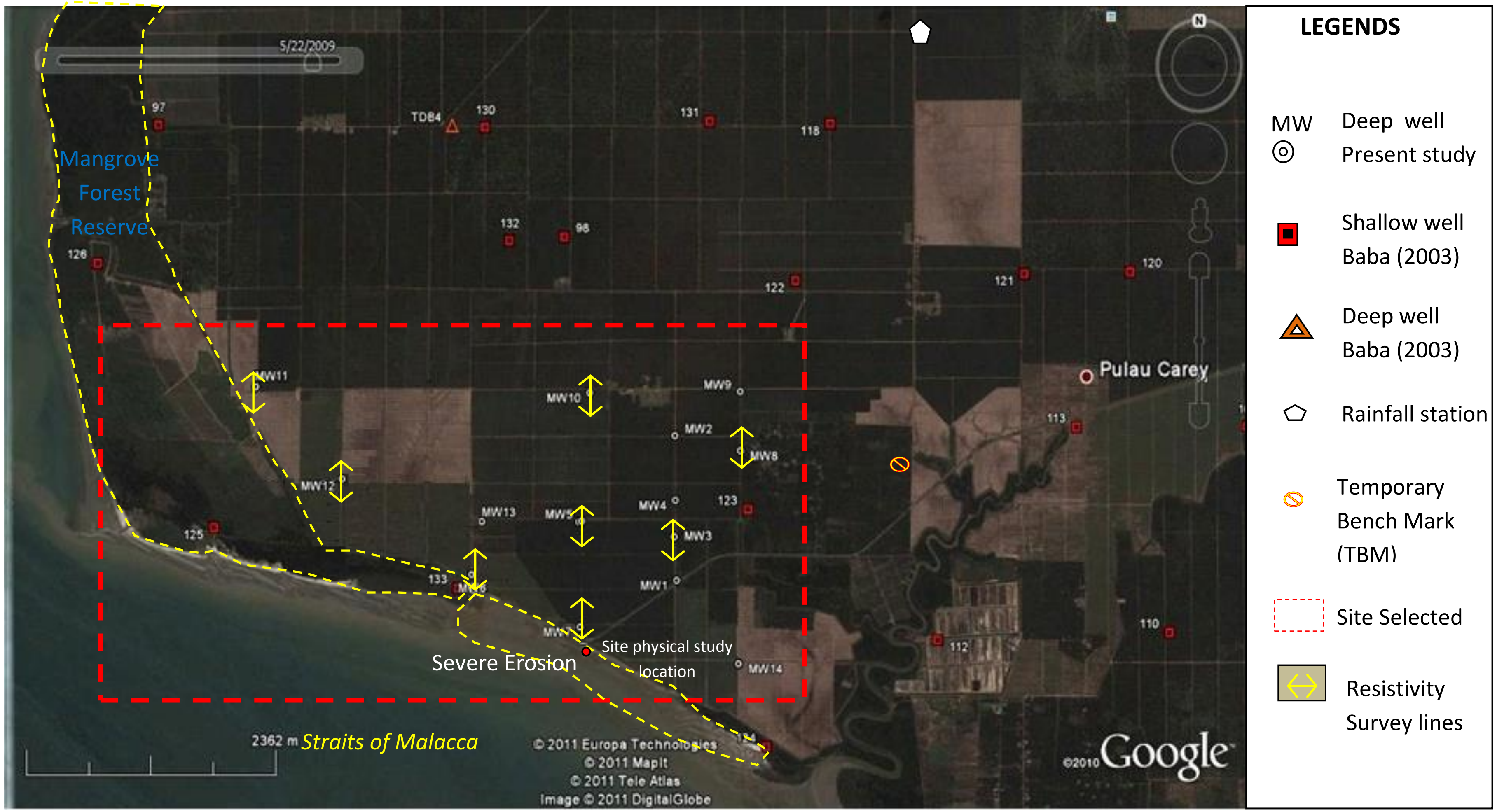


Figure 3.2: Locations of monitoring wells, resistivity survey lines, rainfall station and land survey reference

Figure 3.3: BM 3082 used as referred datum for all elevation of monitoring wells

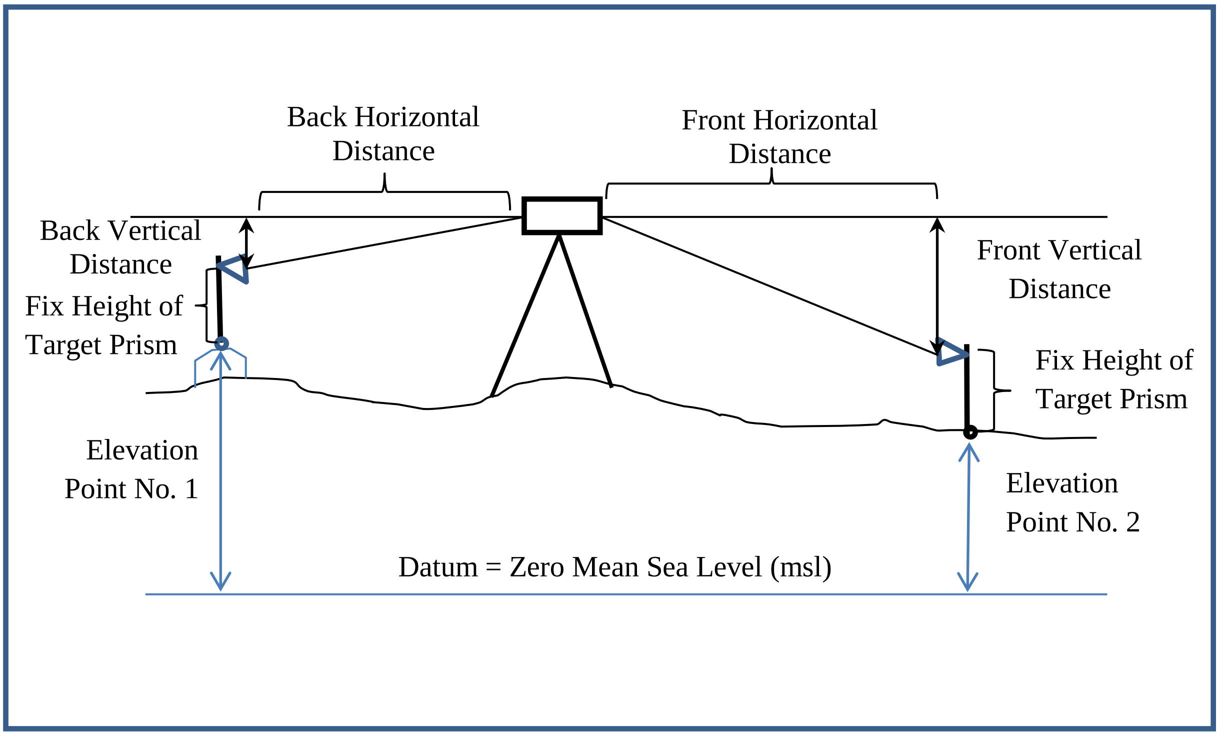


Figure 3.4: Concept of elevation survey

Figure 3.5: Route map of survey elevations and closed loops elevations conducted at study area

An example of the elevation survey and coordinates data are presented in Figure 3.6. All of the data surveys measurements including closed loop surveys were listed in Appendix A. The elevation data surveyed was used to produce the surface elevation mapping and profiles by using Surfer version 8 and AutoCAD software version 2009, respectively. Topography pattern in the study area was assessed from the surface elevation profiles produced. Examples of surface elevation mapping are illustrated in Figures 3.7 and 3.8.

Station	Coordinates WGS 84		VD (Back)	HD (Back)	VD (Front)	HD (Front)	**Elevation**
	Latitude	Longtitude	(m)	(m)	(m)	(m)	**(m)**
BM 3082	2°50'21.19"N	101°21'39.25"E	-0.334	30.850			3.046
P1	2°50'18.89"N	101°21'38.12"E	-0.384	300.280	-0.346	46.930	3.034
P2	2°50'7.05"N	101°21'22.11"E	-0.153	309.650	0.049	311.570	3.467
P3	2°50'6.46"N	101°21'1.16"E	-0.420	317.110	-0.517	310.560	3.103
P4	2°50'6.18"N	101°20'40.33"E	-1.754	113.880	-0.540	344.640	2.983
TBM01	2°50'4.57"N	101°20'36.20"E			-0.164	22.640	4.573
P5	2°50'3.39"N	101°20'34.62"E	0.086	148.110	-1.593	85.820	3.144
P6	2°49'58.61"N	101°20'27.14"E	-0.273	21.010	-0.261	127.950	2.797
TBM02	2°49'58.13"N	101°20'26.04"E			-0.873	18.230	2.197
TBM03	2°49'59.16"N	101°20'25.90"E			-0.418	25.080	2.652
MW1	2°49'59.90"N	101°20'26.90"E			-1.584	42.890	1.486
P7	2°50'6.97"N	101°20'25.94"E	-0.127	224.600	-1.578	259.850	1.492
TBM04	2°50'15.33"N	101°20'26.11"E			-0.212	35.440	1.407
TBM05	2°50'16.99"N	101°20'26.14"E			0.757	83.840	2.376

Figure 3.6: An example of data collection for elevation surveys

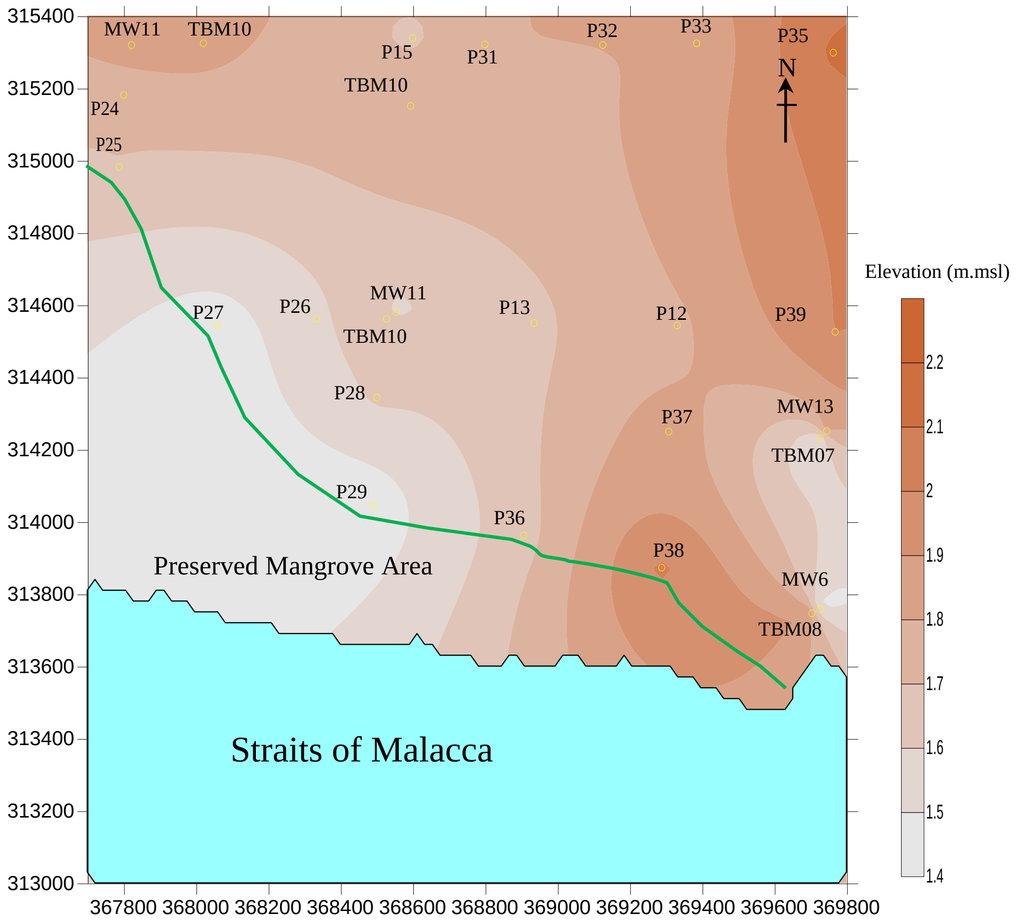


Figure 3.7: Example of topography map (view plan) at the southwest study area

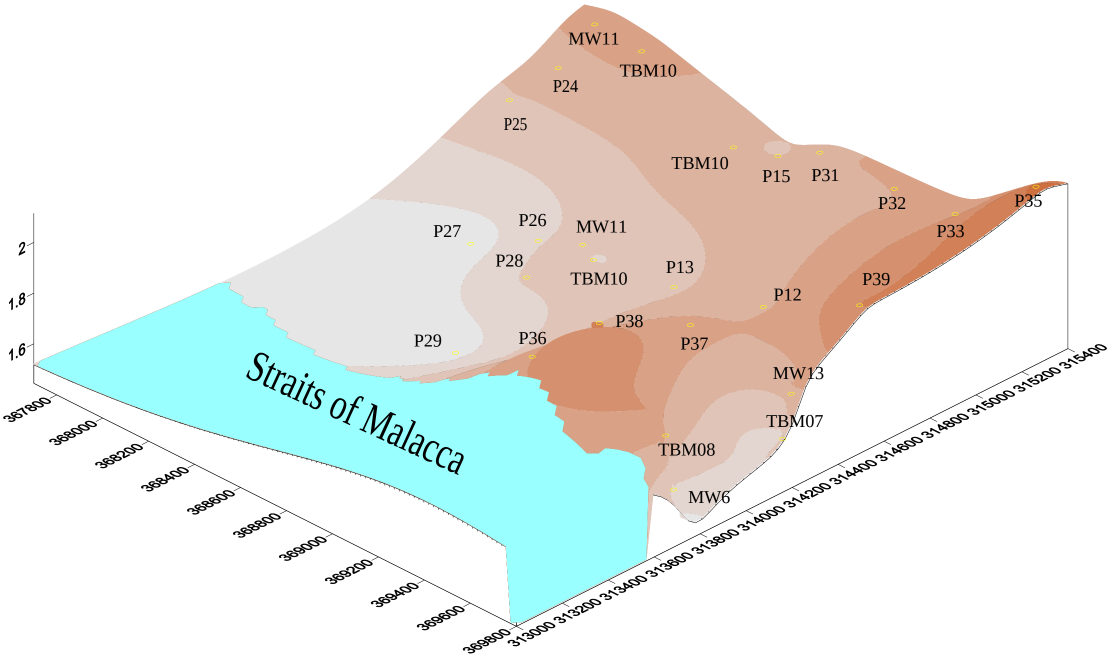


Figure 3.8: Example of 3-D topography map at the southwest study area

3.2.2 Precipitation and sea tide

Precipitation and sea tides surveys were used to assess the relationship between hydrological and subsurface hydro-geological characteristics. The purpose of precipitation study was to determine whether the groundwater recharge on Carey Island was influenced by either local precipitation or regional precipitation. The data acquisition was secondary to the data obtained from Department of Irrigation and Drainage of Malaysia (DID) and Department of Survey and Mapping Malaysia (DSMM). The following section discussed data acquisition, processing, analysis and interpretation of precipitation and tide study.

3.2.2.1 Precipitation

The purpose of precipitation study was to determine the total rainfall received and seasonal pattern in Carey Island. Rainfall data supplied by the DID were from rainfall station number 2913121 (Figure 3.2). Eleven years (2000-2010) of rainfall data used was from the rainfall station at Carey Island's West Estate site office.The original format of rainfall data was dat. file. An example of selected precipitation data from DID is presented in Figure 3.9. The data obtained were complete without any missing data. The rest of the data were enclosed in Appendix B. This format was changed into Excel file format to accommodate the analysis purposes.

The data used in this analysis were monthly rainfall data versus time to analyze the seasonal pattern. The data analysis used XY scatter chart in Microsoft Excel. The data interpretation was used to determine the relationship between seasonal and groundwater table in the same time duration and is discussed in this chapter.

3.2.2.2 Sea tide study

Sea tide study is useful to determine the effect of tides to groundwater quality and quantity. Tide levels data were obtained from the tide table of Malaysia report published by DSMM. Tide levels data of Kelang Station were used as these were the nearest tide gauge available to the study area. Distance from the study area to the Kelang Station tide gauge was about 20 km. The duration of tide levels data used is from year 2009 until 2011 (DSMM 2009, DSMM 2010 and DSMM 2011).

Tide levels data in Figure 3.10 shows an example of hourly tide height predictions at Port Kelang in November and December 2009. The rest of the data are enclosed in Appendix C. Two hours after high tide, the increment data was used for the analysis. Tide levels data of Kelang Station tide gauge were not referring to the mean sea level datum (Figure 3.10). The data must be corrected to the mean sea level datum to correlate the tide levels against groundwater tables which were referring to the same datum. The Kelang Station table of the predicted tides and datum-level observation for 22 years (1984 to 2005) (Figure 3.11) were used for the datum conversion. An example of calculation for the maximum high tide on the 1st Nov 2009 (Figure 3.10) being converted to mean sea level datum is shown below.

