Institute of Hydrology

Natural Environment Research Council

RbB

GROUNDWATER RECHARGE IN DOHA, QATAR

Prepared for Balfours International on behalf of Water Department, Ministry of Water and Electricity, Government of Qatar.

Institute of Hydrology
Wallingford,
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GROUNDWATER RECHARGE IN DOHA, QATAR

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Summary

A numerical groundwater model of the Doha area prepared in 1983 to study the rise in water level beneath the city has been updated with new water level information and a new water balance study.

Water levels have continued to rise, although the recharge mound has spread further inland. Areas with water levels at less than 2.5m bgl occur along the coast and in areas of low topography. The average rise in water levels from 1983 to 1988 was 0.16 m/y. Further studies are required to identify areas at risk from shallow water levels and to improve the monitoring network.

Recharge estimates based on the model differ from those obtained from the water balance study. The latter are not consistent with the observed water level configuration, but a more sophisticated model would be needed to provide better estimates of recharge and to study measures to control water levels.

GROUNDWATER RECHARGE IN DOHA, QATAR

1. INTRODUCTION

In 1983 a hydraulic model of water movement in the Upper Dammam aquifer underlying Doha was developed by the Institute of Hydrology (IH) as part of a study to investigate measures to control rising water levels beneath the city [ASCO ref 1]. The model was used to compute recharge to and discharge from the aquifer system which were then compared to estimates derived from a water balance study. It incorporated water level data for February 1983 derived from a network of about 180 boreholes. Aquifer characteristics were based mainly on pumping tests.

Routine monitoring of water levels has continued since 1983. By 1988 there were some 110 sites with a water level of five years or more. A new water balance study was also undertaken in 1988. At the request of Balfours International on behalf of the Water Department of the Ministry of Water and Electricity, the new water level information has been incorporated into the existing groundwater model to provide new estimates of recharge, which were then compared to the results of the recent water balance.

2. REVIEW OF WATER LEVEL DATA

2.1 Introduction

The elevation of the natural pre-development water table is thought to have been about 1m aQND (Qatar National Datum) with a shallow gradient towards the coast. Urban development has now led to a rise in water levels beneath the city due to a combination of imported water, reduced abstraction and the aquifer characteristics of the underlying sequence. The resulting recharge mound had water levels of up to 9m aQND in 1983.

A network of 180 boreholes had been established by February 1983 to monitor water levels beneath the urban area. The data were used to prepare water level and depth to water table maps. At some locations, mainly in local topographic depressions, water levels were shown to be less than 2m bgl. The rate of water level rise could not be determined as only 22 sites had been monitored for more than one year.

The water level monitoring network in 1988 is shown in Figure 1. Routine water level data has been collected from about 110 sites since 1983, although some are influenced by pumping. Data from a total of 90 boreholes were used to prepare water level maps for December 1988. The monitoring network in 1988 was slightly different than that for 1983, mainly in the western and southern areas. Some local changes in water level between 1983 and 1988 may be due to differences in the monitoring networks rather than real changes in the amount and distribution of recharge.

2.2 Water Level Configuration 1988

The water table elevation for December 1988 is shown in Figure 2. The configuration is broadly similar to that in February 1983 with two local recharge mounds, at Medina Khalifa and just south of Wadi Musheirib, which are superimposed on a more regional mound having a steep gradient on its eastern flank. Most of the western area from Al Gharrafa to Ain Khaled has water level elevations of about 6 to 7m aQND. Water levels of only about 3m aQND are shown by the 1988 data to occur around Muraikh.

2.3 Depth to Water Level 1988

The depth to water level in December 1988 is shown in Figure 3. The pattern is similar to that in 1983. Most of the central urban area has water levels more than 5m bgl but areas having shallow water levels of less than 2.5m bgl occur along the coast, near Old Rayyan, Muraikh, Wadi Musheirib, and in the area of low topography extending north of Abu Hamur.

The occurrence of local areas with shallow water levels could be more extensive than indicated by the monitoring network as water levels in other topographic depressions are not monitored.

2.4 Change in Water Levels 1983 to 1988

Figure 4 shows the net change in water levels between February 1983 and December 1988. Water levels have risen over most of the study area, with the largest rise of 1 to 3m taking place in the south- west towards Ghanim el Jadid. Apparent declines at Medina Khalifa and Muraikh could be due to differences in the data available for these areas in 1983 and 1988.

Water level rises of 0.5 to 1m have occurred in the coastal area at West Bay whereas a similar decline in water level has occured in the coastal area south of the bay. Water levels have also decreased in the Wadi Musheirib by about 0.4 to 0.9m.

2.5 Water Level Trends

Water level hydrographs are given in Annex A. The average annual trends in water level for 59 sites with longer term records are given in Annex B.

A relatively constant rise in water level took place from 1982 to 1987 associated with the recharge of imported water. The more marked change in 1987/8 would appear to be due to the exceptional rainfall event at this time. The average rise in water level is about 0.16 m/y (range -0.14 to +0.35 m/y). This would indicate a net increase in aquifer storage of 0.53 Mm3/y over the model area (assuming a specific yield of 2%), or only 3.7% of the estimated annual recharge of about 14 Mm3/y.

3. RECHARGE ESTIMATES

3.1 Model Description

A description of the hydraulic model used to estimate recharge is available in the 1983 report [ref.1]. Only the main features of the model are summarised here.

Groundwater flow is described in two horizontal dimensions using Darcy's Law with a continuity equation. The model is steady state, making the approximation that the water table does not change in the short term. It estimates the recharge required to sustain an observed head distribution subject to assumptions on the storativity (S) and hydraulic conductivity (K) of the aquifer based on field tests.

The model is written in finite difference form, and recharge estimated using least squares recession analysis of the resulting linear regression equations over the nodal network grid. Recharge is constrained at certain nodes where there is no urban development to a fixed value equal to the estimated annual rainfall recharge in order to stabilise the estimation. The model also computes the discharge across the boundaries of the area considered.

3.2 Comparison of Model and Water Balance Recharge Estimates

Two model runs were undertaken prior to completing the water balance study: a re-run of the model with the 1983 water levels and a model run with the 1988 water levels. The results are presented in Table 1. The results for 1988 are also shown in Figure 5 for each of the areas A to E. The procedure for determining inferred recharge at nodal points was modified which improved the accuracy of the model, as shown by the reduction in the sum of squared residuals in Table 1.

Table 1 Recharge and boundary flows

Model run	Region	Area (km^2)	Net recharge (Mm^3yr)	Flow to sea (mm^3yr)	Flow across eastern boundary (Mm^3yr)	Other boundary flow (Mm^3yr)
1983 water levels	A	24.0	0.47	-	-	0.15
(as presented in Table	B	25.5	0.49	1.00	-	0.17
6.9 of 1983 report)	C	35.125	8.77	6.48	0.83	-
	D	4.925	3.43	3.60	-	-
	E	69.25	0.78	-	0.38	1.22
Total			13.94			
Sum of squared residuals			56.5			
Root mean square residual			0.82			
Re-run of 1983	A	24.0	0.47	-	-	0.18
water levels	B	25.5	0.56	0.92	-	0.42
	C	35.125	9.11	6.74	0.88	-
	D	4.925	3.43	3.82	-	-
	E	69.25	0.77	-	0.38	1.15
Total			14.34			
Sum of squared residuals			15.3			
Root mean square residual			0.43			
1988 water levels	A	24.0	1.09	-	-	0.51
	B	25.5	0.14	1.49	-	0.35
	C	35.125	5.63	4.90	0.73	-
	D	4.925	6.85	6.12	-	-
	E	69.25	1.02	-	0.55	0.51
Total			14.73			
Sum of squared residuals			18.0			
Root mean square residuals			0.46			

A net recharge of 14.3 Mm3/y was derived for 1983 using the improved model procedure compared to 14.7 Mm3/y for 1988. This is an increase of only 2.7% suggesting that recharge has remained constant, although the distribution of recharge may have altered.

Recharge estimates from the water balance study were completed in early 1990. The results have been adjusted to the model areas (A to E) to allow comparison with the recharge estimates derived from the updated model.

The water balance study made in 1983 was based on QAT zones whereas that in 1988 was based on QAR zones. Net recharge is computed for each zone using various assumptions but no allowance is made for subsurface inflow and outflow between zones. The net recharge for the QAT zones were combined for each of the five model areas A to E in order to compare the model and water balance recharge estimates for the same areas, as given in Table 2.

Table 2 Estimates of Net Recharge (Mm3/y)

	Area	Model	Balance	Difference
1983	A	0.47	2.26	1.79
	B	0.56	1.75	1.19
	C	9.11	7.04	2.07
	D	3.43	-0.28	3.71
	E	0.77	3.72	2.95
	Total Annual	14.34	14.49	0.15
1988	A	1.09	3.66	2.57
	B	0.14	2.74	2.6
	C	5.63	7.63	2
	D	6.85	-1.06	7.91
	E	1.02	3.42	2.4
	Total Annual	14.73	16.39	1.66

In 1983 there was rather poor agreement between the model and water balance estimates for each area. Area C accounted for almost two- thirds of the total recharge in the model, although areas D and E show the greatest discrepancy.

The water balance study indicates an increase in the annual recharge of 11% between 1983 and 1988 compared to only 2.7% based on the model study. This may be due to different assumptions being used for each water balance study. Area C accounts for about 40% of the total recharge in the model but area D now shows the greatest discrepancy, although the sum of the model recharge for areas C and D in 1983 is similar to that in 1988.
The pattern of groundwater levels (Figures 2 and 3) may provide a possible qualitative explanation for the differences in the recharge estimates. The main areas of net recharge inferred from the pattern of groundwater levels are:

(a) south-east of Madina Khalifa at the boundary of areas A, B and C. Here a slight shift in the recharge centre between 1983 and 1988 has redistributed the recharge between areas A, B and C.

(b) a ridge trending south-west from the old port through areas C and D. This ridge appears to extend closed to the old port and has a steeper hydraulic gradient towards the sea.

However, the water balance recharge estimates do not match this observed water level configuration. For example, the net recharge for area D is not consistent with the prominent groundwater ridge in the same area. The recharge estimates from the water balance approach are also greater in the other four areas than those estimated from groundwater level data. This could suggest an overestimate in one or more of the assumptions used in the water balance study.

4. DISCUSSION

4.1 Modelling

There are significant differences between the model and water balance recharge estimates. Limitations of the water balance study would account for some of these differences, but this discussion relates to limitations of the model. The model computes the amount of recharge necessary to sustain the observed head distribution. If aquifer conditions are homogeneous then groundwater mounds would be associated with greater recharge. The water balance recharge estimates are not in agreement with the observed water levels with the assumption of aquifer homogeneity. Geological information suggests that there may be significant heterogeneity in the aquifer conditions and to some extent this has been taken into account by the model by averaging recharge over large areas (A to E). If the water balance estimates of recharge are substantially correct then it would be necessary to determine spatial variations in the aquifer characteristics to improve the model estimates of recharge.

Two other modelling assumptions need consideration, although these have less influence on the overall differences in recharge derived from the two methods:

(a) the water level contour map for 1988 indicates that the recharge mound has spread beyond the original model boundaries, which would therefore have to be extended.

(b) the assumption of steady state is only approximate as there has been a steady but slow increase in water levels between 1983 and 1988. Some restructuring and further calibration of the model would be necessary to allow for this change in water levels. [1]

A detailed appraisal of the rise in water levels and local control measures would require a more sophisticated model incorporating at least the features described above and calibrated from the water level data. A major constraint on any modelling of the situation is the variability in aquifer conditions. A regional model to indicate risk areas together with local models to examine control measures in areas at risk would be appropriate.

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1 IH is currently undertaking research with the Centre for Mathematical Research of the Australian National University to examine various methods for stabilising recharge estimation, to develop appropriate treatments for boundary fluxes and to provide measures of the uncertainty associated with recharge estimation. This work is appropriate to the semi-arid zone and will be applied to the Doha data during 1991/2.

4.2 Monitoring

The monitoring network could be extended, for example to include areas to the north and west where water level data are sparse or to provide control points in areas at greater risk. A computerised data base system could be applied to prepare water level maps and graphs to update and review the situation at regular intervals.

Statistical techniques could be applied to study the distribution and number of monitoring points. The frequency of readings could be optimised in terms of the data collection objectives and the costs of collecting and processing the data. Associated information, such as topography and population distribution, could be used to establish risk criteria and areas at greatest risk as well as the need, timing and success of control measures.

REFERENCES

1. Rising Water Table Project, May 1983. ASCO (Qatar) for Ministry of Electricity and Water Department, Qatar.

Figure 1
Monitoring network
1988

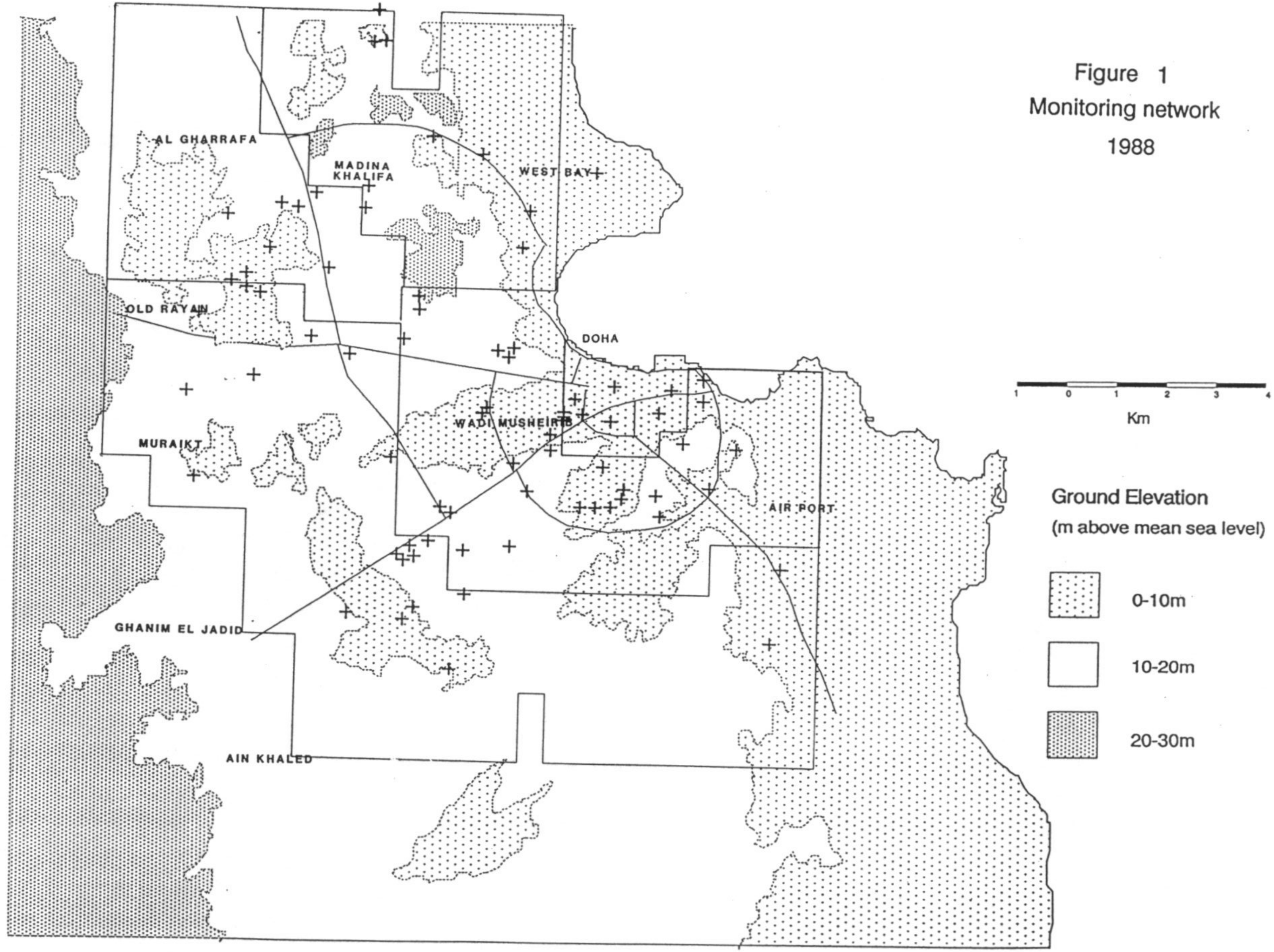
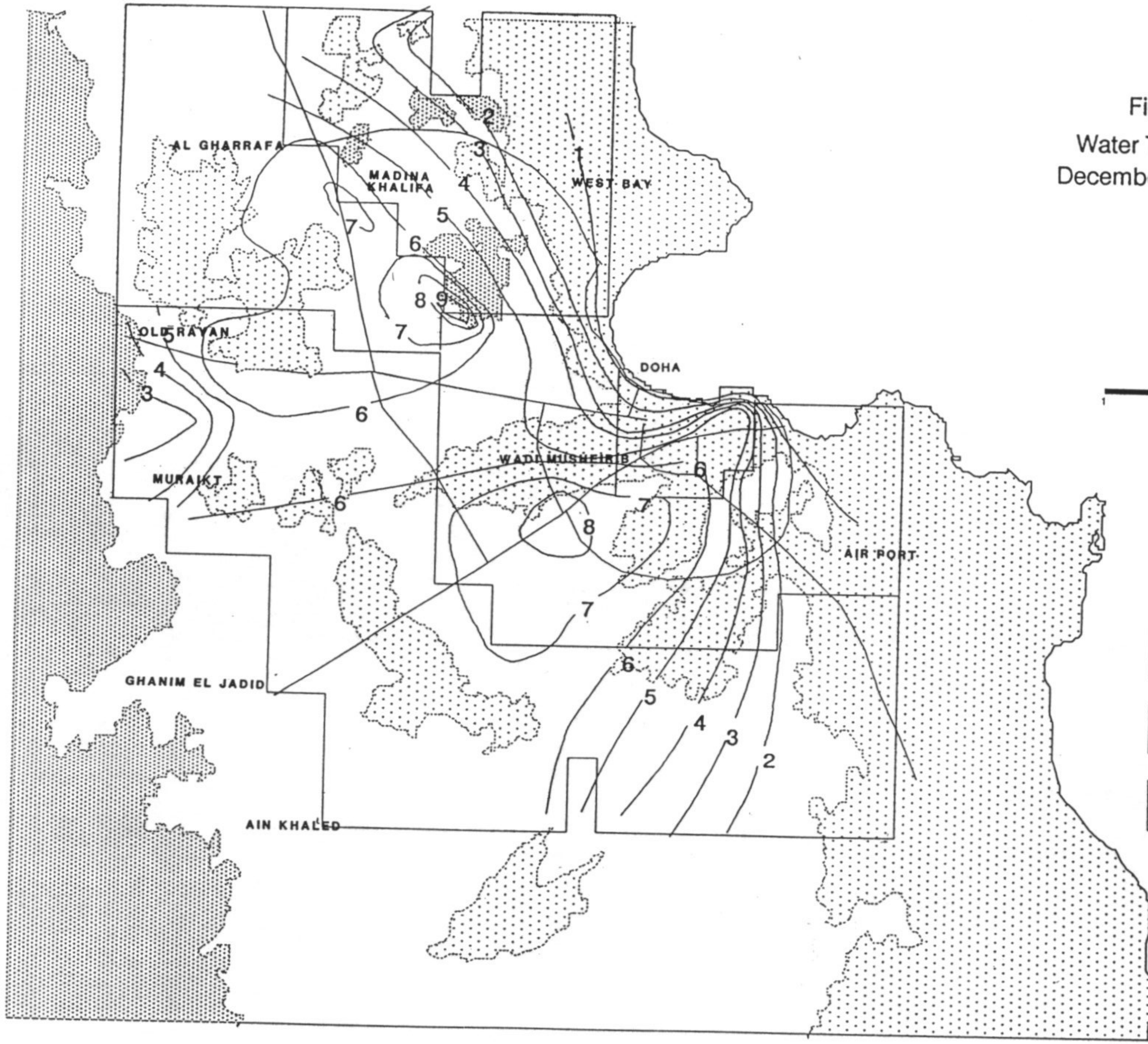


