GEOTHERMAL INVESTIGATION IN SHALLOW OBSERVATION WELLS

Project G/A 9 - Contracts 073-76 and 414-77-11 EGN

THE SHALLOW SUBSURFACE TEMPERATURE FIELD IN THE NETHERLANDS

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SUMMARY

In the period December 1976-September 1979 temperatures were measured in 251 wells in The Netherlands. Nearly all wells are deep groundwater observation wells, which allow a reliable determination of natural subsurface temperatures.
Temperatures were measured with an electrical thermometer, in which a platinum resistance transduces temperature into electrical voltage transmitted to the ground surface. Maximum deviation of most temperature readings from true temperatures is 0,1 $^{\circ}C$; inaccuracy in the difference of two temperature data of one well is in the order of 0,01 $^{\circ}C$.
Based on the temperature data the shallow subsurface temperature field in The Netherlands was delineated on maps every 25 m down to a depth of 250 m below ground surface. Temperature data of greater depths have been added in appendices.
The shallow subsurface temperature field in The Netherlands, delineated to a depth of 250 m below ground surface, shows features which reflect several phenomena. These are (i) convection of heat by infiltrating meteoric water and by groundwater flowing in the hydrologic cycle, (ii) laterally varying thermal conductivities of sediments and (iii) laterally varying heat flow or heat transport at great depths.
A comparison of the isotherm map for a depth of 250 m with the isotherm map for a depth of 500 m, derived from data of oil and gas wells, shows some similarity in the locations of the high-temperature areas at both depths. The temperatures indicated on the map for a depth of 500 m are probably too high for a number of locations.

1. INTRODUCTION

Knowledge of the Earth's subsurface temperature field is important in several aspects. In the last decade the determination of subsurface temperatures has been fostered especially by a growing interest in the exploitation of geothermal energy.

In The Netherlands the 'Gespreksgroep Aardwarmte' (Geothermal Energy Discussion Group), established in 1974, proposed a programme to evaluate the geothermal potential of the country, including systematic compilation and collection of geothermal data. This led to the compilation of early subsurface temperature measurements in The Netherlands (Visser, 1978) and to a processing of temperature data of exploration and exploitation boreholes for oil and gas. The latter work was performed by Prins on the temperature data at the Geological Survey of The Netherlands. His results have been incorporated in the Atlas of Subsurface Temperature in the European Community. This atlas was compiled by Haenel; its publication (1980) was arranged by The Commission of the European Communities.

The geothermal investigation in shallow (< 400 m) observation wells, reported here, has been another point of the above mentioned programme of the 'Gespreksgroep Aardwarmte' and was included in the EC-programme on geothermal energy. The objectives of this investigation were (i) determination of the temperature field to a depth of 250 m (if possible to 400 m), (ii) correlation of the observed temperatures with temperature data of greater depths and (iii) in situ determination of thermal conductivities of unconsolidated sediments around observation wells.
Shallow subsurface temperatures in The Netherlands may be measured in groundwater observation wells, completed to record piezometric heads and to take water samples in penetrated aquifers. These observation wells are also suited to a reliable determination of the shallow subsurface temperature field, since their influence on the natural temperature field, which would exist if there were no well, is normally very small.

The determination of thermal conductivity in a groundwater observation well is not a straightforward procedure. It is possible only by measurement of a cooling curve. The theory and some examples of model cooling curves, pertaining to observation wells, has been presented already (Van Dalfsen, 1979a).

In this report no supplementary work on cooling curves can be reported. This is due to continual breakdowns of the equipment, which urged to postpone the measurement of cooling curves in order to complete at least the determination of the subsurface temperature field.

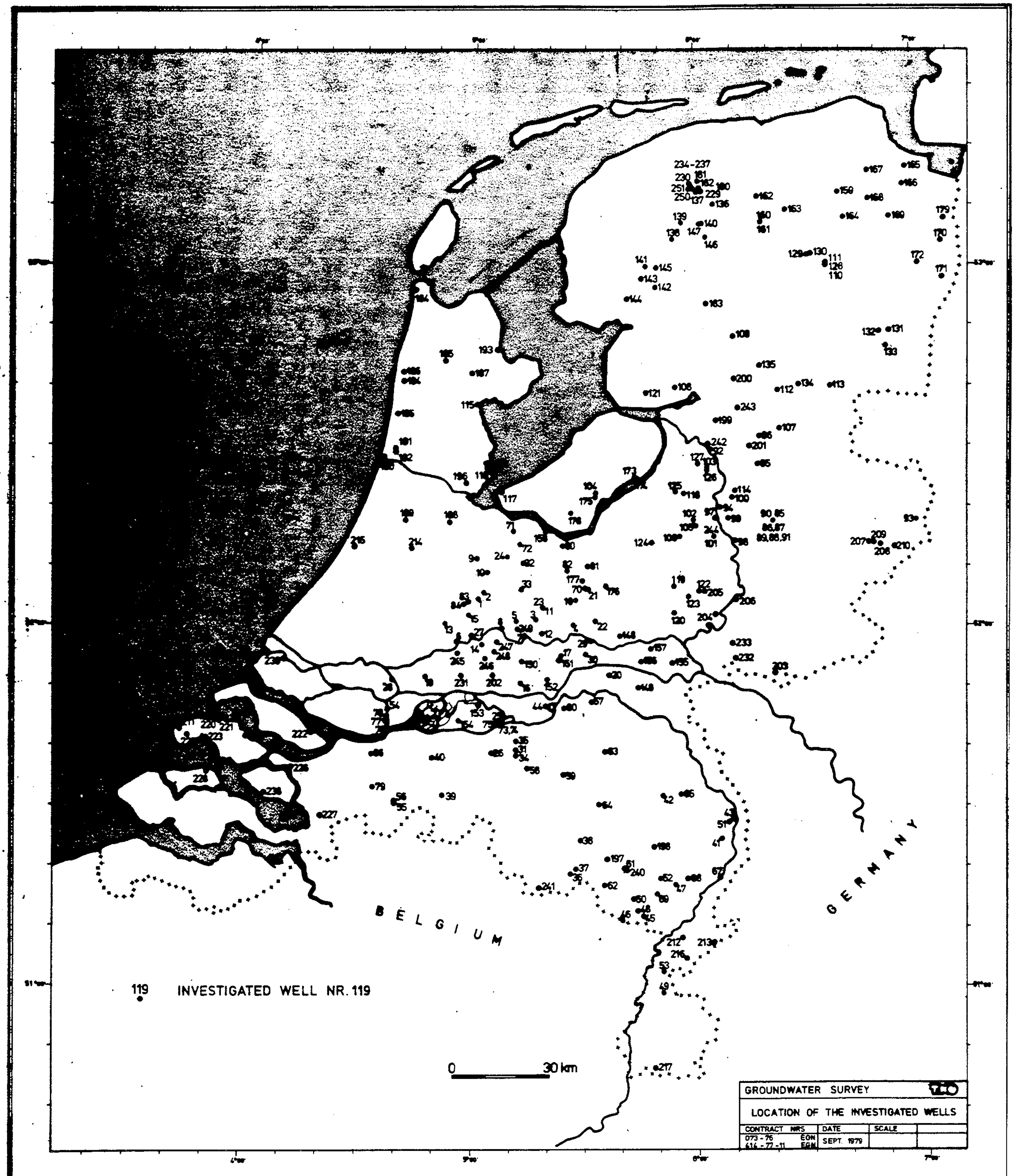


Fig. 1 Location of the investigated wells

2. DESCRIPTION OF THE MEASUREMENTS

2.1. Investigated wells

In the period December 1976 - September 1979 temperatures were measured in 251 wells (Table 1). The locations are, with serial number, shown in Figure 1. By far most wells are groundwater observation wells, some are groundwater pumping wells and three (nrs. 207, 208 and 209) in Twente (Fig. 2) are rock salt exploitation wells.
In the observation wells, and also in most pumping wells, temperatures were measured in a piezometer. The piezometers are PVC pipes with a slotted section (screen) of a few metres at the bottom end (Fig. 3), which were lowered into the borehole after drilling. In one well (Schoorl, nr. 194), however, the piezometers are of steel pipe. The piezometers have inner diameters in the range 18 - 50 mm; the inner and outer diameters of the major part amount to 25 or 33 mm. Diameter of the boreholes in which the piezometers were placed, ranged between 12 and 60 cm. Usually the wells have been completed with gravel packs around the screens and clay plugs at the depths of confining strata. The clay plugs serve to prevent groundwater flow from one aquifer into another through the borehole. The remaining space of the boreholde (annulus) has been filled with sand (backfill). Several piezometers tap artesian aquifers and have been provided with a valve. The highest piezometric heads above ground surface, 6 and 12 m, were met in the wells with nrs. 212 and 213 respectively, both in the province of Limburg. Relatively low piezometric heads, 30 - 51 m below ground surface, were met in 5 wells, nrs. 103, 119, 120, 123 and 125, in The Veluwe.
The piezometric head, or the length of the water column in a piezometer may fluctuate in the order of a few centimetres per day. Only if a pumping well is close to a piezometer, abrupt changes of a few metres can occur immediately after the pumping well has been put in or out of operation.
In each well temperatures were measured at least 3 weeks after its completion. In four groundwater pumping wells (nrs. 52, 53, 92 and 244) temperatures were measured, whilst these wells were pumped. Before the temperature measurements in the rock salt exploitation wells they had been out of active operation for at least 33 months.