Example of calculation;

High tide increment on 1st Nov 2009 = 421 cm =4.21 m

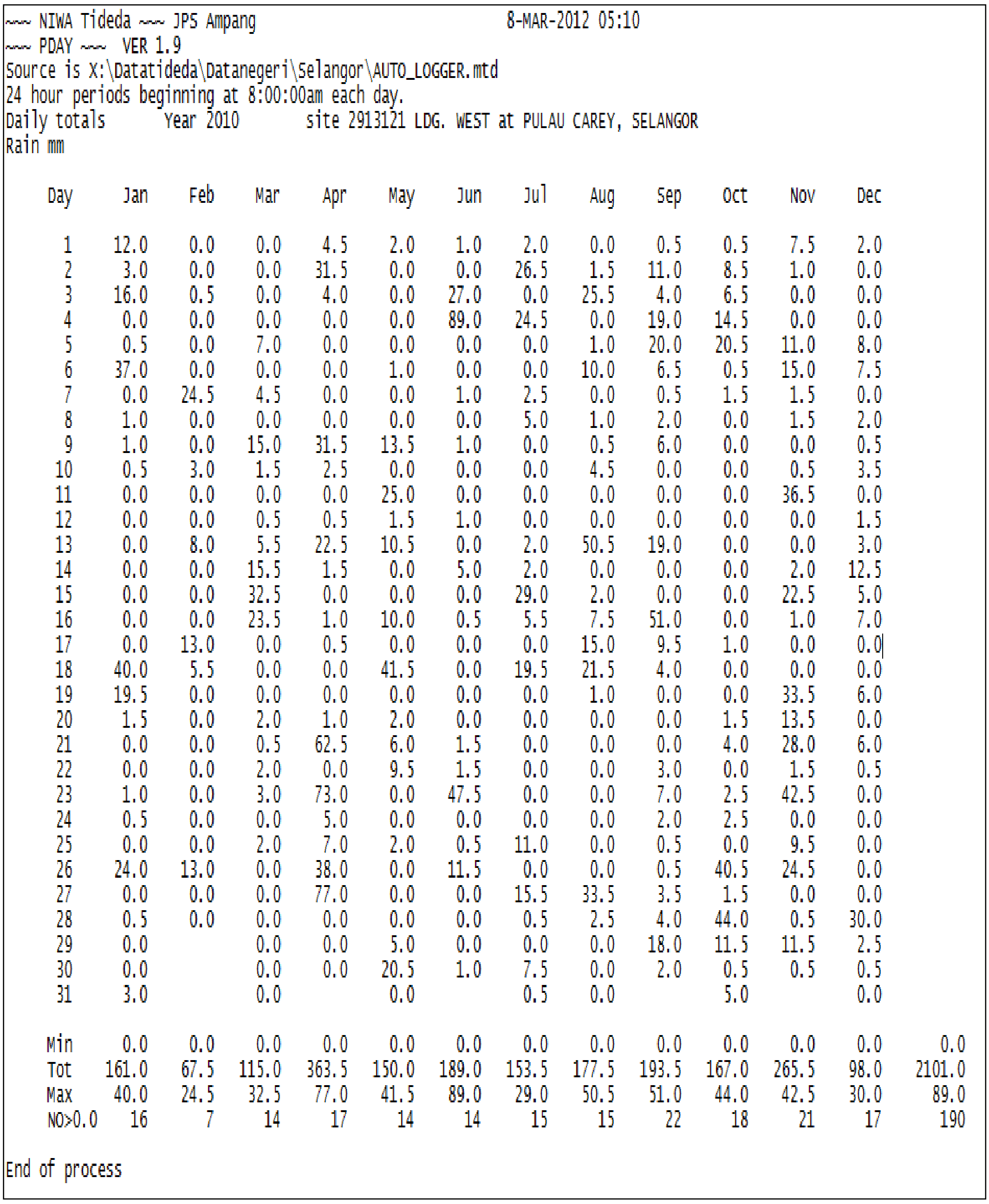
High tide increment refer to datum level = 1.343 m + 4.21 m = 5.553 m

High tide increment refer to mean sea level (m.s.l), where mean sea level is zero,

= 5.553 m- 3.635 m = 1.918 m.msl

All the maximum high tides data from 2009 until 2011 were processed accordingly following the example of calculation above.