Figure 2
Water Table Elevation
December 1988 (maQND)



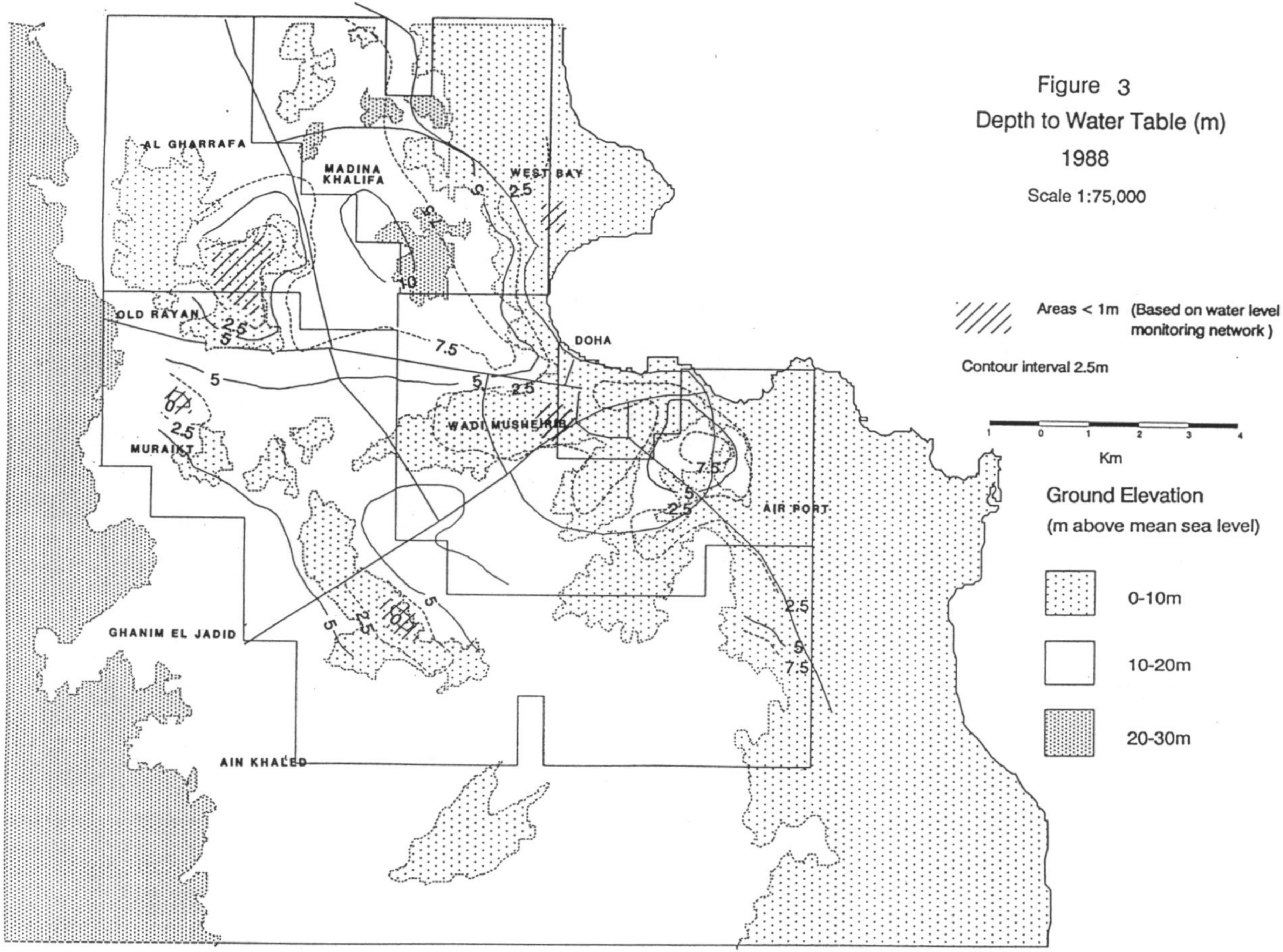


Figure 3
Depth to Water Table (m)
1988
Scale 1:75,000

Figure 4
Change in Water Levels;
1983-1988

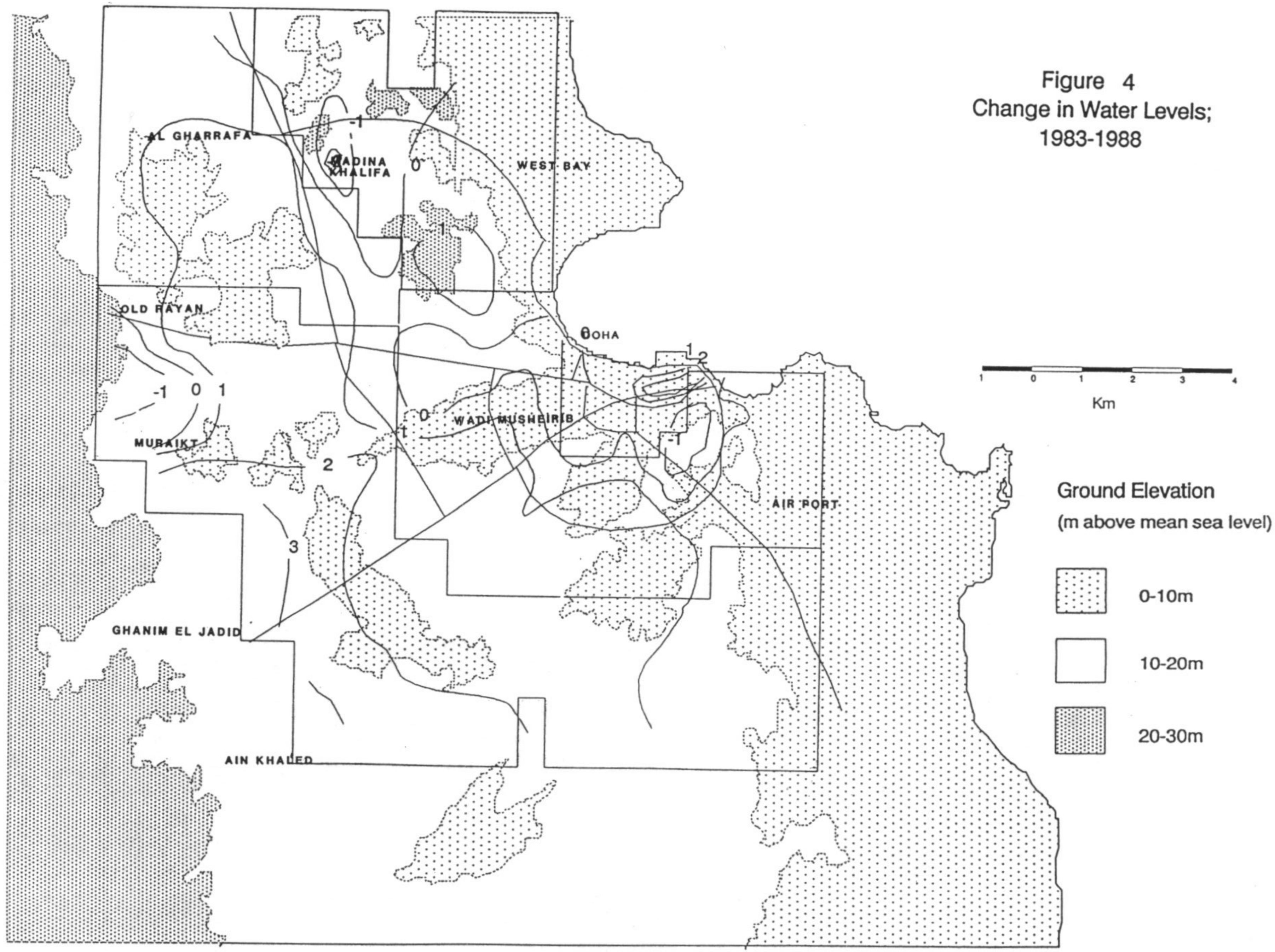
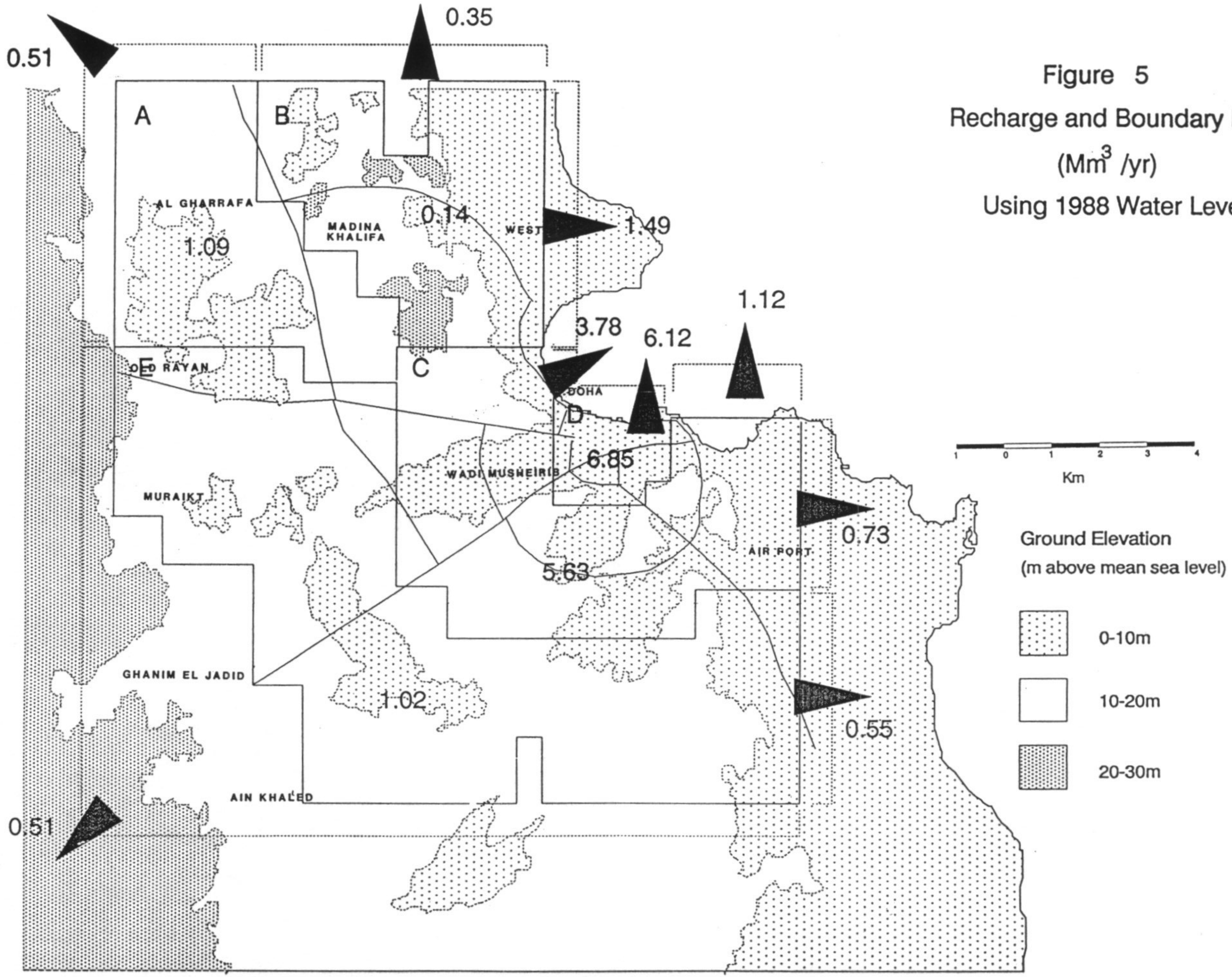


Figure 5

Recharge and Boundary Flows

(Mm^3 /yr)