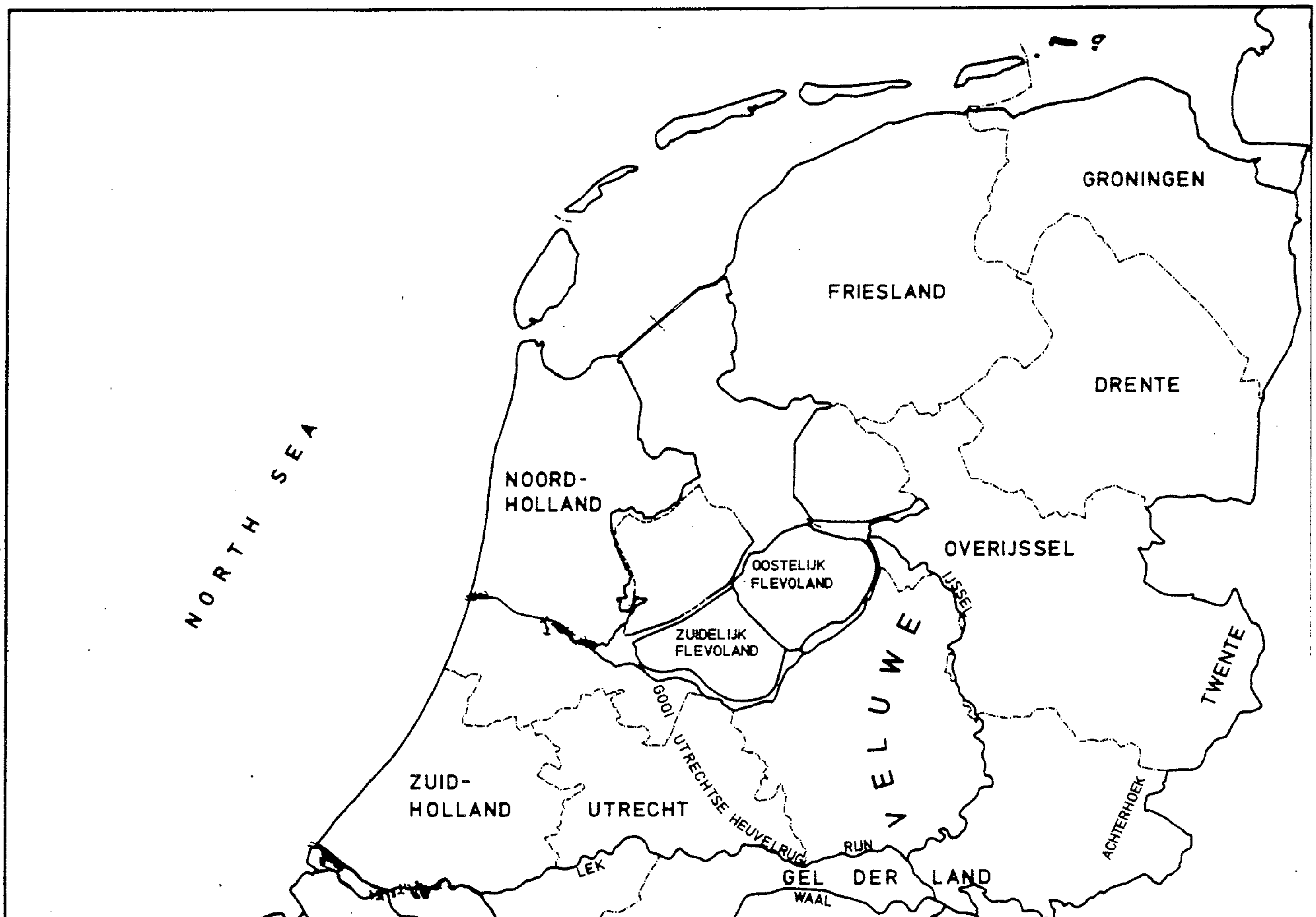


Fig. 2 Geographical map of The Netherlands

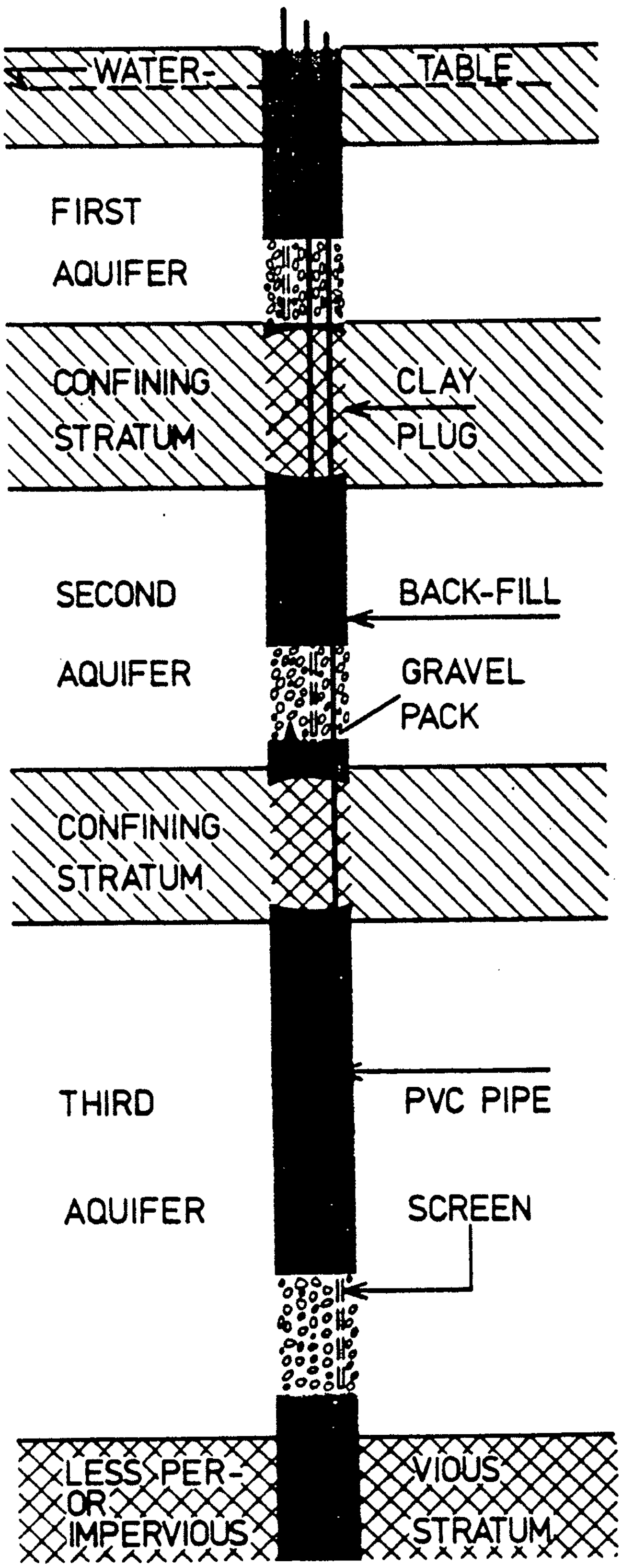


FIGURE 3 SCHEMATIC REPRESENTATION OF A GROUNDWATER OBSERVATION WELL

series nr.	locality	mapsheet-nr. borehole (RGD/RID)	GMS-coordinates λ	GMS-coordinates ϕ	maximum depth of measurement (m)	date	probe nr.
1a	De Meern	31G-147	5°01'14"	52°05'09"	289	011276	1
1b	"	"	"	"	290	040477	2
1c	"	"	"	"	290	240677	3
1d	"	"	"	"	290	310877	4
1e	"	"	"	"	289	120379	5
1f	"	"	"	"	290	050679	6
2	Vleuten	31H-558	5°02'38"	52°06'09"	194	011276	1
3	Langbroek	39A-210	5°15'23"	52°01'49"	148	021276	1
4	Leersum	39B-	5°26'51"	52°00'41"	115	021276	1
5	Houten	39A-208	5°11'21"	52°01'21"	182	021276	1
6	Lopik	38E-98	4°55'32"	51°58'01"	210	091276	1
7	Schalkwijk 1	39A-209	5°13'46"	51°58'54"	238	091276	1
8a	Tull en 't Waal	38F-424	5°07'32"	52°00'10"	190	171276	1
8b	"	"	"	"	183	230277	2
9	Loenen a/d Vecht	31E-163	5°00'58"	52°11'49"	119	201276	1
10	Bethune Polder	31F-272	5°03'39"	52°09'29"	197	110177	1
11	Driebergen 1	32C-233	5°18'32"	52°03'36"	150	110177	1
12	Cothen	39A-187	5°18'20"	51°59'18"	142	130188	1
13	Oudewater	38B-142	4°52'35"	52°00'59"	197	140177	1
14	Lexmond	38F-421	5°02'10"	51°37'30"	214	200177	1
15	Blokland	31G-162	4°58'45"	52°02'26"	194	200177	1
16	Waardenburg	39C-104	5°12'35"	51°51'08"	152	210177	1
17	Zoelen 1	39D-152	5°23'20"	51°55'35"	157	210177	1
18	Woudenberg	32D-135	5°27'26"	52°04'51"	182	260177	1
19	Bleskensgraaf	38D-262	4°47'27"	51°52'14"	113	280177	1
20	Druten	39H-165	5°36'32"	51°52'24"	235	300177	1
21	Glindhorst 1	32G-138	5°30'59"	52°06'44"	249	020277	1
22	Veenendaal	39E-145	5°32'46"	52°01'32"	240	020277	1
23	Driebergen 2	32C-230	5°18'24"	52°03'41"	182	040277	1
24a	Loosdrecht	31F-235	5°08'52"	52°12'10"	104	260177	1
24b	"	"	"	"	224		
25a	Genderen 1	44F-94	5°05'58"	51°44'39"	192	090277	1
25b	"	"	"	"	192	300378	4
26	Waalwijk	44H-34	5°04'52"	51°39'34"	125	100277	1
27	Lopikerkapel	38E-100	4°59'35"	51°59'06"	147	230277	2
28	H.I.-Ambacht	38C-393	4°38'35"	51°51'40"	154	250277	2
29	Lienden 1	39E-84	5°31'40"	51°58'03"	120	280277	2
30	Lienden 2	39E-93	5°30'15"	51°55'54"	84	280277	2
31	Nieuwkuijk	45C-188	5°11'15"	51°40'08"	276	020377	2
32	Lage Vuursche	32A-335	5°13'10"	52°11'03"	311	040377	2
33	De Bilt	32C-336	5°12'45"	52°06'33"	154	050377	2
34	Helvoirt	45C-191	5°11'20"	51°39'03"	300	160377	2
35	Vlijmen	45C-193	5°11'19"	51°41'34"	312	300377	2
36	Valkenswaard 1	57B-47	5°26'06"	51°19'30"	233	070477	2
37	Valkenswaard 2	57B-46	5°27'33"	51°20'21"	202	080477	2
38	Eindhoven	51G-	5°28'57"	51°25'05"	226	080477	2
39	Prinsenbosch	50B-70	4°51'55"	51°32'39"	244	130477	2
40	Oosterhout	44D-177	4°49'22"	51°38'46"	112	130477	2
41a	Californië	52G-198	6°06'43"	52°25'17"	116	070777	3
41b	"	"	"	"	200	040977	4
42	Vredepeel	52A-115	5°51'14"	51°32'28"	169	080777	3
43	Grubbenvorst	52G-165	6°09'56"	51°28'28"	70	080777	3
44	Maasdriel	45B-106	5°19'24"	51°47'20"	195	120777	3

Table 1 List of investigated wells

ies	locality	mapsheet-nr. borehole (RGD/RID)	GMS-coordinates		maximum depth of measurement	date	probe nr.
			λ	φ			
	Hunsel	58C-120	5°45'44"	51°12'25"	145	130777	3
	Stramproij	57H-47	5°40'16"	51°11'50"	86	130777	3
	Roggel	58B-123	5°54'30"	51°17'45"	340	140777	3
	Tungelroij	57H-69	5°44'09"	51°13'25"	296	150777	3
	Sittard	60C-781	5°51'10"	50°59'54"	172	190777	3
	Weert	57F-43	5°43'02"	51°15'21"	205	200777	3
	Homberg	52G-199	6°08'39"	51°28'02"	99	220777	3
	Ospel	58A-	5°50'10"	51°18'36"	89	260777	3
	Susteren	60A-223	5°51'10"	51°03'19"	153	270777	3
	's-Gravendeel 1	44A-310	4°37'18"	51°46'48"	243	020877	3
	Pannenhoef 1	50A-149	4°39'18"	51°31'14"	243	030877	3
	Pannenhoef 2	50A-162	4°39'16"	51°31'40"	231	030877	3
	Macharen	45E-105	5°31'47"	51°48'00"	90	230877	4
	Haaren	45C-192	5°14'25"	51°36'60"	189	230877	4
	Schijndel	45D-	5°24'06"	51°35'60"	307	240877	4
	Lith	45B-109	5°24'17"	41°46'58"	174	240877	4
	Someren 1	57F-57	5°40'34"	51°20'22"	306	250877	4
	Budel	57E-64	5°38'18"	51°17'35"	243	250877	4
	Veghel	45G-59	5°35'22"	51°37'38"	307	260877	4
	Lieshout	51E-55	5°33'48"	51°31'01"	194	260877	4
	Ballonzuil	52B-184	5°56'03"	51°32'42"	187	050977	4
a	Klundert	43H-63	4°33'08"	51°39'18"	309	070977	4
b	"	"	"	"	309	120679	6
	Belfeld	58E-199	6°06'18"	51°18'51"	171	080977	4
	Helden	58B-154	5°57'43"	51°18'45"	173	080977	4
	Leveroij	58A-87	5°49'24"	51°16'13"	399	100977	4
	Glindhorst 2	32G-137	5°30'05"	52°06'49"	289	280278	4
	Bussum	26C-127	5°10'31"	52°16'18"	242	030378	4
	Hilversum	32A-390	5°12'14"	52°14'14"	225	100378	4
	Genderen 2	44F-127	5°06'09"	51°44'36"	30	310378	4
	Genderen 3	44F-128	5°06'09"	51°44'36"	186	310378	4
	Genderen 4	44F-79	5°05'53"	51°44'39"	166	300378	4
	's Gravendeel 2	44A-334	4°37'55"	51°44'22"	170	040478	4
	's Gravendeel 3	44A-	4°36'49"	51°44'53"	213	040478	4
	's Gravendeel 4	44A-	4°37'06"	51°45'32"	224	050478	4
	Seppe	49F-240	4°33'29"	51°33'54"	251	050478	4
	Holk	32B-209	5°23'47"	52°13'55"	206	100478	4
	Zwartebroek	32E-65	5°30'45"	52°10'30"	190	100478	4
	Amersfoort	32B-210	5°25'03"	52°09'43"	186	120478	4
	Reijerscop	31G-170	4°58'48"	52°04'39"	181	170478	4
	Linschoten	31G-118	4°57'26"	52°04'09"	110	170478	4
	Espelose Broek 1	28C-119	6°20'45"	52°17'56"	52	180478	4
	" " 2	28C-123	6°20'42"	52°17'56"	54	180478	4
	" " 3	28C-118	6°20'42"	52°17'56"	130	180478	4
	" " 4	28C-124	6°20'42"	52°17'53"	47	180478	4
	" " 5	28C-122	6°20'37"	52°17'53"	61	180478	4
	" " 6	28C-	6°20'43"	52°18'18"	52	180478	4
	" " 7	28C-	6°21'03"	52°17'46"	38	180478	4
	Zwolle 1	21G-276	6°04'28"	52°29'56"	195	210478	4
	De Lutte	29C-100	6°59'48"	52°17'47"	122	210478	4

able 1 List of investigated wells (continued)

series nr.	locality	mapsheet-nr. borehole (RGD/RID)	GMS-coordinates λ	GMS-coordinates φ	maximum depth of measurement	date	pr(nr.
94	Olst	27G-94	6°06'44"	52°20'13"	195	230578	4
95	Dalfsen 1	27F-42	6°16'54"	52°27'20"	209	230578	4
96	Nieuwleusen	21H-44	6°17'27"	52°32'06"	209	230578	4
97	Terwolde	27G-99	6°05'23"	52°18'24"	208	300578	4
98	Deventer	33E-181	6°10'41"	52°14'35"	212	300578	4
99	Diepenveen	27G-	6°08'47"	52°18'22"	111	300578	4
100	Boerhaar 1	27G-	6°09'58"	52°21'52"	193	300578	4
101a	Twello 1	33E-185	6°05'09"	52°15'20"	188	010678	4
101b	"	"	"	"	243	220678	4
101c	"	"	"	"	244	090879	6
102	Vaassen 1	27D-54	5°59'30"	52°18'02"	169	010678	4
103	Wapenveld 1	27E-138	6°03'09"	52°26'47"	197	010678	4
104	Knardijk	26E-3	5°32'57"	52°22'38"	300	050678	4
105	Vaassen 2	27D-53	6°00'19"	52°17'07"	261	060678	4
106	Wiesel	33B-235	5°55'55"	52°15'25"	199	060678	4
107	Witharen	22C-68	6°22'43"	52°33'15"	75	080678	4
108	Voorsterbos	21B-170	5°54'53"	52°40'19"	142	080678	4
109a	Kallenkote	16G-88	6°10'44"	52°48'44"	150	080678	4
109b	"	"	"	"	150	250479	5
110	Assen 1	12D-120	6°35'48"	53°00'12"	197	130678	4
111	Assen 2	12D-160	6°35'52"	53°00'45"	229	130678	4
112	Veeningen	22A-74	6°22'27"	52°39'44"	166	200678	4
113	Kikkerhoek	22B-33	6°36'30"	52°40'13"	55	200678	4
114	Boerhaar 2	27E-	6°10'44"	52°22'58"	8	200678	4
115a	Scharwoude	19E-85	5°00'46"	52°27'25"	239	210678	4
115b	"	"	"	"	280	090479	5
116	Broek in Waterland	25F- 55	5°04'17"	52°26'20"	250	210678	4
117	Oostvaardersdiep	25F-103	5°07'25"	52°22'53"	150	210678	4
118	't Harde 1	27B-156	5°56'49"	52°22'33"	207	050778	4
119	Hoenderloo	33D-125	5°54'02"	52°07'10"	257	050778	4
120a	Deelen	33D-133	5°54'08"	52°02'45"	158	100778	4
120b	"	"	"	"	165	160878	4
121	Schokland	21A-38	5°46'51"	52°39'29"	106	150878	4
122	Loenen 1	33D-130	6°00'53"	52°06'17"	176	160878	4
123	Loenen 2	33D-135	5°57'59"	52°05'28"	197	160878	4
124	Hoog-Soeren	33A-103	5°48'08"	52°14'22"	192	170878	4
125	't Harde 2	27B-155	5°54'50"	52°22'54"	61	170878	4
126	Wapenveld 2	27E-139	6°03'09"	52°26'28"	135	180878	4
127	Wezep	27B-193	6°00'48"	52°27'23"	188	180878	4
128	Assen 3	12D-121	6°35'48"	53°00'21"	229	210878	4
129	Zeijerveld 1	12D-126	6°30'36"	53°02'05"	189	210878	4
130	Zeijerveld 2	12D-159	6°31'20"	53°02'04"	199	210878	4
131	Valtherbos	17F-45	6°52'49"	52°49'13"	126	220878	4
132	Sleen	17H-282	6°50'14"	52°49'04"	125	220878	4
133	Emmen	17H-75	6°51'60"	52°46'43"	114	220878	4
134	Zuidwolde	22A-93	6°27'54"	52°40'33"	172	220878	4
135	Ruinerwold	16H-55	6°17'40"	52°43'46"	142	230878	4
136	Hoogzand	6G-42	6°05'35"	53°10'44"	105	230878	4
137	Noordbergum 1	6D-205	6°01'00"	53°12'41"	240	230878	4

Table 1 List of investigated wells (continued)

ries	locality	mapsheet-nr. borehole (RGD/RID)	GMS-coordinates λ	GMS-coordinates φ	maximum depth of measurement	date	probe nr.
	Hoornaar	38G-304	4°56'55"	51°52'31"	147	200779	6
	Beek	40G-86	6°10'14"	51°54'58"	176	250779	6
	Didam	40E-190	6°09'42"	51°57'31"	168	250779	6
	Noordbergum 7	6D-209	5°59'59"	53°13'20"	178	260779	6
	Noordbergum 8	6D-207	6°00'27"	53°13'11"	148	260779	6
	Noordbergum 9	6D-214	6°01'17"	53°12'55"	239	260779	6
	Noordbergum 10	6D-208	5°59'38"	53°13'06"	153	270779	6
	St.-Maartensdijk	49A-	4°05'22"	51°32'44"	121	020879	6
	Brielle	37D-134	4°10'07"	51°54'57"	95	020879	6
	Someren 2	57F-82	5°40'56"	51°20'05"	235	030879	6
	Luijksgestel	57A-35	5°17'36"	51°17'05"	341	040879	6
	Zwolle 2	21G-292	6°03'06"	52°30'51"	124	070879	6
	Rouveen	21E-138	6°11'22"	52°36'49"	292	070879	6
a	Twello 2	33E-188	6°05'10"	52°15'22"	184	090879	6
b	"	"	"	"	184	090879	6
c	"	"	"	"	184	090879	6
	Ameide	38E-121	4°56'12"	51°56'11"	198	170879	6
	Middelkoop	38H-177	5°03'22"	51°55'21"	183	170879	6
	Vianen	38F-504	5°06'36"	51°58'04"	207	230879	6
	Hei- en Boeicop	38F-503	5°05'52"	51°56'29"	198	230879	6
	Schalkwijk 2	39A-234	5°12'08"	52°00'07"	164	290879	6
	Noordbergum 11	6D-215	5°58'39"	53°13'11"	125	300879	6
	Noordbergum 12	6D-210	5°59'15"	53°13'40"	112	310879	6

le 1 List of investigated wells (continued)