The data were plotted against groundwater tables graphically using MS Excel 2007. The data interpretation was based on the relationship between high tide and groundwater tables at the same time and is presented in Chapter 4.



```
~~~ NIWA Tideda ~~~ JPS Ampang                         8-MAR-2012 05:10
~~~ PDAY ~~~  VER 1.9
Source is X:\Datatideda\Datanegeri\Selangor\AUTO_LOGGER.mtd
24 hour periods beginning at 8:00:00am each day.
Daily totals      Year 2010       site 2913121 LDG. WEST at PULAU CAREY, SELANGOR
Rain mm

   Day    Jan    Feb    Mar    Apr    May    Jun    Jul    Aug    Sep    Oct    Nov    Dec

     1   12.0    0.0    0.0    4.5    2.0    1.0    2.0    0.0    0.5    0.5    7.5    2.0
     2    3.0    0.0    0.0   31.5    0.0    0.0   26.5    1.5   11.0    8.5    1.0    0.0
     3   16.0    0.5    0.0    4.0    0.0   27.0    0.0   25.5    4.0    6.5    0.0    0.0
     4    0.0    0.0    0.0    0.0    0.0   89.0   24.5    0.0   19.0   14.5    0.0    0.0
     5    0.5    0.0    7.0    0.0    0.0    0.0    0.0    1.0   20.0   20.5   11.0    8.0
     6   37.0    0.0    0.0    0.0    1.0    0.0    0.0   10.0    6.5    0.5   15.0    7.5
     7    0.0   24.5    4.5    0.0    0.0    1.0    2.5    0.0    0.5    1.5    1.5    0.0
     8    1.0    0.0    0.0    0.0    0.0    0.0    5.0    1.0    2.0    0.0    1.5    2.0
     9    1.0    0.0   15.0   31.5   13.5    1.0    0.0    0.5    6.0    0.0    0.0    0.5
    10    0.5    3.0    1.5    2.5    0.0    0.0    0.0    4.5    0.0    0.0    0.5    3.5
    11    0.0    0.0    0.0    0.0   25.0    0.0    0.0    0.0    0.0    0.0   36.5    0.0
    12    0.0    0.0    0.5    0.5    1.5    1.0    0.0    0.0    0.0    0.0    0.0    1.5
    13    0.0    8.0    5.5   22.5   10.5    0.0    2.0   50.5   19.0    0.0    0.0    3.0
    14    0.0    0.0   15.5    1.5    0.0    5.0    2.0    0.0    0.0    0.0    2.0   12.5
    15    0.0    0.0   32.5    0.0    0.0    0.0   29.0    2.0    0.0    0.0   22.5    5.0
    16    0.0    0.0   23.5    1.0   10.0    0.5    5.5    7.5   51.0    0.0    1.0    7.0
    17    0.0   13.0    0.0    0.5    0.0    0.0    0.0   15.0    9.5    1.0    0.0    0.0
    18   40.0    5.5    0.0    0.0   41.5    0.0   19.5   21.5    4.0    0.0    0.0    0.0
    19   19.5    0.0    0.0    0.0    0.0    0.0    0.0    1.0    0.0    0.0   33.5    6.0
    20    1.5    0.0    2.0    1.0    2.0    0.0    0.0    0.0    0.0    1.5   13.5    0.0
    21    0.0    0.0    0.5   62.5    6.0    1.5    0.0    0.0    0.0    4.0   28.0    6.0
    22    0.0    0.0    2.0    0.0    9.5    1.5    0.0    0.0    3.0    0.0    1.5    0.5
    23    1.0    0.0    3.0   73.0    0.0   47.5    0.0    0.0    7.0    2.5   42.5    0.0
    24    0.5    0.0    0.0    5.0    0.0    0.0    0.0    0.0    2.0    2.5    0.0    0.0
    25    0.0    0.0    2.0    7.0    2.0    0.5   11.0    0.0    0.5    0.0    9.5    0.0
    26   24.0   13.0    0.0   38.0    0.0   11.5    0.0    0.0    0.5   40.5   24.5    0.0
    27    0.0    0.0    0.0   77.0    0.0    0.0   15.5   33.5    3.5    1.5    0.0    0.0
    28    0.5    0.0    0.0    0.0    0.0    0.0    0.5    2.5    4.0   44.0    0.5   30.0
    29    0.0           0.0    0.0    5.0    0.0    0.0    0.0   18.0   11.5   11.5    2.5
    30    0.0           0.0    0.0   20.5    1.0    7.5    0.0    2.0    0.5    0.5    0.5
    31    3.0           0.0           0.0           0.5    0.0           5.0           0.0

   Min    0.0    0.0    0.0    0.0    0.0    0.0    0.0    0.0    0.0    0.0    0.0    0.0       0.0
   Tot  161.0   67.5  115.0  363.5  150.0  189.0  153.5  177.5  193.5  167.0  265.5   98.0    2101.0
   Max   40.0   24.5   32.5   77.0   41.5   89.0   29.0   50.5   51.0   44.0   42.5   30.0      89.0
NO>0.0     16      7     14     17     14     14     15     15     22     18     21     17       190

End of process
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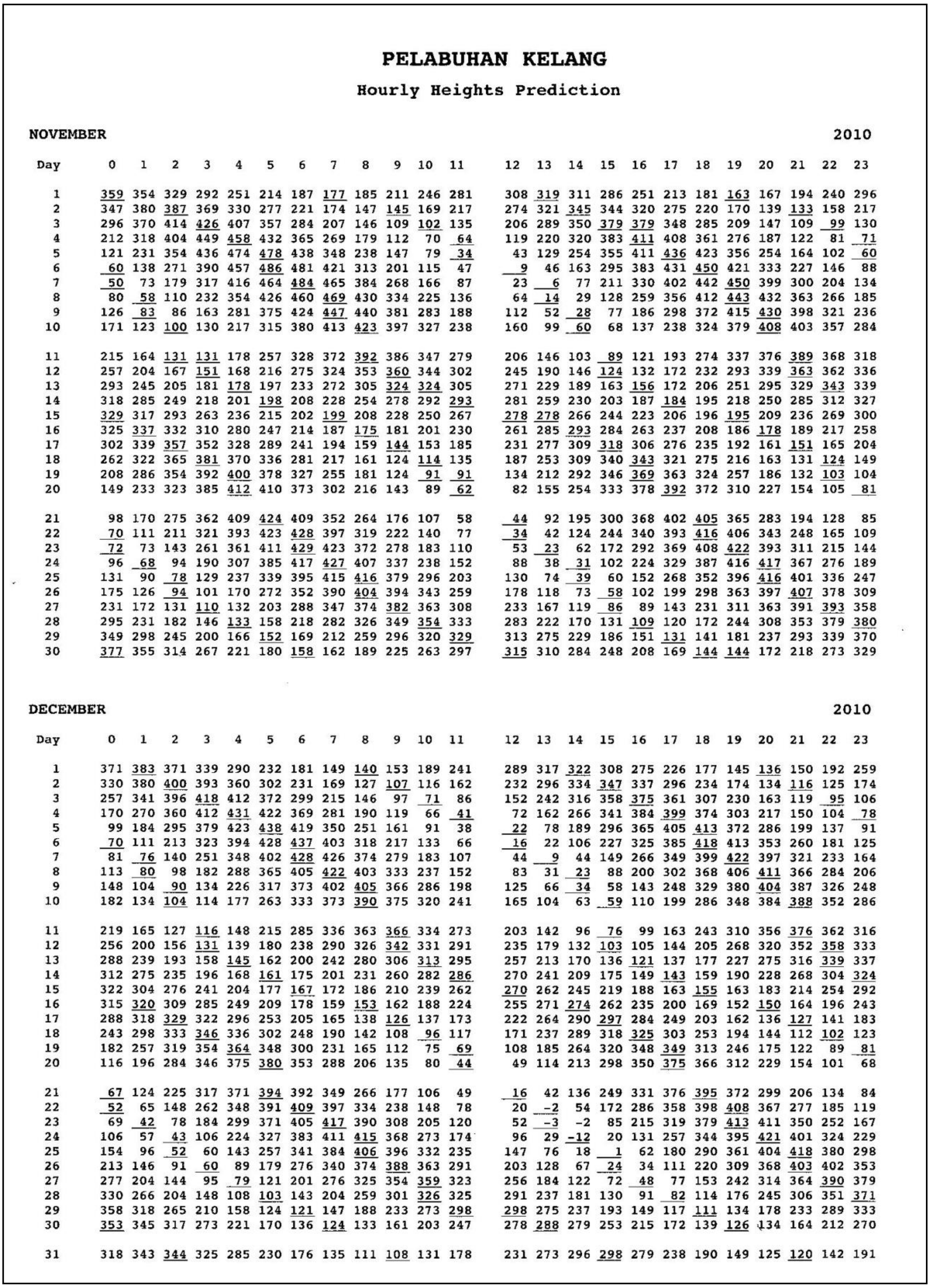
Figure 3.9: An example of rainfall data for year 2010 obtained from DID



PELABUHAN KELANG

Hourly Heights Prediction

NOVEMBER 2010

Day	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23
1	359	354	329	292	251	214	187	177	185	211	246	281	308	319	311	286	251	213	181	163	167	194	240	296
2	347	380	387	369	330	277	221	174	147	145	169	217	274	321	345	344	320	275	220	170	139	133	158	217
3	296	370	414	426	407	357	284	207	146	109	102	135	206	289	350	379	379	348	285	209	147	109	99	130
4	212	318	404	449	458	432	365	269	179	112	70	64	119	220	320	383	411	408	361	276	187	122	81	71
5	121	231	354	436	474	478	438	348	238	147	79	34	43	129	254	355	411	436	423	356	254	164	102	60
6	60	138	271	390	457	486	481	421	313	201	115	47	9	46	163	295	383	431	450	421	333	227	146	88
7	50	73	179	317	416	464	484	465	384	268	166	87	23	6	77	211	330	402	442	450	399	300	204	134
8	80	58	110	232	354	426	460	469	430	334	225	136	64	14	29	128	259	356	412	443	432	363	266	185
9	126	83	86	163	281	375	424	447	440	381	283	188	112	52	28	77	186	298	372	415	430	398	321	236
10	171	123	100	130	217	315	380	413	423	397	327	238	160	99	60	68	137	238	324	379	408	403	357	284
11	215	164	131	131	178	257	328	372	392	386	347	279	206	146	103	89	121	193	274	337	376	389	368	318
12	257	204	167	151	168	216	275	324	353	360	344	302	245	190	146	124	132	172	232	293	339	363	362	336
13	293	245	205	181	178	197	233	272	305	324	324	305	271	229	189	163	156	172	206	251	295	329	343	339
14	318	285	249	218	201	198	208	228	254	278	292	293	281	259	230	203	187	184	195	218	250	285	312	327
15	329	317	293	263	236	215	202	199	208	228	250	267	278	278	266	244	223	206	196	195	209	236	269	300
16	325	337	332	310	280	247	214	187	175	181	201	230	261	285	293	284	263	237	208	186	178	189	217	258
17	302	339	357	352	328	289	241	194	159	144	153	185	231	277	309	318	306	276	235	192	161	151	165	204
18	262	322	365	381	370	336	281	217	161	124	114	135	187	253	309	340	343	321	275	216	163	131	124	149
19	208	286	354	392	400	378	327	255	181	124	91	91	134	212	292	346	369	363	324	257	186	132	103	104
20	149	233	323	385	412	410	373	302	216	143	89	62	82	155	254	333	378	392	372	310	227	154	105	81
21	98	170	275	362	409	424	409	352	264	176	107	58	44	92	195	300	368	402	405	365	283	194	128	85
22	70	111	211	321	393	423	428	397	319	222	140	77	34	42	124	244	340	393	416	406	343	248	165	109
23	72	73	143	261	361	411	429	423	372	278	183	110	53	23	62	172	292	369	408	422	393	311	215	144
24	96	68	94	190	307	385	417	427	407	337	238	152	88	38	31	102	224	329	387	416	417	367	276	189
25	131	90	78	129	237	339	395	415	416	379	296	203	130	74	39	60	152	268	352	396	416	401	336	247
26	175	126	94	101	170	272	352	390	404	394	343	259	178	118	73	58	102	199	298	363	397	407	378	309
27	231	172	131	110	132	203	288	347	374	382	363	308	233	167	119	86	89	143	231	311	363	391	393	358
28	295	231	182	146	133	158	218	282	326	349	354	333	283	222	170	131	109	120	172	244	308	353	379	380
29	349	298	245	200	166	152	169	212	259	296	320	329	313	275	229	186	151	131	141	181	237	293	339	370
30	377	355	314	267	221	180	158	162	189	225	263	297	315	310	284	248	208	169	144	144	172	218	273	329

DECEMBER 2010

Day	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23
1	371	383	371	339	290	232	181	149	140	153	189	241	289	317	322	308	275	226	177	145	136	150	192	259
2	330	380	400	393	360	302	231	169	127	107	116	162	232	296	334	347	337	296	234	174	134	116	125	174
3	257	341	396	418	412	372	299	215	146	97	71	86	152	242	316	358	375	361	307	230	163	119	95	106
4	170	270	360	412	431	422	369	281	190	119	66	41	72	162	266	341	384	399	374	303	217	150	104	78
5	99	184	295	379	423	438	419	350	251	161	91	38	22	78	189	296	365	405	413	372	286	199	137	91
6	70	111	213	323	394	428	437	403	318	217	133	66	16	22	106	227	325	385	418	413	353	260	181	125
7	81	76	140	251	348	402	428	426	374	279	183	107	44	9	44	149	266	349	399	422	397	321	233	164
8	113	80	98	182	288	365	405	422	403	333	237	152	83	31	23	88	200	302	368	406	411	366	284	206
9	148	104	90	134	226	317	373	402	405	366	286	198	125	66	34	58	143	248	329	380	404	387	326	248
10	182	134	104	114	177	263	333	373	390	375	320	241	165	104	63	59	110	199	286	348	384	388	352	286
11	219	165	127	116	148	215	285	336	363	366	334	273	203	142	96	76	99	163	243	310	356	376	362	316
12	256	200	156	131	139	180	238	290	326	342	331	291	235	179	132	103	105	144	205	268	320	352	358	333
13	288	239	193	158	145	162	200	242	280	306	313	295	257	213	170	136	121	137	177	227	275	316	339	337
14	312	275	235	196	168	161	175	201	231	260	282	286	270	241	209	175	149	143	159	190	228	268	304	324
15	322	304	276	241	204	177	167	172	186	210	239	262	270	262	245	219	188	163	155	163	183	214	254	292
16	315	320	309	285	249	209	178	159	153	162	188	224	255	271	274	262	235	200	169	152	150	164	196	243
17	288	318	329	322	296	253	205	165	138	126	137	173	222	264	290	297	284	249	203	162	136	127	141	183
18	243	298	333	346	336	302	248	190	142	108	96	117	171	237	289	318	325	303	253	194	144	112	102	123
19	182	257	319	354	364	348	300	231	165	112	75	69	108	185	264	320	348	349	313	246	175	122	89	81
20	116	196	284	346	375	380	353	288	206	135	80	44	49	114	213	298	350	375	366	312	229	154	101	68
21	67	124	225	317	371	394	392	349	266	177	106	49	16	42	136	249	331	376	395	372	299	206	134	84
22	52	65	148	262	348	391	409	397	334	238	148	78	20	-2	54	172	286	358	398	408	367	277	185	119
23	69	42	78	184	299	371	405	417	390	308	205	120	52	-3	-2	85	215	319	379	413	411	350	252	167
24	106	57	43	106	224	327	383	411	415	368	273	174	96	29	-12	20	131	257	344	395	421	401	324	229
25	154	96	52	60	143	257	341	384	406	396	332	235	147	76	18	1	62	180	290	361	404	418	380	298
26	213	146	91	60	89	179	276	340	374	388	363	291	203	128	67	24	34	111	220	309	368	403	402	353
27	277	204	144	95	79	121	201	276	325	354	359	323	256	184	122	72	48	77	153	242	314	364	390	379
28	330	266	204	148	108	103	143	204	259	301	326	325	291	237	181	130	91	82	114	176	245	306	351	371
29	358	318	265	210	158	124	121	147	188	233	273	298	298	275	237	193	149	117	111	134	178	233	289	333
30	353	345	317	273	221	170	136	124	133	161	203	247	278	288	279	253	215	172	139	126	134	164	212	270
31	318	343	344	325	285	230	176	135	111	108	131	178	231	273	296	298	279	238	190	149	125	120	142	191

Figure 3.10: An example of tide level for year 2010 obtained from DSMM. Note that the high values of the day indicate maximum high tide (units in cm).

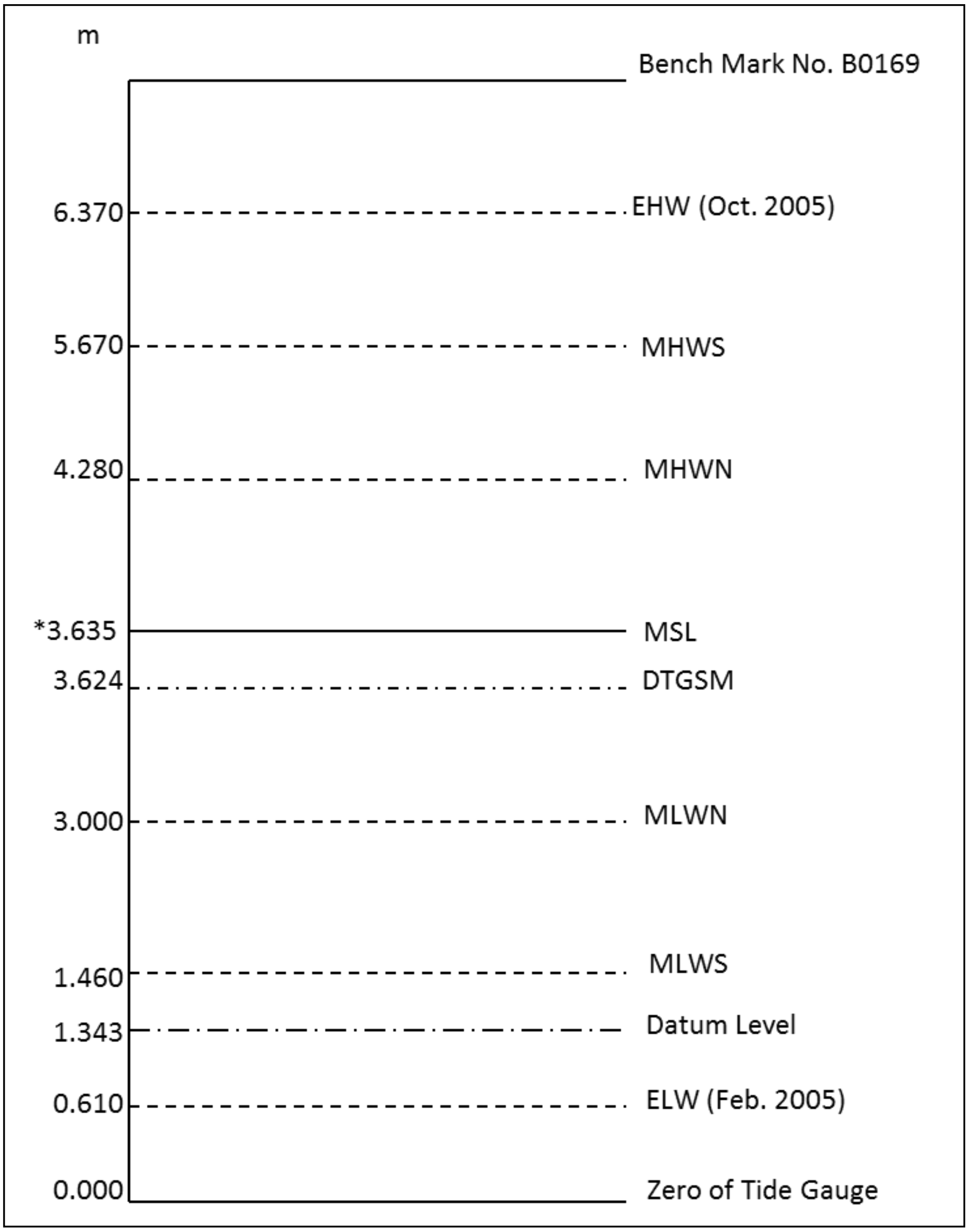


Figure 3.11: Datum-level observation for 22 years (1984 to 2005) for standard national tides of Kelang Station. Note that MSL-Mean Sea Level, EHW-Extreme High Water, ELW-Extreme Low Water, MLWS- Mean Low Water Springs, MLWN-Mean Low Water Neaps, MHWS-Mean High Water Springs, MHWN-Mean High Water Neaps

3.3 Subsurface hydrogeology study

Subsurface hydrogeology study is used to determine the subsurface hydrogeology characteristics of the study area. The subsurface hydrogeology characteristics studies involved identifying subsurface hydrogeology materials, effects of groundwater tables to the seasonal patterns and groundwater quality of the coastal aquifer. The studies will be providing information on the types of material in Quaternary deposits. The types of aquifer in the study area can be identified after the material types of the subsurface hydrogeology have been determined.

The study includes the construction of wells for long-term groundwater quantity and quality monitoring. Changes of groundwater quantity and quality data could be affected by seasonal patterns and tides condition. Therefore, groundwater quantity and quality are correlated with the effect of different seasonal and sea tide conditions in Carey Island. Groundwater chemistry tests are used to determine groundwater ions composition. The cations and anions contents of the groundwater chemistry can be used to identify the source of groundwater salinity.

Subsurface hydrogeology survey consists of the following steps; drilling works, soil sampling, soil properties test, construction of monitoring wells, groundwater table measurement, groundwater sampling and groundwater quality testing. Construction of monitoring wells was done between March and May 2009. Fourteen deep boreholes with the depth of 40 m, 50 m, and 80 m were drilled. The boreholes were drilled on the areas which have not been studied by previous researchers. The boreholes were located facing the Straits of Malacca where seawater intrusion could affect the groundwater aquifer at the coastal area. Boreholes were named MW1, MW2, MW3, MW4, MW5, MW6, MW7, MW8, MW9, MW10, MW11, MW12, MW13 and MW14 (Figure 3.2). The drilling started at MW1 and MW2 with the depth of 80 m. These were done to obtain initial data of the subsurface hydrogeology profile. The initial findings provided the information for the decision on the targeted depth of the other boreholes. MW1, MW2, MW3, MW4, MW5, MW7, MW8, MW9, MW10 and MW14 were located near the severe erosion area whereas MW6, MW11, MW12 and MW13 were located in the area surrounded by reserved mangrove.

3.3.1 Procedures for drilling and material sampling

The drilling works were used rotary wash boring method (Figures 3.12 and 3.13). The technical requirement for drilling works was based on BS 5930 (1999). The materials of the subsurface were sampled during the drilling process. The samples of sandy soil materials were collected using split-spoon barrel. The spring-core catcher was used together with the split-spoon barrel to efficiently trapped sandy materials (Figure 3.14). This was to ensure the core recovery of grained material could be captured at maximum recovery in the split spoon. The sand materials were placed in polyethylene bags for visual examination and laboratory testing.

Undisturbed samples were obtained from soft to firm clays. A thin-walled sampler tube of 57.5 mm I.D. and 610 mm in length was pushed into the clays by the hydraulic pressure of drilling rig. The undisturbed samples obtained were labelled, trimmed and sealed with microcrystalline wax at both ends.

All of the information gathered during the drilling works was described in the field borehole logging. The field borehole logging consists of soil descriptions, groundwater tables and the reduced levels. The drilled holes served as monitoring wells. The monitoring wells facilities are discussed in the sub-section 3.3.5.

Figure 3.12: Drilling by rotary wash boring at MW5

Figure 3.13: Drilling by rotary wash boring at MW14

Figure 3.14: Spring core-catcher embedded in spilt spoon to optimize recovery of sand samples

3.3.2 Procedures for soil tests

The purpose of soil properties test was to identify the subsurface materials characteristics. Soil properties test was conducted after the completion of each borehole. The subsurface materials were collected for visual examination and laboratory test experiments. The soil properties tests were done following BS 1377 (1990). Classification of sand-grain size was based on; fine sand (0.063 to 0.1 mm), medium sand (0.1 to 0.4 mm), and coarse sand (1 to 2 mm). Soil properties tests such as particle-size distribution and moisture content were then conducted. Results of the soil properties tests were used to identify the subsurface hydrogeology materials. An example of the subsurface hydrogeology materials mapping from particle-size distribution (PSD) tests results by using Surfer software is shown in Figure 3.15.

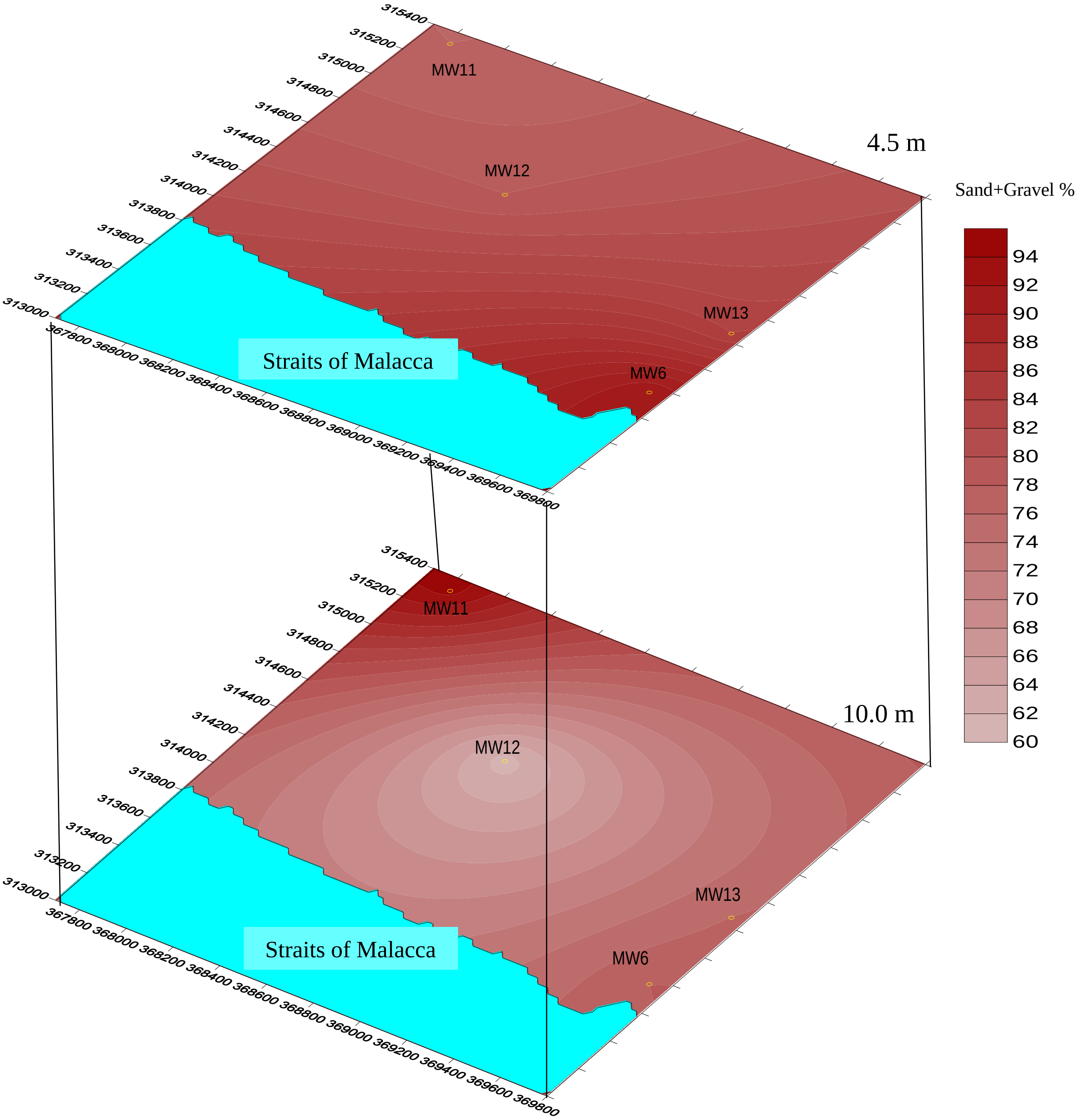


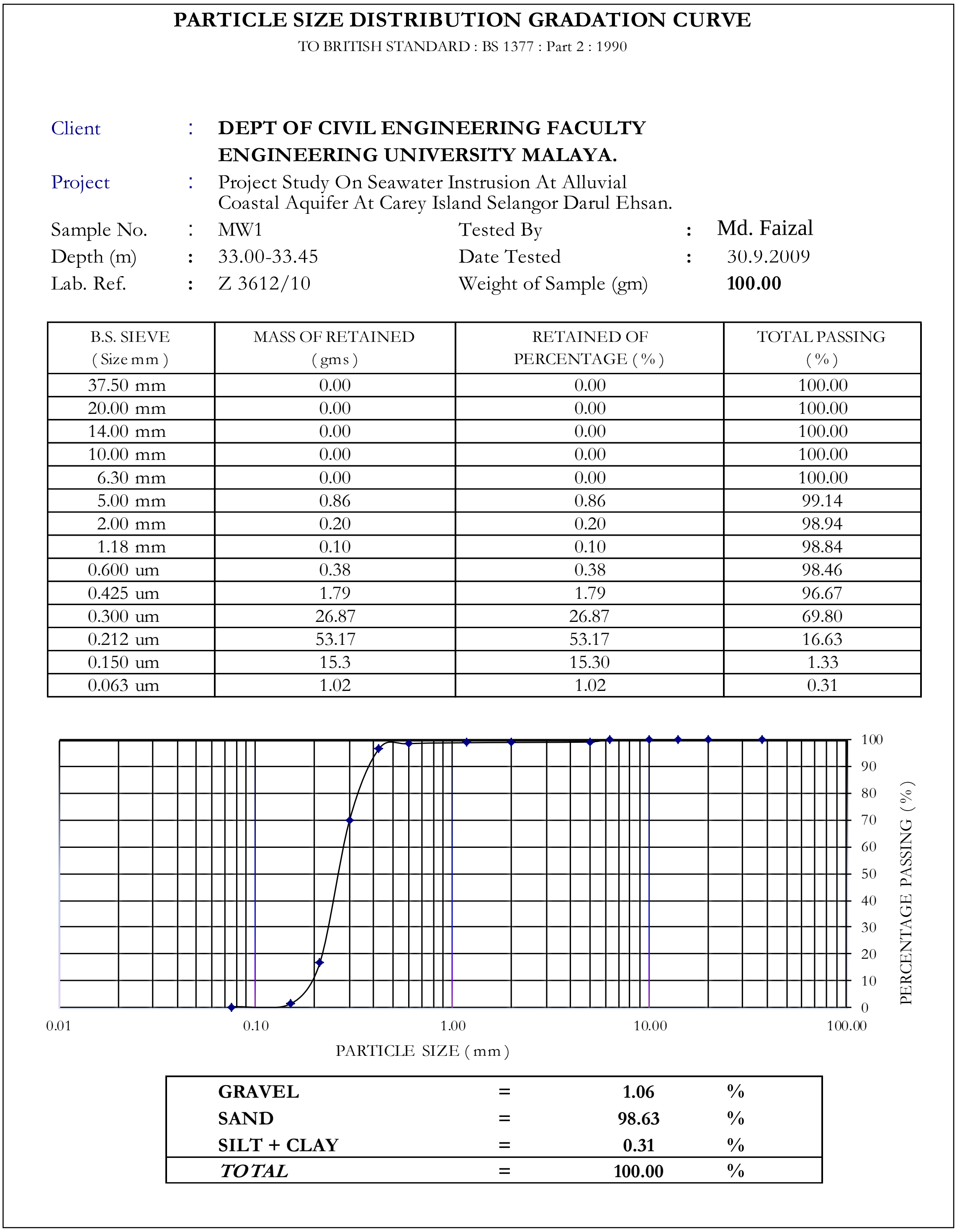
Figure 3.15: An example of subsurface hydrogeology materials mapping from particle size distribution using Surfer software

3.3.3 Procedure for acquiring subsurface hydrogeology

The soil types were identified only through some visual observations, as the drilling and sampling works were being conducted. However, a field logging of the soil strata was done simultaneously in order to estimate the general soil type and subsurface hydrogeology of the study area. Thus, after the results of the physical soil properties tests such as particle size distribution (Figure 3.16) had been obtained, corrections to the field logging of the soil descriptions were done, promptly. Figure 3.17 shows a corrected bore log after the inclusion of laboratory test results. Appendix D and E listed the bore log and particle size distribution results for each boreholes.

3.3.4 Data integration for hydrogeological profiles

Soil description data from the corrected bore log together with the surface elevation from boreholes were used to produce the subsurface hydrogeology profiles by using the AutoCAD software version 2009. This software is able to draft out the subsurface profile on a scaled plan. Figure 3.18 shows an example of the subsurface hydrogeology profiles of the soil investigation works and surface elevation of the study area. A detail of subsurface hydrogeology profile and surface elevation are enclosed in Chapter 4.



PARTICLE SIZE DISTRIBUTION GRADATION CURVE

TO BRITISH STANDARD : BS 1377 : Part 2 : 1990

Client : **DEPT OF CIVIL ENGINEERING FACULTY**
ENGINEERING UNIVERSITY MALAYA.

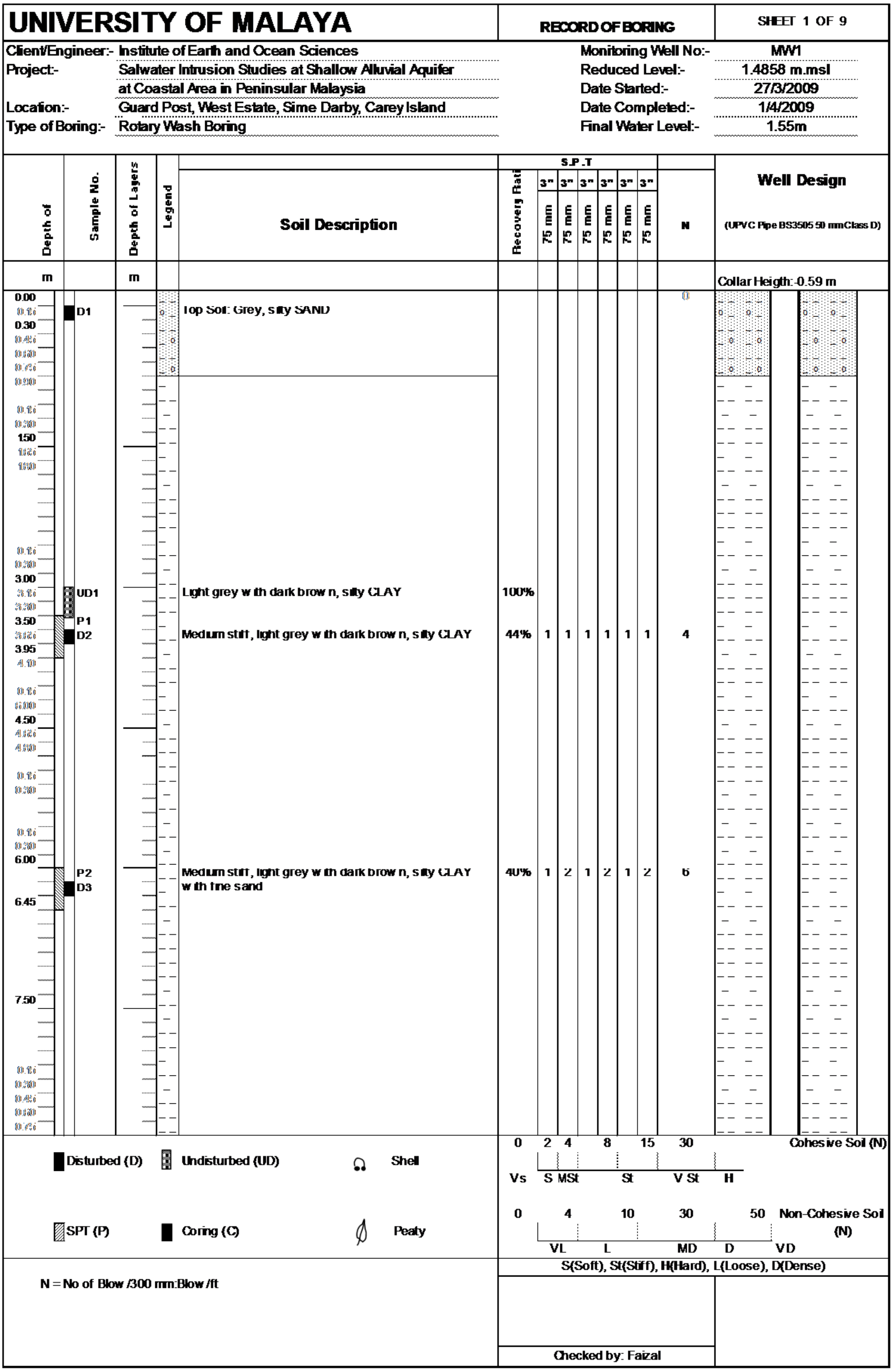
Project : Project Study On Seawater Instrusion At Alluvial
Coastal Aquifer At Carey Island Selangor Darul Ehsan.

Sample No. : MW1 Tested By : Md. Faizal
Depth (m) : 33.00-33.45 Date Tested : 30.9.2009
Lab. Ref. : Z 3612/10 Weight of Sample (gm) **100.00**

B.S. SIEVE (Size mm)	MASS OF RETAINED (gms)	RETAINED OF PERCENTAGE (%)	TOTAL PASSING (%)
37.50 mm	0.00	0.00	100.00
20.00 mm	0.00	0.00	100.00
14.00 mm	0.00	0.00	100.00
10.00 mm	0.00	0.00	100.00
6.30 mm	0.00	0.00	100.00
5.00 mm	0.86	0.86	99.14
2.00 mm	0.20	0.20	98.94
1.18 mm	0.10	0.10	98.84
0.600 um	0.38	0.38	98.46
0.425 um	1.79	1.79	96.67
0.300 um	26.87	26.87	69.80
0.212 um	53.17	53.17	16.63
0.150 um	15.3	15.30	1.33
0.063 um	1.02	1.02	0.31

GRAVEL	=	**1.06**	%
SAND	=	**98.63**	%
SILT + CLAY	=	**0.31**	%
TOTAL	=	**100.00**	%

Figure 3.16: An example of particle size distribution results for MW1



UNIVERSITY OF MALAYA

RECORD OF BORING

SHEET 1 OF 9

Client/Engineer:- Institute of Earth and Ocean Sciences
Project:- Salwater Intrusion Studies at Shallow Alluvial Aquifer at Coastal Area in Peninsular Malaysia
Location:- Guard Post, West Estate, Sime Darby, Carey Island
Type of Boring:- Rotary Wash Boring

Monitoring Well No:- MW1
Reduced Level:- 1.4858 m.msl
Date Started:- 27/3/2009
Date Completed:- 1/4/2009
Final Water Level:- 1.55m

Depth of (m)	Sample No.	Depth of Layers (m)	Legend	Soil Description	Recovery Rati	S.P.T 3" 75 mm	3" 75 mm	3" 75 mm	3" 75 mm	3" 75 mm	3" 75 mm	N	Well Design (UPVC Pipe BS3505 50 mmClass D) Collar Heigth:-0.59 m
0.00													
	D1			Top Soil: Grey, silty SAND									
0.30													
1.50													
3.00													
	UD1			Light grey with dark brown, silty CLAY	100%								
3.50	P1												
	D2			Medium stiff, light grey with dark brown, silty CLAY	44%	1	1	1	1	1	1	4	
3.95													
4.50													
6.00													
	P2			Medium stiff, light grey with dark brown, silty CLAY with fine sand	40%	1	2	1	2	1	2	6	
	D3												
6.45													
7.50													

■ Disturbed (D) ▩ Undisturbed (UD) Shell
▨ SPT (P) ■ Coring (C) Peaty

N = No of Blow /300 mm:Blow /ft

S(Soft), St(Stiff), H(Hard), L(Loose), D(Dense)

Checked by: Faizal

Figure 3.17: An example of corrected bore log results for MW1

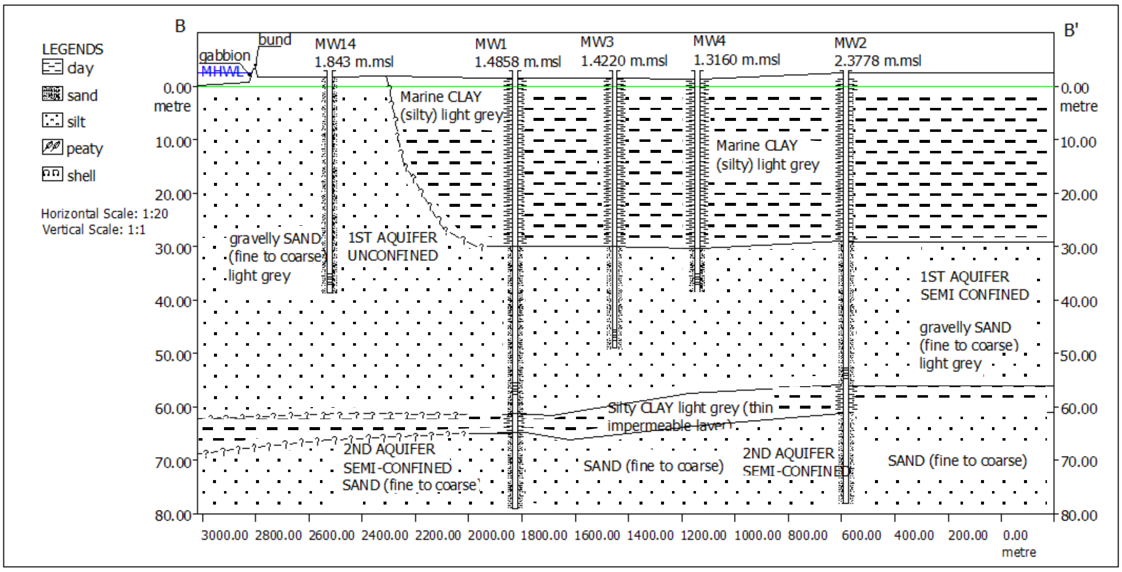


Figure 3.18: An example of subsurface profile at studied area

3.3.5 Groundwater monitoring

Groundwater monitoring involves the monitoring wells construct, groundwater table monitoring, groundwater sampling and groundwater quality test. The purpose of groundwater monitoring is to determine the changes of groundwater quantity and quality due to the seasonal patterns and tides condition.

3.3.5.1 Procedures of monitoring wells construction

The monitoring wells were constructed after the drilling of the boreholes has been completed. The materials used were PVC pipe Class D, gravel pack, bentonite, and cement grout (Figures 3.19, 3.20 and 3.21). Deep monitoring wells were constructed using a single opening screen to ensure good data quality. A single opening screen can prevent varieties of groundwater concentration compared to by using multiple opening screens (Bear and Cheng, 2010b). The schematic diagram for the construction of deep monitoring well is shown in Figure 3.22.

Pre-development of the wells were carried out after the deep monitoring wells had been constructed. The pre-development of wells step was taken to remove sedimentary materials that existed during the drilling process. The drilling works were causing fine materials such as clay and silt to settle in the wells. It could bring about screen aperture clogging with cohesive finer materials. Pre-development of wells were done to remove the trapped sediments using bailer and suction pump equipment (Figures 3.23 and 3.24). Water was bailed out from the wells one month after the construction date. This was to ensure the concentration of the groundwater sample equalled to the natural groundwater before groundwater sampling can be preceded. Pre-development of well procedure ensured good groundwater quantity and quality obtained during groundwater monitoring.

Figure 3.19: Installation of 2m-thick well screen at MW5

Figure 3.20: Installation of PVC pipe at MW12

Figure 3.21: Pouring of sandy gravel of 1.2-2.4mm grain size post-installation of PVC pipe

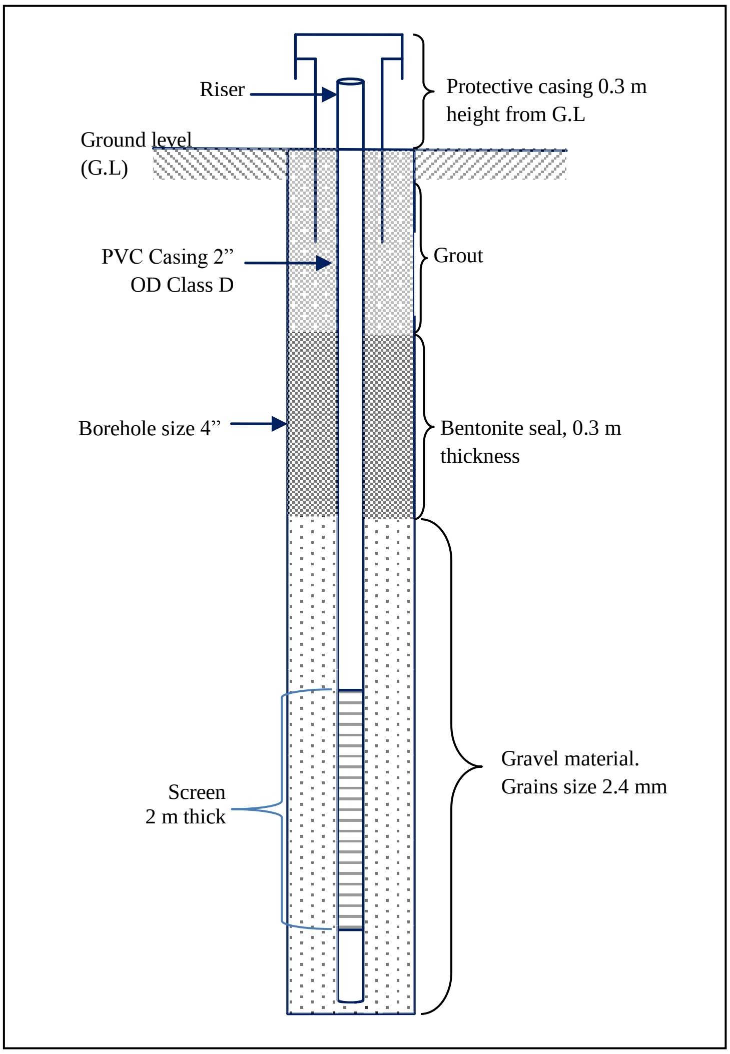


Figure 3.22: Schematic diagram of the monitoring well at the site

Figure 3.23: Suction pump to remove sedimentary materials from the monitoring well

Figure 3.24: Fine soil materials (silt and clay) removed from well

3.3.5.2 Procedures for groundwater sampling and monitoring

Groundwater tables monitoring were done once or twice a week starting from August 2009 until April 2011. Groundwater tables' measurements were taken after 2 hours (maximum) of the daily high tide. It was referring to the hourly height of tides table prediction obtained from DSMM 2009, DSMM 2010 and DSMM 2011.Groundwater tables were measured by using a dip meter instrument in all of the fourteen (14) deep monitoring wells. The groundwater table data collected had been datum corrected. This was to ensure that the groundwater table data referred to the same datum. In this study, the reference datum used was the mean sea level. The conversion of groundwater tables from ground level into mean sea level is shown in Figure 3.25. Equation (3.3) is gives groundwater table at mean sea level.

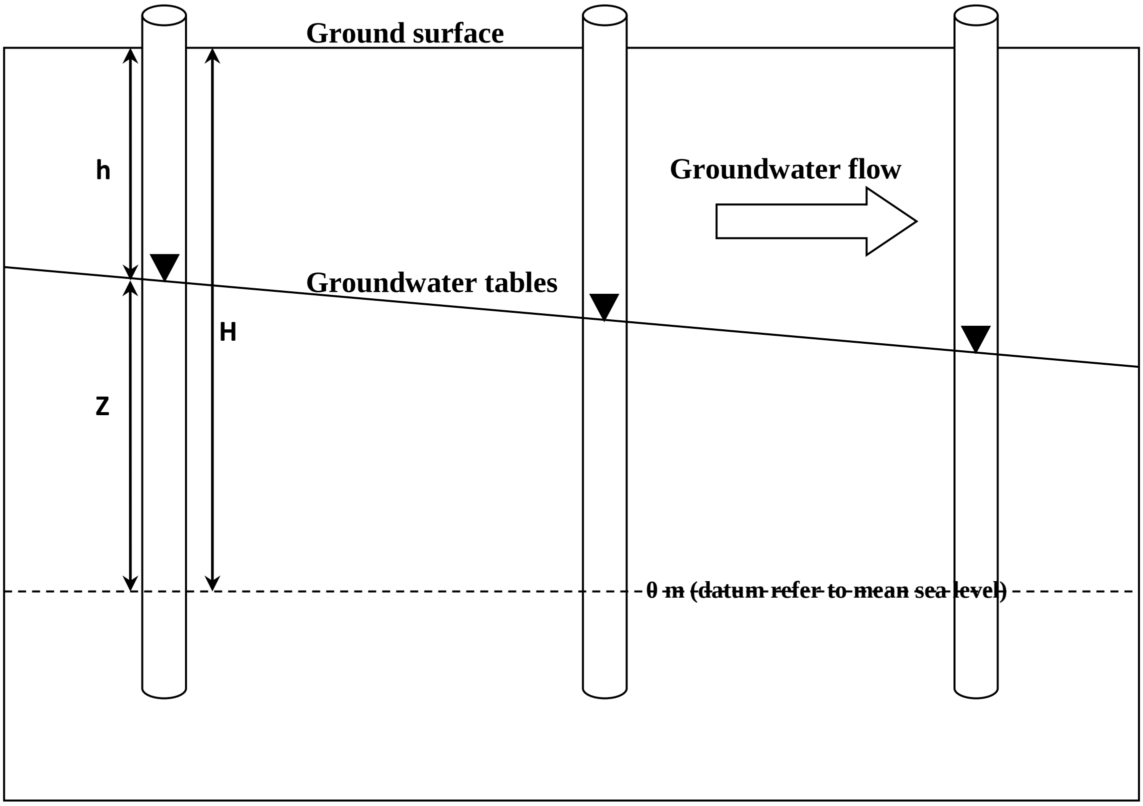


Figure 3.25: Measurements of groundwater table when referring to mean sea level datum

$$Z = H - h \tag{3.3}$$

where;

H is reduced level of well in unit meter and;

h is groundwater table measured from ground level.

Heads in terms of the aquifer groundwater tables, h, varies not only to pressure and elevation, but also as to water density, ρ. Thus, at two points having equal pressures and the same elevation but different water densities, different values of h are recorded (Figure 3.26). For example, the elevation of the groundwater table in piezometer B (Figure 3.26) above point N is $P_N/\rho g$. The head expressed in terms of the saline aquifer is the level in piezometer B above datum and is given by:

$$h = \frac{P_N}{\rho g} + Z_N \tag{3.2}$$

where:

h is head [L]

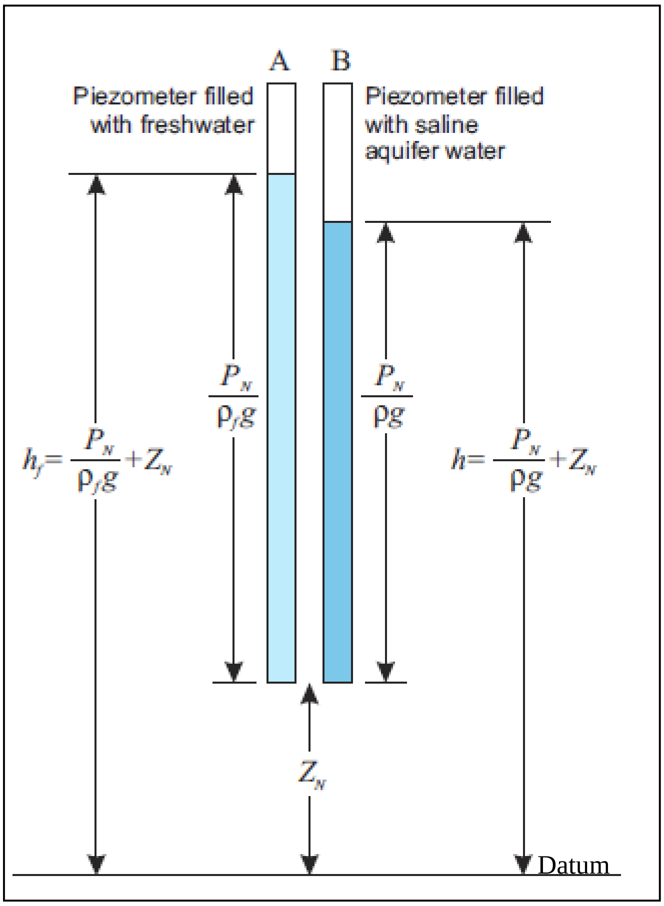
ρ is density of saline groundwater at point N [M/L^3]

P_N is Pressure [MT^2/L^1]

g is acceleration due to gravity [LT^2]

Z_N is elevation [L]

Figure 3.26 shows head for fresh water type is much higher compared to the saline water type. This is due to the fact that saline water density is higher than freshwater. Density of saline water was 1.025 g/cm^3 whereas density of freshwater was only 1.000 g/cm^3. TDS of the saline water is above 10,000 mg/L whereas TDS of freshwater is below 1,000 mg/L (Fetter, 2002). The density of water is highly influenced by the concentration of ions. In general, the head for fresh water will always be higher than the head of saline water at the same datum depth and screen level (Figure 3.26).



EXPLANATION

h_f	Equivalent freshwater head [L]
h	Head [L]
P_N	Pressure [$ML^{-1}T^{-2}$]
ρ_f	Density of freshwater [ML^{-3}]
ρ	Density of saline aquifer water [ML^{-3}]
g	Acceleration due to gravity [LT^{-2}]
Z_N	Elevation [L]

NOTE: L = Length, M – mass, T = time

Figure 3.26: Two piezometers, one filled with freshwater and the other with saline aquifer water, open to the same datum in the aquifer

Times of the maximum high tides from DSMM (2009 and 2010) reports were used to plan for the measurement of groundwater tables and its salinity. Groundwater sampling was carried out after the groundwater table's measurement had been taken. After 2 hours (maximum) of the daily high tide, groundwater samples were collected from all the monitoring wells. This procedure is done to obtain the maximum concentration of salinity. It was assumed that the seawater had effectively intruded the aquifer system after two hours of the high tide. The groundwater samples were collected at the opening screen depths by using bailer (Figure 3.27). The groundwater samples were then dispensed into sample bottle containers for further testing.

Figure 3.27: Groundwater sampling via bailer at MW12

3.3.6 Procedures for groundwater quality tests

Groundwater quality test consists of physical and chemical analyses. The physical tests were conducted immediately after the groundwater sampling had been taken for groundwater salinity degree determination. Chemical tests include the determination of cations and anions contents of the groundwater. The chemical analysis of the groundwater then could be used to determine the dominant ions in the water in order to identify the source of groundwater salinity.

3.3.6.1 Physical test

Physical tests involved conductivity, TDS and salinity measurements. Figure 3.28 shows the equipment used for obtaining groundwater tables and groundwater quality. Specific electrical conductance defines the conductance of a cubic centimetre of water at a standard temperature of 25^{o}C (Todd and Mays, 2005). It is a function of water temperature, types of ions present and their concentrations. Therefore, all measurements of electrical conductivity were adjusted to a temperature of 25^{o}C on the equipment. This was to ensure that the variations in the conductance would only reflect the variations in the concentration and types of the dissolved solids. Measuring the electrical conductance of the groundwater provided a rapid determination on the TDS.

The TDS in a water sample was a measure of all solid materials in a solution whether it was ionized or not. It did not include suspended sediments, colloids or dissolved gases. The TDS content in groundwater was an indication of its salinity. TDS can be used to determine the degree of groundwater salinity. TDS was recorded in milligrams of the dissolved solid in one litre of water (mg/L) meanwhile for salinity the unit is expressed in parts per thousand (ppt). TDS value was estimated using electrical conductivity as expressed in equation (3.4) (Hem, 1989).

$$\text{TDS} = \text{EC} \times \text{A} \qquad (3.4)$$

where

TDS = total dissolved solid (mg/L)

EC = Electrical Conductivity $(\mu S/\text{cm})$at 25^{o}C

A = a value between 0.3 and 1.0. The default value was used is 0.65.

Physical parameters such as conductivity, salinity and TDS were measured using precision equipment EC300 YSI immediately after the sampling. The equipment was calibrated against a standard potassium chloride (KCl) solution of 1.411 mS/cm conductivity (Figure 3.29).

Figure 3.28: The field equipment: (a) bailer, (b) dip meter, and (c) physical parameter tester EC 300 YSI. Direct field measurement is obtained for groundwater table and groundwater quality

Figure 3.29: The EC300 YSI is calibrated against a standard potassium chloride (KCl) solution of 1.411 mS/cm conductivity before direct measurement is made on site

3.3.6.2 Chemical test

Chemical analyses were conducted to measure the major cations and anions. The groundwater samples collected were separated into two containers. As for cations analysis, they were filtered by Whatman 42 filter paper and preserved with 2% nitric acid (HNO_3). While for the anions analysis, they were filtered and preserved by maintaining the temperature at 4^{o}C. The anions analysis was conducted within 48 hours of collection time. The cations analysed consist of Sodium (Na), Calcium (Ca), Magnesium (Mg), Potassium (K) and Iron (Fe)on the Perkin Elmer Inductive Coupled Plasma(ICP) Optical Emission Spectrometer (OES) model Optima 3300RL. Meanwhile, the anions analysed consist of Chloride (Cl^-), Sulphate (SO_4^{2-}), Nitrate (NO_3^-) and Bromide (Br^-) on the Dionex Ion Chromatography (IC) model ICS2000 (Figure 3.30). The analyses were conducted according to the standard methods (APHA, 2005) where 5 point calibrations were used to quantify the analyses with correlation co-efficient of the calibration curve between 0.995 and 0.999.

3.3.7 Classification of groundwater salinity

A classification for the groundwater salinity based on total concentration of dissolved constituents was proposed by Fetter, 2002 (Table 3.1). Four types of groundwater salinity were deduced from the classification; brine water (TDS>100,000 mg/L), saline (10,000<TDS<100,000 mg/L), brackish (1,000<TDS<10,000 mg/L) and fresh (TDS<1,000 mg/L). The classification was used to identify the groundwater salinity in the study area. Subsequently, the classification was correlated with subsurface resistivity data.

Figure 3.30: Dionex Ion Chromatography model ICS2000 used for the anion tests

Table 3.1: Groundwater salinity based on TDS concentration in mg/L (Fetter, 2002)

Water Types	**TDS mg/L**
Fresh water	0-1000
Brackish water	1000-10000
Saline water	10000-100000
Brine water	>100000

3.3.8 Groundwater monitoring data

The example for the physical and well parameters data is given in Table 3.2. The data presented both physical parameters (TDS, conductivity, salinity) and the well parameters (X, Y, well depth, well elevation, groundwater table relative to mean sea level and time measured groundwater tables). An example of the selected data for anion and cation are presented in Figures 3.31 and 3.32.

The groundwater chemistry data obtained from a single screen at a specific depth of the monitoring wells gave a single point data of an aquifer. Meanwhile, for the subsurface resistivity study, it could give more than sixty metres extending depth of information on subsurface resistivity distribution values. The resistivity depth profile extension is depended on the resistivity array method selected (Loke, 2013a). Subsurface resistivity values could be correlated with the groundwater chemistry (Ebraheem et al., 1997, Sherif et al., 2006 and Ebraheem et al., 2012). Therefore, the combination methods of groundwater chemistry and subsurface resistivity were applied at the site.

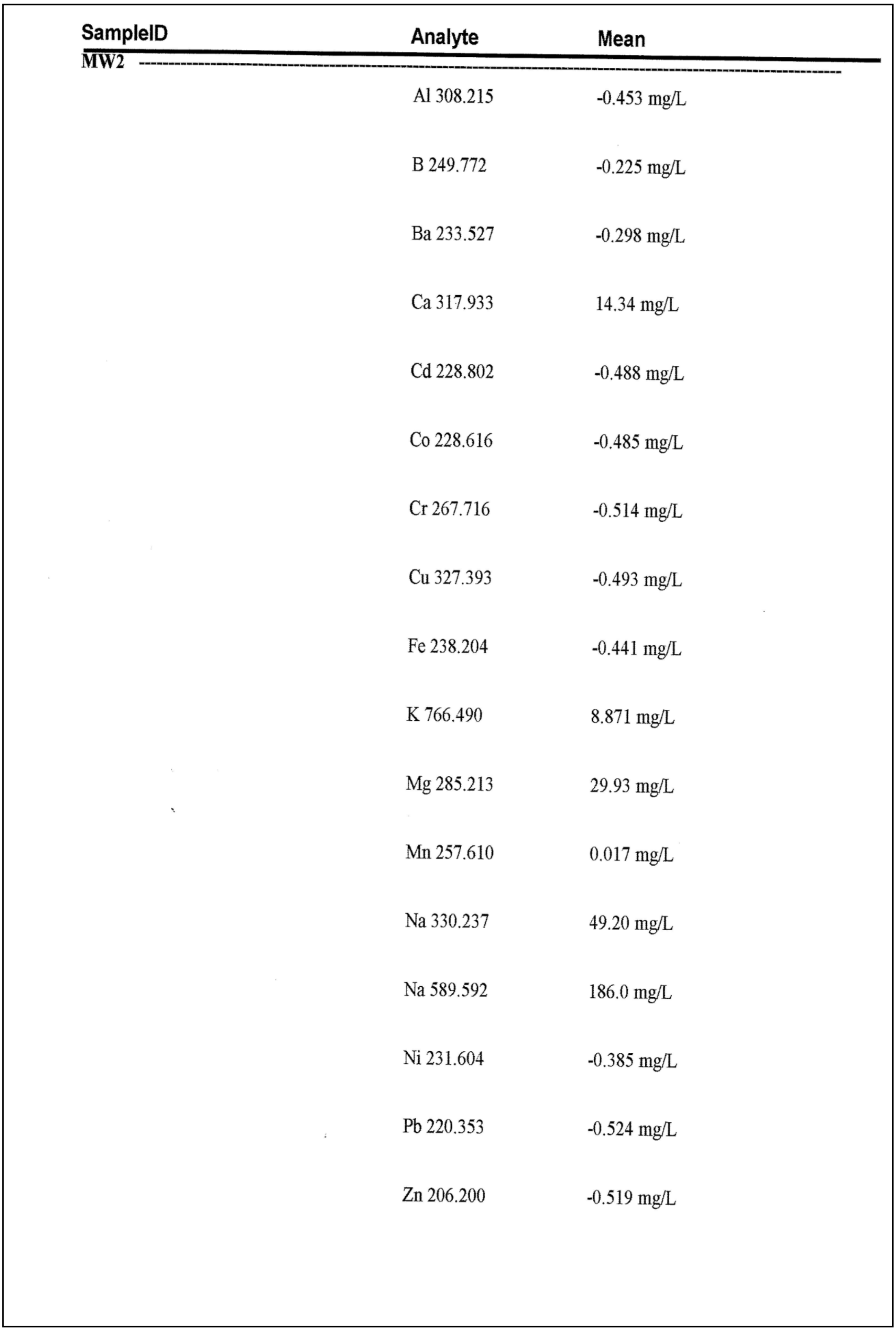
Table 3.2: Physical well and physical in-situ parameter data

Well ID	Location X (m)	Location Y (m)	Well Depth (m)	Screen Depth (m)	Elevation of well (m.msl)	Date	Time (2h after Max.high Tide)	Groundwater table (m.msl)	Conductivity mS/cm	Salinity ppt	TDS g/L
MW1	371705	313677	80	66-68	1.486	3/12/09	8.10AM	0.825	16.16	8.7	9.74
MW2	371693	314921	80	66-68	2.378	3/12/09	10.19AM	1.384	8.4	4.3	5.1
MW3	371684	314052	50	46-48	1.422	3/12/09	8.20AM	0.510	34.54	19.8	20.79
MW4	371694	314365	40	34-36	1.316	3/12/09	8.40AM	0.336	24.54	13.7	14.84
MW5	370807	314189	40	34-36	1.326	3/12/09	8.49AM	0.240	33.78	19.5	20.48
MW6	369765	313734	40	34-36	1.474	3/12/09	9.10AM	0.817	16.28	8.8	9.86
MW7	370789	313277	40	34-36	1.553	3/12/09	8.55AM	0.434	34.69	20	20.89
MW8	372311	314790	50	46-48	1.491	3/12/09	10.37AM	0.498	22.53	12.5	13.62
MW9	372312	315298	40	34-36	1.607	3/12/09	10.52AM	0.588	17.36	9.4	10.52
MW10	370886	315292	40	34-36	1.391	3/12/09	9.54AM	0.197	37.37	21.7	22.56
MW11	367728	315308	40	34-36	1.862	3/12/09	9.42AM	0.643	26.37	14.9	15.98
MW12	368558	314542	40	34-36	1.581	3/12/09	9.30AM	0.846	10.21	5.3	6.19
MW13	369767	314211	40	34-36	1.832	3/12/09	9.22AM	0.742	13.76	7.3	8.29
MW14	372290	312958	40	34-36	1.843	3/12/09	8.00AM	0.648	24.8	13.8	14.92

Sample Name :	MW 2	Inj. Vol. :	20.0
Sample Type :	Groundwater	Dilution Factor	1000
Program :	AS17C_25 uL	Operator :	N.A
Inj. Date / Time :	01.06.10 13:18	Run Time :	14.00

No.	**Time (min)**	**Peak Name**	**Type**	**Area uS*min**	**Height (uS)**	**Amount ppm**
1	1.77	Fluoride	BMB	0.050	0.626	46.3459
2	3.71	Chloride	BMB	1.414	12.767	5872.6920
3	4.35	Nitrite	BMB	0.007	0.034	42.3472
4	9.67	Sulfate	BMB	0.007	0.095	45.0767
TOTAL :				1.48	13.52	6006.46

Figure 3.31: Anion data from Ion Chromatography (IC) equipment



SampleID	Analyte	Mean
MW2		
	Al 308.215	-0.453 mg/L
	B 249.772	-0.225 mg/L
	Ba 233.527	-0.298 mg/L
	Ca 317.933	14.34 mg/L
	Cd 228.802	-0.488 mg/L
	Co 228.616	-0.485 mg/L
	Cr 267.716	-0.514 mg/L
	Cu 327.393	-0.493 mg/L
	Fe 238.204	-0.441 mg/L
	K 766.490	8.871 mg/L
	Mg 285.213	29.93 mg/L
	Mn 257.610	0.017 mg/L
	Na 330.237	49.20 mg/L
	Na 589.592	186.0 mg/L
	Ni 231.604	-0.385 mg/L
	Pb 220.353	-0.524 mg/L
	Zn 206.200	-0.519 mg/L

Figure 3.32: Cation data from Inductive Couple Plasma (ICP) equipment

3.4 Subsurface Resistivity Study

Subsurface resistivity study was used to determine the resistivity distribution values for different types of subsurface hydrogeology materials in the study area. Correlation between the groundwater chemistry and subsurface resistivity data could be used to derive the groundwater salinity degree (fresh, brackish and saline). Subsequently, the groundwater salinity map of different land use in the study area can be constructed. This correlation was also used in the time-lapse resistivity tomography measurement (TLERT). It was used to observe the salinity changes in the aquifer system during tide event.

Subsurface resistivity measurements were taken four times, in August 2009, November 2009, February 2010 and December 2010. The resistivity survey was conducted by using an ABEM Terrameter SAS4000 combined with an ES10-64 electrode selector (Figures 3.33 and 3.34). The strategy for conducting the resistivity surveys in assessing the environmental impact caused by seawater intrusion is planned into two phases. The first phase involved the finding of correlation between subsurface resistivity and geochemical data from the monitoring wells. Groundwater samples were collected using a bailer as the resistivity measurement was being conducted. Physical parameters, such as conductivity, salinity and TDS were measured using precision equipment EC300 YSI immediately after the sampling. In August 2009, November 2009, and February 2010, subsurface resistivity was measured at a large-scale area; had resulted eight resistivity-image profiles and were used for earth resistivity and geochemistry correlation. The second phase involved an extensive resistivity survey in the area of severe erosion while it was still intact with the mangrove trees.

In the second phase, the subsurface resistivity study was conducted only in unconfined aquifer. The justification for conducting the resistivity survey in an unconfined aquifer will be elaborated in the subtitle 3.6.

About seventeen resistivity lines in unconfined aquifer only were carried out in December 2010. The sixteen resistivity lines (labelled as L1-L1’ to L16-L16’) were conducted as shown in Figure 3.35. Resistivity survey lines L1-L1’ to L14-L14’ were surrounded by mangrove on the west whereas survey line L14-L14’ to L16-L16’ were located in severe coastal erosion area.

Figure 3.33: Terrameter equipment's and accessories; a-ABEM Terrameter SAS4000, b-battery, c-ES10-64 electrode selector, d-cable reel, e-cable joint, f-wyre clips and g-steels electrodes


[redacted]

Figure 3.34: Resistivity measurement conducted at MW11

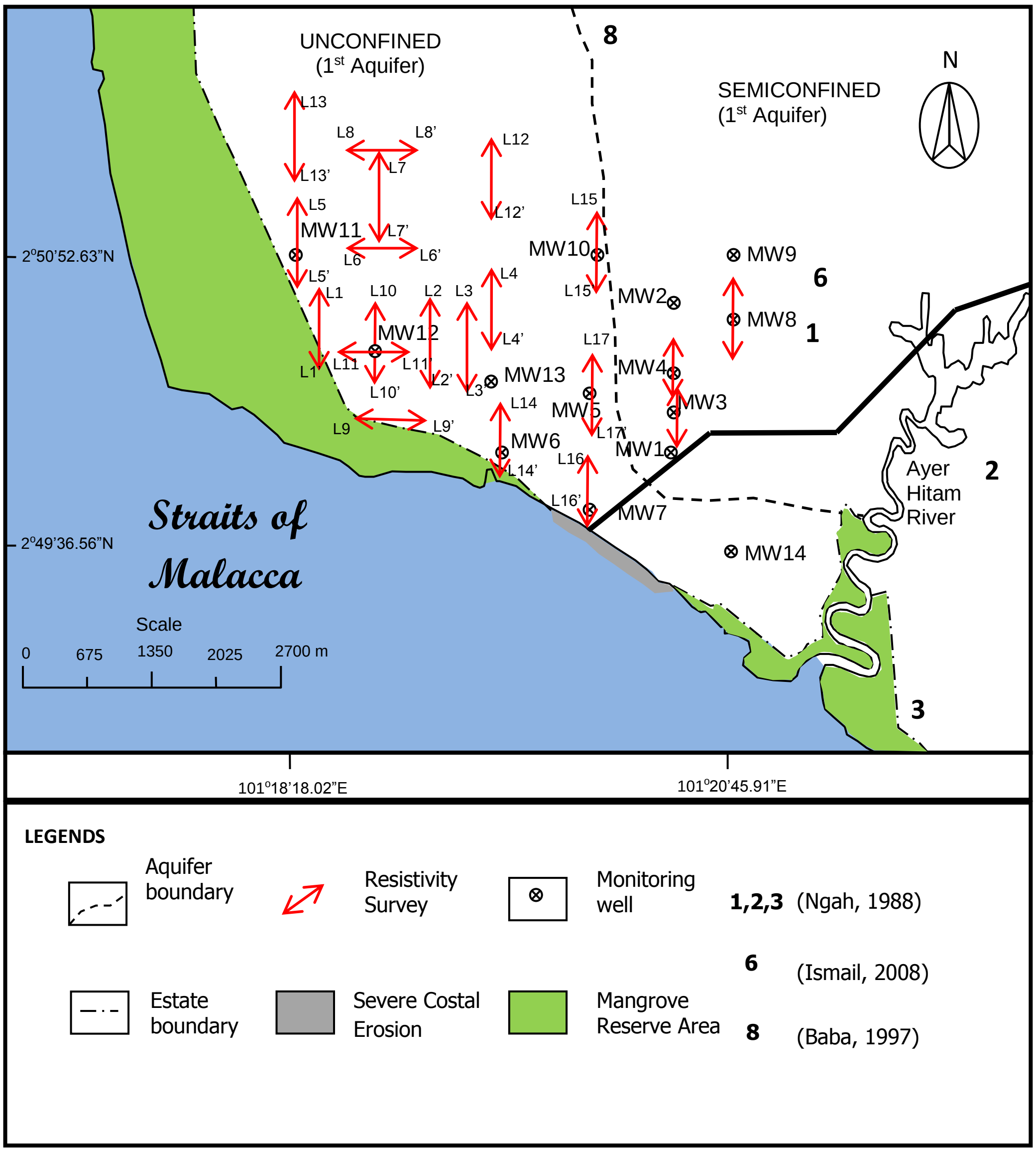


Figure 3.35: Locations of resistivity measurement and monitoring wells in the study area. Some of resistivity measurement crossed over the monitoring wells.

3.4.1 Data acquisition procedure

Identifying the site condition is important in order to obtain good resistivity data during subsurface resistivity measurement. Things to avoid while conducting resistivity measurements are vehicle disturbances, long space and external noise source. After the location for resistivity measurements was confirmed, the coordinates were determined by using GPS.

The Wenner array was chosen for the resistivity measurements because it gave a dense near-surface cover of resistivity data. Also, it produced horizontal structures, good vertical resolution and clear images of groundwater, saltwater intrusion, and sand-clay boundaries (Hamzah et al., 2006). The Wenner array provided the basic configuration, with electrodes of 1a constant spacing. By using the Wenner array, current was injected into, and received from, the ground, through two outer electrodes, C1 and C2. The potential difference was measured between two inner electrodes, P1 and P2. The configuration was kept constant and moved along the profile until all possible measurements had been made with 1a electrode spacing. Measurements were then made by using electrode combinations that give basic separations of 2a, 3a, 4a, etc. (Figure 3.36) so that information about deeper structures beneath the profiles could be obtained (Loke, 2013a).

The ABEM Terrameter SAS 4000 combined with ES 10-64 electrode selector had specific field arrangement when used with four cables set up with 61 takeout of electrodes as shown in Figure 3.37. A number of 61 electrode rods were suitably spaced at 5 and 10 m intervals. The data acquisition for this set up was using Wenner-L and Wenner-S configurations. The two end cable sections (1st and 4th) were placed with electrodes spaced at 10 m intervals while the two middle cable sections (2nd and 3rd) were placed with electrodes at 5 m intervals.

A battery-powered resistivity meter, together with an electrode selector, was installed at the mid-section of the cable. The battery was supplying current to each of the electrodes via the connection at the cable mid-point. A 400 m resistivity measurements line was laid into the ground surface for all resistivity measurements on the study site. Figure 3.38 illustrates the subsurface resistivity distribution for four wheel cables using ABEM Terrameter SAS4000.

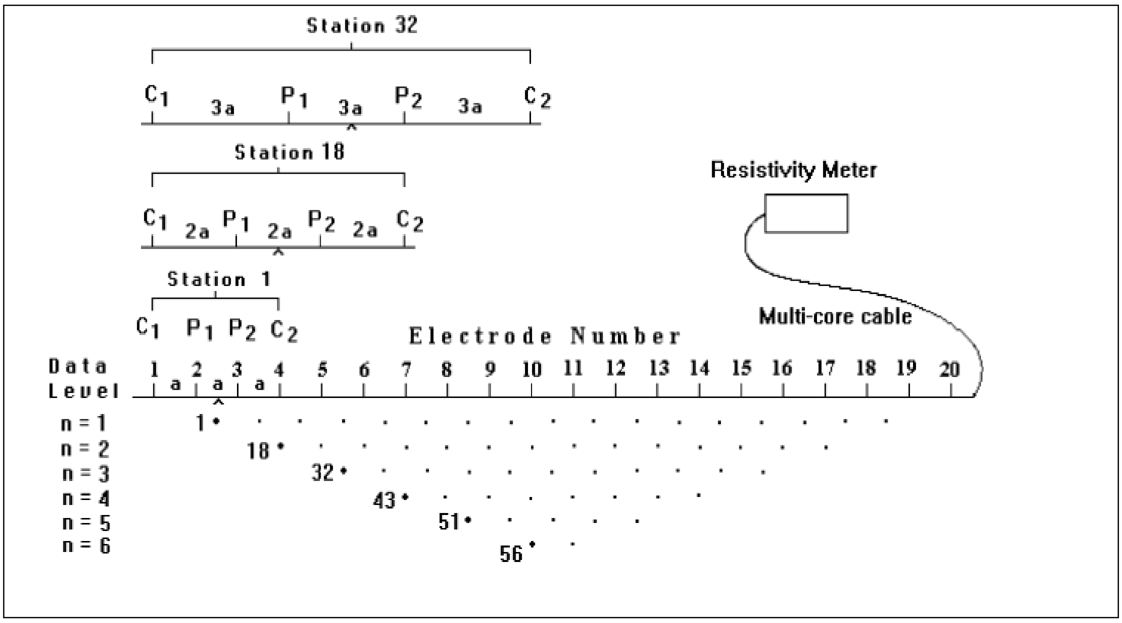


Figure 3.36: The arrangement of electrodes for a 2-D electrical measurements and the sequence of measurements used to build up a pseudo-section (Loke, 2013a)

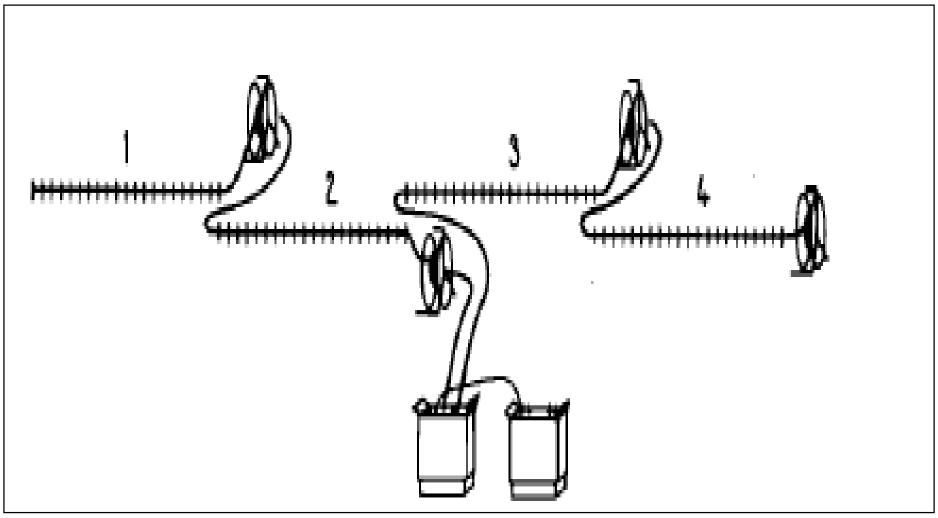


Figure 3.37: Equipment set up and cable arrangement for four wheel cables (ABEM, 2010)

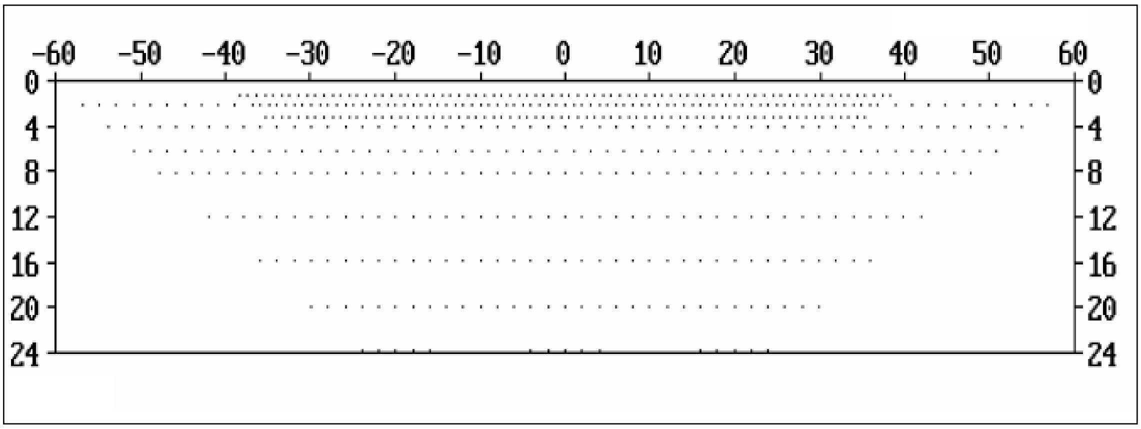


Figure 3.38: Examples of subsurface resistivity distribution using Wenner-L and Wenner-S configuration with takeout spacing 1 meter (ABEM, 2010)

From earlier attempts at measuring subsurface resistivity, nearly half of the data obtained comprised of negative readings, resulting in inaccurate apparent resistivity data. The negative readings were due to poor grounding of the electrical current injected. Extreme tropical-rainforest climate exhibits high temperatures that can reach up to 36^{o}C in the afternoon, which also causes poor grounding especially to soil containing unsaturated sand materials. As for good apparent-resistivity data, a few steps were taken for good ground contact and injection current, including hammering the electrodes down to more than 0.3 m deep, maintaining sufficient moisture for ground contact, and by using more powerful battery (current injection more than 60Ah). A formulated solution (bentonite polymer solution mixed with salt solution) was used in order to maintain sufficient moisture and provide good ground contact. The solution composition consisted about 1 litre bentonite polymer, 100 gram of salt and 10 litre of water. The function of bentonite polymer was to maintain sufficient moisture for ground contact. Meanwhile, the function of salt solution was to provide good dispersion of injection current.

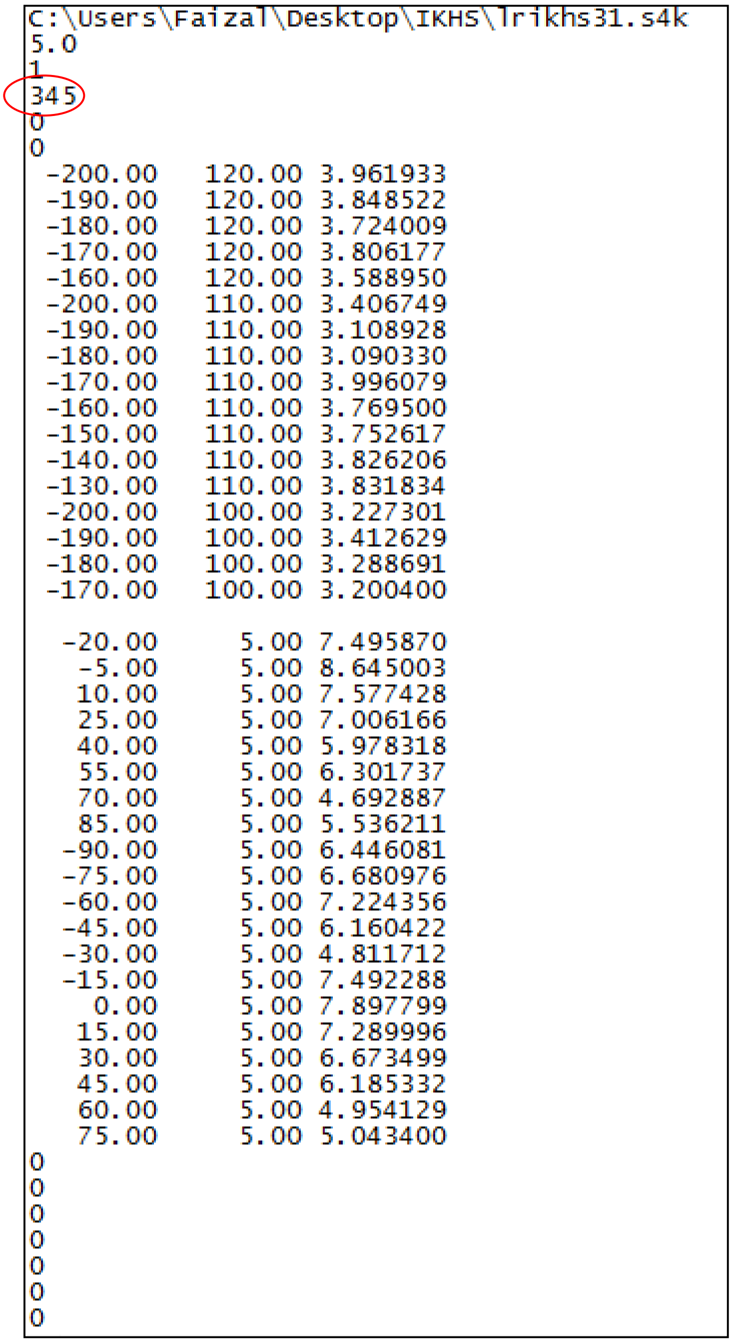
3.4.2 Data collection and processing

The raw data from Terrameter were saved in a binary format with the file extension .S4K. The raw data was transferred and converted into a standardised format readable by Res2Dinv. The extension file .S4K data obtained from Terrameter was converted into the extension file of DAT data by using the latest Terrameter SAS4000/SAS1000 utility programme version 3.16.018.

Figure 3.39 shows the data processed in extension of DAT file format in Wenner configuration. The format data could be divided into three sections; section one was header, section two was data body and section three was the end. The data header showed the path location of the raw data file before conversion. The second row was the number of electrode spacing (5.0) in meter. The third row was the Wenner code (1) and the fourth row designated the total number of data samples obtained (345).

The first column in the data body (Figure 3.39) indicated the starting point of the C1 position, the second column was the electrode spacing, and the third column gave the apparent resistivity.

The whole measured resistivity data were converted into a DAT file format and interpreted using Res2Dinv (Loke, 2013a) software provided together with the Terrameter instrument.



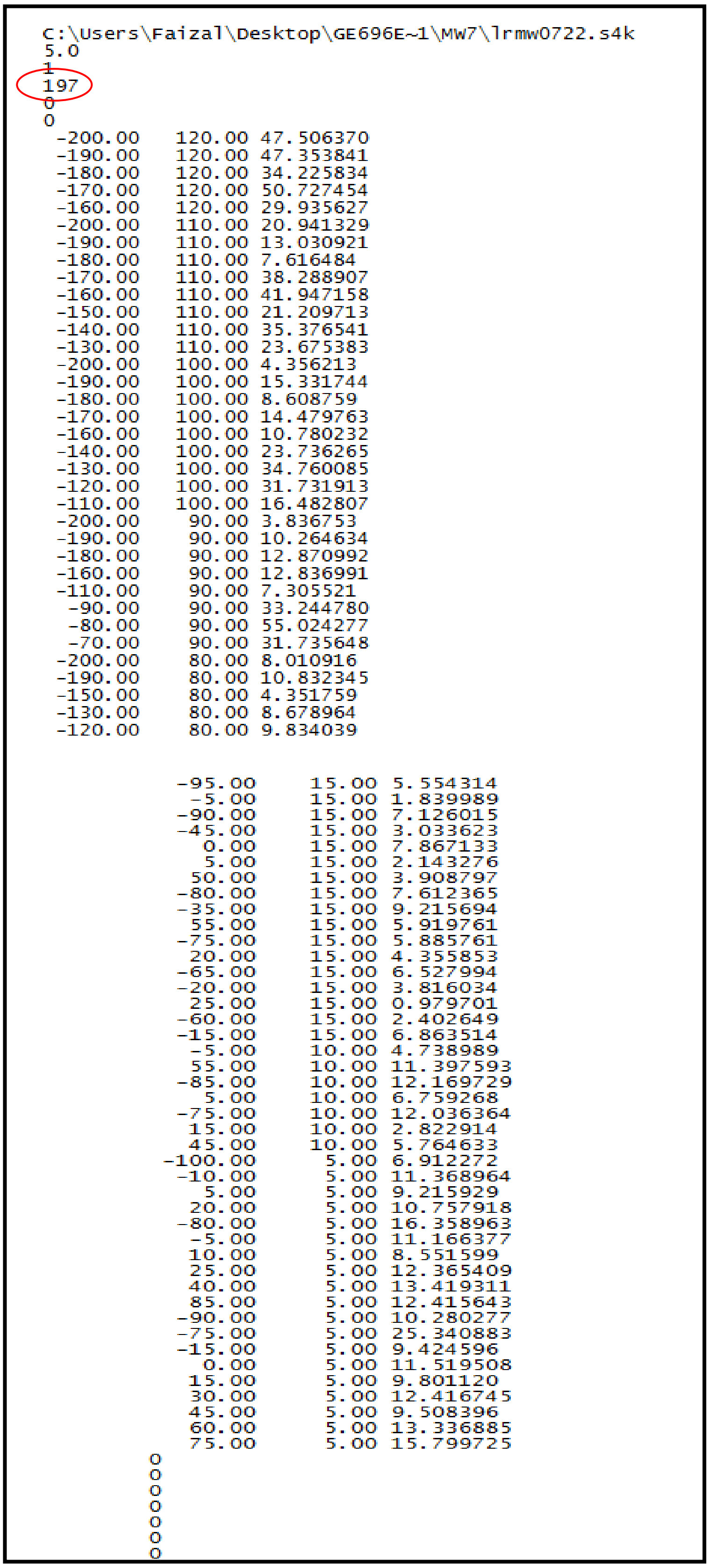
```
C:\Users\Faizal\Desktop\IKHS\Irikhs31.s4k
5.0
1
345
0
0
 -200.00   120.00 3.961933
 -190.00   120.00 3.848522
 -180.00   120.00 3.724009
 -170.00   120.00 3.806177
 -160.00   120.00 3.588950
 -200.00   110.00 3.406749
 -190.00   110.00 3.108928
 -180.00   110.00 3.090330
 -170.00   110.00 3.996079
 -160.00   110.00 3.769500
 -150.00   110.00 3.752617
 -140.00   110.00 3.826206
 -130.00   110.00 3.831834
 -200.00   100.00 3.227301
 -190.00   100.00 3.412629
 -180.00   100.00 3.288691
 -170.00   100.00 3.200400