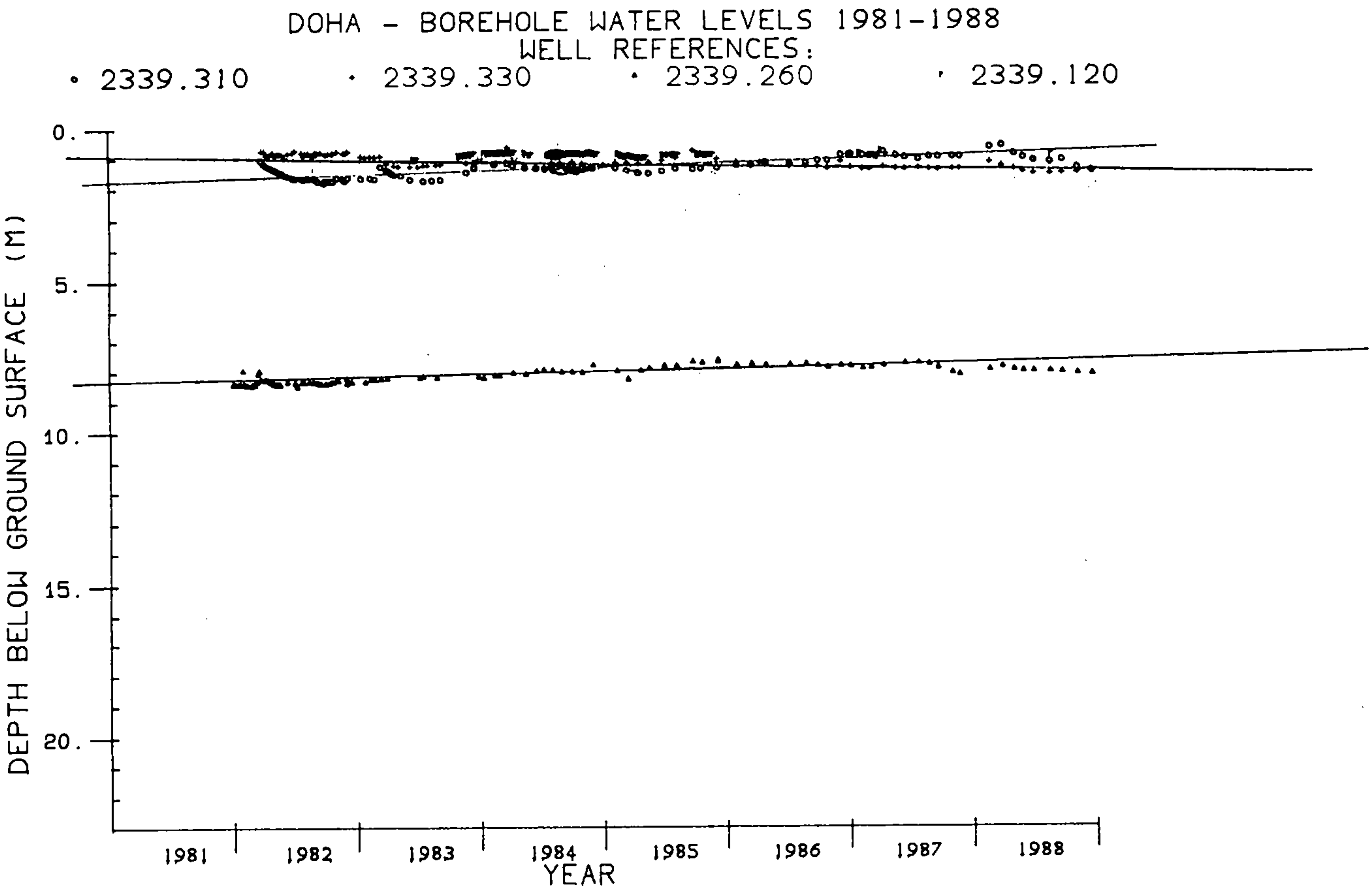
Using 1988 Water Levels



Annex A

Water Level Hydrograph 1981-1988

Note: Visual trends are indicated for each monitoring site where possible. Average annual trends are listed in Annex B.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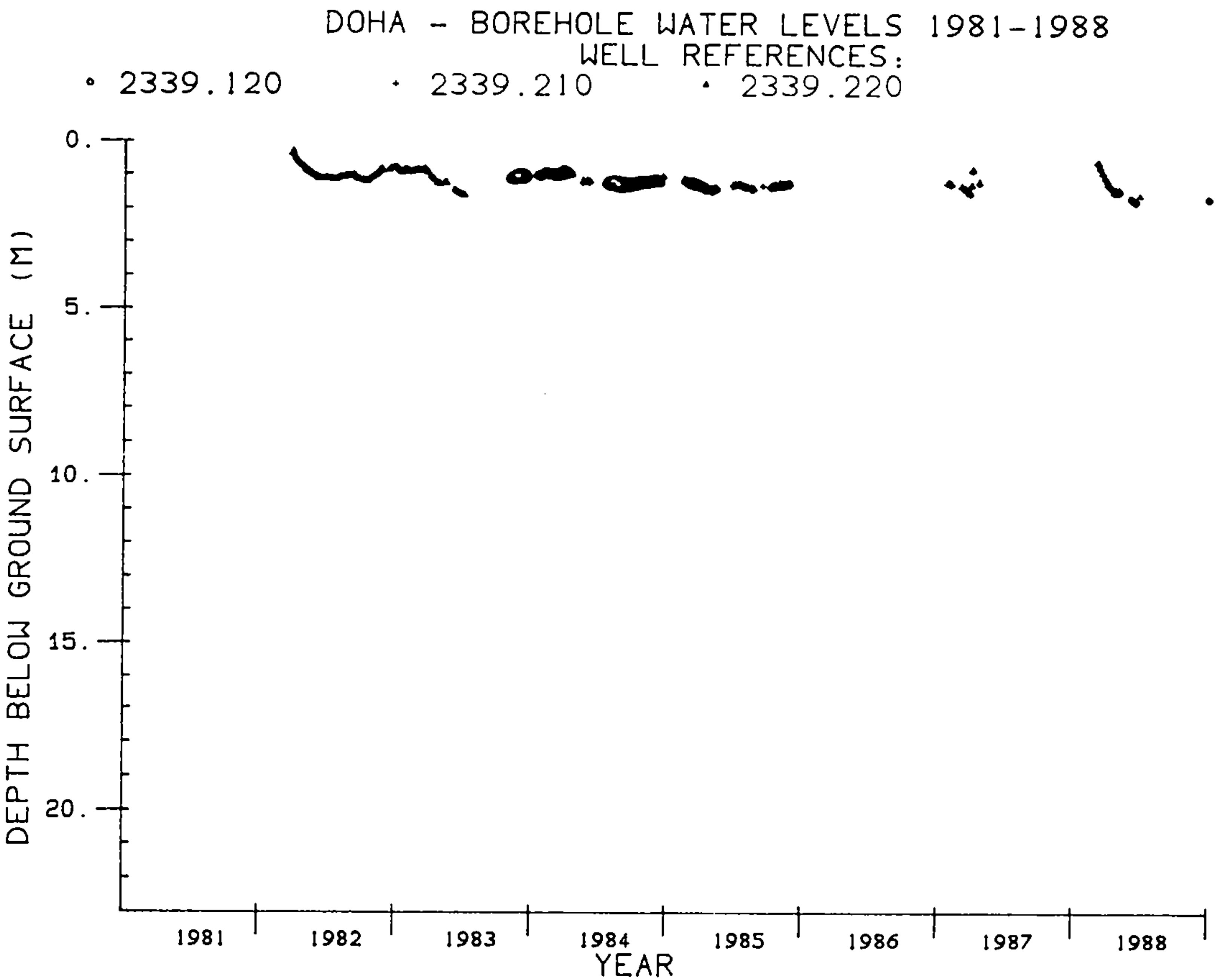
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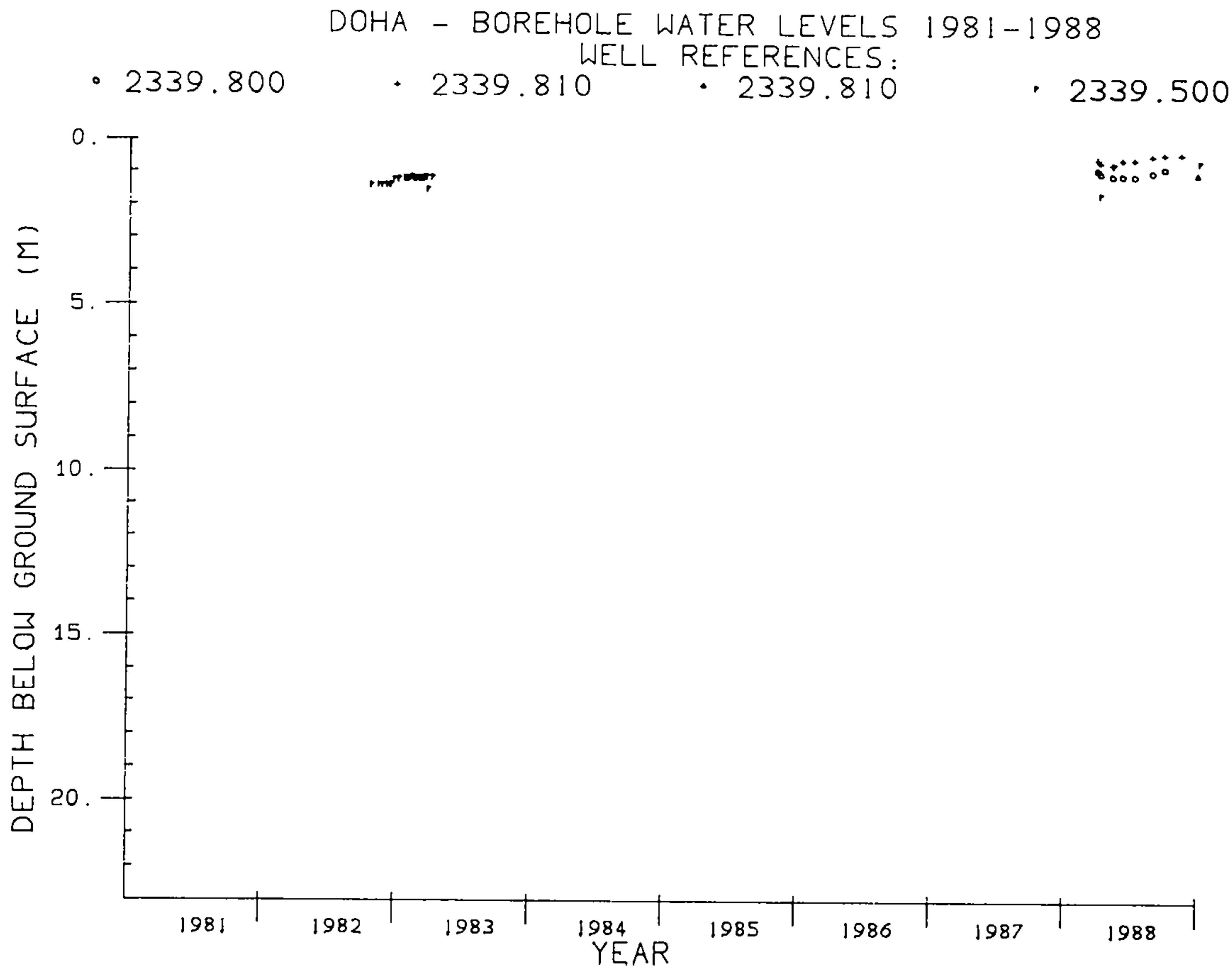
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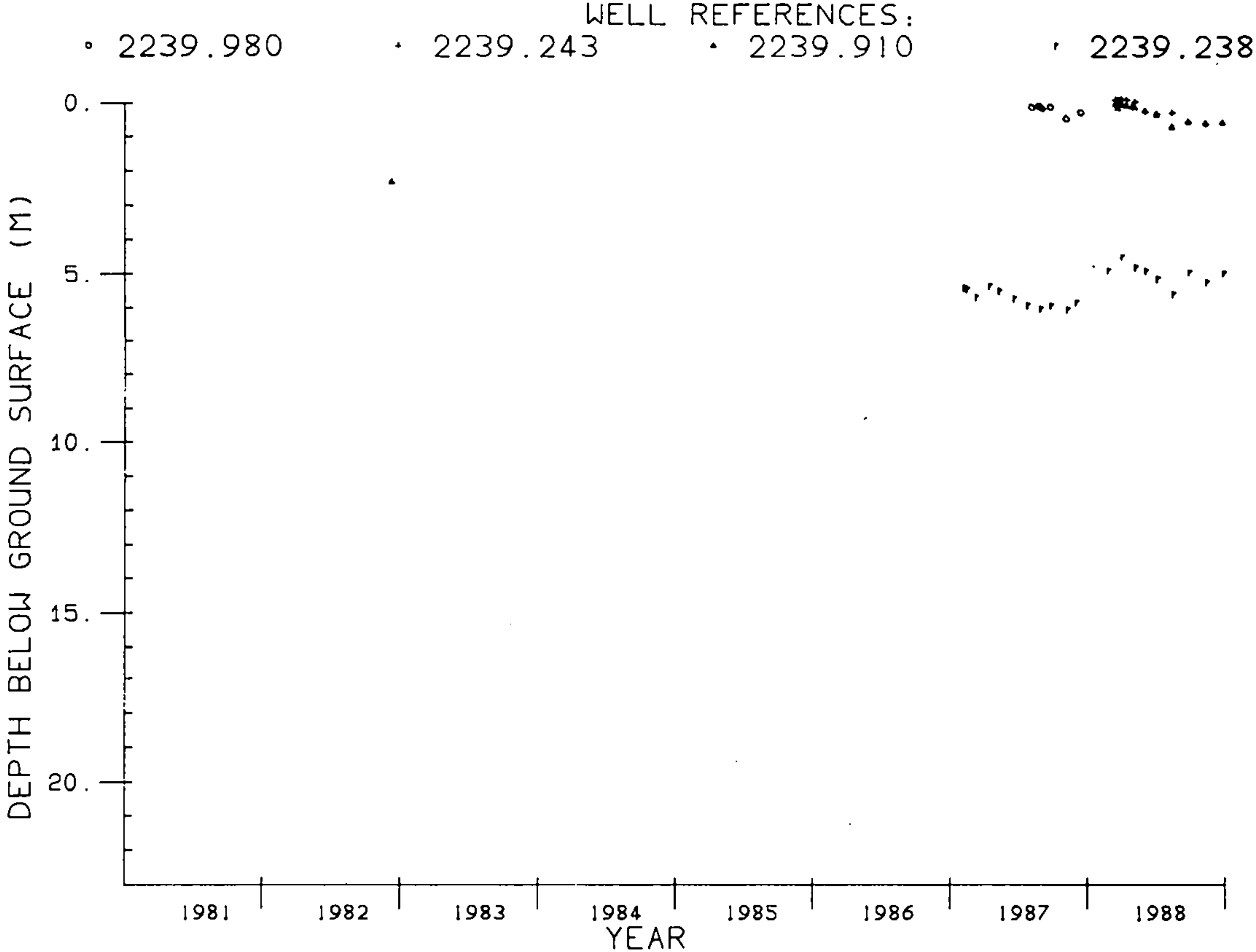