ies	locality	mapsheet-nr. borehole (RGD/RID)	GMS-coordinates		maximum depth of measurement	date	probe nr.
			λ	φ			
	Goëngahuizen	11A-64	5°54'23"	53°04'59"	117	240878	4
	Eernewoude	11B-23	5°56'50"	53°07'40"	118	240878	4
a	Nyega 1	11B-67	6°02'34"	53°07'34"	16	240878	4
b	"	"	"	"	175	251078	4
	Goingarijp	11C-60	5°46'46"	53°00'29"	217	260878	4
	Haskerhorne	11C-90	5°49'36"	52°57'00"	225	260878	4
	Joure 1	11C-61	5°49'47"	53°00'19"	121	300878	4
	Spannenburg	15F-115	5°41'37"	52°55'01"	165	300878	4
	Joure 2	11C-62	5°45'43"	52°58'27"	113	300878	4
	Boornbergum	11E-67	6°03'34"	53°05'17"	200	300878	4
	Nyega 2	11B-25	6°01'43"	53°07'27"	245	300878	4
	Wageningen	39F-305	5°39'22"	51°58'52"	294	060978	4
	Beuningen	39H-119	5°44'24"	51°50'20"	197	060978	4
	Beesd	39C-142	5°12'50"	51°54'43"	201	070978	4
	Zoelen 2	39D-150	5°22'44"	51°54'55"	29	070978	4
	Est	39D-195	5°19'52"	51°51'42"	200	070978	4
	Giessen	44E-119	5°01'18"	51°47'26"	228	080978	4
	Dussen	44E-118	4°56'09"	51°44'55"	213	080978	4
	Bemmel	40C-393	5°53'28"	51°54'21"	187	090978	4
	Andelst	40C-421	5°45'16"	51°54'37"	144	110978	4
	Fikkersdries	40A-400	5°47'55"	51°56'45"	191	110978	4
	Eemnes	26D-5	5°19'13"	52°16'16"	296	120878	4
	Engelbert	7D-281	6°39'22"	53°12'22"	204	240978	4
	Marum 1	11F-38	6°18'19"	53°07'36"	217	250978	4
	Marum 2	11F-	6°18'18"	53°07'34"	69	250978	4
	Grootegast	6H-53	6°17'19"	53°11'50"	126	250978	4
	Nietap	12A-	6°24'53"	53°09'30"	243	260978	4
	Onnen	12E-166	6°40'43"	53°08'41"	201	260978	4
	Zomerdijk	8A-54	6°58'12"	53°16'22"	97	270978	4
	't Waar	7H-80	6°57'20"	53°13'32"	170	270978	4
	Schildwolde	7G-93	6°47'44"	53°15'49"	147	270978	4
	Froombosch	7G-97	6°47'55"	53°11'07"	151	270978	4
	Muntendam	12F-92	6°53'24"	53°08'08"	151	280978	4
	Veelerveen	13B-61	7°07'36"	53°03'57"	174	290978	4
	Sellingen	13D-42	7°07'44"	52°57'51"	221	290978	4
	Stadskanaal	13C-54	7°01'17"	53°00'21"	131	290978	4
	Bremerberg 1	26F-55	5°43'38"	52°25'12"	116	091078	4
	Bremerberg 2	26F-12	5°44'15"	52°25'02"	206	091078	4
	Hardenbroek	26G-139	5°32'49"	52°21'57"	154	091078	4
	Barneveld	32G-127	5°35'43"	52°07'11"	163	111078	4
	Achterveld	32G-136	5°29'22"	52°08'05"	168	111078	4
	Zuidelijk Flevo-land	26D-42	5°26'04"	52°19'21"	346	131078	4
	Bellingwolde	13B-49	7°08'17"	53°07'31"	141	241078	4
	Noordbergum 2	6D-49	6°01'37"	53°13'30"	101	251078	4
	Noordbergum 3	6D-102	6°01'17"	53°14'38"	180	251078	4
a	Noordbergum 4	6D-206	6°01'24"	53°12'28"	260	251078	4
b	"	"	"	"	263	270779	6
a	Oldeholtpade	16B-105	6°03'06"	52°54'08"	150	251078	4
b	"	"	"	"	139	251078	4
	Den Helder	9D-186	4°44'06"	52°57'04"	293	140379	5

ble 1 List of investigated wells (continued)

series nr.	locality	mapsheet-nr. borehole (RGD/RID)	GMS-coordinates λ	GMS-coordinates φ	maximum depth of measurement	date	pr nr.
185	't Veld	14D-62	4°51'53"	52°44'58"	324	220379	5
186	Groet	14C-28	4°40'41"	52°43'04"	193	230379	5
187	Sybekarspel	19E-101	4°59'02"	52°42'41"	375	230379	5
188	Ouderkerk a/d Amstel	25G-376	4°53'42"	52°17'42"	148	270379	5
189	Hoofddorp	25C-340	4°41'55"	52°18'01"	97	270379	5
190	Velsen	25A-926	4°35'53"	52°28'45"	274	300379	5
191	Heemskerk	19C-556	4°38'30"	52°30'23"	148	300379	5
192	Beverwijk	19C-557	4°38'34"	52°29'46"	149	300379	5
193	Medemblik	14H-43	5°06'13"	52°46'42"	265	090479	5
194	Schoorl	19A-21	4°40'45"	52°41'36"	308	110479	5
195	Egmond-Binnen	19A-259	4°39'04"	52°36'11"	343	110479	5
196	Zunderdorp	25E-344	4°58'05"	52°24'29"	115	110479	5
197	Heeze	57E-76	5°35'54"	51°21'40"	386	190479	5
198	Asten	52C-190	5°48'24"	51°23'45"	139	190479	5
199	Hasselt	21G-390	6°05'48"	52°34'39"	169	250479	5
200	Meppel	21E-137	6°10'42"	52°41'33"	167	250479	5
201	Dalfsen 2	21H-45	6°14'40"	52°30'19"	210	240479	5
202a	Asperen	38H-178	5°05'39"	51°52'38"	265	010579	5
202b	"	"	"	"		050579	5
202c	"	"	"	"	264	240779	6
203	Gendringen	41C-35	6°20'50"	51°52'28"	70	070579	5
204	Ellecom	33G-164	6°05'27"	52°02'18"	160	080579	5
205	Eerbeek	33D-139			187	080579	5
206	Bronkhorst	33G-154	6°10'45"	52°04'43"	162	080579	5
207	Twekkelo 1	34F-	6°46'48"	52°14'00"	479	100579	5
208	Twekkelo 2	34F-	6°49'46"	52°13'35"	402	100579	5
209	Twekkelo 3	34F-	6°48'02"	52°13'59"	410	110579	5
210	Enschede	34F-	6°53'32"	52°13'10"	71	110579	5
211	Haamstede	42B-40	3°42'26"	51°43'01"	143	160579	5
212	Linne	58D-313	5°56'07"	51°08'36"	37	250579	5
213	Vlodrop	60E-17	6°04'27"	51°07'47"	400	250579	5
214	Kudelstaart	31B-111	4°43'46"	52°13'34"	149	060679	6
215	Voorhout	30F-422	4°28'17"	52°13'40"	210	060679	6
216	Echt	60B-95	5°57'05"	51°05'13"	201	070679	6
217	Mheer	62C-59	5°48'32"	50°47'01"	99	070679	6
218	Haamstede 2	42B-53	3°42'25"	51°42'44"	139	110679	6
219	Haamstede 3	42B-51	3°41'33"	51°42'46"	150	110679	6
220	Osse 1	42F-25	3°53'09"	51°44'37"	110	110679	6
221	Osse 2	42F-24	3°53'14"	51°44'37"	82	110679	6
222	Den Bommel	43B-49	4°17'26"	51°57'38"	76	120679	6
223	Schelphoek	42G-22	3°49'32"	51°41'14"	110	120679	6
224	Dreischor	42F-23	4°00'37"	51°41'51"	84	130679	6
225	Haamstede 4	42E-	3°44'39"	51°41'45"	157	130679	6
226	St.-Philipsland	43D-17	4°12'34"	51°36'45"	23	140679	6
227	Bergen op Zoom	49E-65	4°20'32"	51°28'54"	86	140679	6
228	Colijnsplaat	42G-40	3°50'09"	51°35'44"	120	140679	6
229a	Noordbergum 5	6D-213	6°02'00"	53°12'55"	179	160779	6
229b	"	"	"	"	250	270779	6
229c	"	"	"	"	125	300879	6
230	Noordbergum 6	6D-211	5°58'53"	53°14'02"	127	160779	6

Table 1 List of investigated wells (continued)

2.2. Equipment

Temperatures are measured with a platinum resistance (100 Ω) thermometer. A temperature transducer (platinum resistance) has been mounted - thermally isolated - at the lower end of a probe, made of brass and approximately 45 cm long. To this platinum resistance a small (≈ 2,5 mA) direct current is applied. A cable (> 500 m) on a hand-driven reel transmits separately the current and the signal (the potential drop across the platinum resistance) between transducer and the ground surface. After amplification the signal is shown digitally up to one hundredth's of a degree centrigrade on the display of a measuring box. In the same box the direct current is generated with power supply of a portable 220 V AC-generator. A depth-meter has been mounted on top of a tripod, which conducts the cable into the well. All parts of the equipment are portable so as to be able to measure also at locations which are not accessible by car.
During the investigation six probes were used in succession. Three of them were lost in wells together with several hundred metres of cable, probe nr. 1 in well nr. 26, probe nr. 2 in well nr. 40 and probe nr. 5 in well nr. 211. The third probe, with a larger diameter (13 mm) than the other ones (10 mm), was an emergency-probe, which was used until a new series of probes had been manufactured. Probe nr. 4 was replaced after temperature measurements in several wells had shown a mis-functioning (see section 2.4.) of the equipment. This was caused by leakage water, that had penetrated into the cable at its connection with the probe. With the subsequent probes such leakage could be avoided. After loss of the second probe the 4 mm thick polyurethane cable, used till then, was replaced by a stronger cable. The tensile strength of this 6 mm thick PVC cable, internally strengthened with a steel core, is 900 N.
With the replacement of the polyurethane cable by the thicker PVC cable, the cable reel had to be replaced by a larger one. Later on persistent failures arose with this cable reel, especially of the electrical sliding contacts, which showed to be increasingly vulnerable.

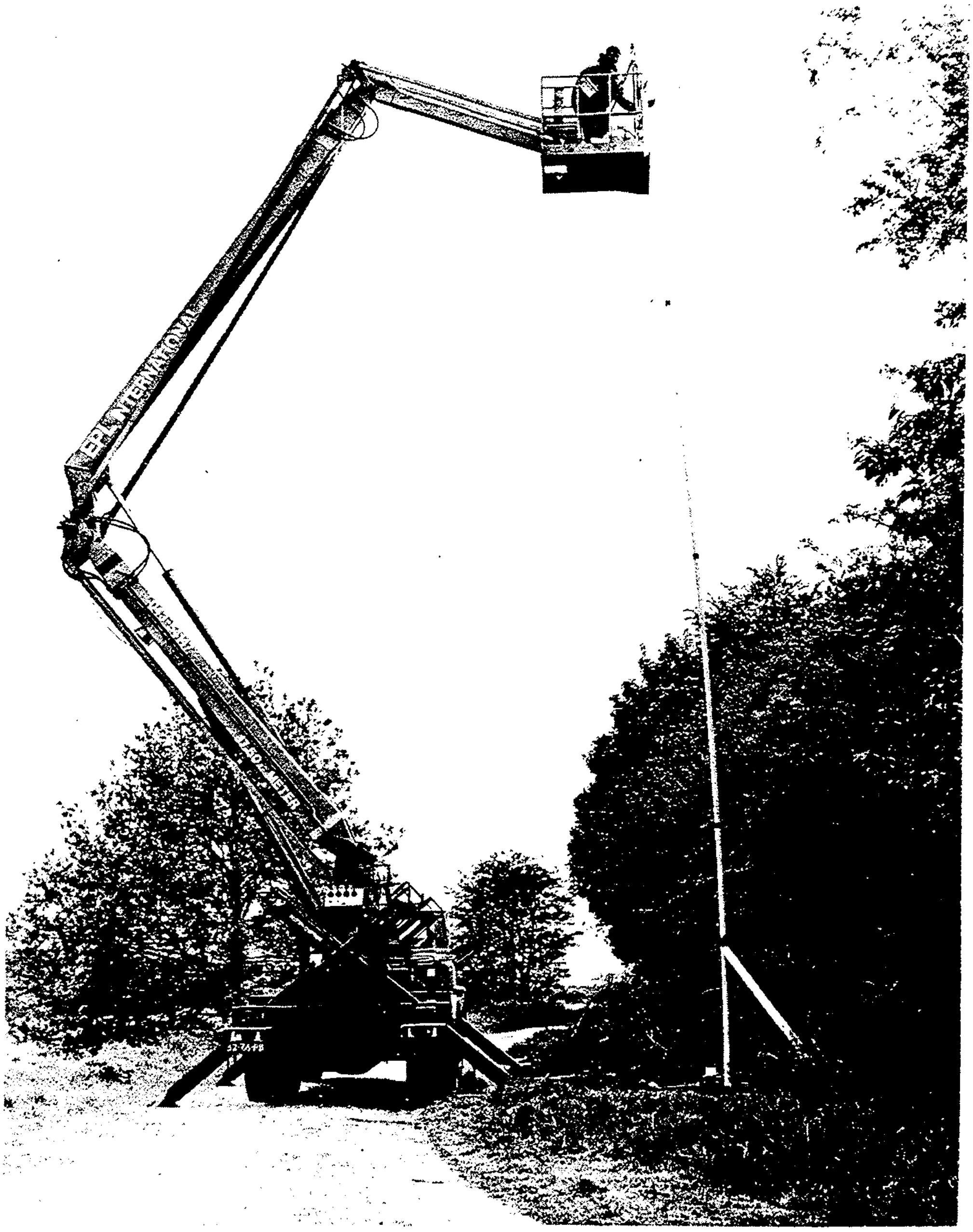


FIGURE 4 : MEASURING THE ARTESIAN WELL VLODROP (Nr. 213)

2.3. Measuring method

In the observation wells temperatures were measured in the water column in one of the piezometers, normally the deepest one. The measurements were taken at depths increasing with intervals of 1 or 2 m. The depths were tabulated with respect to the top of the piezometer pipe. Temperature was recorded after a short halt (10 - 20 s) of the probe, after which the temperature transducer should be in thermal equilibrium with the surrounding water column. In most wells such measurements could be carried on to the bottom of the piezometer pipe, thus resulting in temperature data along the whole column.
In quite a number of wells, however, the probe stuck on its way down and had to be withdrawn. In such cases the probe was lowered into another piezometer of the well, if this could extend the range of depths. The probe stuck mostly in relatively old wells. As these wells predominate in the province of Zeeland, here only small maximum depths of temperature measurements (Table 1) could be reached.
Some piezometers, which tap an artesian aquifer, had to be extented by an additional length of pipe. In this way the water could be confined in the pipe, as is necessary to measure equilibrium temperatures. The two strongly artesian wells, nrs. 212 and 213, were measured with the aid of a truck with hoist (Fig. 4). At this occasion it was disappointing that in all piezometers of well nr. 212, of which the deepest one is 396 m, the probe stuck at a depth of only 37 m.

.4. Reliability of the temperature data

The reliability of the measured temperatures involves three aspects: (i) the inherent accuracy, concerning temperature and depth, of the equipment (ii) the influence of the borehole with its piezometers, clay plugs, gravel packs and back-fill on the natural temperature field (which would exist if there were no well) and (iii) the influence of the water-displacement by probe and cable upon the temperatures in a piezometer.

Inherent accuracy of the equipment

Each time another probe had been mounted, the equipment was calibrated at two temperatures, in melting ice and in water at 29,9 ± 0,1 °C. The latter value was read from a mercury thermometer. In this way a sufficient absolute accuracy of temperature indication could be obtained, as appeared after the equipment - measuring box, cable and the second probe - had been calibrated at the Netherlands Institute for Weights and Measures (Table 2).

temperature indication (°C) on measuring box	correction (°C) which should be applied to obtain true temperature
0,00	- 0,02
5,00	- 0,02
10,00	- 0,02
15,00	- 0,02
20,00	- 0,01
25,00	+ 0,01

Table 2   Calibration results with probe nr. 2

The above results hold for ambient temperatures from 5 to 20 °C. Besides the calibration with a mercury thermometer, each time another probe had been mounted also a temperature profile was recorderd in observation well De Meern (nr. 1). Consequently the accuracies of the equipment with probes 1, 3, 4, 5 and 6 could be inferred from a comparison of their temperature profiles in observation well De Meern with the temperature profile obtained with probe 2 in the same well (Table 3).

probe of temperature equipment	correction (°C) which should be applied to obtain true temperature
1	- 0,05
2	- 0,02
3	- 0,01
4	+ 0,03
5	- 0,06
6	- 0,04

Table 3   Inaccuracies of the temperature equipment inferred from comparison of temperature profiles in observation well De Meern

FIGURE 5 TEMPERATURE PROFILES WITH PROBE NR. 4 (LEFT, 770831) AND WITH PROBE NR. 5 (RIGHT, 790312) IN OBSERVATION WELL DE MEERN

Hereby it is assumed tacitly that temperatures in observation well De Meern did not change notably between first (December 1976) and last (June 1979) measurements, which is most likely true for great depths. The temperature profiles with probes 4 and 5 have been represented in Figure 5. Based upon this it can be expected that the measured temperatures are accurate to within 0,1 °C. This accuracy, however, does not hold for all temperature data as about 20 temperature profiles, most of them measured with the fourth probe, show jumps of about 0,1 °C. These jumps are due to leakage of water into the probe. Therefore temperatures measured in those wells are less accurate; their inaccuracy may be as much as 0,2 °C.
It is remarked that, apart from the calibration error, an error arises because the value of the platinum resistance slightly decreases with increasing pressure exerted by the water column in a piezometer. Based on data of Landolt and Börnstein (1959), it is calculated that with the pressure of a water column of 250 m the temperature indication would be too low by about 0,01 °C. This value, also if it should be slightly higher due to the effect of sealing, may be neglected.
Inaccuracies in depth due to cable-stretching may be neglected, especially for the second cable with a steel core. The deviation of the boreholes from the vertical is too small to give inaccuracies of more than a few decimetres. The depths, which were tabulated with respect to the top of the piezometer pipe, deviate in most cases a few decimetres from depths to the ground surface. Therefore they were not corrected to depths with respect to ground surface, unless the difference between both levels amounts to over 2 m.