  -20.00     5.00 7.495870
   -5.00     5.00 8.645003
   10.00     5.00 7.577428
   25.00     5.00 7.006166
   40.00     5.00 5.978318
   55.00     5.00 6.301737
   70.00     5.00 4.692887
   85.00     5.00 5.536211
  -90.00     5.00 6.446081
  -75.00     5.00 6.680976
  -60.00     5.00 7.224356
  -45.00     5.00 6.160422
  -30.00     5.00 4.811712
  -15.00     5.00 7.492288
    0.00     5.00 7.897799
   15.00     5.00 7.289996
   30.00     5.00 6.673499
   45.00     5.00 6.185332
   60.00     5.00 4.954129
   75.00     5.00 5.043400
0
0
0
0
0
0
0
```

Figure 3.39: Apparent resistivity data collected from site resistivity measurement

3.4.3 Pre-inversion methods to remove bad data points

According to Loke (2013a), to obtain a good inversion model, the data on the file must be of equally good quality. Bad data points can be divided into two categories, namely “systematic” and “random” noise. Systematic noise is related to failure during the resistivity measurement at the field. Some examples of the systematic noise include insufficient current injected into poor ground contact, breaks in cable, forgetting to attach the clip to the electrode and connecting the cables in the wrong direction. Random noise is related to telluric currents that are affecting all the readings. The noise can cause the readings to be lower or higher than the equivalent noise-free readings. The noise is usually more common with arrays such as the Dipole-dipole and Pole-dipole that have very large geometric factors, compared to other arrays as the Wenner have small geometric factor (Loke, 2013b). In this study, during the field procedure, bad data points from background noise were avoided by taking few additional steps to provide good ground contact and injection current and by selecting appropriate array before the resistivity measurement. Among the steps to provide good ground contact and injection current had been discussed in section 3.4.1. Figure 3.40 presents an example of incomplete apparent resistivity data. A total of 345 data were supposedly measured from the resistivity line crossing over MW7 area, but only 197 resistivity data were obtained. The incomplete resistivity data was due to negative readings that were caused by poor grounding of the electrical current injected to the underground. Figure 3.41 showed an incomplete resistivity data in a profile form. Figures 3.42 and 3.43 showed a completed data of apparent resistivity data (345 data) obtained from Wenner array measurement after a few steps taken in providing good ground contact and injection current. The bad data points showed up as spots with unusually low or high values as shown in Figures 3.41 and 3.43. The bad data points can be removed using Res2Dinv program utilities. Figure 3.44 shows a complete apparent resistivity data profile where bad data points had been removed for the profile of MW7.