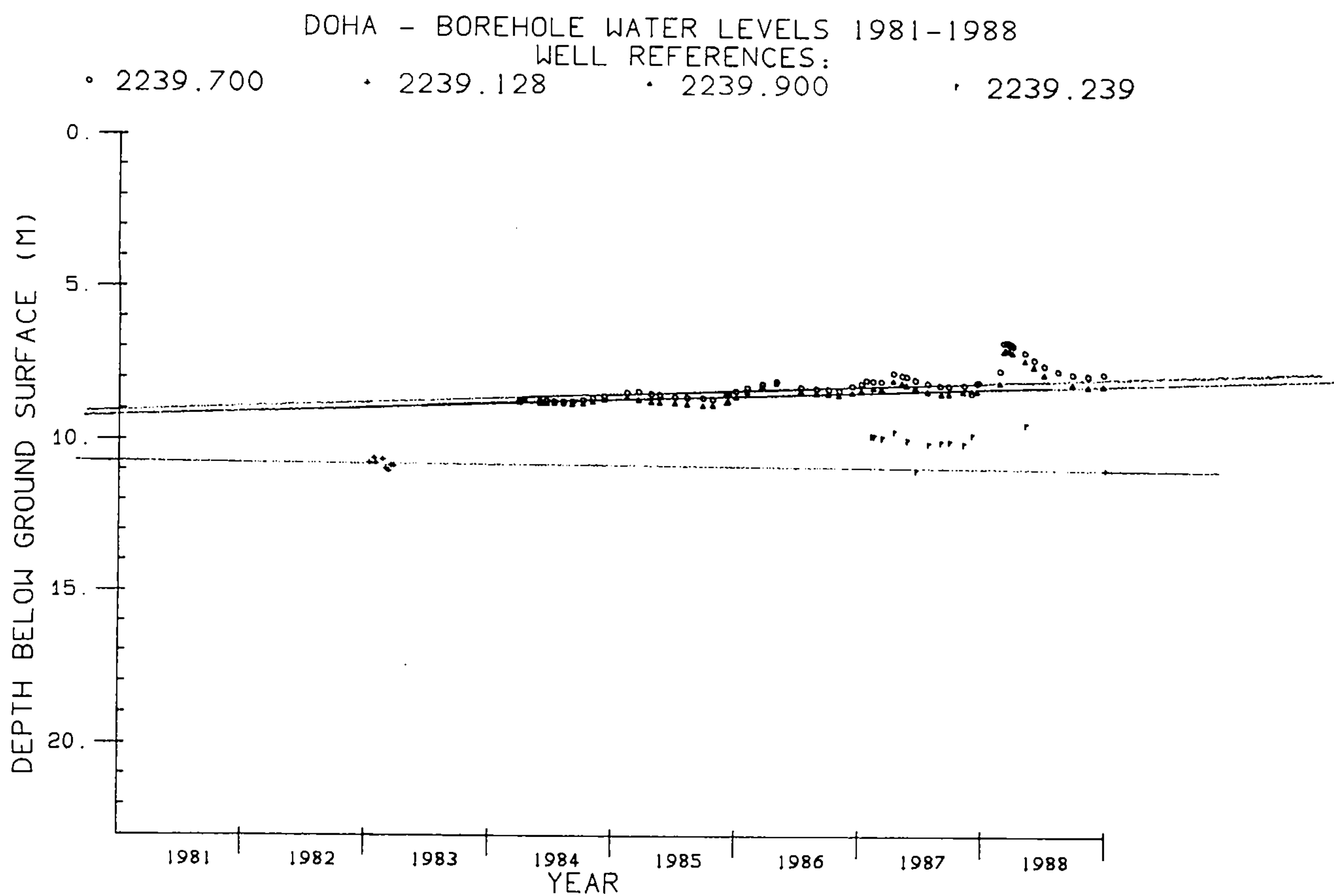
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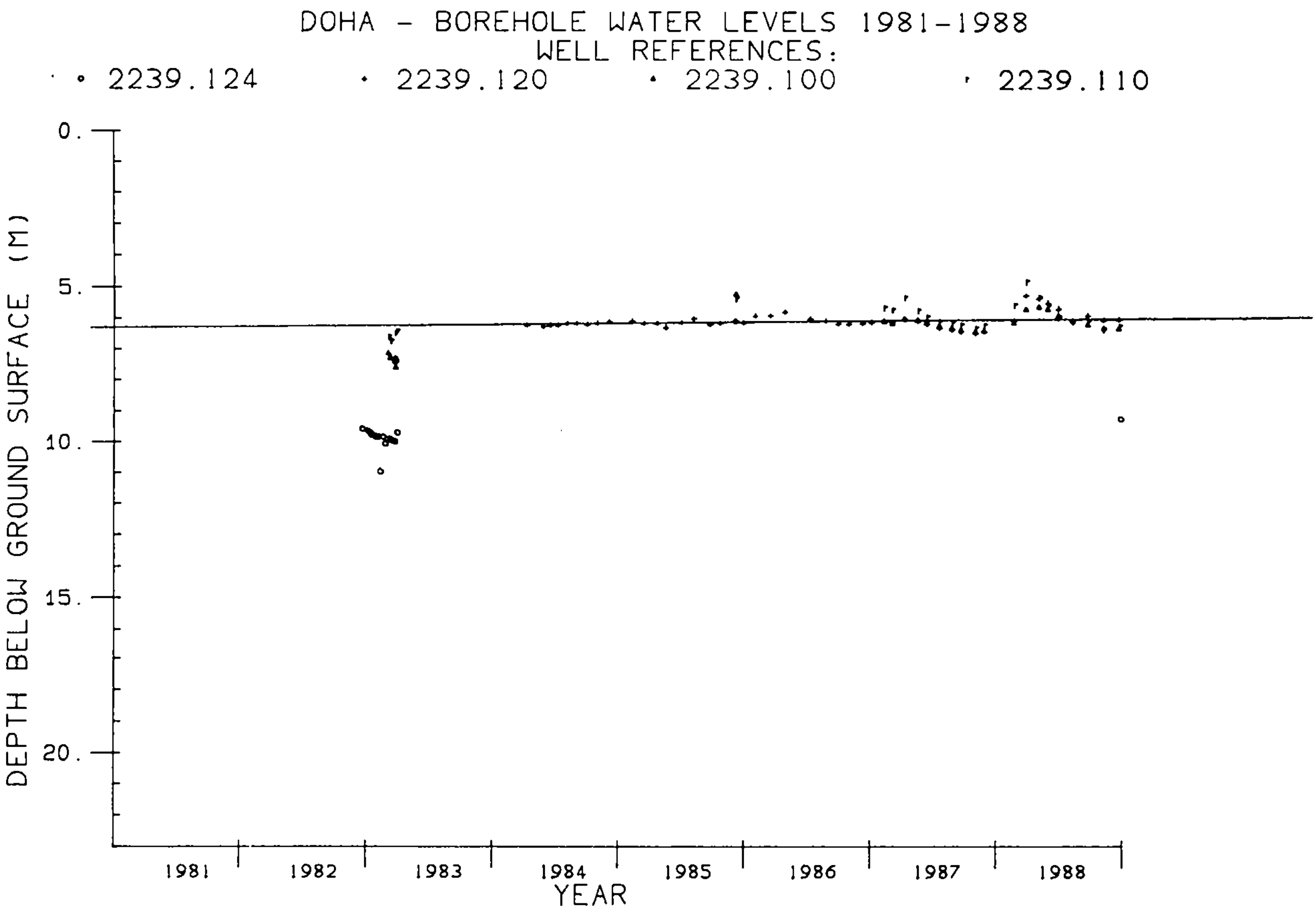
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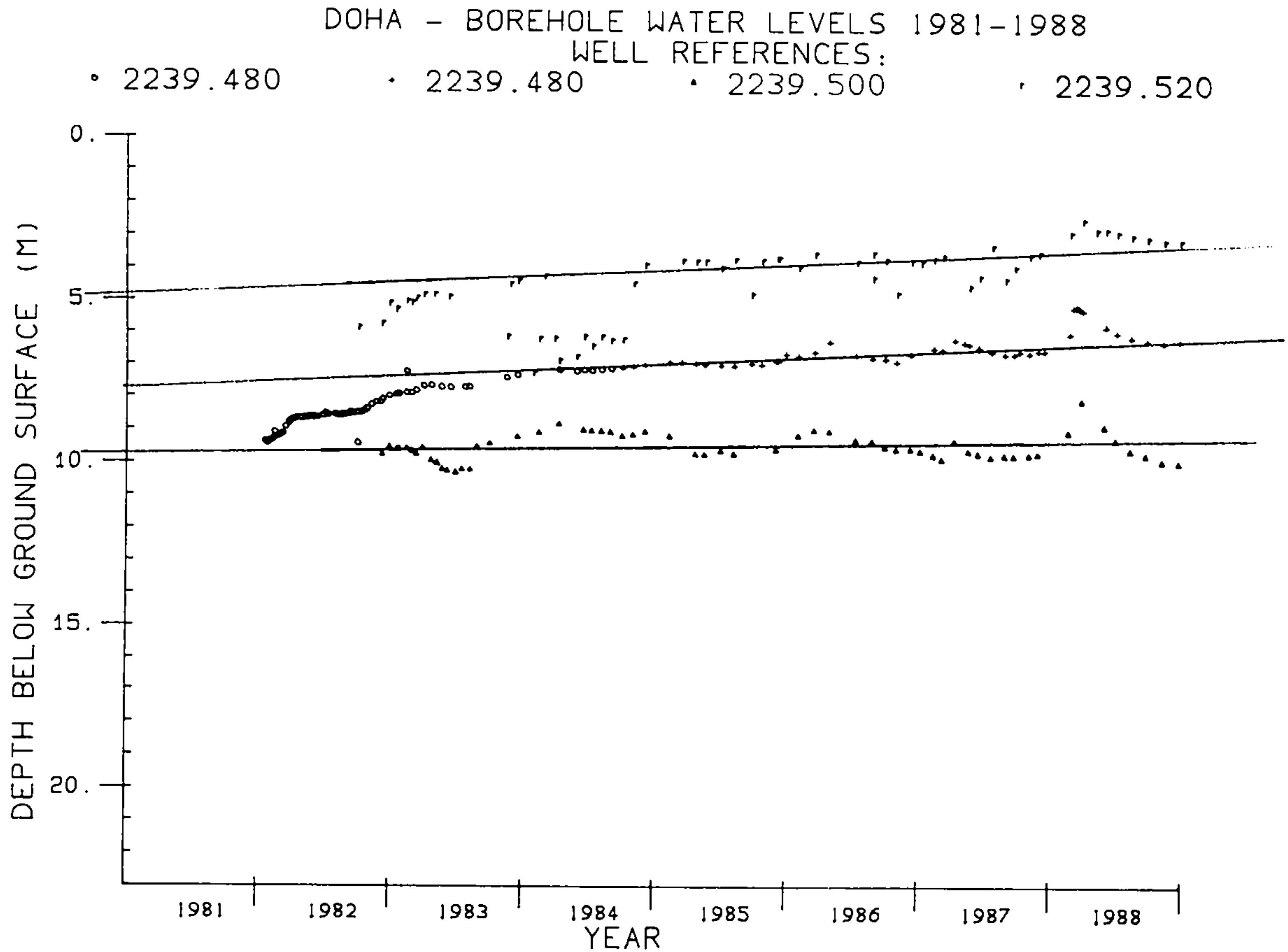
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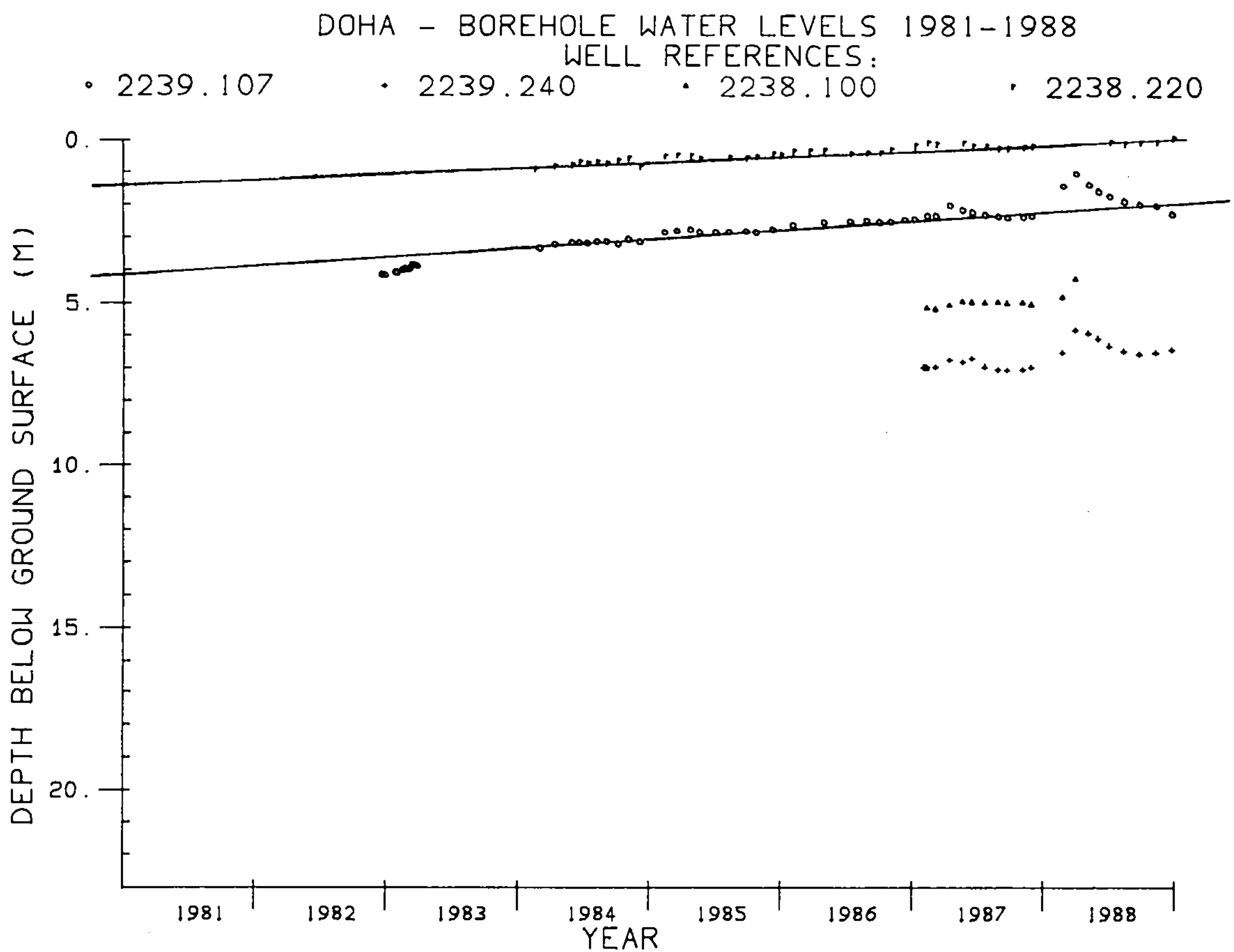
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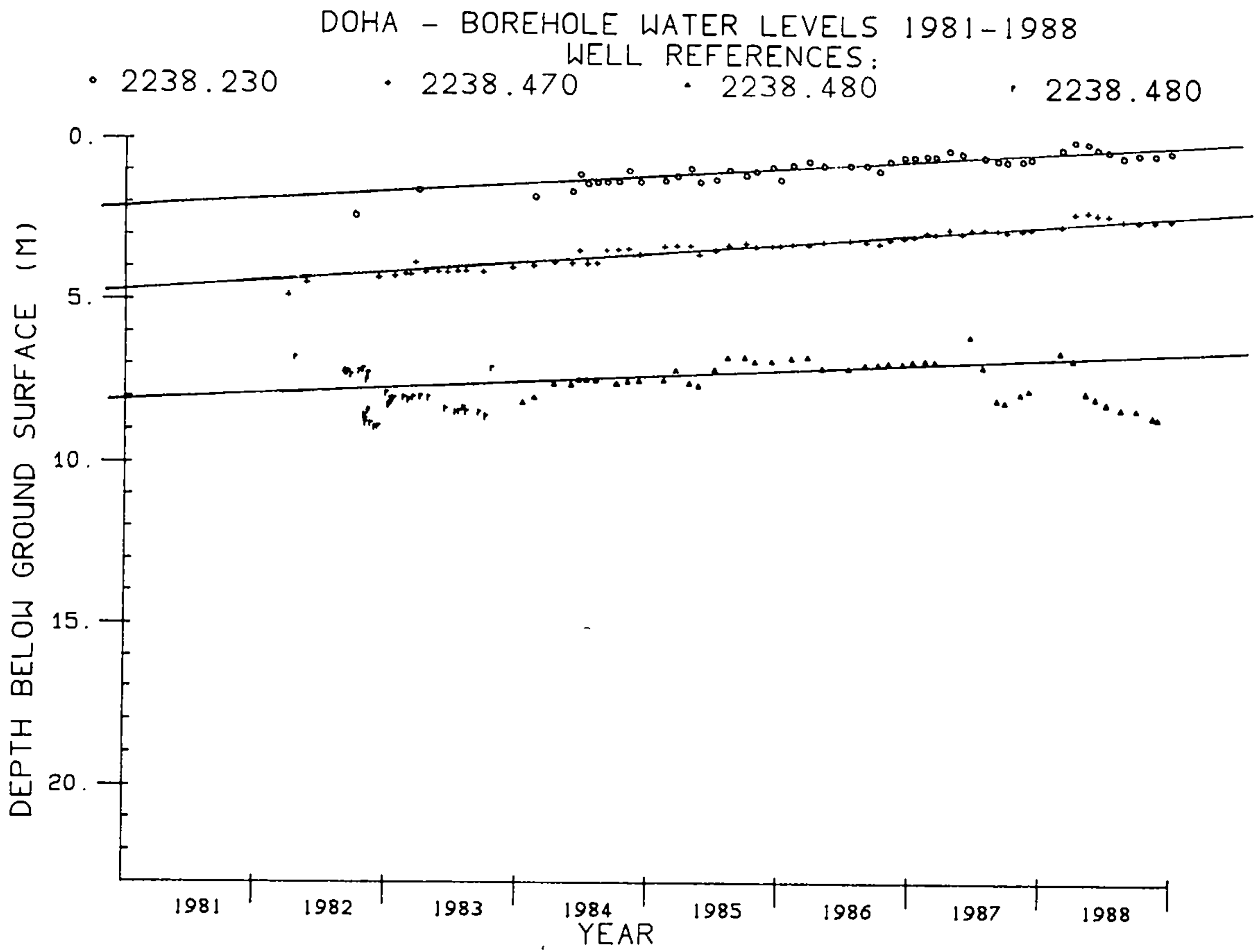
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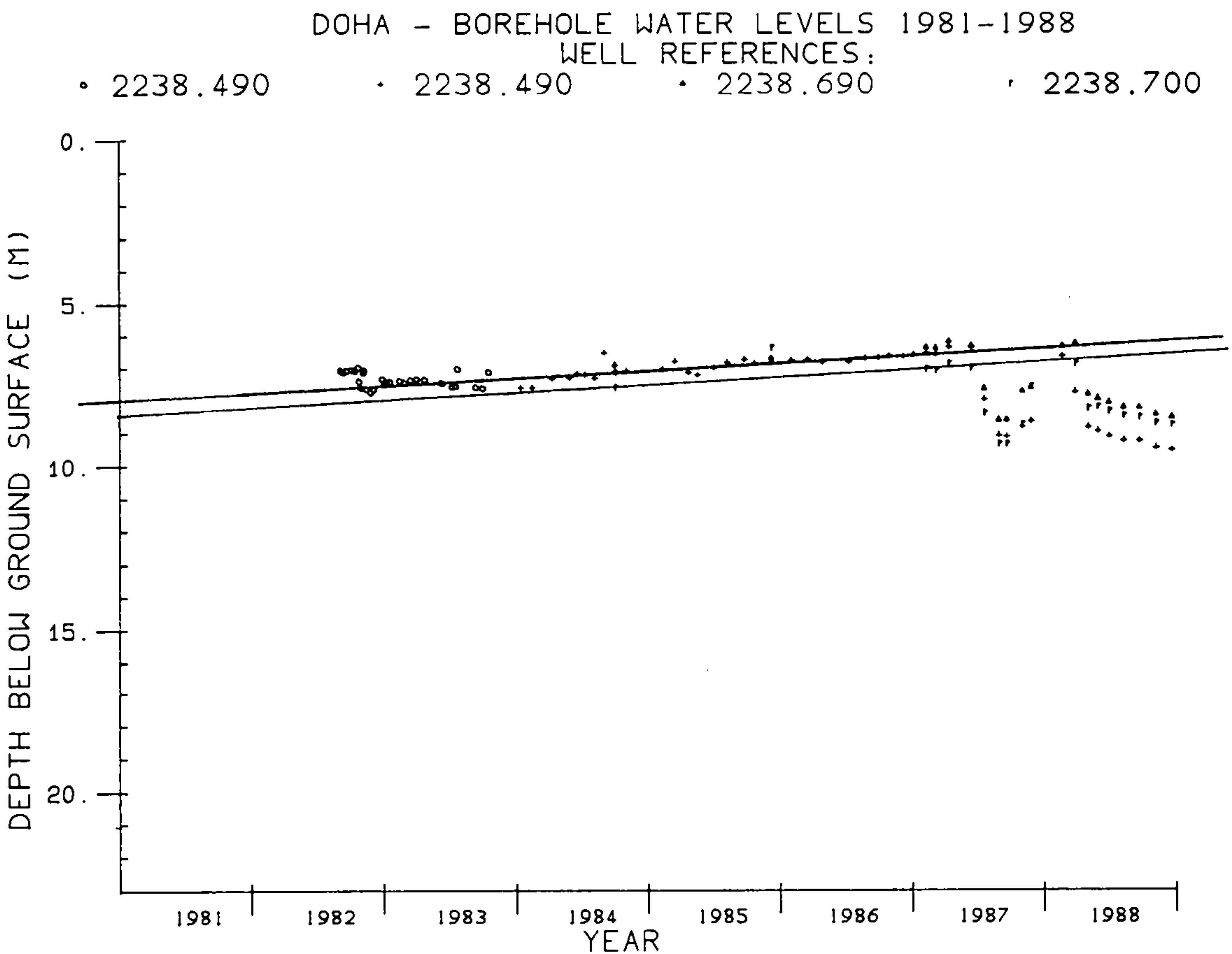
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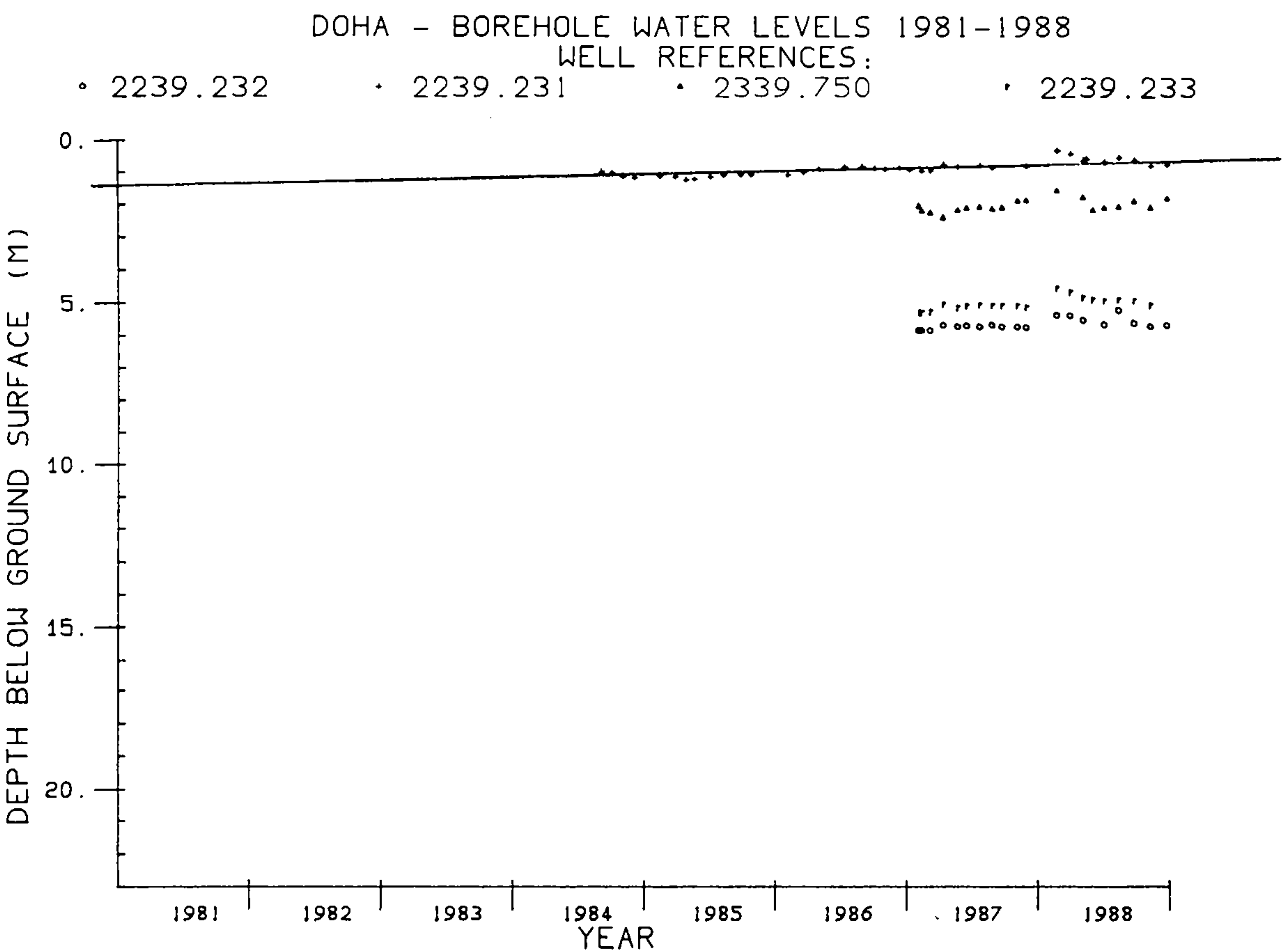
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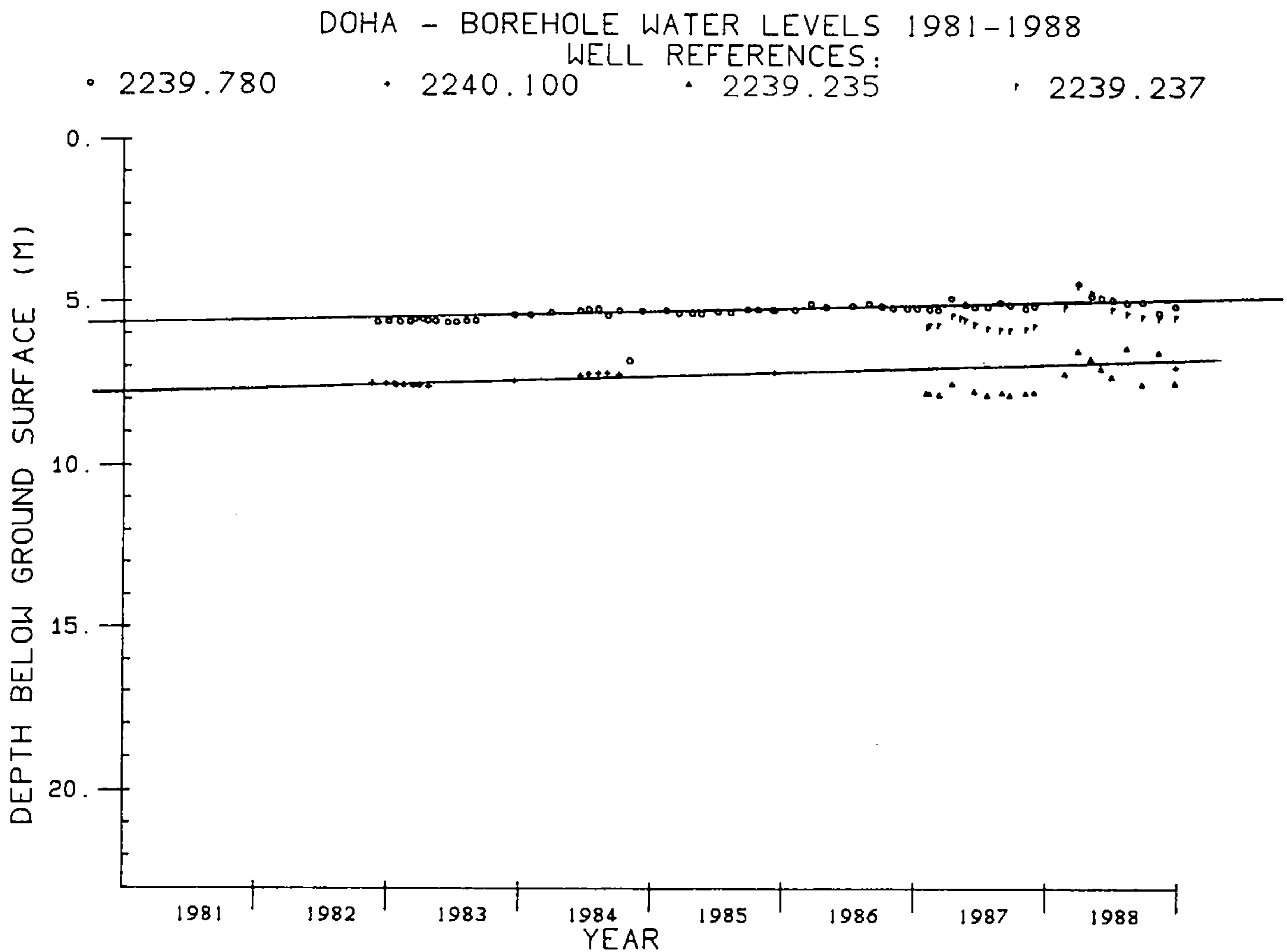
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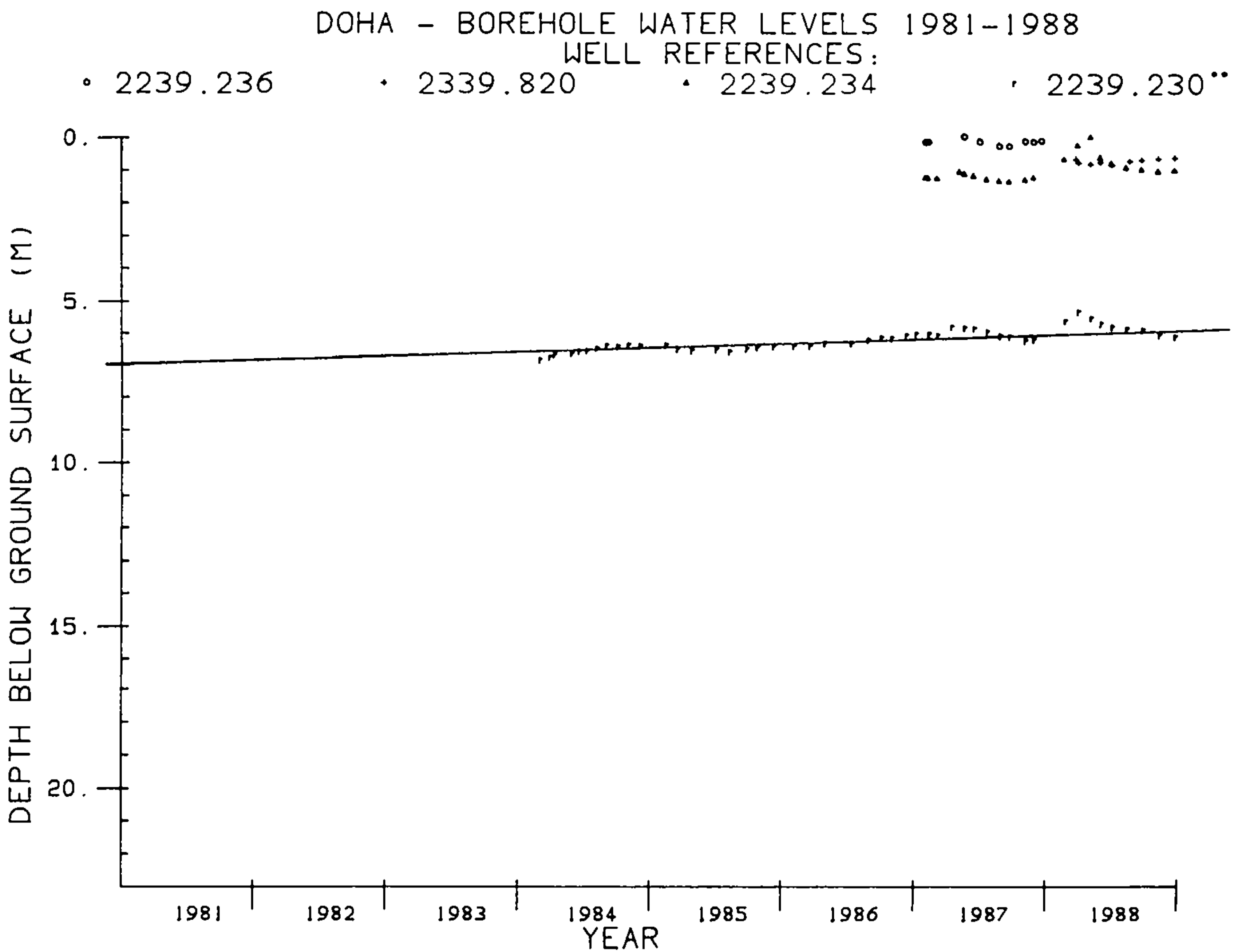
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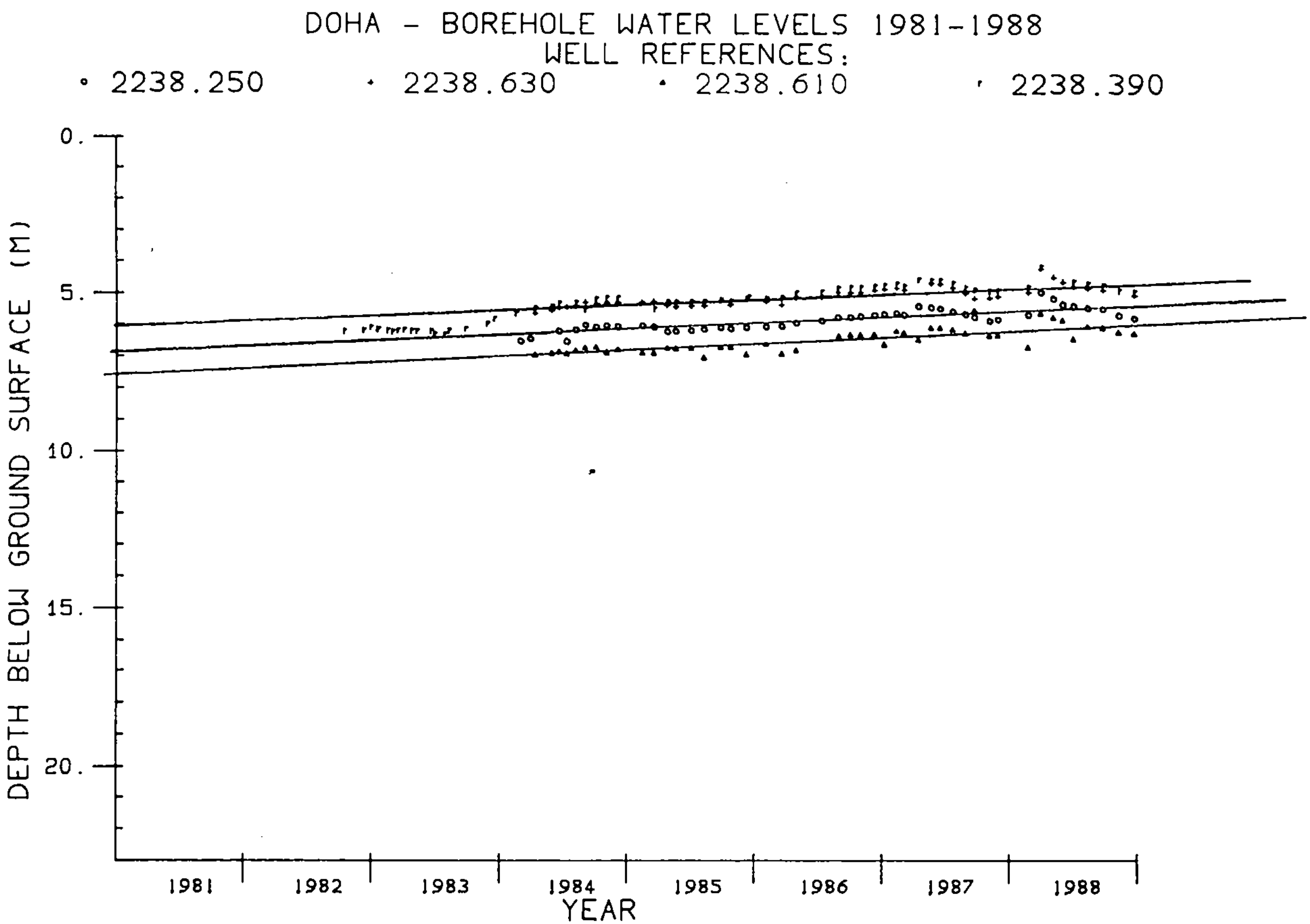
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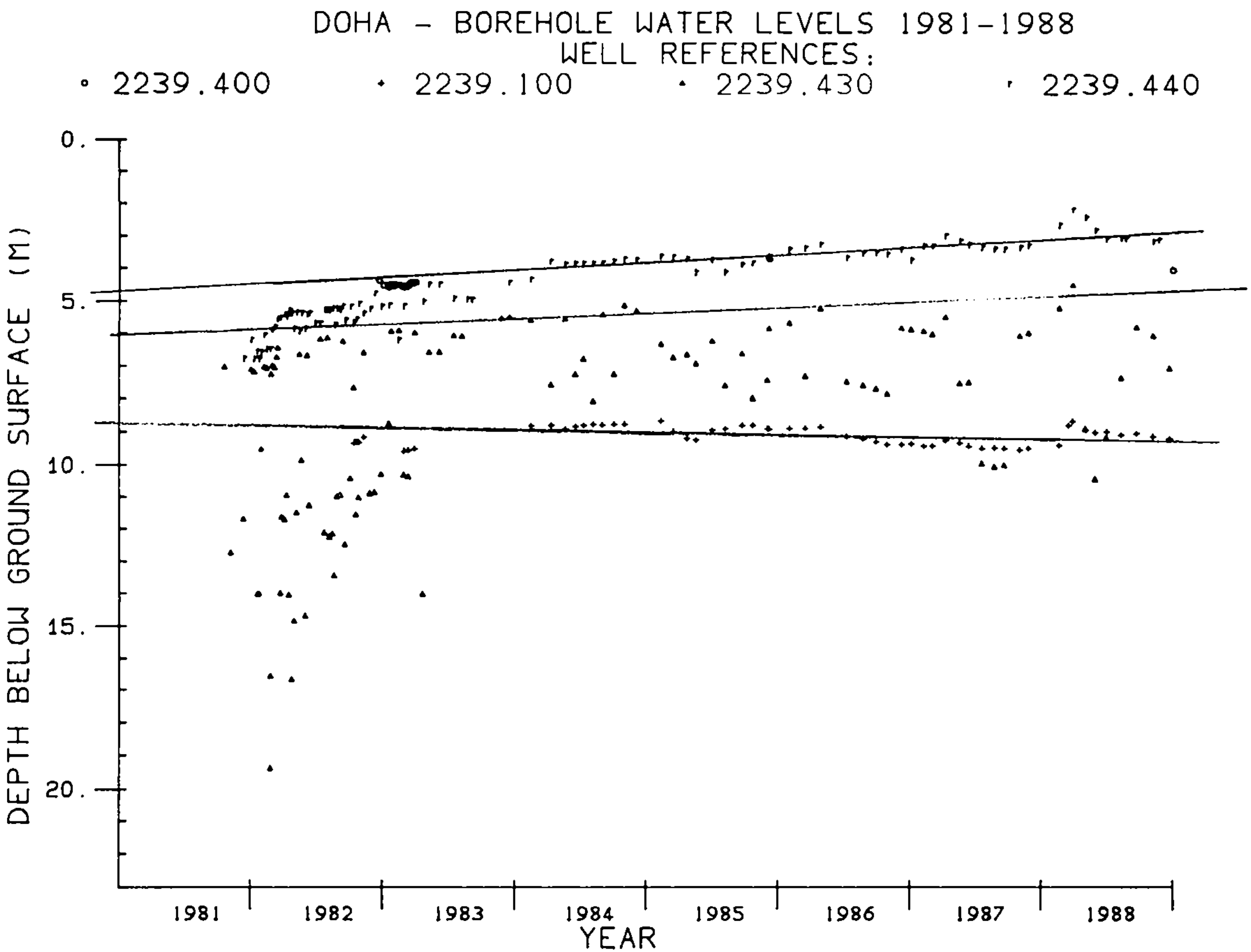
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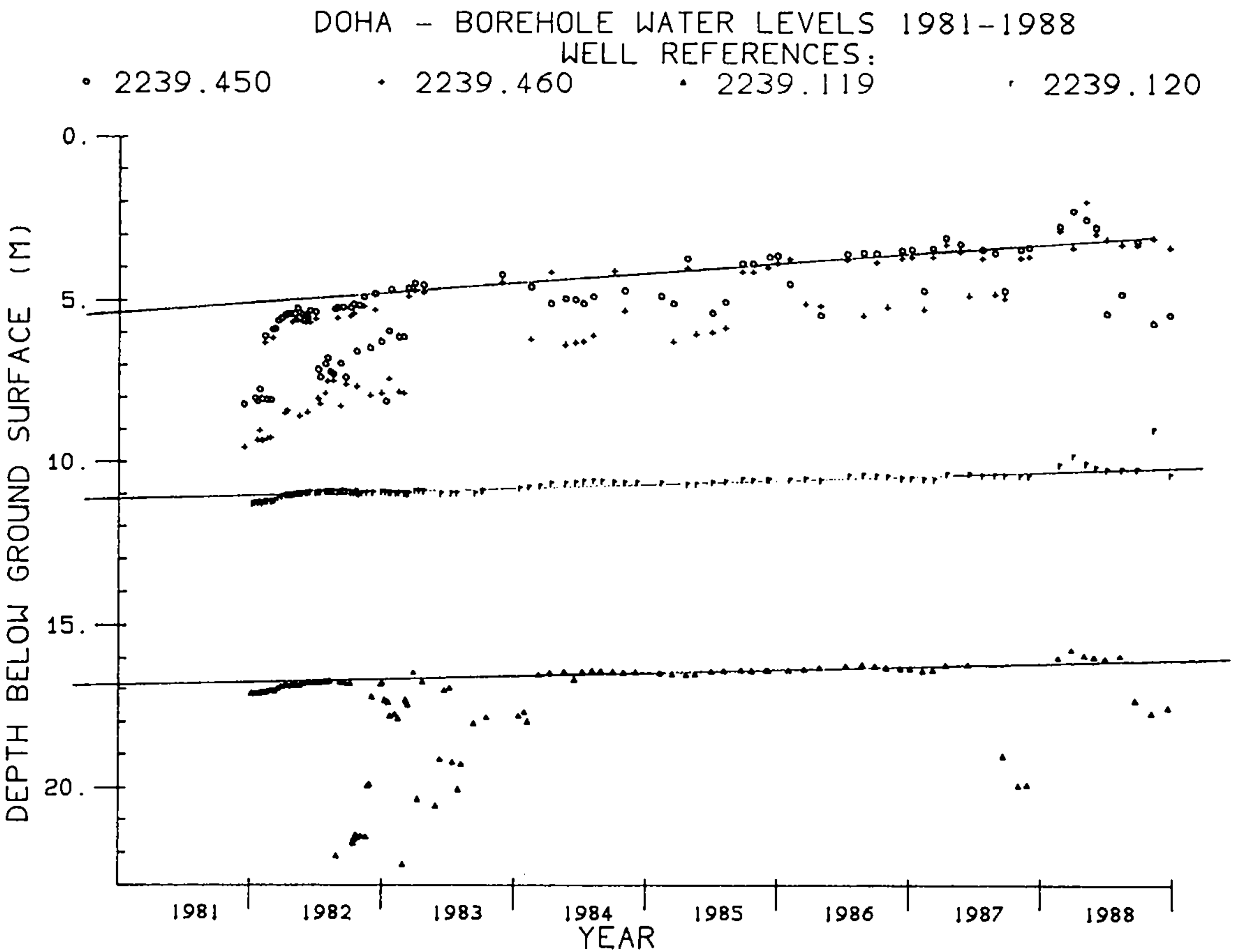
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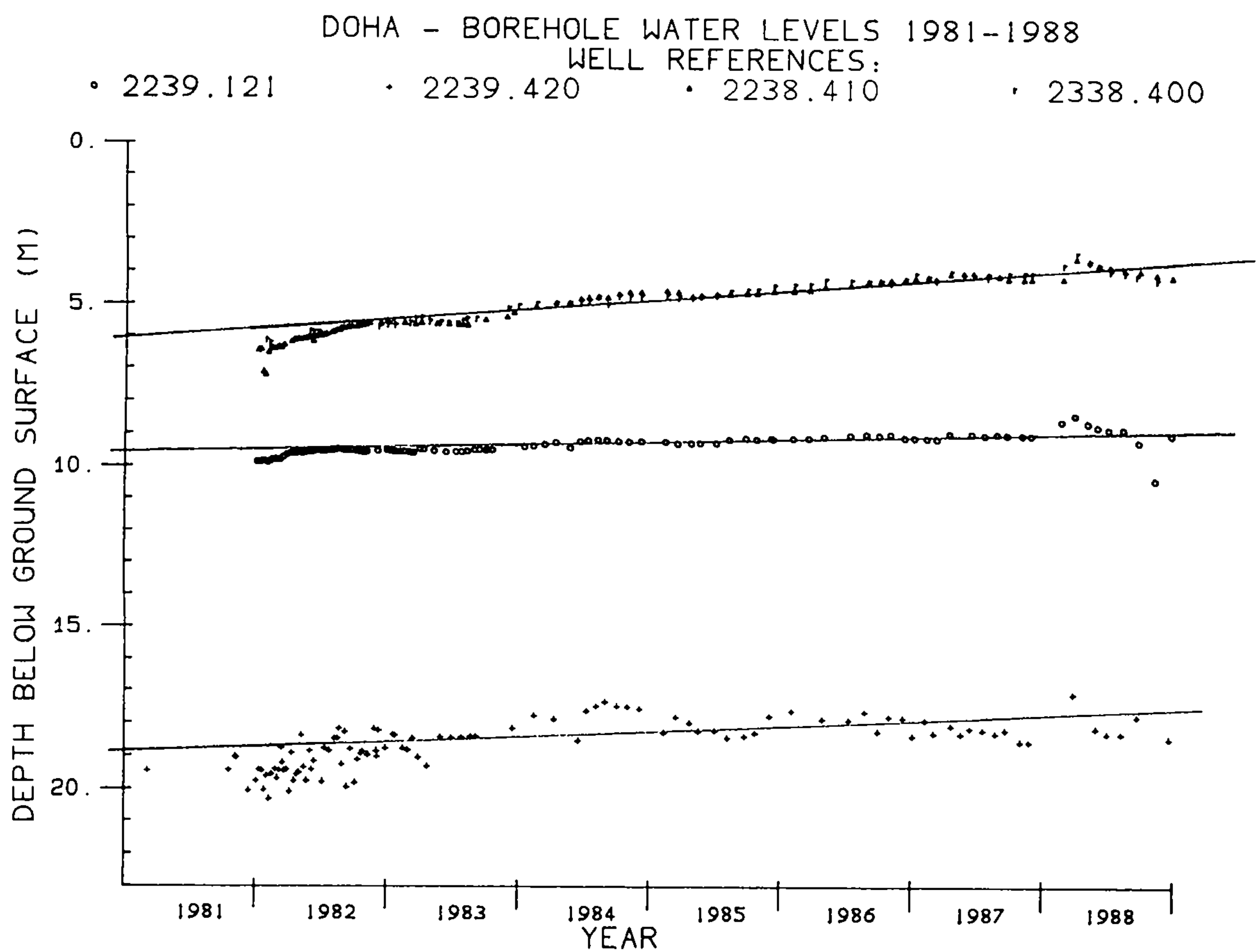