Influence of the borehole

Even when a well is in thermal equilibrium, the temperature field in and around it will be disturbed. This occurs because the material in the borehole has thermal properties which generally differ from those of the original rock. With a properly completed well these disturbances are negligible thanks to the small borehole diameters, and the use of poorly heat-conducting materials. An exception has to be made for observation well Schoorl (nr. 194), as this well has steel piezometer pipes.
Temperatures can be disturbed also by turbulences in the water column of a piezometer. Such turbulences have been investigated by several authors (e.g. Diment, 1967). They indicate that at normal geothermal gradient the heat transfer by turbulences in a water column of sufficiently small dia-

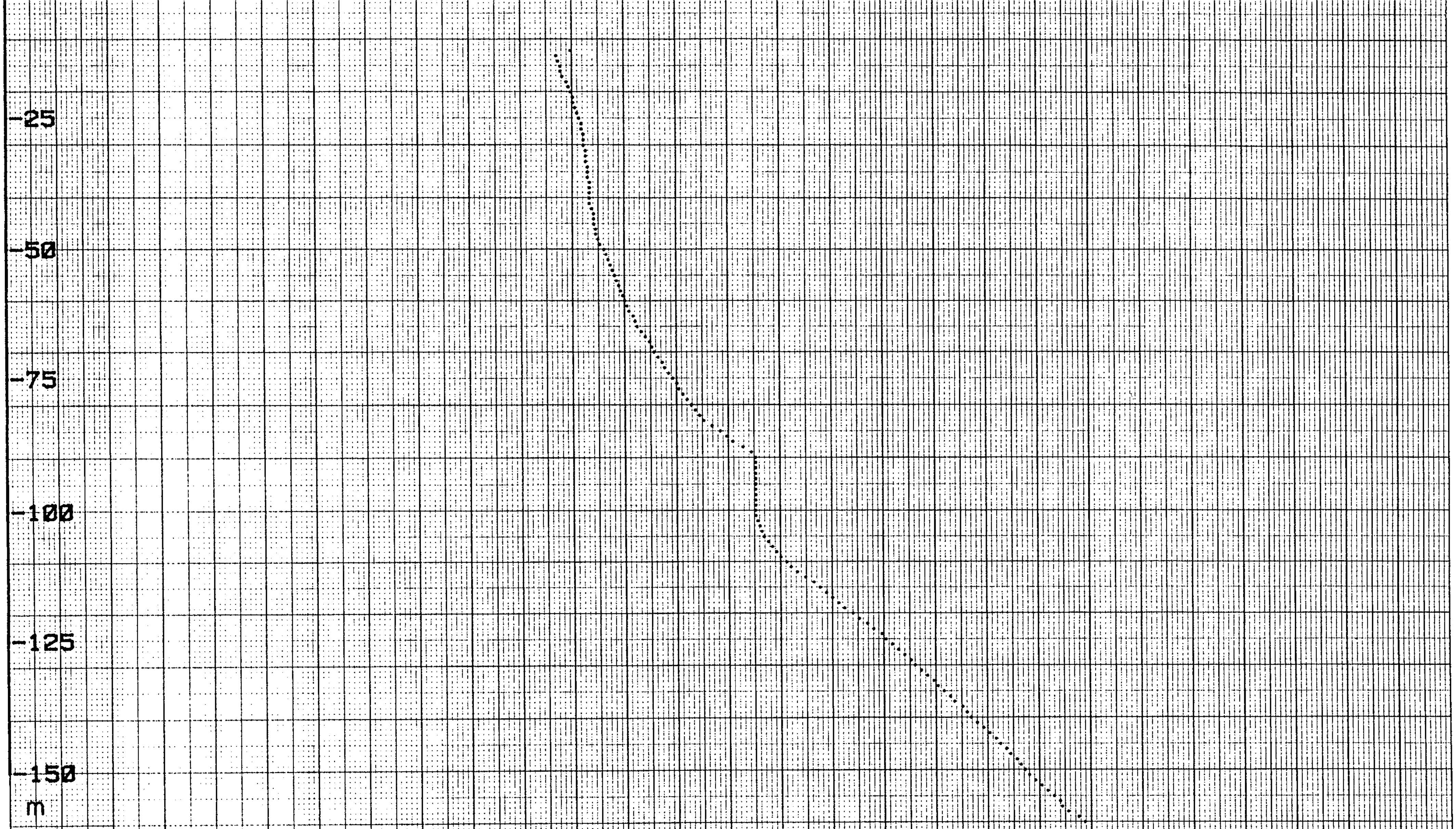


FIGURE 6 DISTURBANCE OF TEMPERATURES IN OBSERVATION WELL ELLECOM (NR. 204), DUE TO UPWARD GROUNDWATER FLOW, AT ABOUT 95 M, THROUGH THE BOREHOLE

meter - as is the case in this survey - can be neglected.
In an improperly completed observation well the temperature field will be disturbed if groundwater flows from one aquifer into another through the back-fill in the borehole. This 'hydraulic short-circuiting', between aquifers with different piezometric heads, occurs if no clay plug has been placed, or if one has been placed improperly.
The temperatures measured in observation well Ellecom (nr. 204) provide an example of the influence of 'hydraulic short-circuiting' on the temperature profile (Fig. 6). Obviously in this well, at the depth of a confining stratum at about 95 m depth, there is no clay plug which prevents groundwater to flow from the lower into the upper aquifer.
This temperature profile serves also to stress the importance of temperature measurements at small depth intervals. If temperatures would have been measured only at depth intervals of 10 or 20 m, groundwater flow would have been much less evident. With the measurements taken at depth intervals of 1 or 2 m such disturbed temperature data could be discarded.

Influence of the water-displacement by probe and cable

Another source of error to be considered is the displacement of water by the probe and cable in a piezometer. For example, in a 25 mm wide pipe the probe and 250 m of immersed, 6 mm thick, cable cause a displacement of water which is equivalent to a water column of 14,5 m length. This water is displaced out of the piezometer, through its screen, into the porous material surrounding it. Therefore the measured temperatures will be systematically too low, as the water in the piezometer sinks together with the probe.
Assuming an abrupt fall of the water column in a piezometer instead of the real occurring steady fall, the error can be estimated from a suitable cooling curve (Van Dalfsen, 1979a). In case of an abrupt fall, in the usual type of piezometer (PVC 25/33 mm), at normal geothermal gradient (0,025 $^{o}C\ m^{-1}$), 1¼ h after starting the measurements, the temperature at 250 m would be too low by about 0,01 ^{o}C (Fig. 7). In this example it is assumed that the piezometer were surrounded by sand with thermal conductivity of 2,2 $Wm^{-1}K^{-1}$ and volumetric heat capacity of 3,0 $MJm^{-3}K^{-1}$. As the temperature disturbance in case of a steady fall of

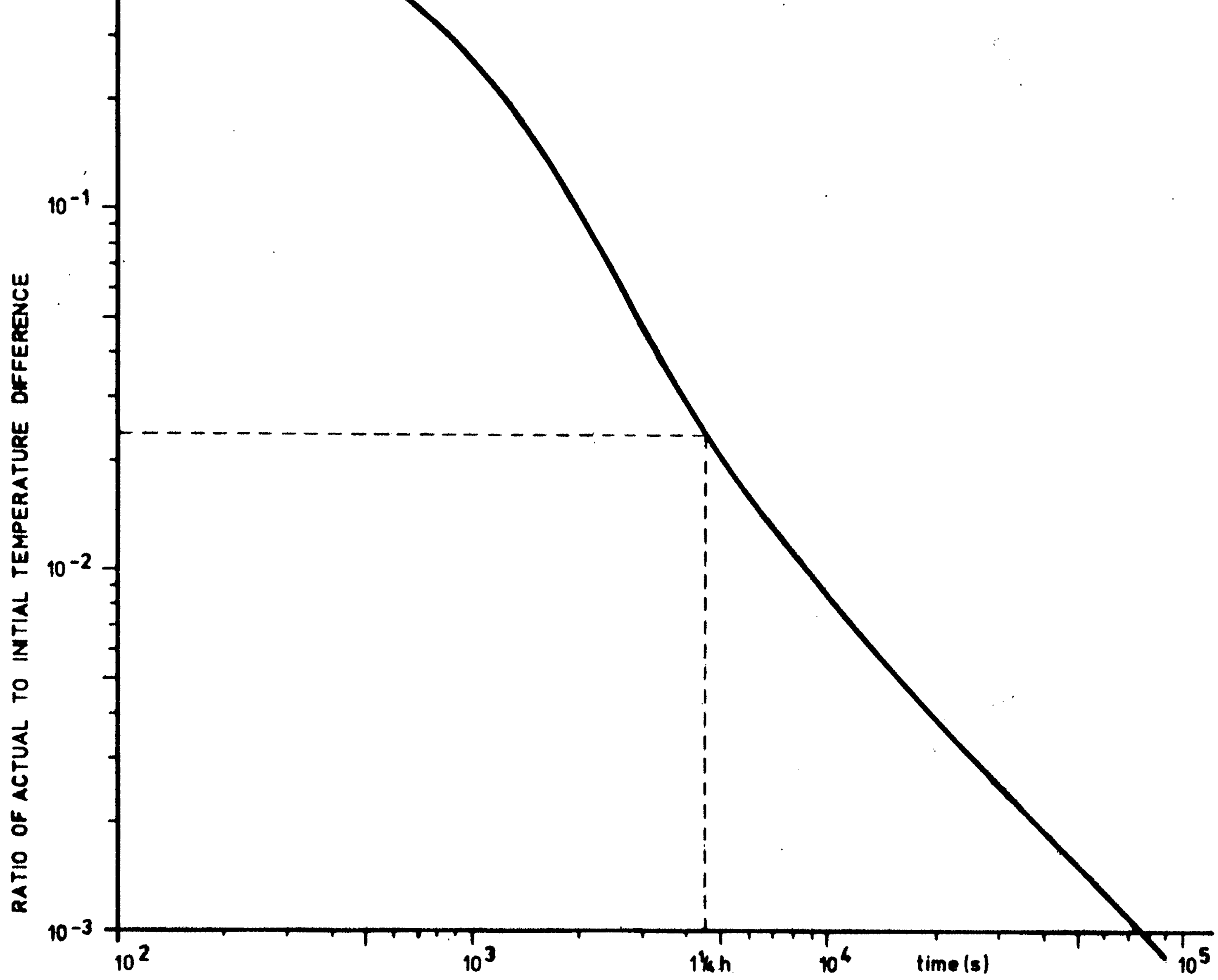


FIGURE 7 COOLING CURVE OF WATER IN A 25/33 mm PVC PIPE SURROUNDED BY SATURATED SAND

the water is of the same order of magnitude as that in the above example, it may be concluded that the error due to water-displacement is negligible.
After the examination, into some detail of above mentioned sources of error, it may be stated that most temperature readings are reliable if one allows an inaccuracy margin of 0,1 ^{o}C.

3. RESULTS

3.1. Representation of the temperature data

Ten subsurface temperature maps of The Netherlands have been assembled, showing temperature intervals of one degree centigrade at depths of 25, 50, 75, ... 225 and 250 m below ground surface (Figs. 8 - 17). On these maps the locations of the measured temperature entries have been dotted. Their number decreases with increasing depths. For example, the map for depth of 100 m has over 200 entries, whereas the map for depth of 250 m has only 39. The temperatures measured at depths below 250 m have been presented on temperature profiles (Appendices 1 - 39). Contouring started on the map for depth of 25 m, and was continued on the maps of successive greater depths. Isotherms on maps for depths greater that 200 m have been based mainly on extrapolated temperature profiles. In most cases the depth, to which a temperature profile has been extrapolated, does not exceed the maximum depth of temperature measurement (Table 1) by more than 25%. Extrapolation was based only on the temperature gradient of the deepest section of the measured temperature profile. This method implies some arbitrariness in choosing the length and depth of a section; furthermore it does not take into account the average air temperature at ground surface. Though such a method is disputable, it may be justified after the following considerations:

(i) With the accurate temperature measurements at small depth intervals (1 or 2 m) as obtained in this investigation, even a small section of a temperature profile (some tens of metres) suffices for an accurate determination of the temperature gradient of that section.

(ii) At many locations the rock around the deepest part of a well resembles the rock below the well, down to a depth of 250 m. This implies that the same holds true for their thermal conductivities. Therefore - in case of uniform stationary heat transfer by conduction - the temperature gradient may only change slightly at these depths.

(iii) Uniform stationary heat transfer by conduction is more likely to occur at greater depths, as groundwater fluxes and the temperature effects of climatological variations decrease with depth.

(iiii) The use of the average air temperature at ground surface may be disputable, as appeared in this investigation (section 4.1.).

At contouring, on each map a small number (≤ 10) of temperature entries was discarded. Obviously these temperatures do not represent natural