```
C:\Users\Faizal\Desktop\GE696E~1\MW7\lrmw0722.s4k
5.0
1
197
0
0
  -200.00    120.00 47.506370
  -190.00    120.00 47.353841
  -180.00    120.00 34.225834
  -170.00    120.00 50.727454
  -160.00    120.00 29.935627
  -200.00    110.00 20.941329
  -190.00    110.00 13.030921
  -180.00    110.00 7.616484
  -170.00    110.00 38.288907
  -160.00    110.00 41.947158
  -150.00    110.00 21.209713
  -140.00    110.00 35.376541
  -130.00    110.00 23.675383
  -200.00    100.00 4.356213
  -190.00    100.00 15.331744
  -180.00    100.00 8.608759
  -170.00    100.00 14.479763
  -160.00    100.00 10.780232
  -140.00    100.00 23.736265
  -130.00    100.00 34.760085
  -120.00    100.00 31.731913
  -110.00    100.00 16.482807
  -200.00     90.00 3.836753
  -190.00     90.00 10.264634
  -180.00     90.00 12.870992
  -160.00     90.00 12.836991
  -110.00     90.00 7.305521
   -90.00     90.00 33.244780
   -80.00     90.00 55.024277
   -70.00     90.00 31.735648
  -200.00     80.00 8.010916
  -190.00     80.00 10.832345
  -150.00     80.00 4.351759
  -130.00     80.00 8.678964
  -120.00     80.00 9.834039