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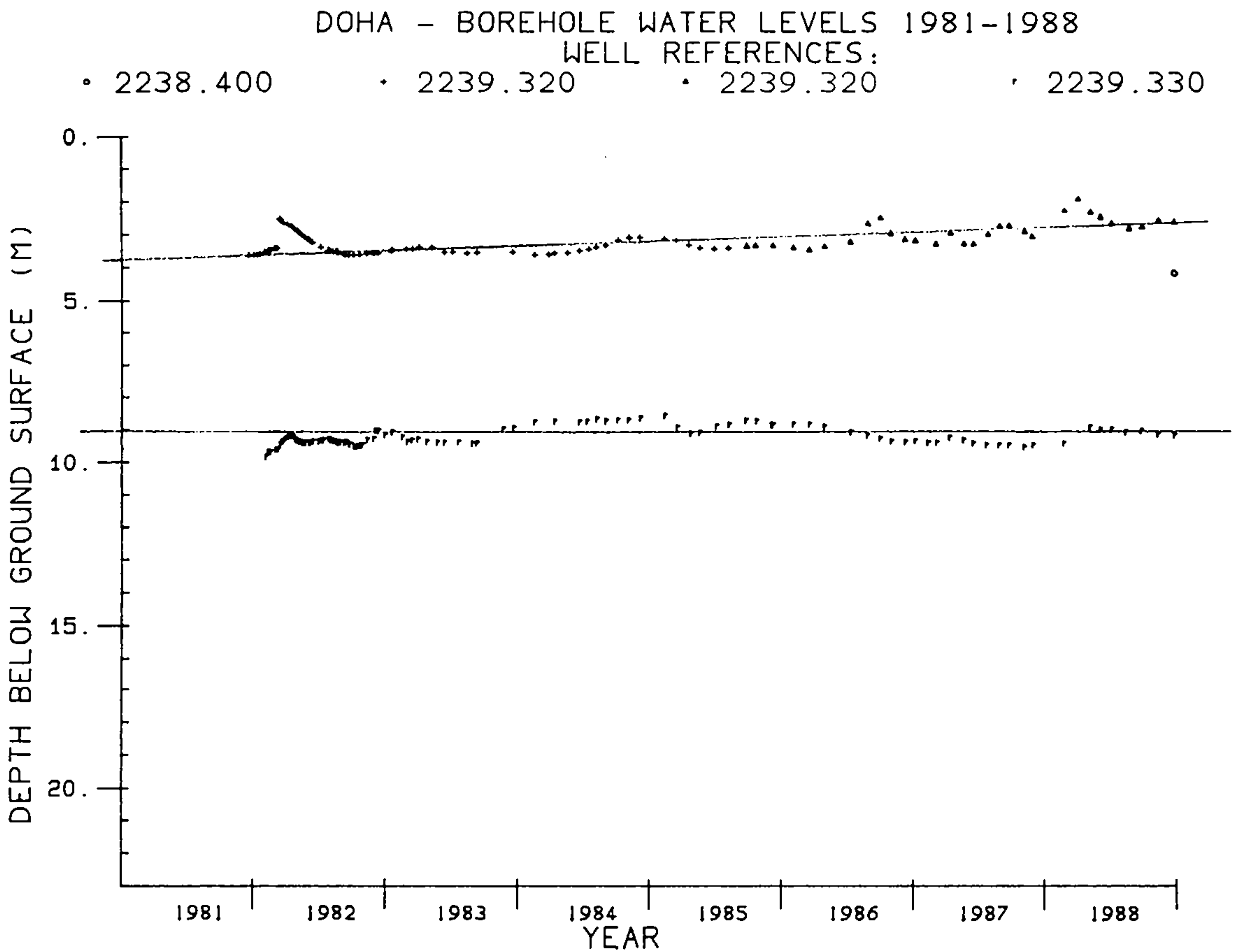