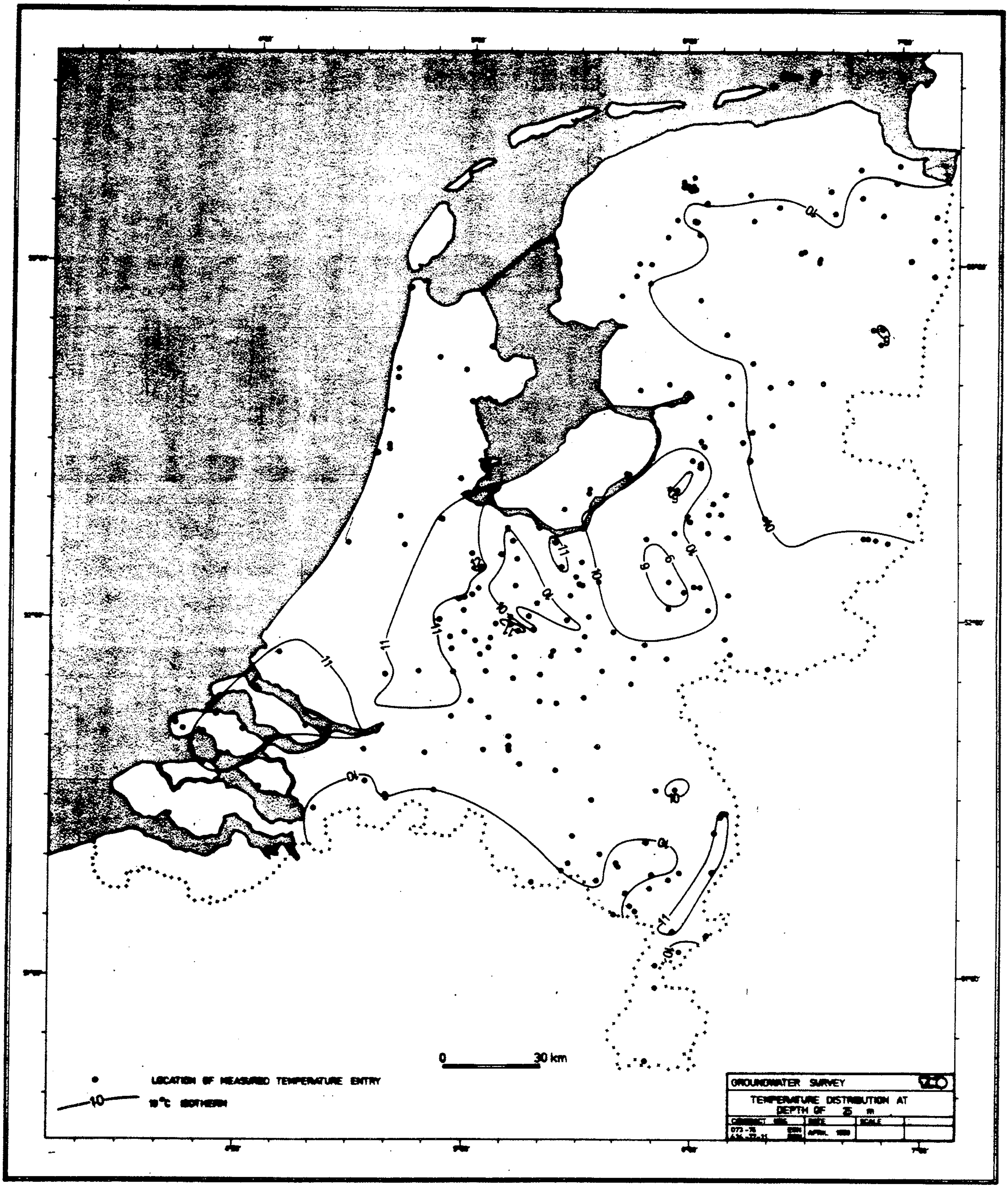
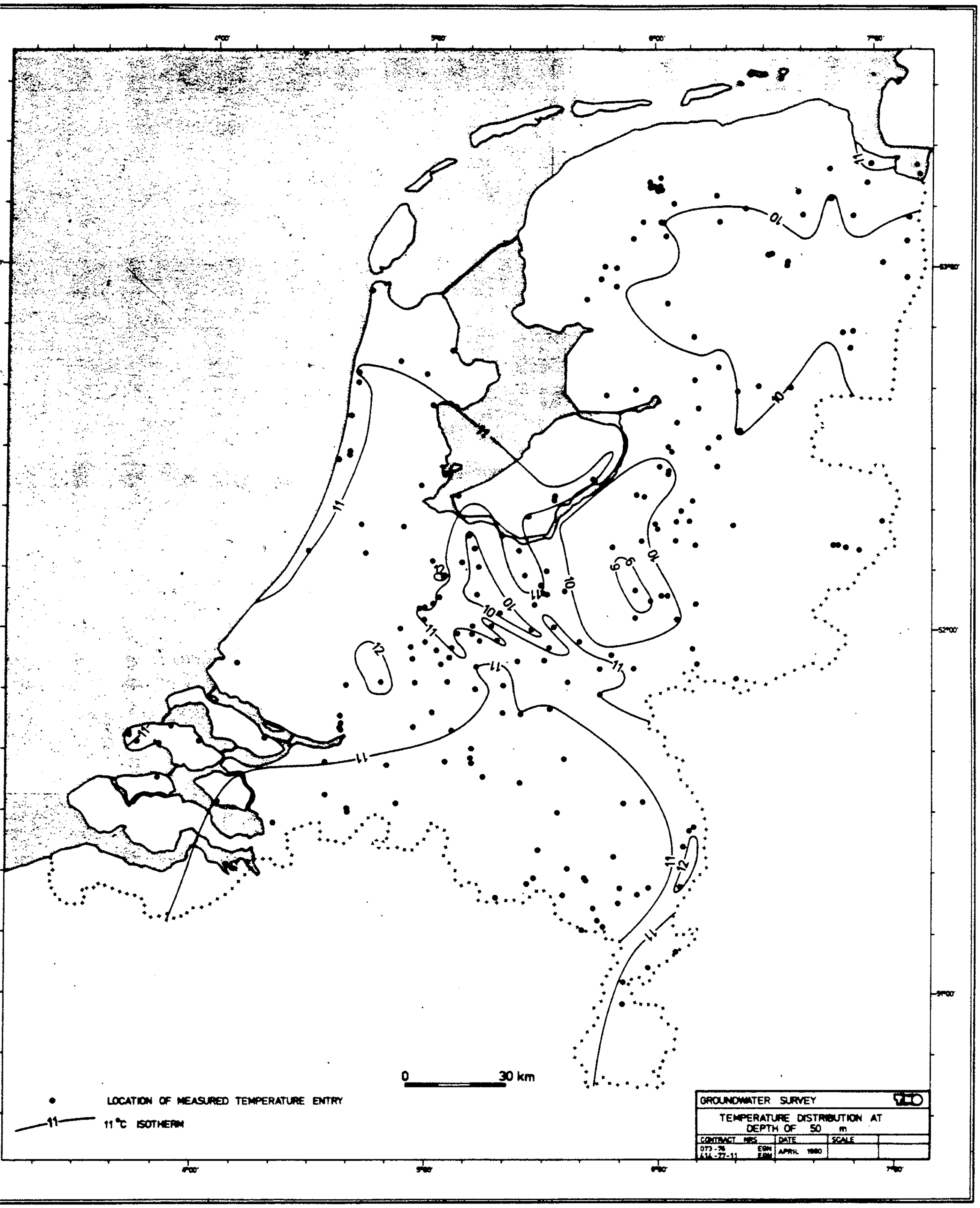


Fig. 8 Isotherm map for a depth of 25 m in The Netherlands



.9 Isotherm map for a depth of 50 m in The Netherlands

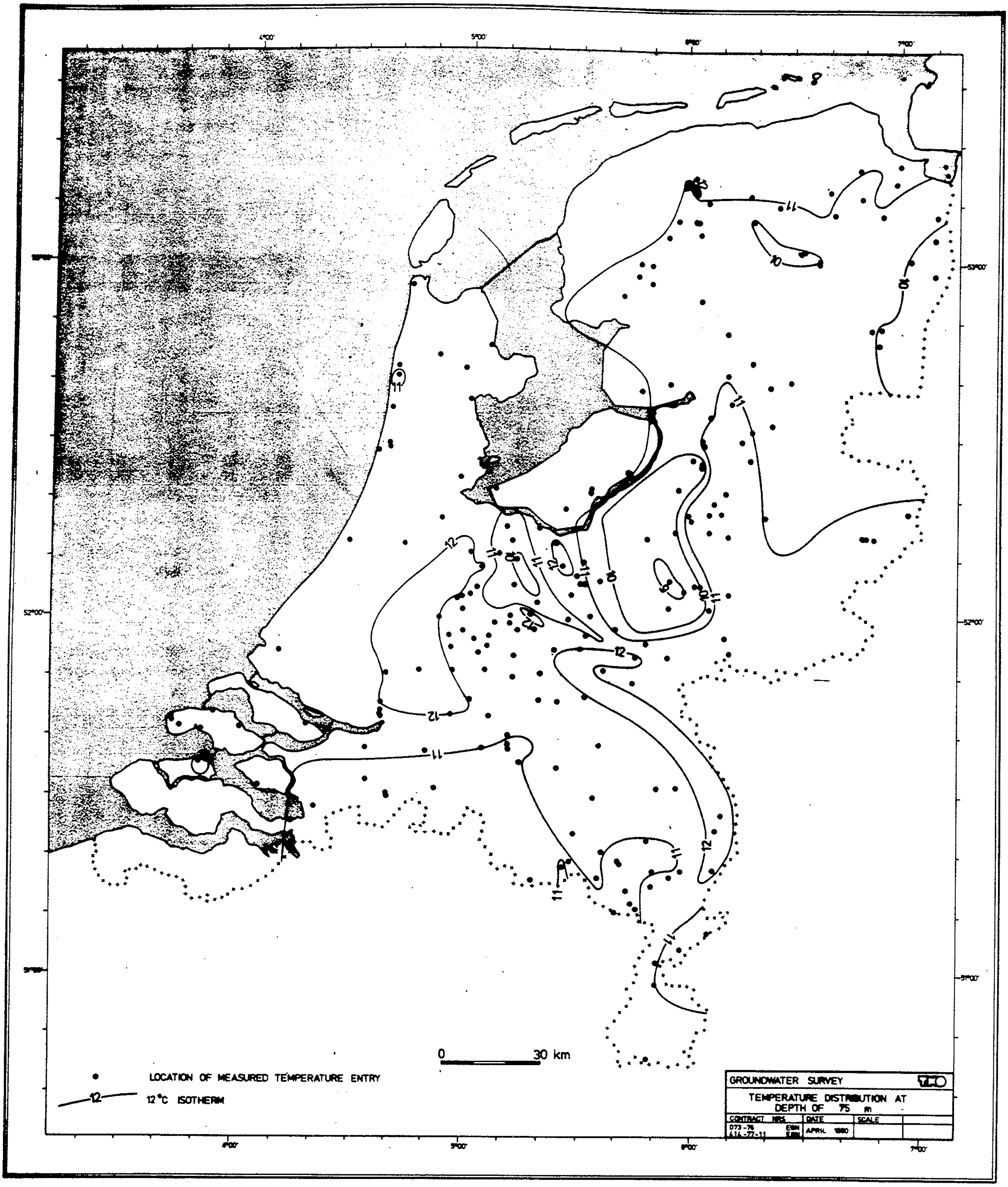
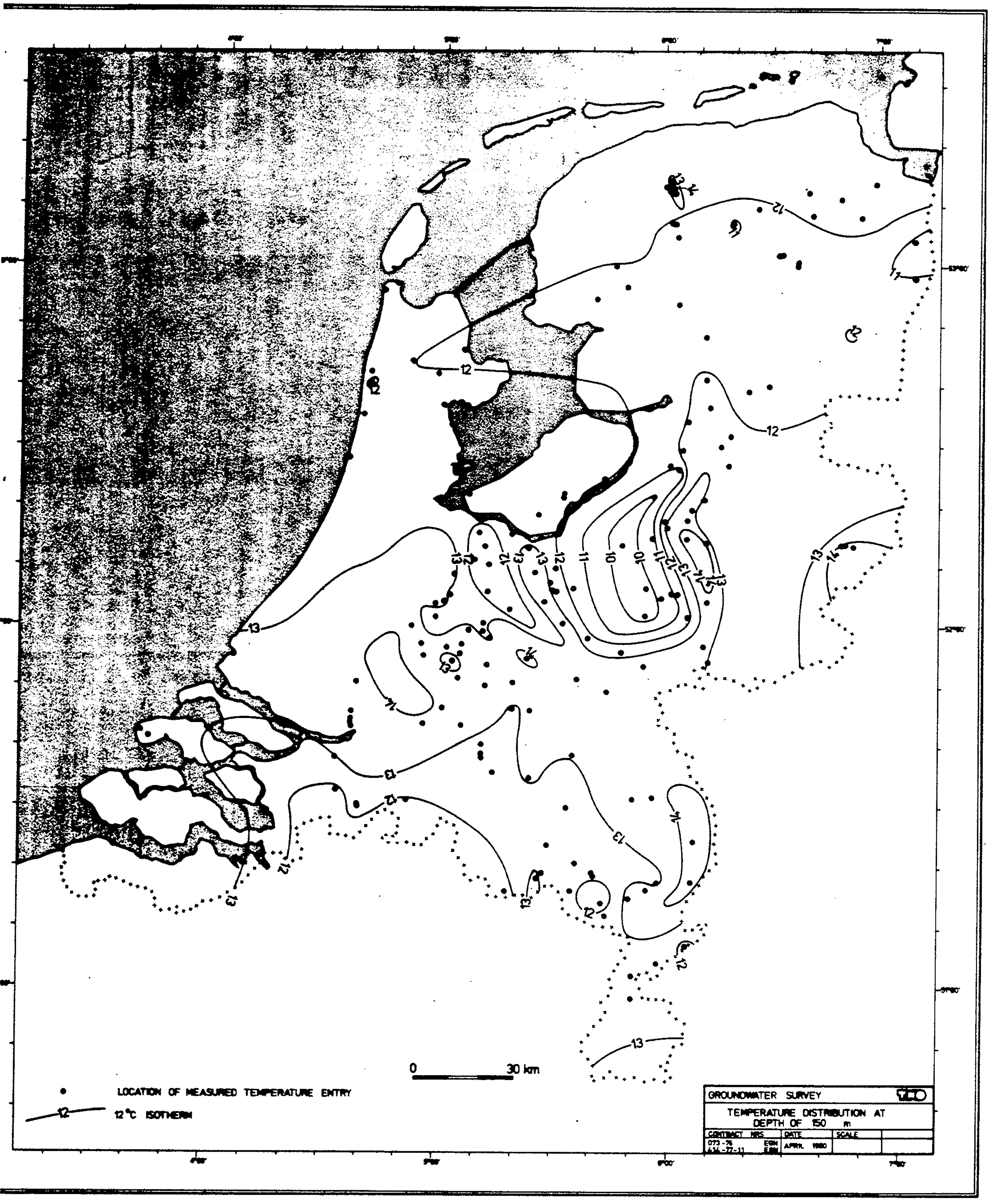