                -95.00     15.00 5.554314
                 -5.00     15.00 1.839989
                -90.00     15.00 7.126015
                -45.00     15.00 3.033623
                  0.00     15.00 7.867133
                  5.00     15.00 2.143276
                 50.00     15.00 3.908797
                -80.00     15.00 7.612365
                -35.00     15.00 9.215694
                 55.00     15.00 5.919761
                -75.00     15.00 5.885761
                 20.00     15.00 4.355853
                -65.00     15.00 6.527994
                -20.00     15.00 3.816034
                 25.00     15.00 0.979701
                -60.00     15.00 2.402649
                -15.00     15.00 6.863514
                 -5.00     10.00 4.738989
                 55.00     10.00 11.397593
                -85.00     10.00 12.169729
                  5.00     10.00 6.759268
                -75.00     10.00 12.036364
                 15.00     10.00 2.822914
                 45.00     10.00 5.764633
               -100.00      5.00 6.912272
                -10.00      5.00 11.368964
                  5.00      5.00 9.215929
                 20.00      5.00 10.757918
                -80.00      5.00 16.358963
                 -5.00      5.00 11.166377
                 10.00      5.00 8.551599
                 25.00      5.00 12.365409
                 40.00      5.00 13.419311
                 85.00      5.00 12.415643
                -90.00      5.00 10.280277
                -75.00      5.00 25.340883
                -15.00      5.00 9.424596
                  0.00      5.00 11.519508
                 15.00      5.00 9.801120
                 30.00      5.00 12.416745
                 45.00      5.00 9.508396
                 60.00      5.00 13.336885
                 75.00      5.00 15.799725
              0
              0
              0
              0
              0
              0
              0
```

Figure 3.40: An example of apparent resistivity data due to poor grounding at MW7

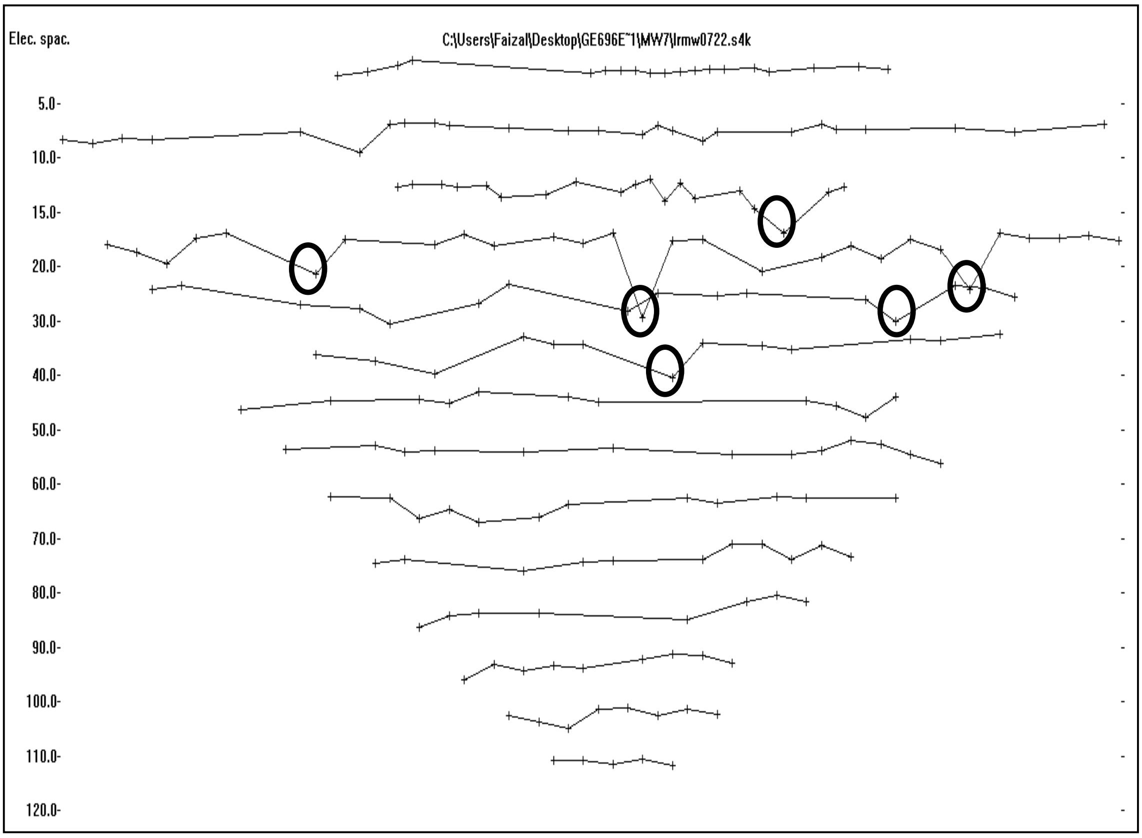
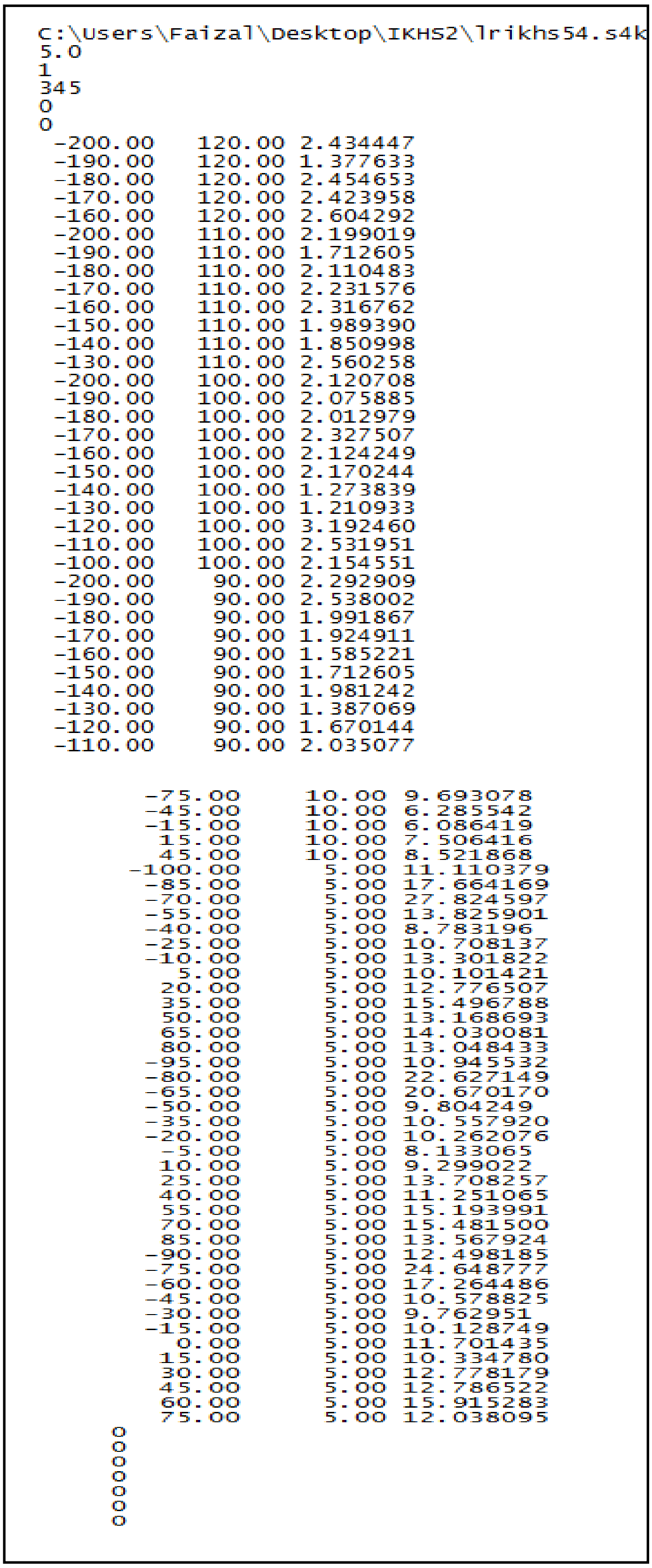


Figure 3.41: An example of apparent resistivity data in profile form. Note the circles show the bad data points