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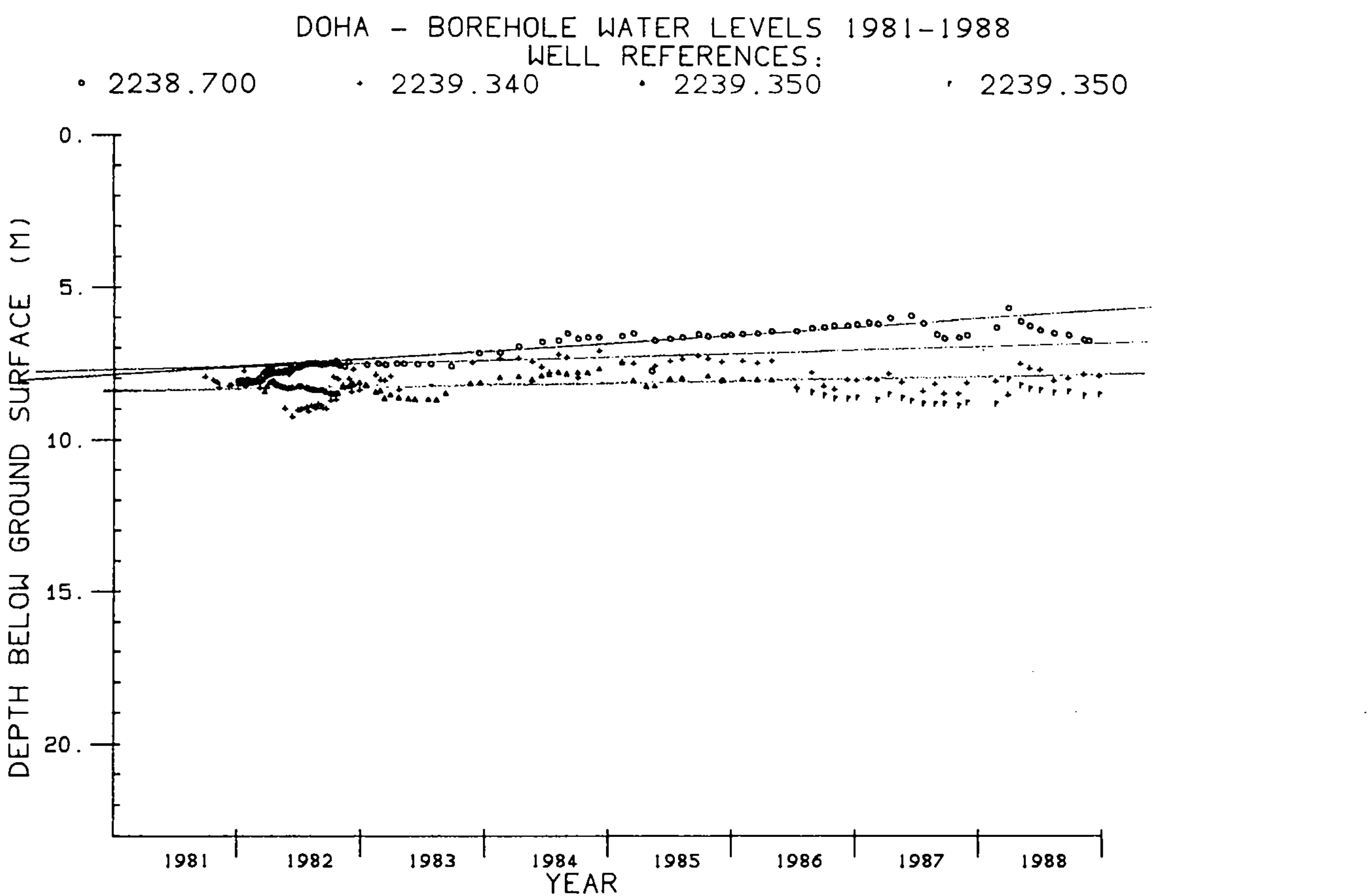
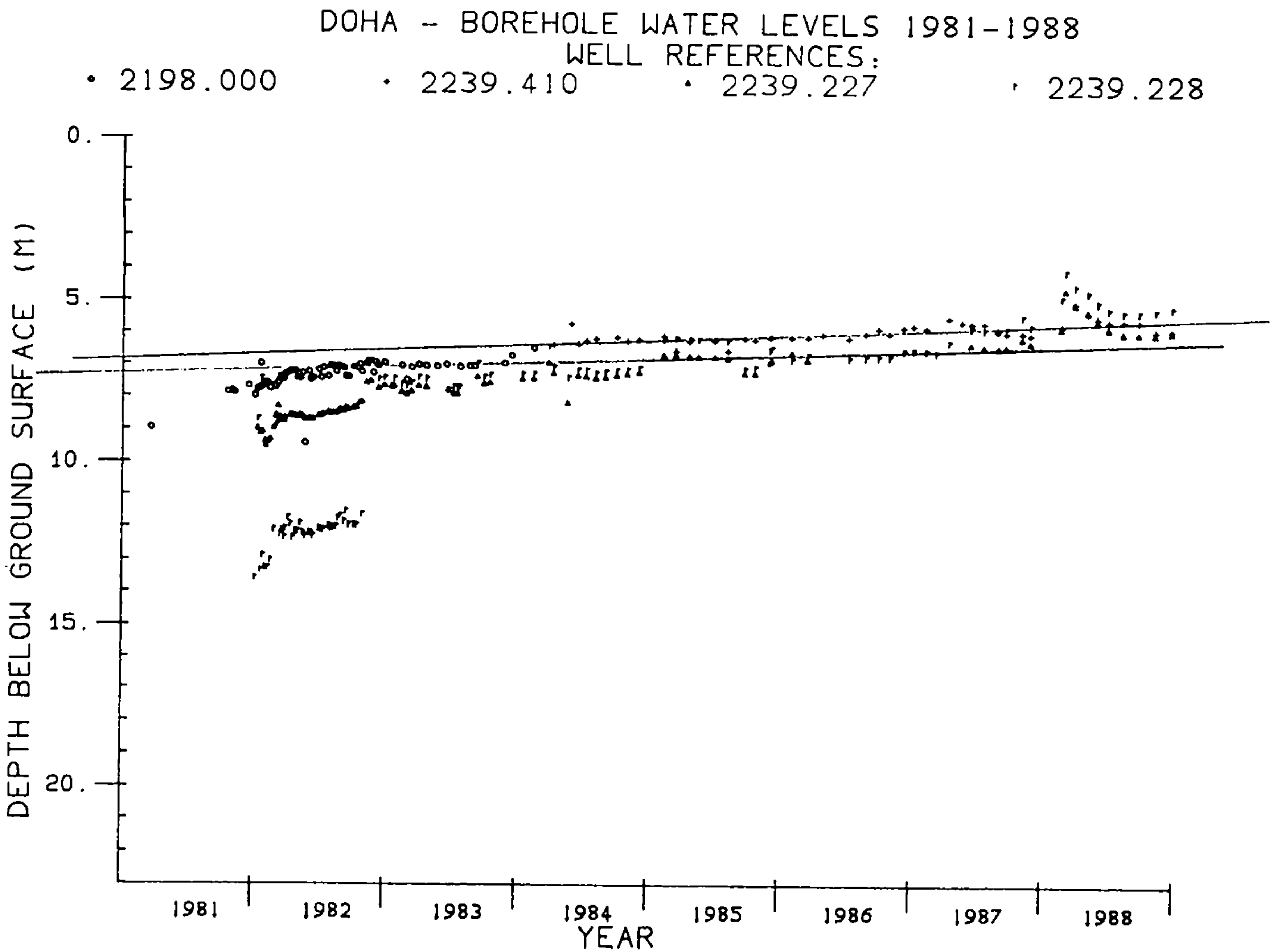

DOHA - BOREHOLE WATER LEVELS 1981-1988
WELL REFERENCES:
2238.700
2239.340
2239.350
2239.350
DEPTH BELOW GROUND SURFACE (M)
0.
5.
10.
15.
20.
1981
1982
1983
1984
1985
1986
1987
1988
YEAR


DOHA - BOREHOLE WATER LEVELS 1981-1988
WELL REFERENCES:
2198.000
2239.410
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2239.228
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1981
1982
1983
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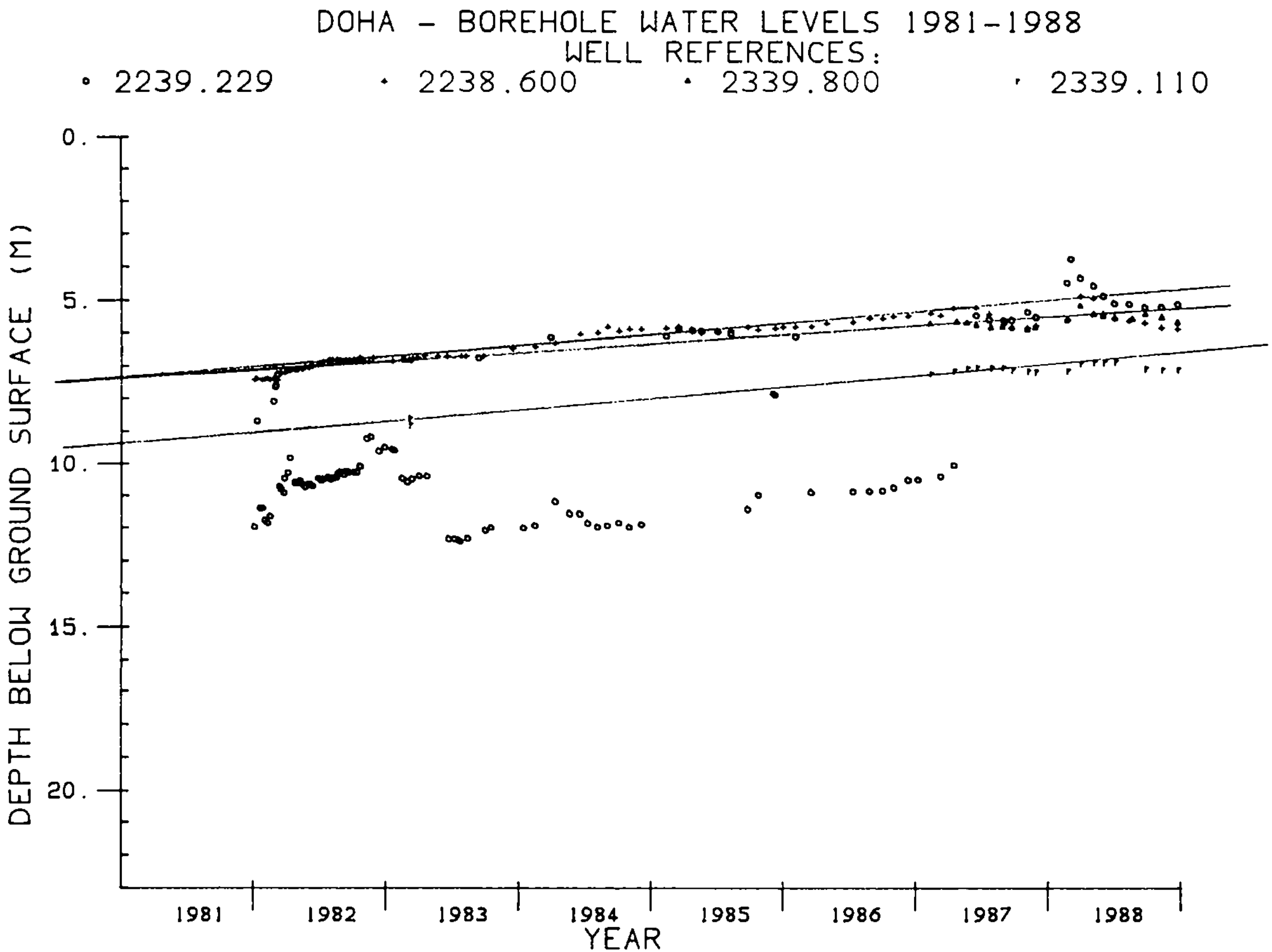
1987
1988
YEAR