Fig. 10 Isotherm map for a depth of 75 m in The Netherlands



g.13 Isotherm map for a depth of 150 m in The Netherlands

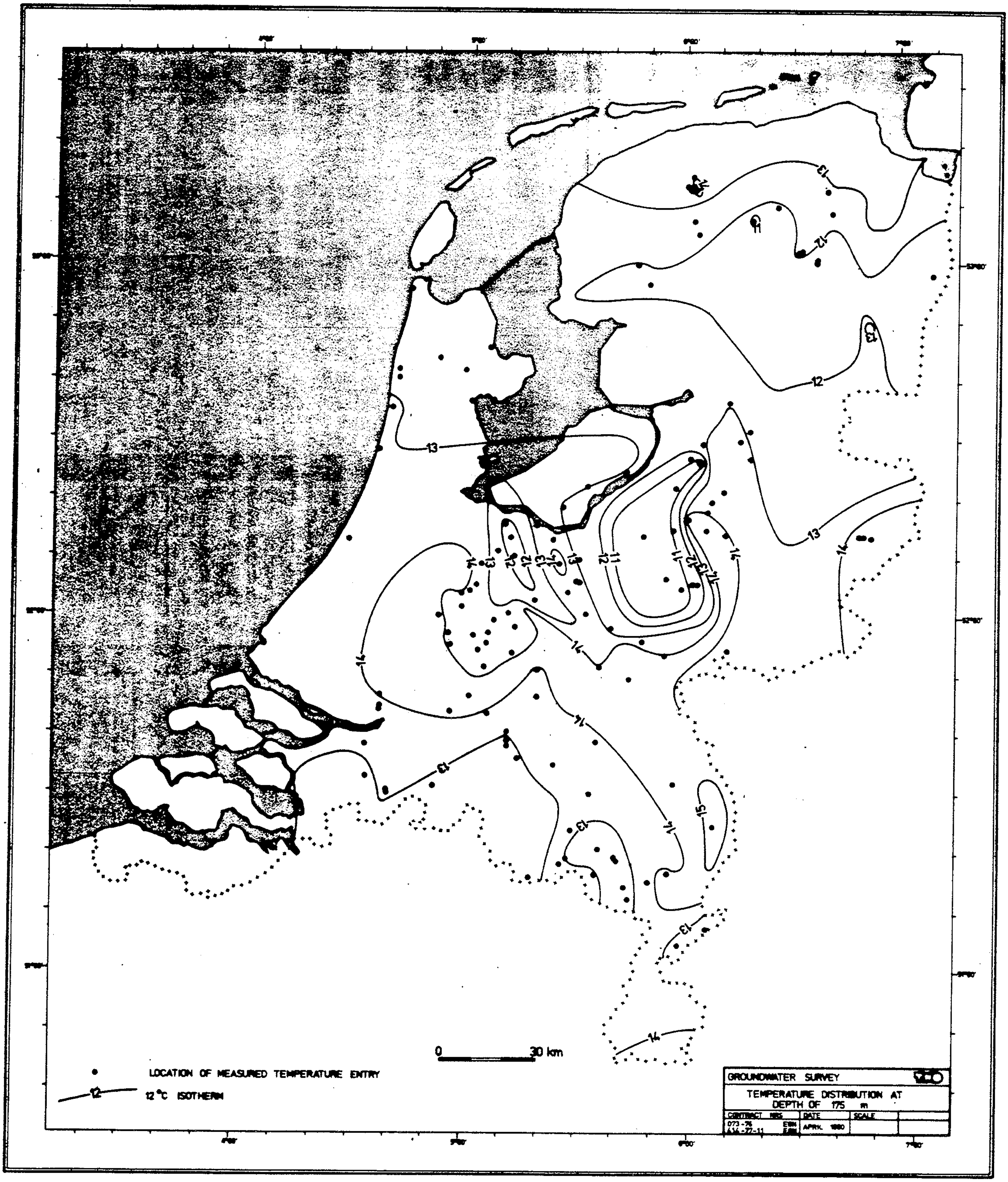
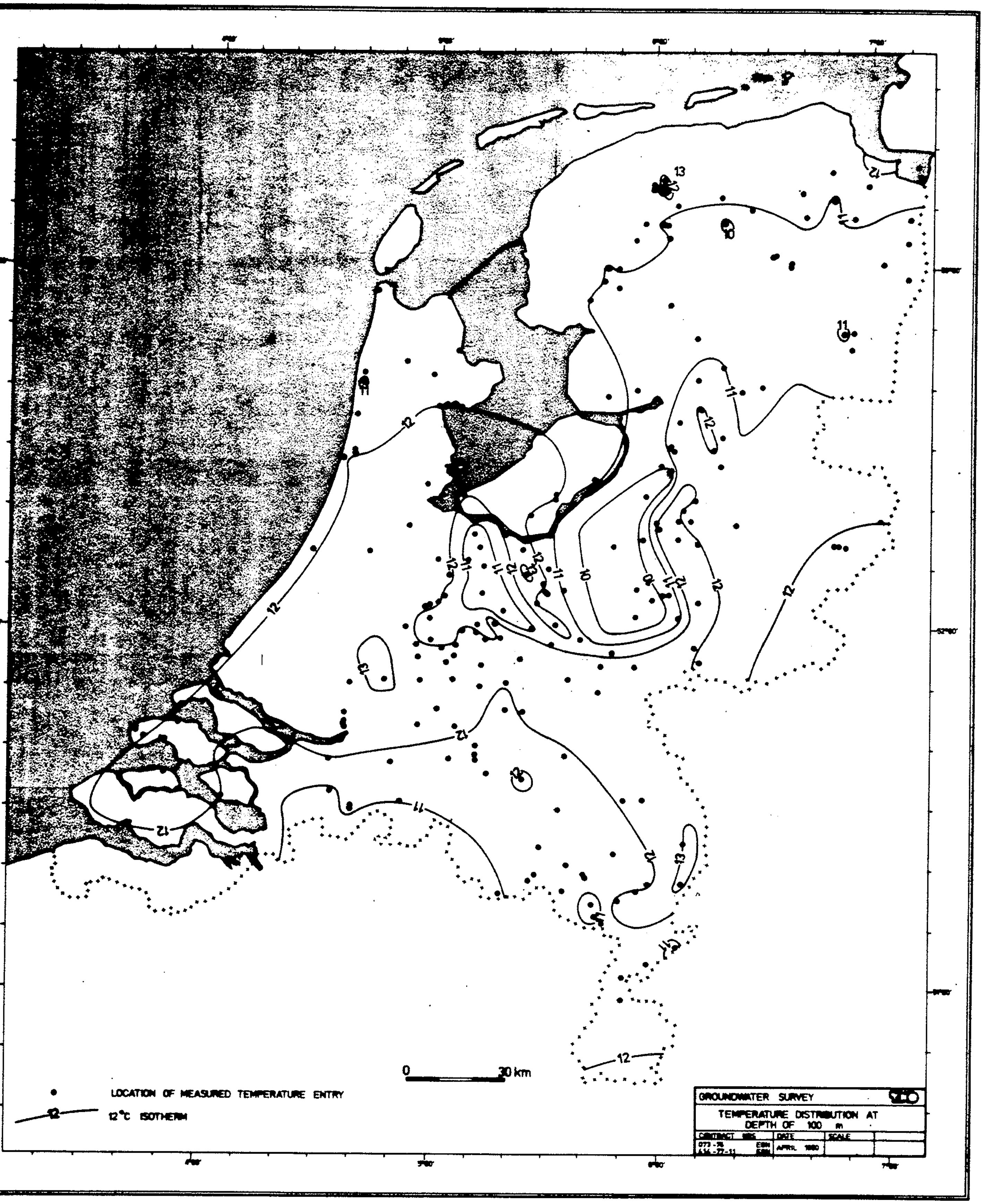


Fig. 14 Isotherm map for a depth of 175 m in The Netherlands



.11 Isotherm map for a depth of 100 m in The Netherlands

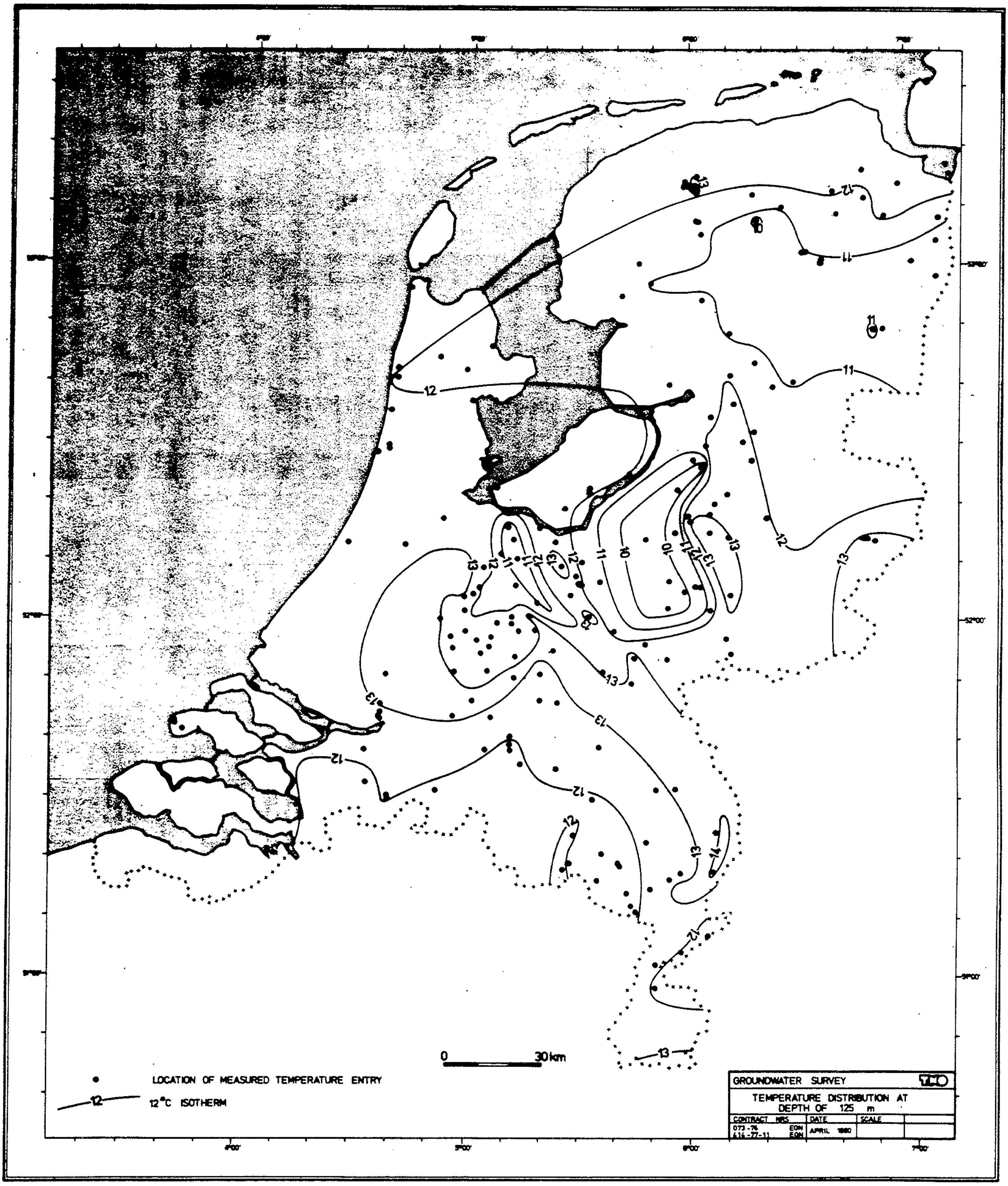
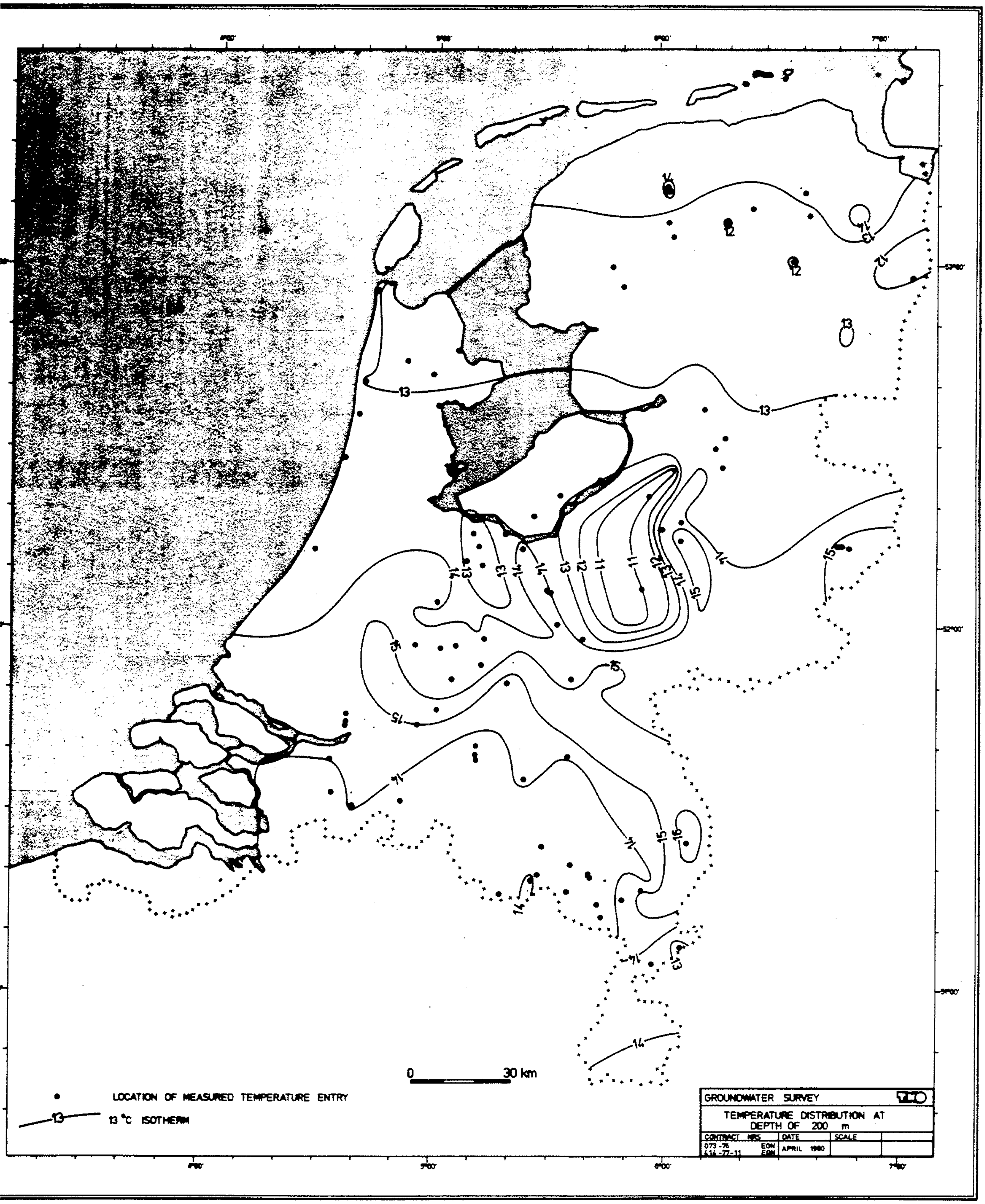


Fig. 12 Isotherm map for a depth of 125 m in The Netherlands



15 Isotherm map for a depth of 200 m in The Netherlands

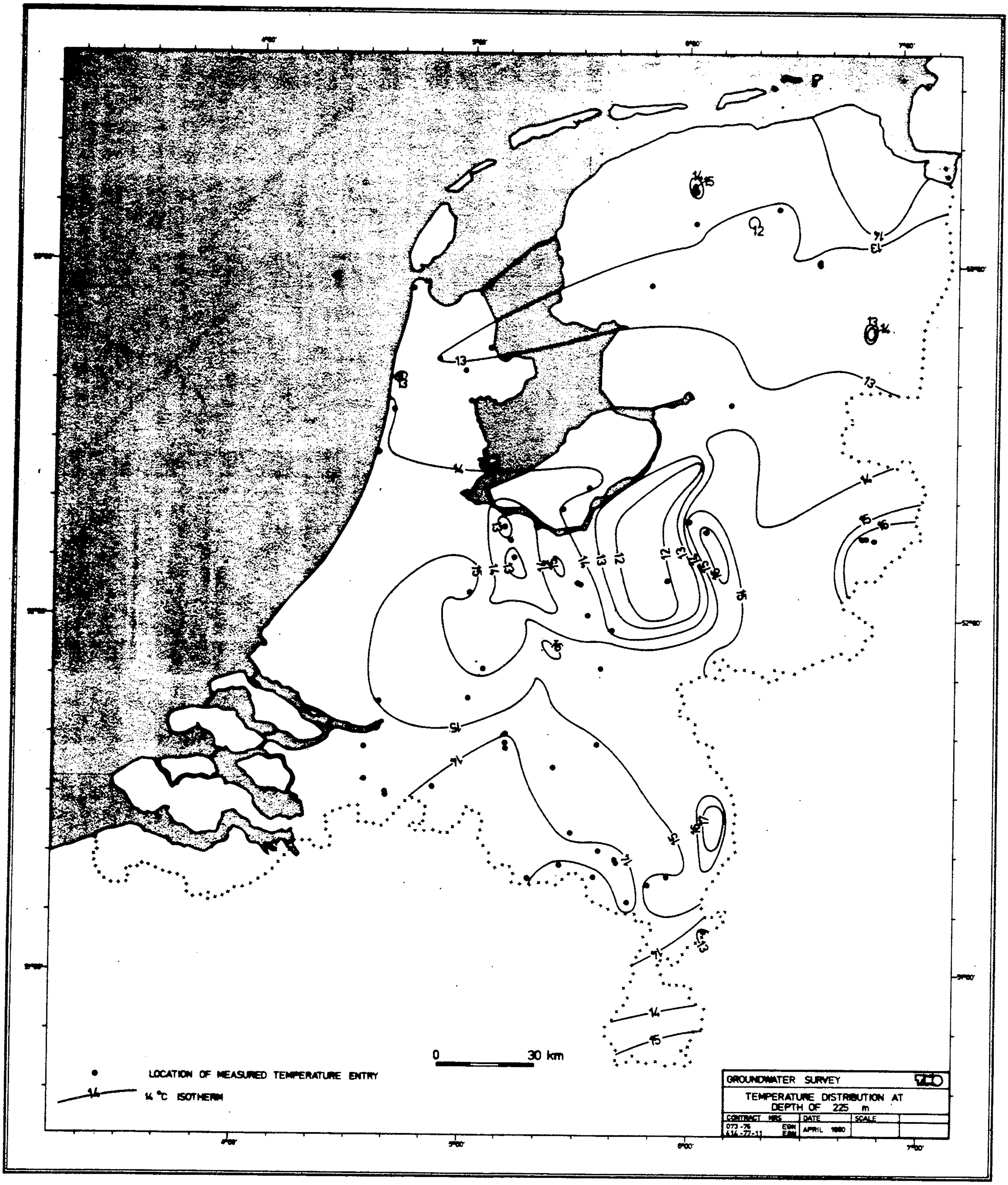


Fig. 16 Isotherm map for a depth of 225 m in The Netherlands

such areas (Θ > 13 °C) are situated in the IJssel valley, the central, the eastern and probably also in the southernmost part of the country. The highest temperatures at a depth of 250 m (Fig. 17) are expected in an area north of Venlo, in the province of Limburg, where temperature probably exceeds 18 °C. This has been based mainly on the temperatures measured to a depth of 200 m in observation well Californië nr. 41 (Fig. 18), and also on those measured in observation well Homberg nr. 51 (Fig. 18). The latter well, however, reaches a depth of only 99 m. Another high-temperature area is situated in Twente, where in the shafts of three rock salt exploitation wells (nrs. 207, 208 and 209) temperatures of 17,5, 17,6 and 18,1 °C were measured (Appendices 33-35). The value in well nr. 208, 17,6 °C, is considered to be the most reliable one, as this well, since its completion in September 1976, had not been in active operation before the temperature measurements in May 1979. With the available temperature data no more areas could be indicated with temperatures exceeding 17,0 °C at 250 m.
The lowest temperature, observed at depth of 250 m, amounts to 12,3 °C in observation well Hoenderloo nr. 119 (Appendix 19) in The Veluwe. Extrapolation of the temperature profiles of two other observation wells in the Veluwe, 't Harde (nr. 118) and Hoog-Soeren (nr. 124), indicated an area with temperatures even less than 12 °C. Thus temperatures at a depth of 250 m in The Netherlands range from about 12 °C to approximately 18 °C.