```
C:\Users\Faizal\Desktop\IKHS2\lrikhs54.s4k
5.0
1
345
0
0
 -200.00   120.00 2.434447
 -190.00   120.00 1.377633
 -180.00   120.00 2.454653
 -170.00   120.00 2.423958
 -160.00   120.00 2.604292
 -200.00   110.00 2.199019
 -190.00   110.00 1.712605
 -180.00   110.00 2.110483
 -170.00   110.00 2.231576
 -160.00   110.00 2.316762
 -150.00   110.00 1.989390
 -140.00   110.00 1.850998
 -130.00   110.00 2.560258
 -200.00   100.00 2.120708
 -190.00   100.00 2.075885
 -180.00   100.00 2.012979
 -170.00   100.00 2.327507
 -160.00   100.00 2.124249
 -150.00   100.00 2.170244
 -140.00   100.00 1.273839
 -130.00   100.00 1.210933
 -120.00   100.00 3.192460
 -110.00   100.00 2.531951
 -100.00   100.00 2.154551
 -200.00    90.00 2.292909
 -190.00    90.00 2.538002
 -180.00    90.00 1.991867
 -170.00    90.00 1.924911
 -160.00    90.00 1.585221
 -150.00    90.00 1.712605
 -140.00    90.00 1.981242
 -130.00    90.00 1.387069
 -120.00    90.00 1.670144
 -110.00    90.00 2.035077