DOHA - BOREHOLE WATER LEVELS 1981-1988
WELL REFERENCES:
2239.229
2238.600
2339.800
2339.110
DEPTH BELOW GROUND SURFACE (M)
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15.
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1982
1983
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1985
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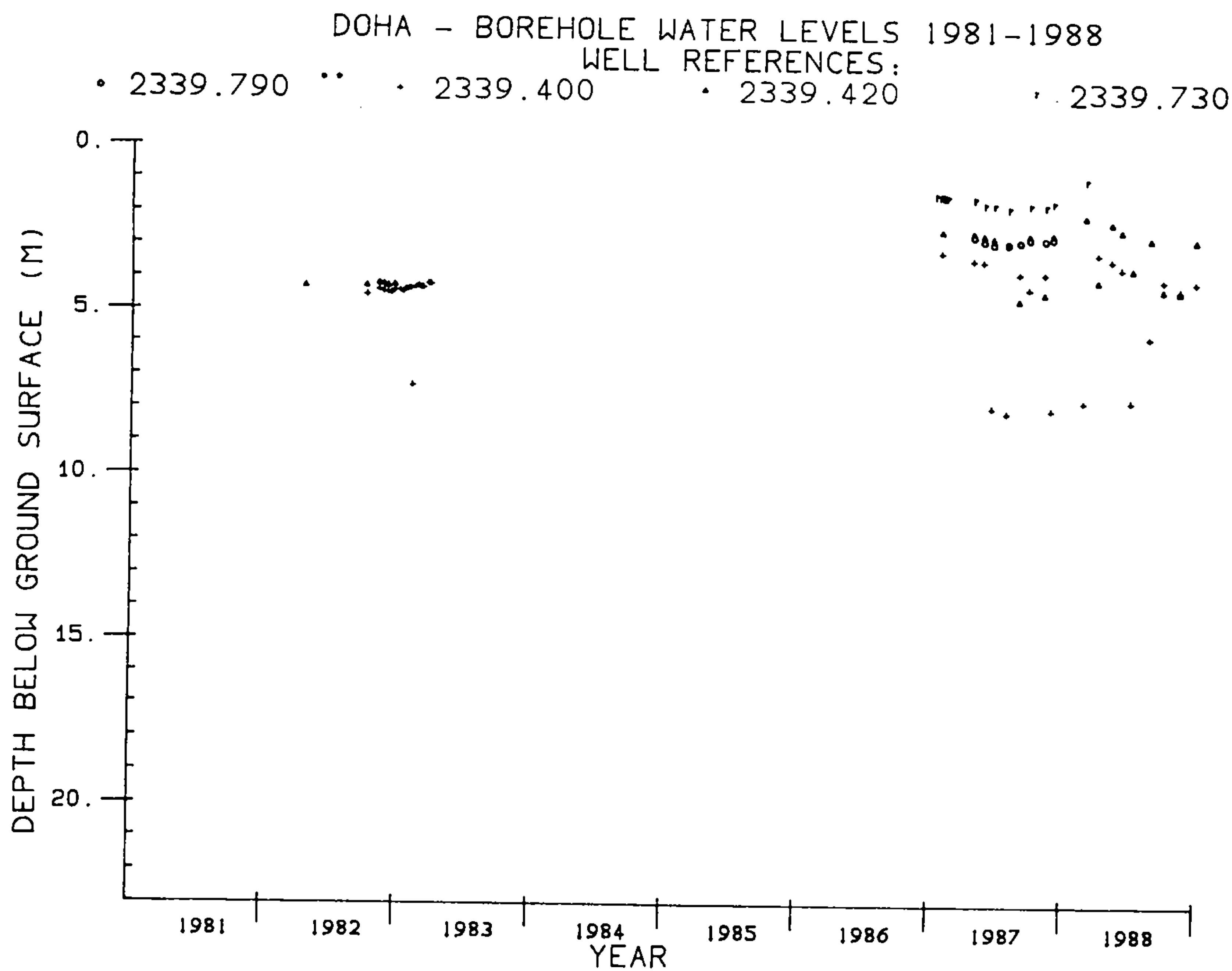
1988
YEAR


DOHA - BOREHOLE WATER LEVELS 1981-1988
WELL REFERENCES:
2339.790
2339.400
2339.420
2339.730
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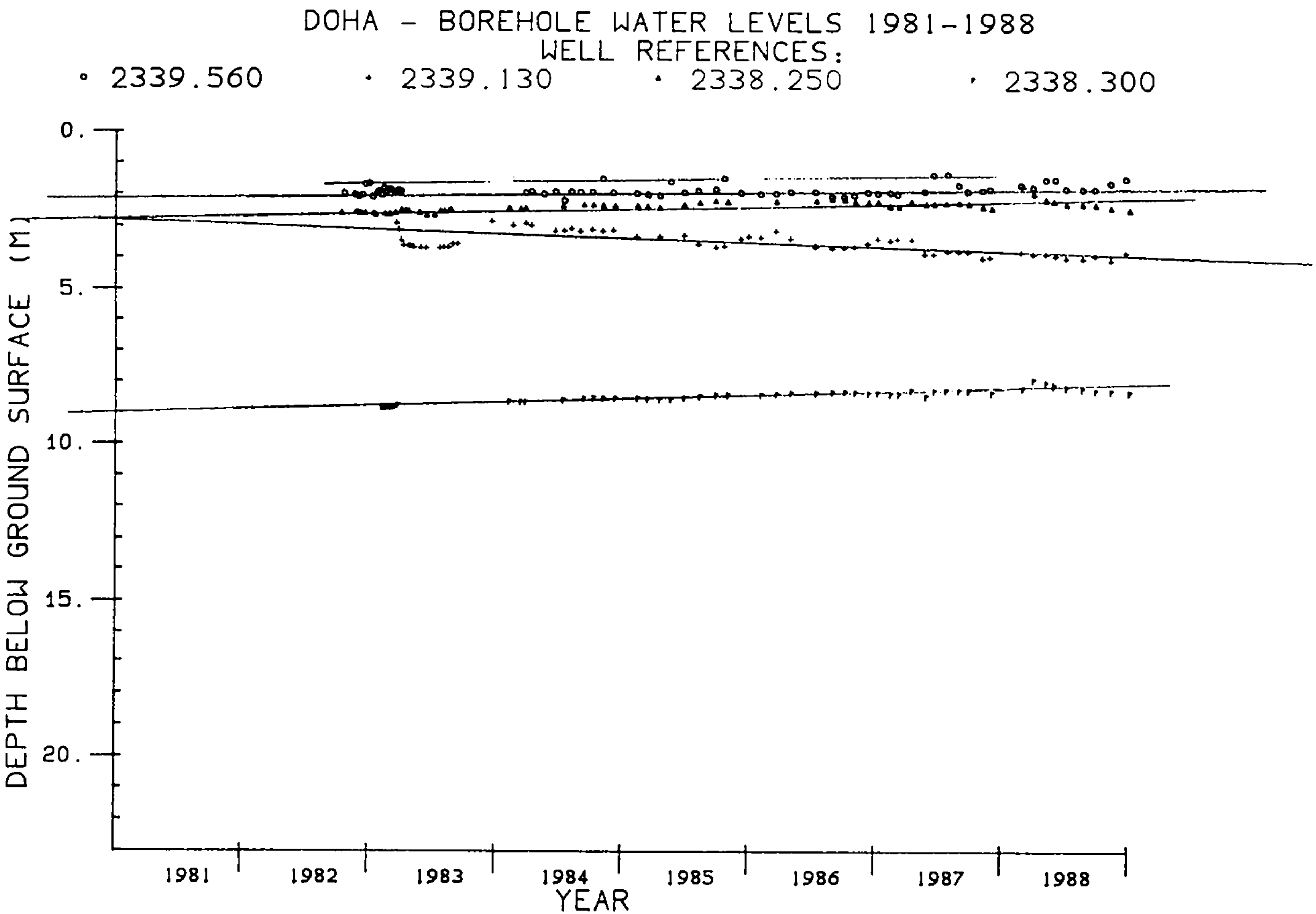
YEAR



DOHA - BOREHOLE WATER LEVELS 1981-1988
WELL REFERENCES:
2339.560
2339.130
2338.250
2338.300
DEPTH BELOW GROUND SURFACE (M)
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5.
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15.
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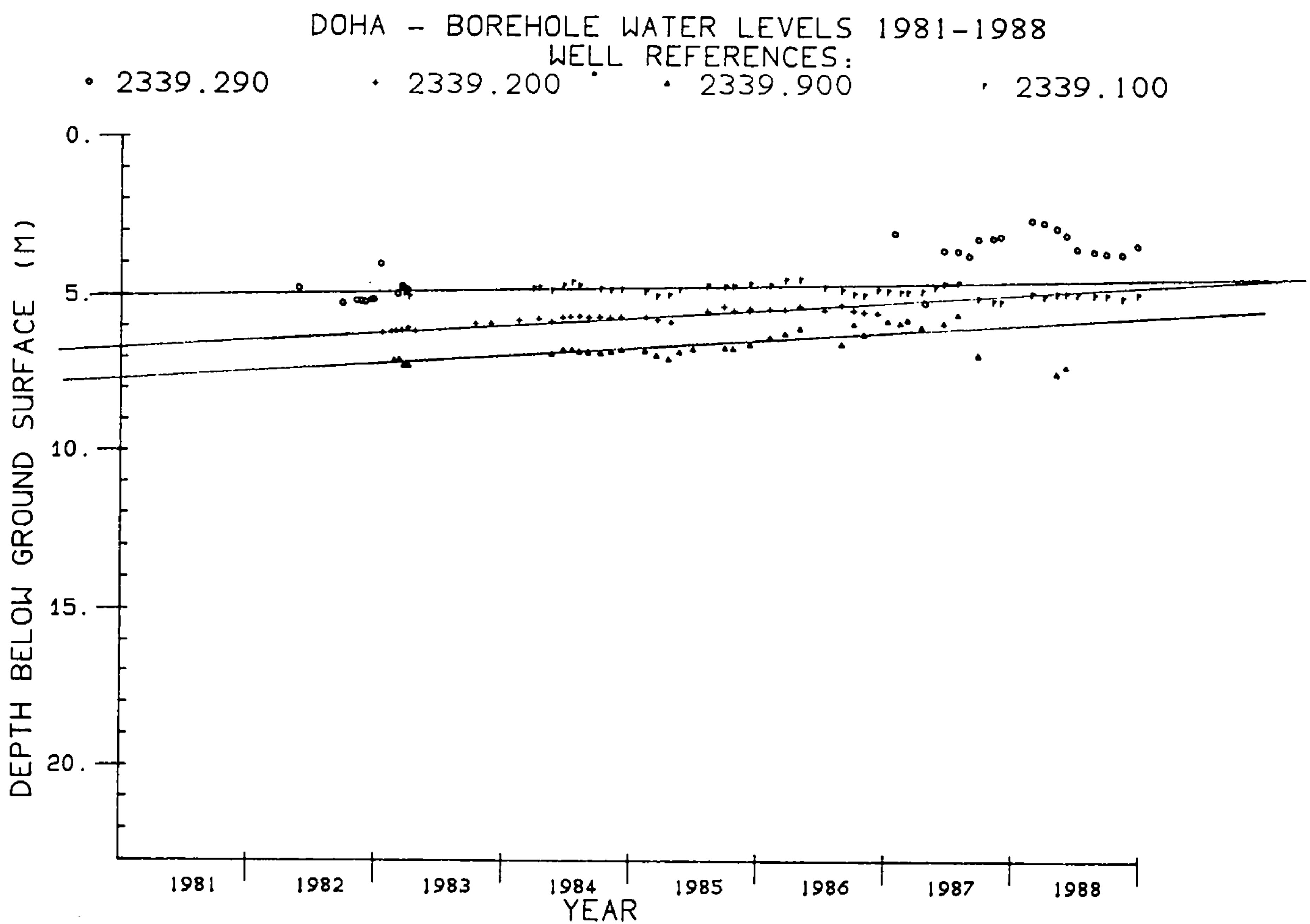
1981
1982
1983
1984
1985
1986
1987
1988
YEAR



DOHA - BOREHOLE WATER LEVELS 1981-1988
WELL REFERENCES:
2339.290
2339.200
2339.900
2339.100
DEPTH BELOW GROUND SURFACE (M)
0.
5.
10.
15.
20.
1981
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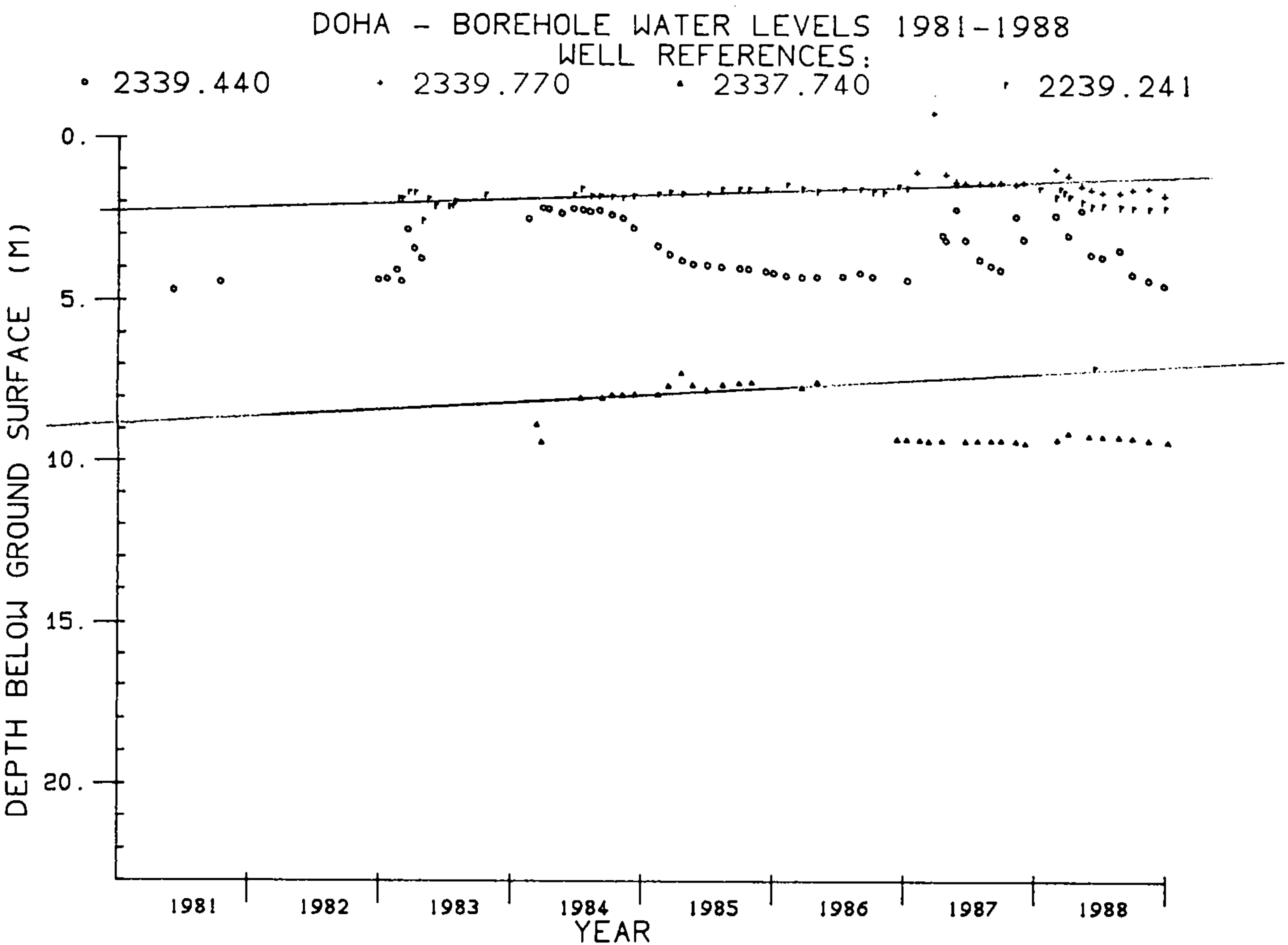
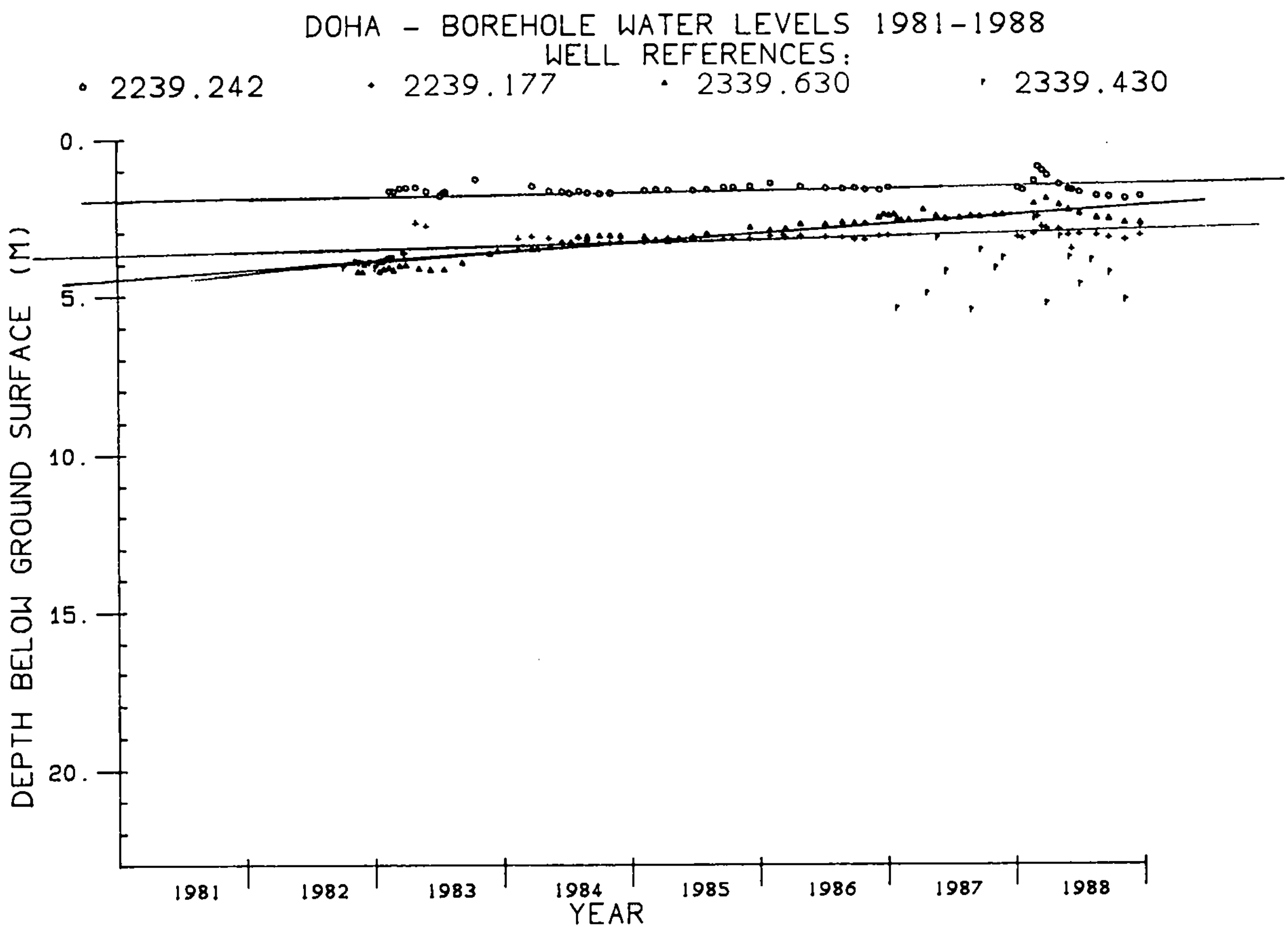
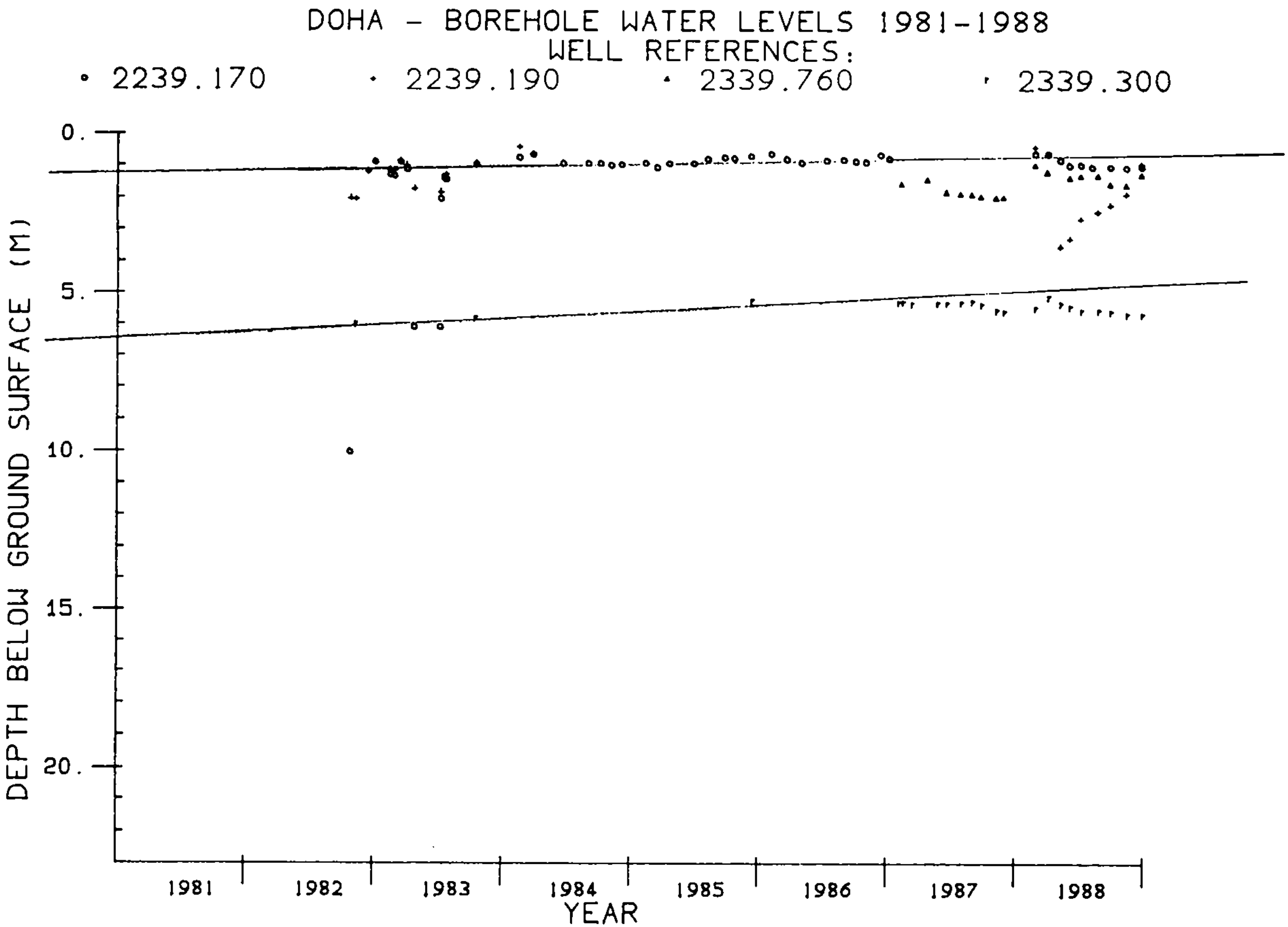
1987
1988
YEAR