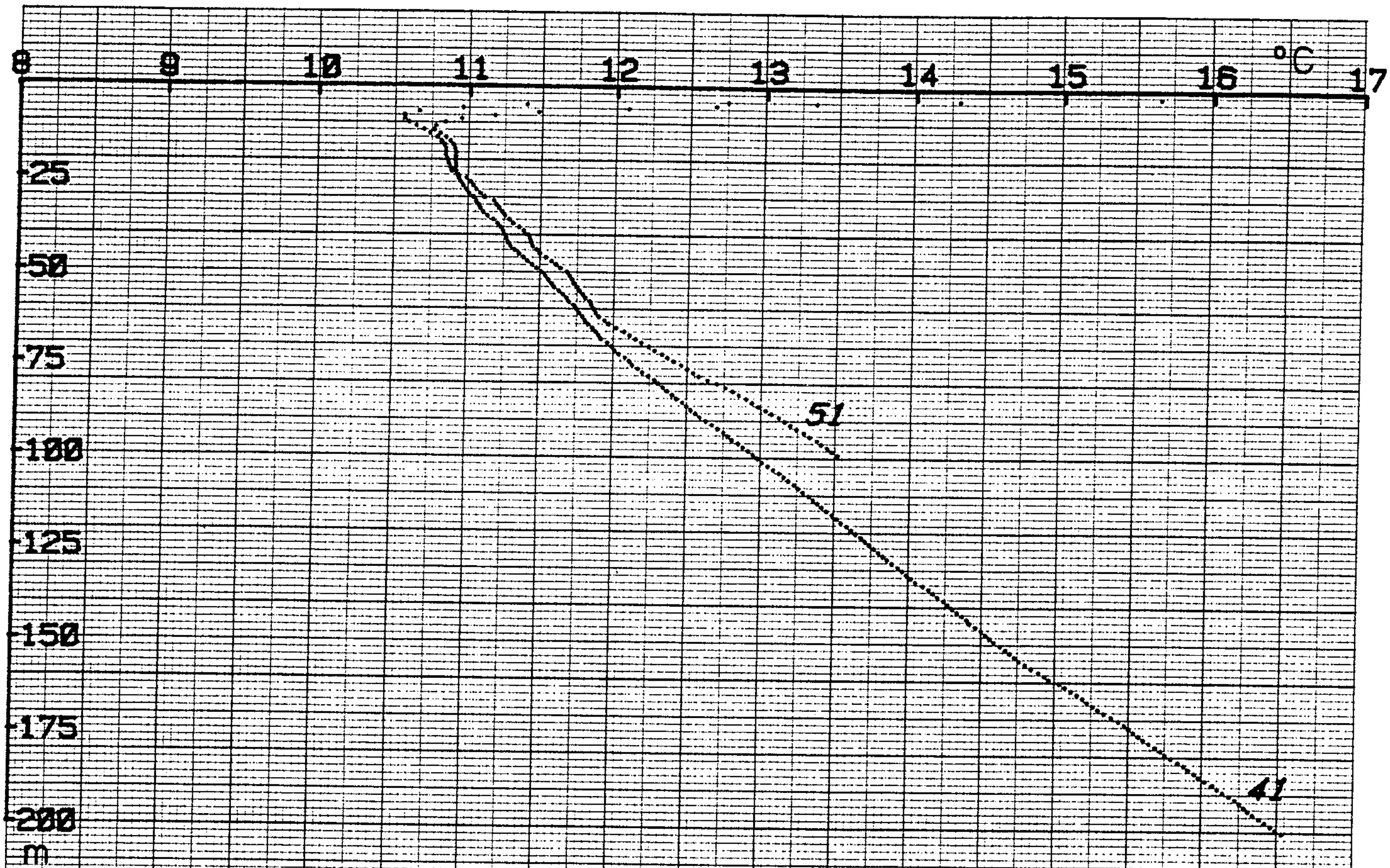


FIGURE 18 TEMPERATURES (770904) IN OBSERVATION WELL CALIFORNIE NR. 41, AND (770722) IN OBSERVATION WELL HOMBERG NR. 51

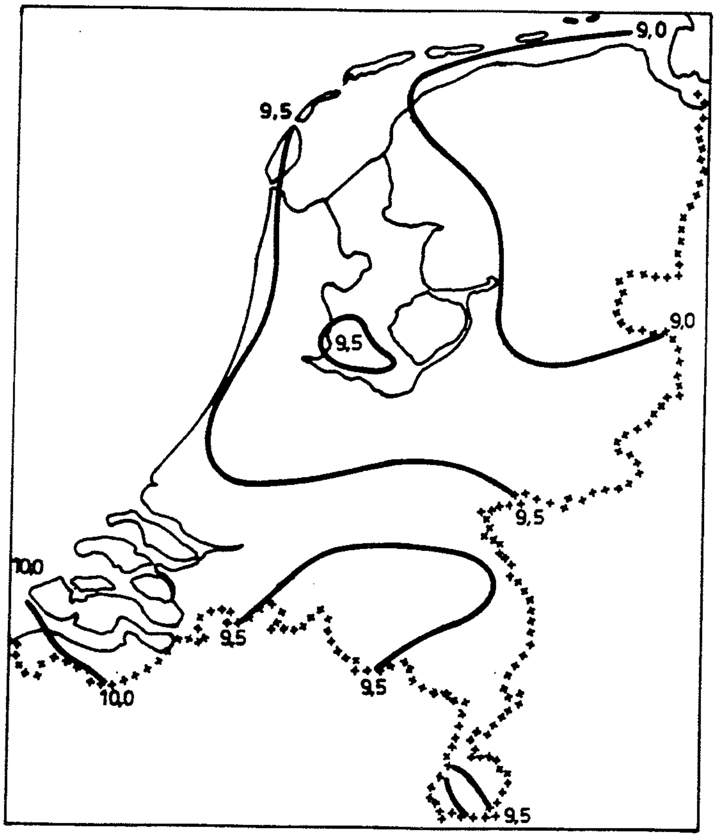
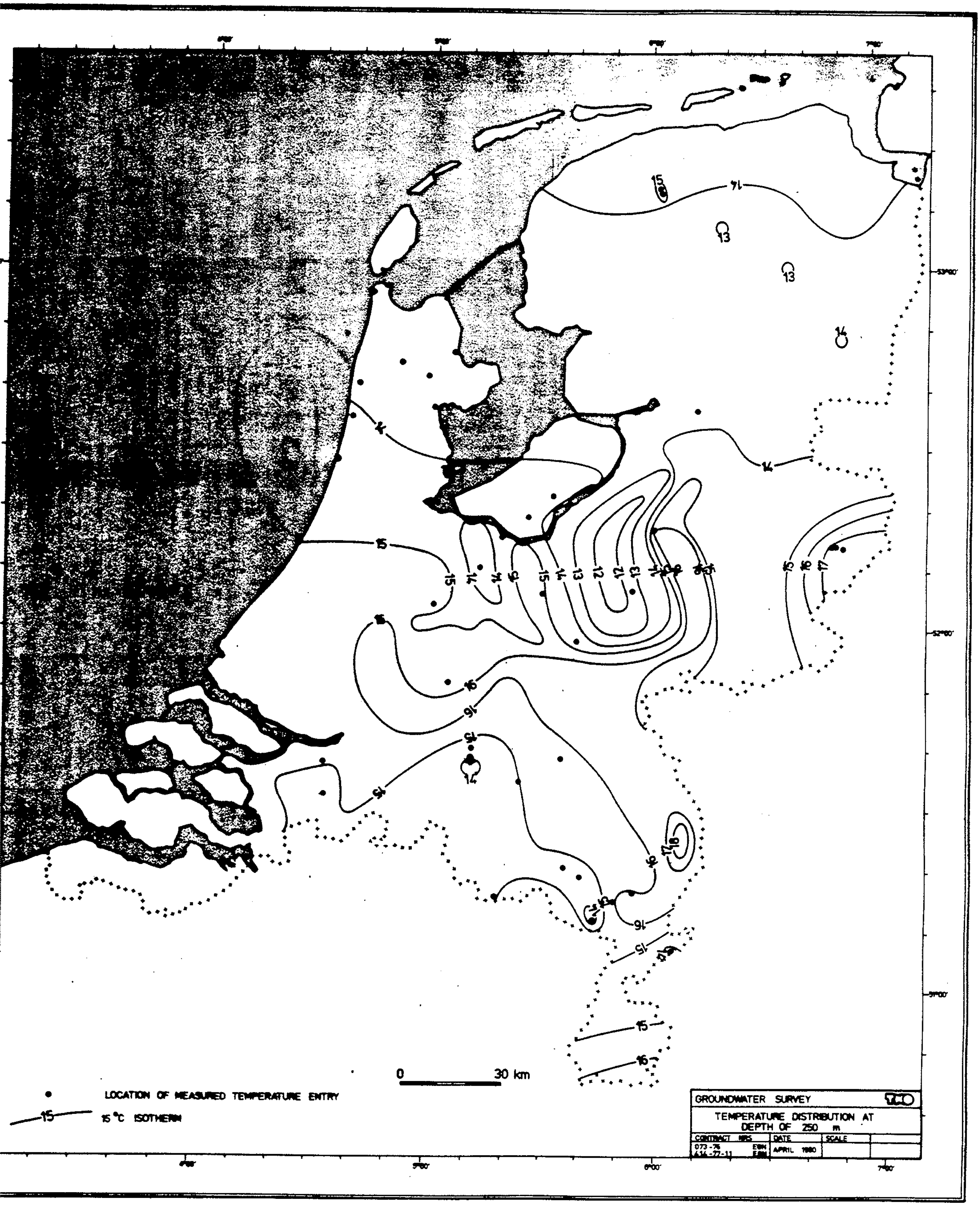


FIGURE 19. AVERAGE AIR TEMPERATURE AT ABOUT 2 m ABOVE GROUND SURFACE (AFTER KNMI, 1972)



17 Isotherm map for a depth of 250 m in The Netherlands

subsurface temperatures, but stem mainly from such man-made interventions as pumping wells and improperly completed observation wells. The 11 °C-isotherm, drawn across the Flevo polders (Fig. 2), on the temperature map for depth of 50 m, is also based on some older temperature data which were published by Csoňka (1968) and by De Jong and Geirnaert (1979). Both authors indicate the influence of natural groundwater flow on the subsurface temperature field in these areas.
This investigation approves the concept of subsurface heat transfer by groundwater flow and verifies this concept with temperature measurements in groundwater observation wells, to relatively great depths, over the whole of The Netherlands (chapter 4).
The temperature intervals, presented on the maps, are not all equally reliable. Of course, their reliability should be judged by the ratio between dots in a temperature interval and its area, and by the distribution of dots over the area. Besides this it is admitted that the temperature intervals along the boundary of the country are less reliable than those for the central part of the country, simply by lack of data pertaining to the other side of the boundary.

3.2. Features of the observed temperature field

Comparing the temperature maps to each other, one learns that temperature, as is to be expected, generally increases with depth, indicating an overall upward heat flow.
Less self-evident, at first glance, is the pattern of relatively low-temperature areas at a depth of 25 m (Fig. 8). These relatively low-temperature areas ($\Theta < 10$ °C) are The Veluwe (Fig. 2), The Utrechtse Heuvelrug and Gooi, the province of Drente with adjacent parts of the provinces of Friesland, Groningen and Overijssel and some areas in the southern part of the country. This pattern persists, most clearly in The Veluwe and The Utrechtse Heuvelrug with Gooi, and even becomes more pronounced at greater depths.
The pattern of relatively high-temperature areas at depth of 25 m ($\Theta > 11$ °C) is less persistent. The relatively high-temperature area in the southwestern part of the country fades out at greater depths, where another pattern of relatively high-temperature areas appears. At a depth of 125 m (Fig. 12)

4. INTERPRETATION OF THE TEMPERATURE DATA

After the delineation of the subsurface temperature field to a depth of 250 m, the question arises how it should be interpreted. In this chapter an interpretation is presented, which takes its starting point in the identification of a heat sink in The Veluwe.

4.1. Heat transfer in groundwater recharge areas

Comparing the average air temperatures ($\Theta > 9\ ^{o}C$), published by KNMI (1972), at about 2 m above ground surface (Fig. 19) with the temperatures ($\Theta < 9\ ^{o}C$) at depths of 25 m and 50 m (Figs. 8 and 9) in The Veluwe, it appears that here subsurface temperatures are less than the average air temperatures. This area constitutes a heat sink that with the usual simplified radiation-conduction model of heat exchange between atmosphere and solid earth cannot be explained satisfactorily (Van Dalfsen, 1979b).

The phenomenon can be explained if one takes the hydrologic cycle into account. Firstly, it is noted that The Veluwe, being an ice-pushed ridge, is a groundwater recharge area (Atlas of The Netherlands, plate VII-3A, 1976). The total annual precipitation surplus in this area almost totally infiltrates into deeper permeable, unconsolidated sands. Therefore an effect of heat transfer between infiltrated water and sediments should be considered. Secondly it is noted that the precipitation surplus occurs mainly in the cold season (October - April). This implies that the average temperature of the water percolating down to the water table is less than average air temperature. The result of this hydrologic regime in The Veluwe is a thermal regime with very low temperatures even down to a depth of 50 m.

With the infiltration-heat convection model, as outlined above for The Veluwe, the interpretation of the other relatively low-temperature areas at a depth of 25 m is straightforward. The Utrechtse Heuvelrug and Gooi, another ice-pushed ridge, is also a groundwater recharge area as well as large areas in the provinces of Drente and Noord-Brabant. Comparing the relatively low temperatures in the northeastern part of the country with the average air temperatures, 8,5 - 9 ^{o}C (Fig. 19), it appears however that here the effect of groundwater recharge on the temperature field is less pronounced.

4.2. Notes about the hydrogeologic constitution of The Netherlands

The above considerations about the relatively low temperatures at shallow depths in groundwater recharge areas, provide a starting point to the interpretation of the temperatures observed at greater depths. First a few pertinent notions should be made, which pertain to the hydrogeologic constitution of The Netherlands and to groundwater flow in the hydrologic cycle. These notions are essential in the subsequent interpretation of the subsurface temperature field.

Geologically The Netherlands is situated at the southern tip of the North Sea Basin (Van Staalduinen et al., 1980). The depositional regime in this part of the basin resulted in an alternation of sandy and clayey layers at most places. The Tertiary deposits in the basin are for the major part of marine origin, particularly the older Tertiary consists predominantly of marine clays and clayey glauconitic sands.
Since the Miocene fluviatile sedimentation progressively replaced marine sedimentation and predominantly fluvial deposits were laid down over the present mainland. Glacial action during the Quaternary, however, disturbed the original stratification in many parts of the northern half of the country. This resulted in such regional glacial phenomena as the ice-pushed ridges of The Veluwe and The Utrechtse Heuvelrug with Gooi, and in the glacial valleys along these ridges.
Geohydrologically the sand and clay deposits constitute a system of aquifers and confining strata (Atlas of The Netherlands, plate VII-4, 1976). The aquifers and confining strata are elements of the hydrologic cycle, since they determine the patterns of groundwater flow.