        -75.00     10.00 9.693078
        -45.00     10.00 6.285542
        -15.00     10.00 6.086419
         15.00     10.00 7.506416
         45.00     10.00 8.521868
       -100.00      5.00 11.110379
        -85.00      5.00 17.664169
        -70.00      5.00 27.824597
        -55.00      5.00 13.825901
        -40.00      5.00 8.783196
        -25.00      5.00 10.708137
        -10.00      5.00 13.301822
          5.00      5.00 10.101421
         20.00      5.00 12.776507
         35.00      5.00 15.496788
         50.00      5.00 13.168693
         65.00      5.00 14.030081
         80.00      5.00 13.048433
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        -80.00      5.00 22.627149
        -65.00      5.00 20.670170
        -50.00      5.00 9.804249
        -35.00      5.00 10.557920
        -20.00      5.00 10.262076
         -5.00      5.00 8.133065
         10.00      5.00 9.299022
         25.00      5.00 13.708257
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         70.00      5.00 15.481500
         85.00      5.00 13.567924
        -90.00      5.00 12.498185
        -75.00      5.00 24.648777
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        -45.00      5.00 10.578825
        -30.00      5.00 9.762951
        -15.00      5.00 10.128749
          0.00      5.00 11.701435
         15.00      5.00 10.334780
         30.00      5.00 12.778179
         45.00      5.00 12.786522
         60.00      5.00 15.915283
         75.00      5.00 12.038095
     0
     0
     0
     0
     0
     0
     0
```

Figure 3.42: An example of apparent resistivity data after provided good grounding for MW7

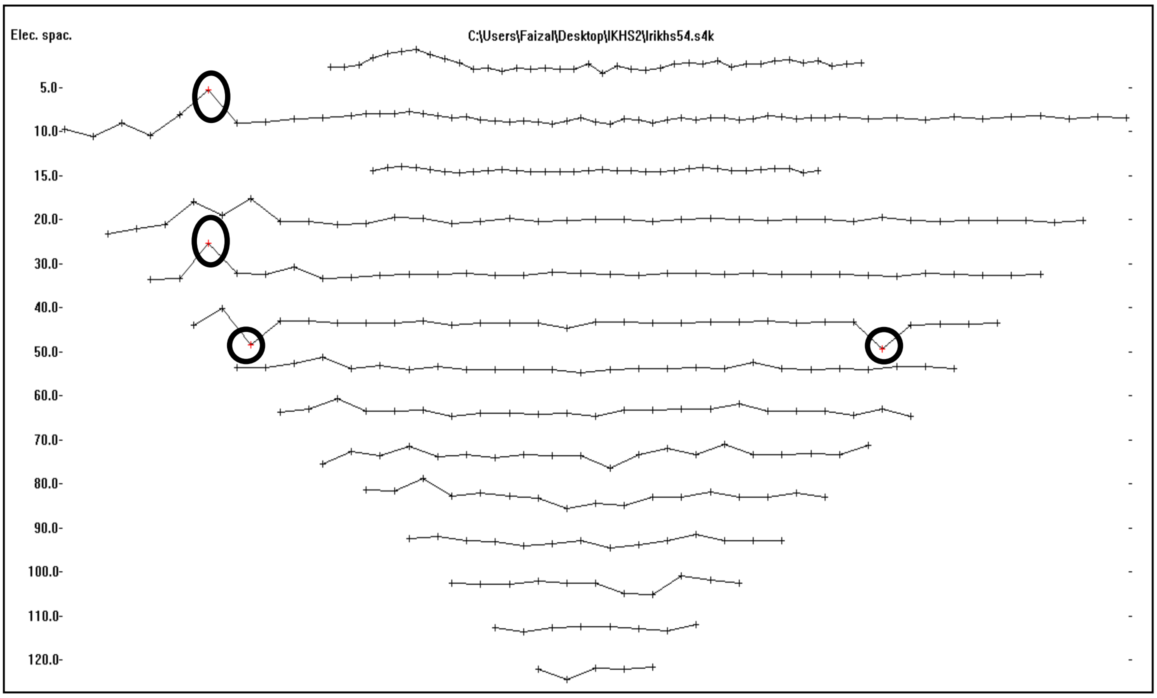


Figure 3.43: An example of apparent resistivity data on profile form. Note the circles show the bad data points

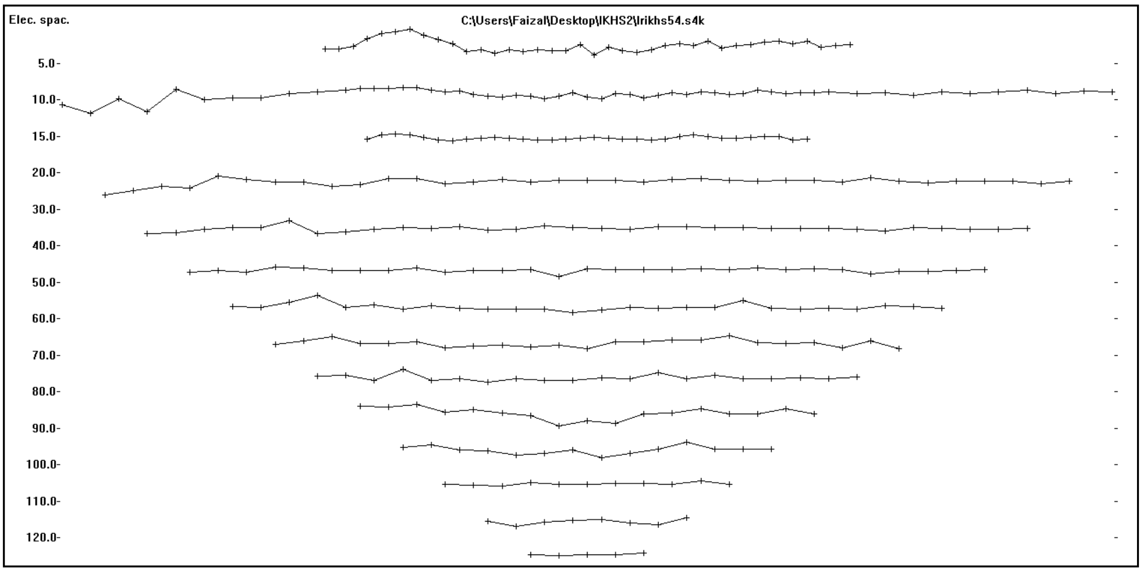


Figure 3.44: An example of apparent resistivity data after bad data points has been removed using edit data in Res2Dinv program

3.4.4 Data interpretation

Data converted into the extension DAT file format are interpreted by using the Res2Dinv software of Loke et al., (2003). Res2Dinv program produced an inverse model that approximates the actual subsurface resistivity distribution.

This program divides the two-dimensional model used in the subsurface into a number of rectangular blocks (Loke and Barker 1996). In order to minimise the difference between the measured and the calculated apparent resistivity values, the blocks' resistivity values are adjusted iteratively. The latter is calculated by the finite-difference method of Dey and Morrison (1979). Resistivity field data collected through the Wenner array from individual survey lines were inverted individually to generate a two-dimensional Wenner resistivity model. The inversion constraint used is the least-square-smoothness type, which shows the images' smooth changes in domains of space and time. The inversion constraint is adopted with the same conditions as those of natural seawater or of saltwater intrusion, which exhibited smooth changes in salinity as there is no groundwater extractions there that can rapidly change the salinity. Compared to another inversion constraint in Res2Dinv package, robust inversion, it should be used when sharp boundaries are expected to be present at such fault zones (Loke, 2013a).

The inversions are performed on an AMD Athlon(tm) 64 X2 Dual-Core Processor TK-57 1.90GHz with 3.00GB RAM. An initial model is produced, from which a response is calculated and compared to a measured data. The model is then modified, to reduce the differences between its response and the data. The differences are quantified as root-mean-squared (RMS) errors. The process continued iteratively until the RMS error fell into within acceptable limits, usually below 5%, or until the change between RMS values calculated for consecutive iterations became insignificant (Awni, 2006 and Loke, 2013a). The model with the lowest possible RMS errors, however, is not always the most appropriate one as it can show unrealistic variations in the resistivity model. Finite difference method is used as the data does not include topography. Given the area's near-flatness as discussed in Chapter 2, the topography is concluded to not significantly affect the resistivity models.

Two-dimensional inversion techniques are common and often acceptable in assessing resolution and in determining data-set limitations, as shown by Dahlin and Loke (1998). Resistivity of fresh groundwater varies from 10 to 100 Ω.m depending on dissolved-salt concentration. Seawater's low resistivity (less than 0.2Ω.m) is due to its high salt content (Loke 2013a), making the resistivity method an ideal technique for mapping of saline-freshwater interface. Note that alluvium resistivity ranges from 10 to 800 Ω.m depending on the soil type.

Figures 3.45 and 3.46 show data interpreted using Res2Dinv program. Figure 3.45 shows resistivity image with poor grounding whereas Figure 3.46 shows resistivity image with improved grounding steps as discussed in section 3.4.1.

The final data is inverse resistivity model derived from apparent resistivity values after the inversion process using Res2Dinv. As for a better and easier interpretation process, the scale of resistivity values of the inverse resistivity model needs to be standardized in terms of same resistivity values and colour contours (Figures 3.45 and 3.46). The 2-D contour plots of inverse resistivity model represent the true subsurface resistivity for certain areas.

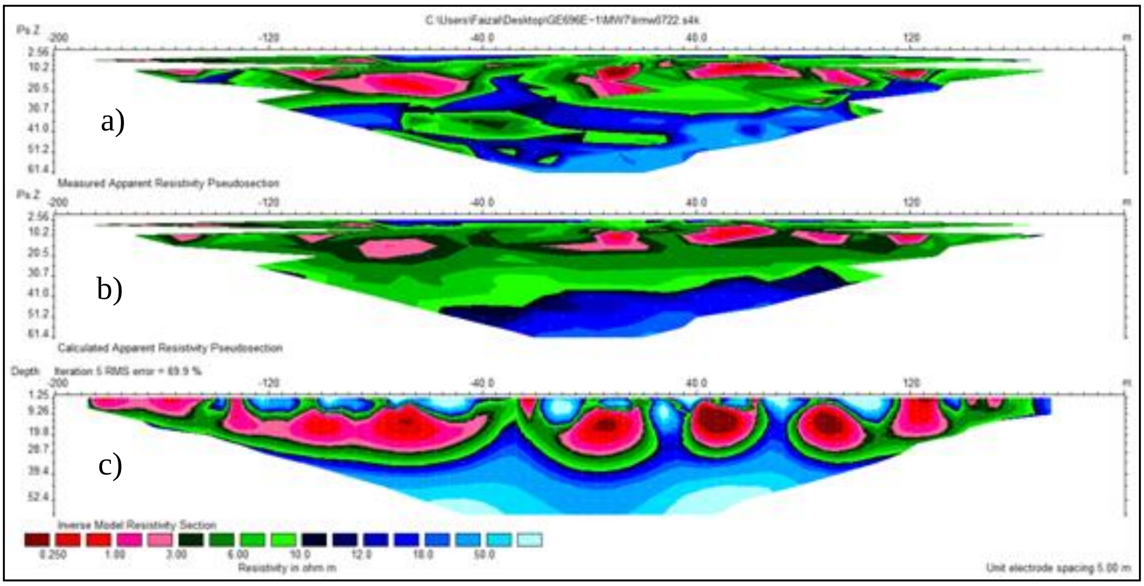


Figure 3.45: MW7 resistivity images inversion from incomplete resistivity data; a) measured apparent resistivity (Wenner Array), b) calculated apparent resistivity and c) inverse model resistivity

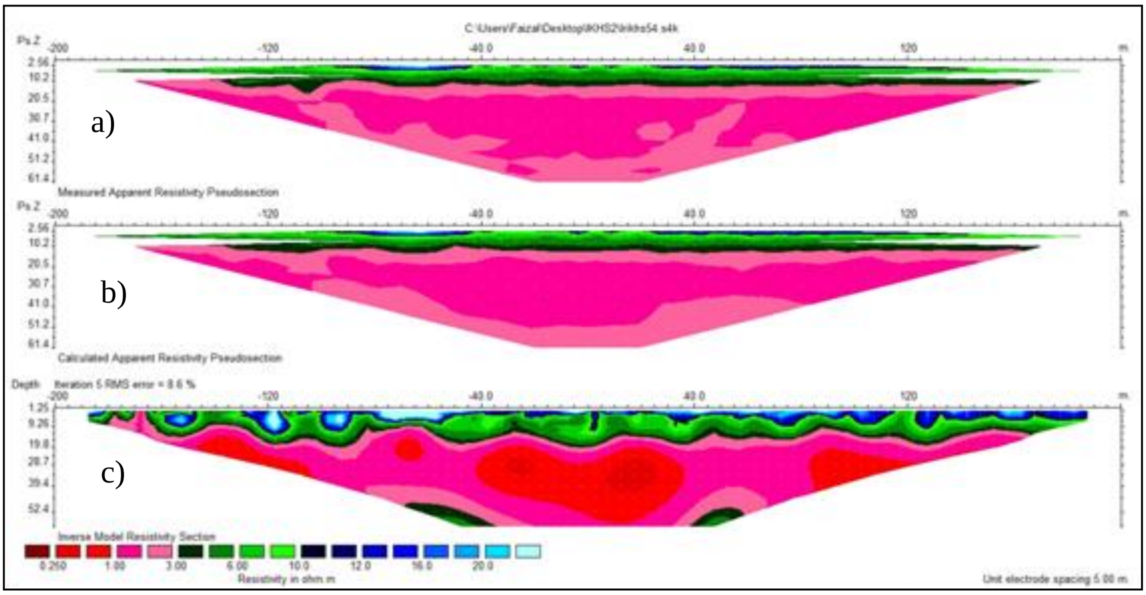


Figure 3.46: MW7 resistivity images inversion after steps taken for improvement ground contact and injected current. Bad point's data are removed before inversion process started; a) measured apparent resistivity (Wenner Array), b) calculated apparent resistivity and c**)** inverse model resistivity

3.5 Correlation between subsurface resistivity and groundwater quality

The correlation between subsurface resistivity and groundwater quality data has been found to be successful in the study of seawater intrusion by geo-electrical method (Ebraheem et al., 1997; Wilson et al., 2006; Sherif et al., 2006; Pujari and Soni, 2008 and Ebraheem et al., 2012).

Ebraheem et al., (1997), Sherif et al., (2006) and Ebraheem et al., (2012) have mentioned that the empirical relationship between geochemistry and geophysical methods could be derived when dissolved ions in the pore-fluid was more apparent in the electrical images compared to the host medium of soils under fully saturated groundwater condition. The empirical relationship study conducted by earlier research work could be used for establishing of new empirical relationship between geochemistry and geophysical methods in this study. In order to derive the empirical relationships between geochemistry and geophysical information, geochemistry data from eight monitoring wells, and subsequently resistivity measurements from eight transverse geo-electric data, were used. Procedures in obtaining these relationships were described by Cartwright and McComas (1968), Ebraheem et al., (1990), Sherif et al., (2006) and Ebraheem et al., (2012). Specific conductance of groundwater samples was converted into water resistivity ($\rho_w = {}^1/_{\sigma_w}$) and soil conductance was derived by inversing earth-resistivity data $\left(\sigma_s = {}^1/_{\rho_e}\right)$. The relationship derived from the equations, could revealed the types of groundwater that could be depicted in the resistivity images by using classification for the groundwater salinity degree based on total concentration of dissolved constituents that was proposed by Fetter (2002). The inversion model for MW7 and location of the screen for groundwater sampling at the depths of 34 to 36 m is showed in Figure 3.47. The inversion model data on DAT extension format for MW7 at depth of 36.45 m is showed in Figure 3.48.

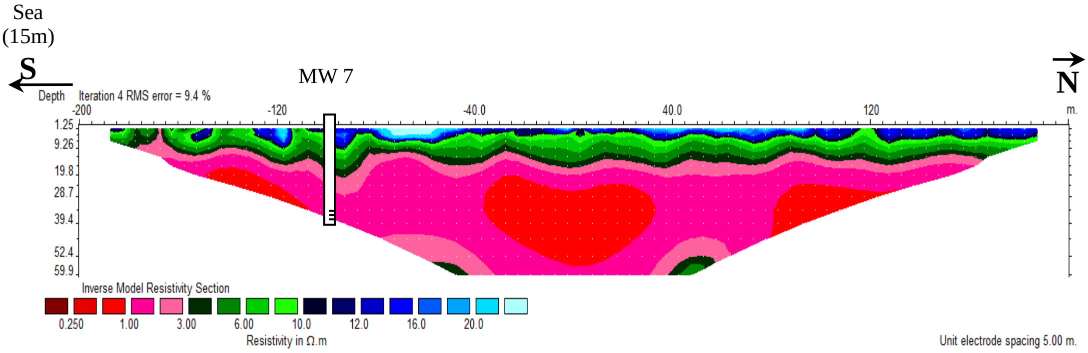
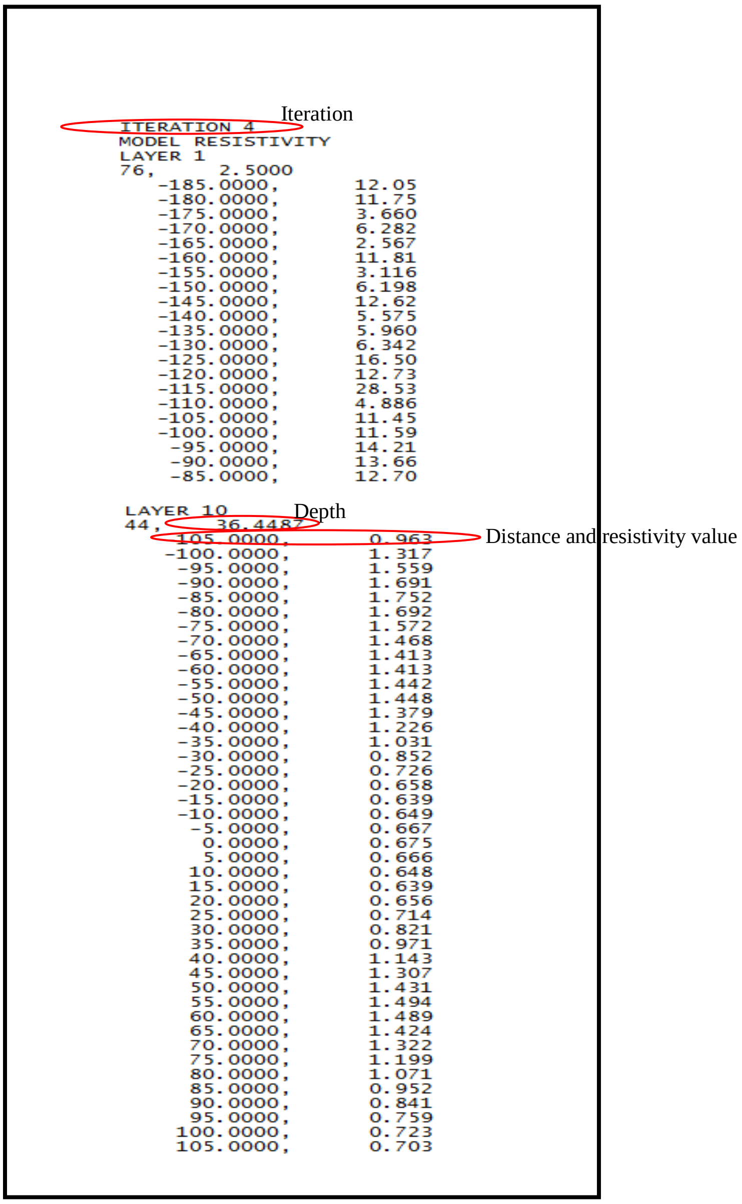


Figure 3.47: MW7 resistivity image, August 2009



```
ITERATION 4
MODEL RESISTIVITY
LAYER 1
76,          2.5000
     -185.0000,          12.05
     -180.0000,          11.75
     -175.0000,          3.660
     -170.0000,          6.282
     -165.0000,          2.567
     -160.0000,          11.81
     -155.0000,          3.116
     -150.0000,          6.198
     -145.0000,          12.62
     -140.0000,          5.575
     -135.0000,          5.960
     -130.0000,          6.342
     -125.0000,          16.50
     -120.0000,          12.73
     -115.0000,          28.53
     -110.0000,          4.886
     -105.0000,          11.45
     -100.0000,          11.59
      -95.0000,          14.21
      -90.0000,          13.66
      -85.0000,          12.70

LAYER 10
44,          36.4487
     -105.0000,          0.963
     -100.0000,          1.317
      -95.0000,          1.559
      -90.0000,          1.691
      -85.0000,          1.752
      -80.0000,          1.692
      -75.0000,          1.572
      -70.0000,          1.468
      -65.0000,          1.413
      -60.0000,          1.413
      -55.0000,          1.442
      -50.0000,          1.448
      -45.0000,          1.379
      -40.0000,          1.226
      -35.0000,          1.031
      -30.0000,          0.852
      -25.0000,          0.726
      -20.0000,          0.658
      -15.0000,          0.639
      -10.0000,          0.649
       -5.0000,          0.667
        0.0000,          0.675
        5.0000,          0.666
       10.0000,          0.648
       15.0000,          0.639
       20.0000,          0.656
       25.0000,          0.714
       30.0000,          0.821
       35.0000,          0.971
       40.0000,          1.143
       45.0000,          1.307
       50.0000,          1.431
       55.0000,          1.494
       60.0000,          1.489
       65.0000,          1.424
       70.0000,          1.322
       75.0000,          1.199
       80.0000,          1.071
       85.0000,          0.952
       90.0000,          0.841
       95.0000,          0.759
      100.0000,          0.723
      105.0000,          0.703
```

Figure 3.48: MW7 inversion file, August 2009

3.6 Pore fluids resistivity calibration

Relation of formation resistivity to fluid conductivity depends on sediment type and pore-water conductivity. Archie (1942) has related linearly formation $\rho_f(\Omega.\mathrm{m})$ and pore-water resistivity ρ_w(Ω.m); in terms of electrical conductivities σ_w and σ_f (S/m),

$$\sigma_w = F\sigma_f \tag{3.5}$$

where the proportionality constant F is the "formation factor" related to sediment porosity. Equation (3.5) is valid for sediments which matrix resistivity distribution is high, and the main conductor is pore water.

Correlation between surface resistivity and fluid resistivity, from the inversion model and site physical model, were investigated in Dec 2010. Clean, fine-to-medium sand was used. Experimental sites along 1.5 km of coastal area were eroded, exposing sedimentary white sand bar (Figure 3.2).The clean, fine sand used was about 120 m away from MW7 (Figure 3.2). Soil-sample tests were conducted inland 20 m away from the coast to avoid maximum high tide arrived.

Wenner Four-Pin-Point is used in measuring to IEEE Standard 81 (1984), the earth resistivity and fluid resistivity. A trench was dug, 1 m long, 0.5 m wide, 0.5 m deep (Figure 3.49). At the physical model's base, a plastic bag was retained to saturation, collected water. ABEM SAS 1000, clip wires and four electrodes copper-clad were used; the four electrodes buried in one line spaced 'a' apart, 25 cm (6 in) between rods (Figure 3.50). They were driven into depths not exceeding 0.1a each, and gave, up to depth 'a', approximate average resistivity of the soil. Seawater and irrigation water were used in the measurements. TDS of the irrigation water post-rain was 500 mg/L. Fluids prepared to filling pores of fine clean sand has TDS ranging from 26,000 mg/L to 500 mg/L. Surface resistivity and fluid resistivity were measured from high TDS (26,000 mg/L) to low TDS (500 mg/L).

Figure 3.49: A trench is dug, 1 m long, 0.5 m wide, 0.5 m deep

Figure 3.50: The pore fluids measurements conducted at the field

3.7 Time-lapse resistivity tomography measurement (TLERT)

TLERT measurements were used to determine the dynamic salinity changes in the groundwater aquifer. Subsurface resistivity values changes accordingly with the salinity changes that occurred during tides condition. The changes of the subsurface resistivity values are processed using the commercial Res2Dinv software. The study used a joint-inversion technique to minimize possible distortions of sections (inverse model resistivity images) showing relative changes in subsurface resistivity (Loke, 2013b). The technique used the inversion model from the initial data set to limit inversion of the later data sets. The time-lapse inversion constraint used the least-square-smoothness type to show smooth changes of the images in domains of space and time. Sequential inversion was used for the section models with very large resistivity contrasts. In sequential inversion, full inversion of the first data set was between one and about five iterations. The model for the first data set's final iteration was used as a reference model for the inversion of later data sets. The iteration will start only upon completion of the inversion. The first inversion model data set remained a reference inversion model for the second data set and for subsequent other data sets. Output of each resistivity measurement series model is presented here as percent change of resistivity, obtained through Equation 3.6:

$$\frac{(x_i - x_1) \times 100}{x_1} \qquad (3.6)$$

Where x_i is the measurement series at time *i* and x_1 the initial series.

The initial series, x_1, presented as reference model from inversion results of the first data set, remained forever a reference model in this equation. Measurement series at time *i* represented other data-set inversion models at various times.

3.8 Statistical analysis

Statistical analysis is conducted to determine the relationship between the geochemical and subsurface resistivity data. Statistical analysis used is kurtosis, skewness, root mean square (RMS) and linear correlation which was calculated using Microsoft Excel 2010 software.

3.9 Resistivity and conductivity contours

The process of data acquisition, processing and interpretation of geo-electrical resistivity surveys are made on resistivity survey line at the second phase. The results of subsurface resistivity in the second phase (December 2010) were interpolated as an estimation of resistivity and conductivity map area using Surfer 8 software. The product of this presentation is the mapping of subsurface resistivity distribution values in the study area.

3.10 Summary

Detection of saltwater or seawater is more difficult in complex subsurface hydrogeology conditions. In the monitoring of the groundwater salinity changes using monitoring wells, the presence of saltwater in the groundwater aquifer is not apparent where it only provides data for a single point measurement. If the screen of the boreholes is long or comprises of multiple short screens, water enters the borehole from various depths and is then mixed in the borehole. In aquifers where a thick saltwater-freshwater transition zone exists, continuous change in salt concentration across the transition zone should be monitored. The monitoring is requiring unmixed water to be sampled at different depths. This can be achieved by the use of packers selectively blocking the well’s seal sections so that each section has its own screen and the water samples are not mixed. Such operation is tedious, and the data obtained is limited to the well's location and to the elevation of the screened portions of the well at that location. Huge area will require many drilling wells therefore increasing associated costs. The data obtained is the most direct and probably the most accurate. The data is often used to calibrate the data obtained by indirect methods such as geo-electrical resistivity method. Geo-electrical resistivity method provides the advantages of representing wider resistivity subsurface profile compared to geochemical method. Resistivity and conductivity value obtained from geo-electrical resistivity method will not provide the data on the groundwater quality unless correlation between geochemical method and geo-electrical resistivity method is done. Statistical analysis is conducted to confirm a good correlation between geochemical and geo-electrical method.