DOHA - BOREHOLE WATER LEVELS 1981-1988
WELL REFERENCES:
2339.440
2339.770
2337.740
2239.241
DEPTH BELOW GROUND SURFACE (M)
0.
5.
10.
15.
20.
1981
1982
1983
1984
1985
1986
1987
1988
YEAR


DOHA - BOREHOLE WATER LEVELS 1981-1988
WELL REFERENCES:
2239.242
2239.177
2339.630
2339.430
DEPTH BELOW GROUND SURFACE (M)
0.
5.
10.
15.
20.
1981
1982
1983
1984
1985
1986
1987
1988
YEAR


DOHA - BOREHOLE WATER LEVELS 1981-1988
WELL REFERENCES:
2239.170
2239.190
2339.760
2339.300
DEPTH BELOW GROUND SURFACE (M)
0.
5.
10.
15.
20.
1981
1982
1983
1984
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1986
1987
1988
YEAR

Annex B

Water Level Trends

Annex B

Water Level Trends

Borehole Number	Estimated Annual Rate of Change in Water Level (m/year)
2339.310	0.137
2339.330	-0.050
2339.260	0.087
2239.700	0.137
2239.900	0.137
2239.128	0.112
2239.120	0.037
2239.480	0.212
2239.500	0.200
2239.520	0.212
2239.107	0.275
2238.220	0.175
2238.230	0.250
2238.470	0.300
2238.480	0.187
2238.490	0.250
2238.700	0.250
2239.231	0.075
2239.780	0.100
2240.100	0.137
2239.230	0.137
2238.250	0.200
2238.630	0.162
2238.610	0.212
2238.390	0.162
2239.100	-0.050
2239.430	0.175
2239.440	0.237
2239.460	0.300
2239.119	0.112

Borehole Number	Estimated Annual Rate of Change in Water Level (m/year)
2239.120	0.137
2239.121	0.075
2239.420	0.175
2238.410	0.300
2338.400	0.300
2239.320	0.287
2239.330	0.000
2238.700	0.162
2239.340	0.125
2239.350	0.075
2239.410	0.175
2239.228	0.137
2238.600	0.337
2239.800	0.262
2339.110	0.350
2339.200	0.250
2339.900	0.262
2339.100	0.087
2337.740	0.225
2239.241	0.150
2239.242	0.087
2239.177	0.100
2339.630	0.312
2239.170	0.075
2339.300	0.225
2339.560	0.037
2339.130	-0.137
2338.250	0.100
2338.300	0.125

Annex C

Site List

Annexe C

Site Listing

GRID REFERENCE		WELL REF. NO.	DATUM ELEVATION (M)	SURFACE ELEVATION (M)
0	0	2339.790	-9.900	-9.900
223086	392370	2339.120	4.620	4.145
223303	393930	2239.237	11.570	11.570
223320	390664	2239.240	12.476	12.416
223668	396257	2239.235	13.409	13.409
223690	395910	2239.229	11.490	11.150
223750	395920	2239.228	11.730	11.370
223840	395910	2239.227	12.370	11.370
224017	394598	2239.243	6.100	5.800
224217	394714	2239.236	5.621	5.461
224250	394470	2239.980	6.650	5.450
224392	392703	2239.238	11.587	11.587
224560	394340	2239.910	6.660	6.580
224695	395240	2239.234	7.100	7.017
224900	396200	2239.460	9.720	9.620
225100	396200	2239.450	9.820	9.420
225200	396100	2239.440	9.410	9.410
225560	393510	2239.700	14.240	14.140
225570	396380	2239.430	14.550	13.850
225930	394870	2239.900	14.690	14.690
226380	393190	2239.480	13.100	12.620
226380	393190	2239.480	13.120	12.620
226520	387970	2238.100	11.190	11.090
226630	396120	2239.128	17.020	16.470
226630	396600	2239.500	15.390	15.190
226660	399150	2239.119	18.440	18.200
226680	399440	2239.120	12.580	12.280
226720	400060	2240.100	9.100	8.500
226790	399450	2239.121	11.170	10.870
227250	391120	2239.520	10.070	9.770
227460	393460	2239.120	13.110	12.900
227460	393470	2239.100	12.950	12.800
227460	393480	2239.110	13.000	12.900
227470	389180	2238.430	13.680	12.860
227500	389200	2238.480	13.680	12.360
227500	389200	2238.490	14.140	12.860
227520	389150	2238.490	14.140	13.290
227530	389030	2238.690	13.900	13.800
227620	387900	2233.220	6.840	6.440
227690	389040	2238.700	13.800	13.300
227720	394080	2239.124	16.950	16.640
227730	389170	2238.700	13.710	13.410
227747	394363	2239.239	19.603	19.500
227800	389300	2238.600	13.290	12.740
227810	388120	2233.230	7.280	6.970
227900	397600	2239.730	8.870	8.080
228050	389450	2238.630	12.830	12.350
228200	396060	2239.420	21.710	21.360
228290	390130	2239.230	-9.900	-9.900
228300	390100	2198.000	13.680	13.460
228300	390180	2239.410	13.680	13.460
228430	389990	2238.250	13.060	13.060
228520	336380	2238.470	9.130	8.540

GRID REFERENCE	WELL REF. NO.	DATUM ELEVATION (M)	SURFACE ELEVATION (M)
228690 389270	2238.390	12.770	12.240
228810 388410	2238.610	14.060	13.510
228956 397285	2239.233	6.469	6.469
229020 392060	2239.190	6.840	5.960
229030 392150	2239.241	7.220	6.700
229030 392160	2239.242	7.280	6.780
229030 392140	2239.177	7.070	6.710
229090 392150	2239.170	6.950	6.290
229300 393300	2239.340	12.940	12.610
229400 393200	2239.350	13.620	13.280
229420 393170	2239.350	13.620	13.280
229600 393400	2239.330	14.030	13.680
229610 393410	2239.100	14.140	13.830
229700 391100	2239.320	11.750	11.450
229710 389350	2238.410	11.950	11.580
229710 389350	2238.400	11.950	11.580
229710 391050	2239.320	11.750	11.450
229747 395398	2239.232	7.689	7.309
229880 396080	2239.231	2.465	2.215
230010 390480	2339.800	14.390	14.290
230010 390470	2339.110	14.440	14.370
230450 391310	2339.440	11.840	11.140
230462 391613	2339.770	8.322	8.322
230718 392087	2339.800	4.905	4.905
230732 392040	2339.810	5.729	5.422
230732 392040	2339.810	4.922	5.422
230748 391967	2339.820	5.060	4.962
230900 392400	2339.120	4.620	4.145
230900 392400	2339.210	4.400	4.040
230900 392400	2339.220	4.550	4.000
230980 392040	2339.500	5.350	5.350
231060 390210	2339.630	9.320	9.300
231310 396943	2339.750	2.049	2.049
231395 390200	2339.730	8.412	8.200
231480 391030	2339.310	9.000	8.620
231670 390210	2339.400	9.260	8.920
231670 391920	2339.330	7.310	7.010
231690 392680	2339.130	6.350	6.100
231890 390400	2339.430	8.470	8.270
231910 390490	2339.420	8.910	8.810
232010 389360	2338.400	10.520	9.790
232560 390450	2339.290	10.320	9.320
232608 392204	2339.760	7.097	7.157
232626 390060	2239.107	8.400	7.950
232813 392600	2239.400	10.520	10.420
233150 391550	2339.900	11.220	10.960
233420 392830	2339.560	2.640	2.230
233460 392350	2339.100	9.200	9.000
233680 390660	2339.300	7.780	7.600
233680 390670	2339.200	7.650	-9.900
234210 391470	2339.260	9.800	9.200
234990 387500	2338.300	9.970	9.890
235110 389020	2338.250	4.430	3.870
236800 379400	2337.740	3.800	-9.900

Legend

-9.9 No elevation available

0 No grid reference available

Annex D

Water Levels, December 1988

Annexe D

Water Levels, December 1988

GRID REFERENCE	WATER LEVEL DECEMBER 1988 (METRES B.G.L.)
223036 392370	0.00
223303 393930	5.45
223320 390664	6.40
223668 396237	7.49
223690 395910	5.14
223750 395920	5.20
223840 395910	5.95
224017 394598	0.60
224217 394714	0.03
224250 394470	0.25
224392 392703	4.93
224560 394340	0.57
224695 395240	0.97
224900 396200	3.38
225200 396100	3.15
225560 393510	7.78
225570 396380	6.10
225930 394870	8.18
226380 393190	6.20
226520 387970	4.25
226630 396600	9.95
226630 396120	10.92
226680 399440	10.40
226720 400060	5.16
226790 399450	8.98
227250 391120	3.13
227460 393460	6.06
227460 393470	6.38
227460 393480	6.29
227470 389180	6.08
227520 389150	6.64
227530 389030	6.27
227620 387900	-0.08
227720 394080	9.25
227730 389170	6.74
227747 394363	9.43
227800 389300	5.37
227810 388120	0.37
227900 397600	5.11
228050 389450	5.05
228300 390180	5.35
228430 389990	5.81
228520 386380	2.46
228670 389270	4.98
228810 388410	6.29
228956 397285	5.00
229020 392060	0.93
229030 392150	2.09
229030 392160	1.91
229030 392140	3.14

GRID REFERENCE	WATER LEVEL DECEMBER 1988 (METRES B.G.L.)
229090 392150	1.03
229300 393300	7.38
229420 393170	3.49
229600 393400	9.14
229610 393410	9.21
229710 389350	4.16
229710 389350	4.16
229710 391050	2.61
229747 [illegible]	5.57
229830 396030	0.76
230010 390430	5.70
230010 390470	7.12
230450 391310	4.54
230462 391613	1.77
230718 392037	0.80
230732 392040	0.50
230748 391967	0.67
230900 392400	1.67
230900 392400	1.65
230980 392040	0.61
231060 390210	2.78
231310 396943	1.82
231395 390200	0.96
231480 391030	1.47
231670 390210	4.06
231670 391920	1.47
231690 392680	3.82
231890 390400	2.89
231910 390490	2.80
232560 390450	3.42
232608 392204	1.30
232626 390060	2.28
232813 392600	4.03
233150 391550	7.31
233420 392830	1.50
233460 392350	4.97
233630 390360	5.72
234210 391470	3.14
234990 387590	3.36
235110 389020	2.52

Annex E

Net Recharge from Water Balance Study (adjusted to model areas A - E)

Zone A QAT Zone	Percentage	Total Recharge	Outflow	Net Recharge
55	100	1226953	373030	853922.5
57	100	450761	81760	369000.8
82	90	1048996	274883.2	774112.5
83	50	455218	119287.1	335930.7
85	100	1591543	745505.1	846037.4
86	70	1127774	383750.4	744023.4
Totals		5901243	1978216	3923027

Zone B QAT Zone	Percentage	Total Recharge	Outflow	Net Recharge
15	100	598151	0	598151.5
32	100	98762	0	98762.03
52	100	114368	0	114367.8
53	100	726418	0	726417.6
54	100	514008	0	514008.2
56	100	501928	16272	485656.5
98	40	222297	0	222296.9
100	100	48580.3	0	48580.3
101	50	73226	48727.5	24498.54
102	100	193528	159505	34022.68
103	100	212252	229950	-17698.1
104	100	207175	174835	32339.87
105	100	263621	212900	50721.35
		3774315	842189.5	2932125

Zone C QAT Zone	Percentage	Total Recharge	Outflow	Net Recharge
16	100	633385	277400	355985.1
28	100	160427	118893.3	41534.15
29	100	69333.9	40962.07	28371.87
33	100	308551	0	308551.1
34	100	233262	0	233262
35	100	413062	164980	248082.2
36	100	365381	127584.1	237797.3
37	100	438458	153100.9	285356.8
38	100	329861	115734.5	214126.8
39	100	355235	124637.2	230598.1
40	100	717237	251648.3	465588.5
41	100	365940	232889.1	133050.9
42	100	464527	295630.9	168895.7
43	100	243290	0	243289.6
44	100	496523	0	496523
45	100	169041	107747.6	61293.57
46	100	190439	121386.5	69052.25
47	100	404415	257775.9	146639.1
48	100	201376	0	201375.7
49	100	172128	0	172128.2
50	100	116627	0	116626.9
58	100	964706	473728.3	490977.8
59	100	165889	73745.65	92142.96
61	100	270000	377384.8	-107385
62	100	725994	119575.9	606417.8
63	100	585915	319810.4	266104.7
64	100	346737	49310.46	297426.4
65	100	833219	118494.5	714724.7
66	100	214369	26648.59	187720.4
67	100	211375	26276.41	185098.6
68	100	228757	0	228756.6
69	100	249091	0	249090.6
70	100	151827	0	151826.6
71	100	61029.6	15254.67	45774.92
72	100	459612	-	459611.9
78	50	183752	338666.5	-154915
Totals		12500770	4329267	8171503

Zone D QAT Zone	Percentage	Total Recharge	Outflow	Net Recharge
1	100	56642.3	105949.5	-49307.2
2	100	140976	250031.5	-109055
3	100	446831	252945	193886.3
4	100	71055.5	186538.1	-115483
5	100	117922	309573.8	-191652
6	100	98268.2	257978.2	-159710
7	100	114423	370644.8	-256222
8	100	125586	406805.2	-281219
9	100	148799	359342.5	-210543
10	100	148799	359342.5	-210543
11	100	129411	80082.09	49329.36
12	100	77030.6	47667.91	29362.72
13	100	54142.8	263613	-209470
14	100	45787.4	222932	-177145
17	100	227276	112394.1	114882.1
18	100	428877	212090.9	216785.9
19	100	151968	94255.2	57712.38
20	100	143454	88974.8	54479.19
21	100	223629	288456.2	-64827.5
22	100	160645	207213.8	-46569.1
23	100	188321	182520.7	5799.906
24	100	174344	168974.3	5369.444
25	100	243396	185158.8	58237.26
26	100	177390	134946.2	42444.1
27	100	101587	75286.68	26300.62
30	100	65349.2	38607.93	26741.3
31	100	66158	0	66158.01
Totals		4128068	5262326	-1134258

Zone E QAT Zone	Percentage	Total Recharge	Outflow	Net Recharge
60	100	500326	699317.2	-198991
73	100	141435		141434.7
74	100	598842	281756.6	317085.4
75	100	221143	104048.4	117094.8
76	100	48977.6		48977.57
77	100	172654		172654.5
87	40	747886	242800	505085.9
88	100	1416266	739114.4	677151.8
89	100	966602	562723.7	403878
90	100	716985	281253	435731.8
91	50	557894	353582.3	204312
94	100	79031.1	19754.25	59276.88
95	50	217963	54480.96	163481.9
96	100	160885	40214	120670.8
97	40	447341	111815.3	335526
107	40	154643		154642.7
		7148874	3490860	3658014

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