Groundwater in the hydrologic cycle, which is steadily recharged in some area, flows through the subsurface rock and, after some time, reappears somewhere at the surface. Its flow, on a macroscopic scale, is determined by the geohydrologic conditions, both natural and man-made. These comprise on the one hand the areal and temporal distribution of recharge and discharge or withdrawal by pumping, and on the other hand the spatial and temporal distribution of the geohydrologic parameters, viz. porosity, storativity and hydraulic conductivity.
A general rule pertaining to groundwater flow fields is expressed below by considering groundwater fluxes through horizontal planes.
In recharge areas groundwater fluxes through horizontal planes have a

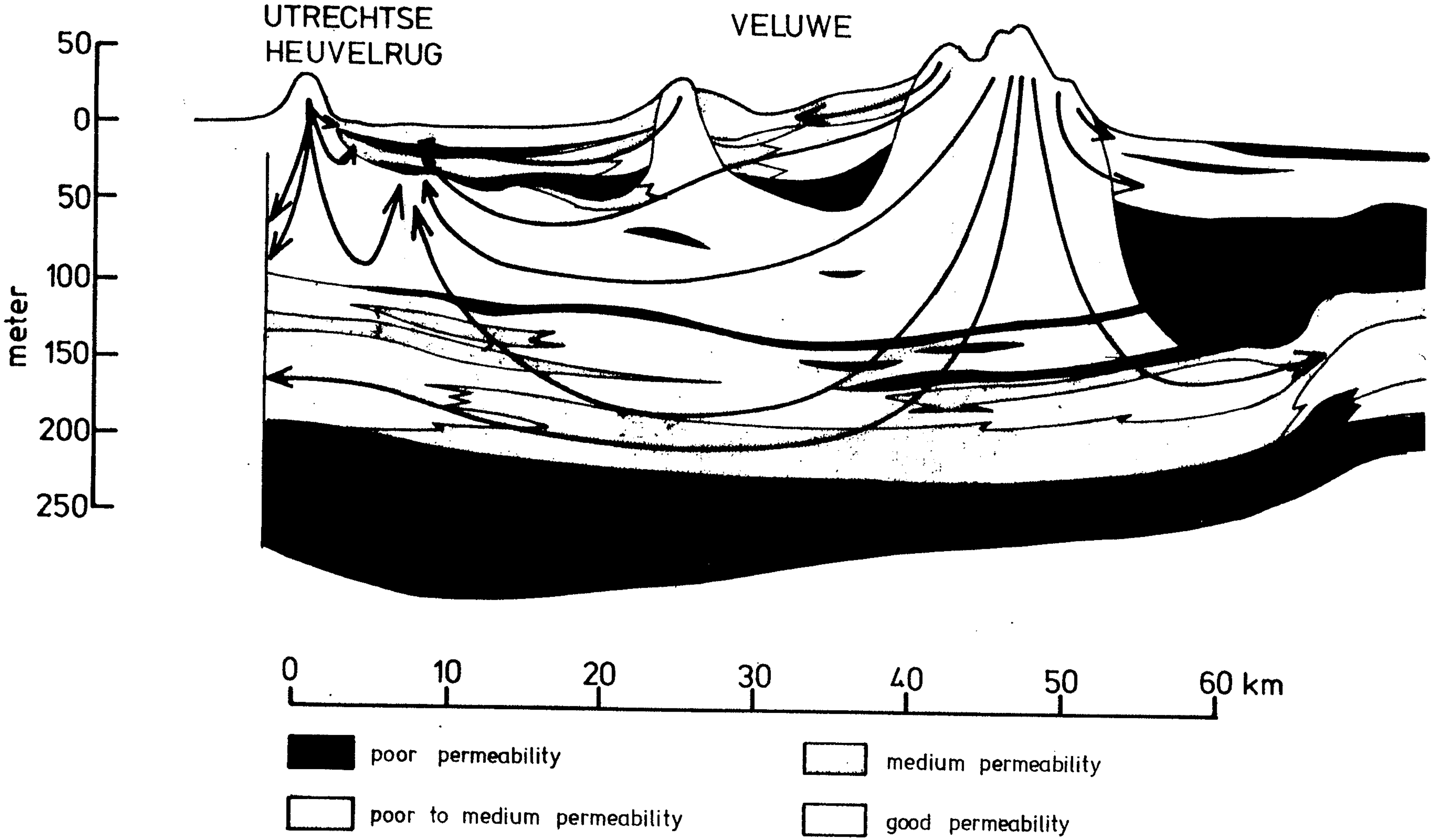


FIG. 20 SCHEMATIC GROUNDWATER FLOW PATTERN IN THE NETHERLANDS
(FLOW PATTERN OUTLINED ON PLATE VII-4, ATLAS OF THE NETHERLANDS)

downward direction and decrease with increasing depths. Conversely in discharge areas the fluxes have an upward direction and increase with decreasing depth.
Usually geohydrologists indicate a less pervious stratum below which - in their view - groundwater fluxes are negligible. The depth of the less pervious base of the water-bearing strata in The Netherlands increases from a few tens of metres below ground surface in Twente, The Achterhoek and in the southern parts of the provinces of Zeeland, Noord-Brabant and Limburg to over 250 m in the Central Graben and the north-western part of the country (Atlas of The Netherlands, plate VII-3D, 1976). The above notions are illustrated with the representation (Fig. 20) of a schematic groundwater flow pattern in the central part of The Netherlands.

4.3. Balance of heat transfer in groundwater recharge areas

In a groundwater recharge area the downward groundwater flow tends to reduce temperatures along its flow-paths to the temperature of the infiltrating water. This reduction of temperature is opposed by the Earth's heat flow, as is outlined below.
At great depths, where groundwater fluxes are small, only a small part of the Earth's heat flux suffices to balance the convective heat transfer by groundwater flow. At these depths temperatures are only slightly below those which would exist if no groundwater flow occurred. At smaller depths, however, increasing parts of the Earth's heat flux are used to balance the convective heat transfer by the increased groundwater fluxes. Therefore only a reduced part of the Earth's heat flow reaches shallow depths in recharge areas. This implies the reduction of temperatures at shallow depths to nearly that of the infiltrating water. From these notions it will be clear that in recharge areas subsurface temperatures are lower than those which would exist if no groundwater flow occurred (negative temperature anomaly), and temperature gradient decreases with decreasing depth (concave shape of temperature profile).
These features are illustraded by the temperature profile (Appendix 19) of observation well Hoenderloo (nr. 119) in The Veluwe. This curve shows the low temperatures (< 9 ^{o}C) of infiltrated water at shallow depths and also increasing temperature gradients up to 150 m. For the sake of completeness it should be noted that this increase of temperature gradient

cannot be explained by decreasing thermal conductivities as the perforated rock consists of sands up to a depth of 170 m. The cusp at 195 m in the curve is probably caused by groundwater flow, of which the details are not yet clear. It is important to note that the temperatures measured below the less pervious base at 200 m are also lower than would be expected if no groundwater flow occurred.

4.4. Balance of heat transfer in groundwater discharge areas

Outside a recharge area, groundwater flow is mainly horizontal until it reaches its discharge basin. This may be a river valley or a polder in the lower parts of The Netherlands. In its discharge basin, and in some cases also in an area of artifical groundwater withdrawal, flow becomes predominantly vertical. Through convective heat transfer this upward groundwater flow tends to raise the temperatures along its flowpaths to the temperature at the deepest section of the flow-path.
The rise of temperature is opposed by heat losses to the atmosphere. Effective heat transfer processes at the Earth's surface (radiation and convection) keep the natural average soil temperature in discharge basins at a value which is slightly above the average air temperature. It should be clear that the temperature anomalies, due to both upward and downward groundwater flow, depend on the amount and areal extent of the groundwater fluxes and on their depth ranges.
As groundwater fluxes decrease with increasing depth, one should be careful in simulating subsurface temperatures with a uniform vertical groundwater flow field as done by De Jong and Geirnaert (1979). A more realistic approach would be a model, in which the recharge and discharge area are represented by a line source and sink, respectively, of groundwater. The two-dimensional flow field of this model should be calculated first, assuming an hydraulically horizontal subsurface layering. This flow field should be inserted in the equation describing the subsurface heat balance, the solution of which then yields the subsurface temperature field. In this procedure a uniform heat current density should be assumed as a boundary condition on some deep layer, across which the groundwater flux is negligible.
Having identified upward groundwater flow as a cause of relatively high subsurface temperatures, the relatively high-temperature areas in the Maas, Rijn, and IJssel valleys and also in the low western and northern parts of the country, may be ascribed to patterns of upward groundwater

flow. A typical temperature profile of a groundwater discharge area is that of observation well Amersfoort (nr. 82), in the Eem valley located between the Veluwe and Utrechtse Heuvelrug (Fig. 20). The temperature profile of observation well Amersfoort in the Eem valley is represented in Fig. 21. The temperature effect of upward groundwater flow is expressed by the convexity of the curve, together with the relatively high temperatures at shallow depths.

4.5. Influence of thermal conductivity on the subsurface temperature field

The interpretation of the subsurface temperature field, up to now, is not complete without considering the effects of varying thermal conductivities. According to Fourier's law, the temperature gradients in two successive layers are inversely proportional to their thermal conductivities, if there is a stationary vertical heat transfer by conduction only and if there are no heat sources in these layers. As, concerning unconsolidated water saturated porous media, sands are better conductors than clays and clays are better conductors that peat or brown coal, it should be expected that temperature gradients in peat or brown coal are higher than those in clay, the latter gradients being higher than those in sands. This phenomenon is demonstrated clearly in Appendix 7, which shows the temperature profile in observation well Tungelroy (nr. 48) and also the lithological column of this borehole. Obviously temperature gradients in layers with clay and brown coal are much higher than those in sands.

Temperature gradients may vary in a lateral direction as well as in the vertical direction due to changing thermal conductivities. Lateral variations of thermal conductivity, over considerable depth ranges, are connected with two geological phenomena in The Netherlands. These are the occurrence of deep glacier-tongue basins and gully-like depressions in the northern half of the country, and the appearance of older (mainly Mezozoic) strata at shallow depths in Twente, The Achterhoek and in the southern part of the province of Limburg (Van Staalduinen et al, 1980). The glacial-tongue basins or erosion channels were filled by glacial lake-sediments, mainly clays. Therefore these basins or gullies have relatively low thermal (and hydraulic) conductivities. The same holds probably true for the thermal and hydraulic conductivities of the Mezozoic strata in comparison with the Quaternary formations in the greater

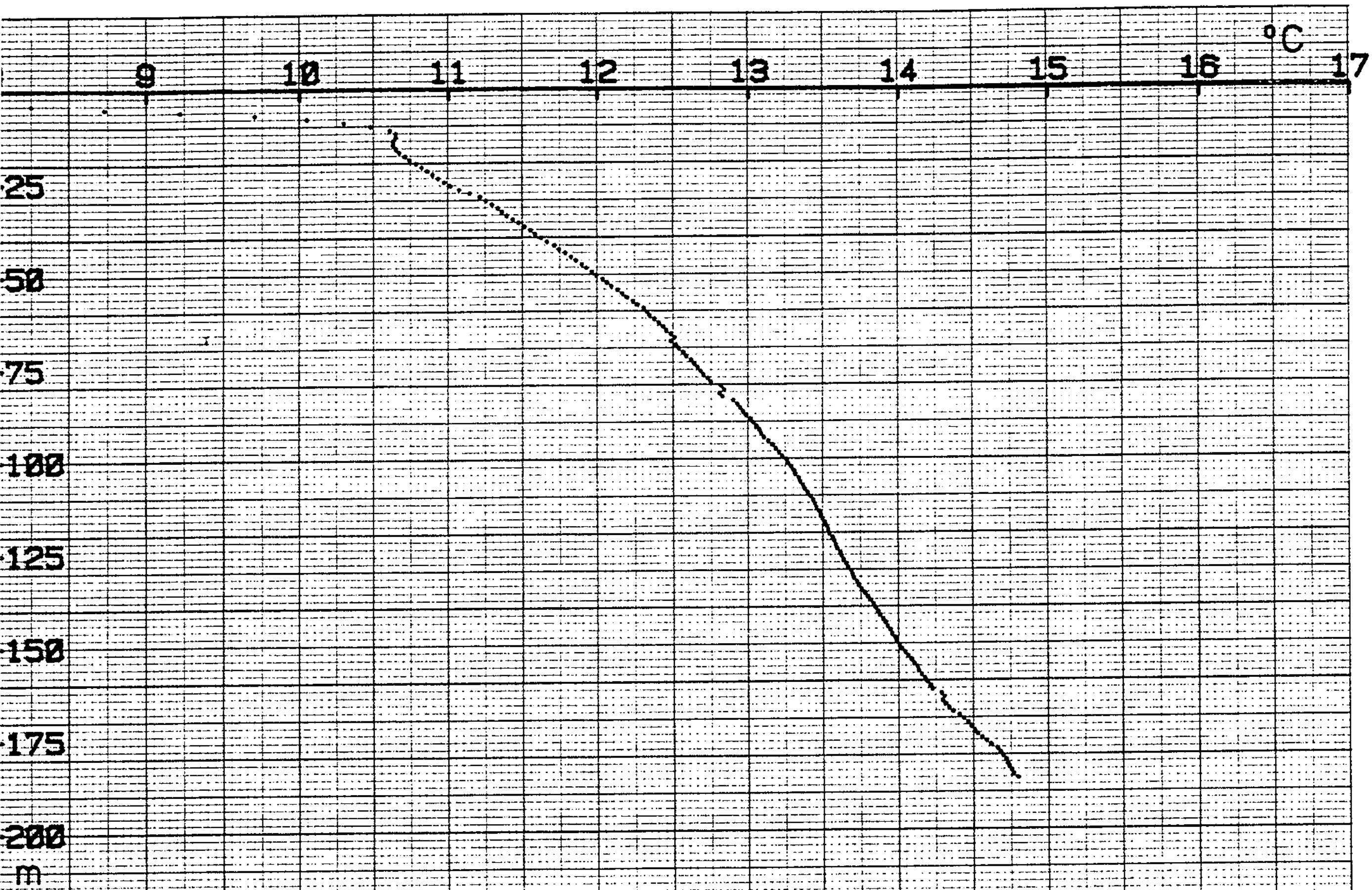


FIGURE 21 TEMPERATURE PROFILE (780412) OF OBSERVATION WELL AMERSFOORT NR. 82, INDICATING UPWARD GROUNDWATER FLOW

part of The Netherlands.
Therefore it is possible to (re-)interprete some relatively high-temperature areas in terms of lateral changes in thermal conductivity. These are the areas located in (i) Twente/The Achterhoek and in the southern part of the province of Limburg with older (mainly Mezozoic) strata of shallow depths, (ii) in the province of Friesland where some observation wells near Noordbergum perforate a gully-like depression of Elsterian age, partially filled with the so-called "pot"-clay and (iii) in the IJssel valley, east of The Veluwe (Fig. 20), where a deep glacial-tongue basin was filled with clays. The effect of the clays on the temperature gradient is demonstrated in Appendix 16, which shows the temperature profile in observation well Vaassen 2 (nr. 105) together with the lithological column of this borehole in the IJssel valley. In respect to this the relatively high temperature in the IJssel valley should be ascribed to the relatively low thermal conductivities of the clays, wherever they occur over substantial depth ranges.

4.6. Other causes of relatively high subsurface temperatures

So far a great deal of the temperature data has been interpreted in terms of (i) heat sinks caused by natural infiltration of the precipitation surplus in the cold season, (ii) convective heat transfer of groundwater flowing along its path from recharge to discharge area and (iii) lateral changes in thermal conductivity due to geological structures of relatively large scale, which interrupt the predominantly horizontal bedding in The Netherlands.

These factors, however, do not suffice to explain the temperature profiles in the Rijn and Maas valleys satisfactorily. This applies especially to the temperature profiles in the observation wells Californië and Homberg (Fig. 18), north of Venlo (Fig. 2). To a lesser extent it applies also to the temperature profiles in the observation wells Zoelen 1 (nr. 17) and Andelst (nr. 157), in the area between the rivers Rijn and Waal (Betuwe), and in the observation well Bleskensgraaf (nr. 19) in the western part of the area between the rivers Lek and Waal (Alblasserwaard). All these profiles show relatively high temperature gradients, but no perceivable convexity indicating upward groundwater flow. Neither occur there thick strata of relatively low thermal conductivities to be related with the relatively high temperature gradients.

Two more factors should be regarded, which exert an influence on the subsurface temperature field. These are the average air temperature at the ground surface and the horizontal distribution of heat flow at great depths. They constitute thermal boundary conditions on the upper and lower levels, respectively, of the subsurface under investigation.
Average temperatures of the air at ground surface in the Rijn and Maas valleys appear to be slightly higher than those in the surrounding areas (Fig. 19). Consequently in the former areas subsurface temperatures may expected to be some tenths of a degree centigrade higher than in the latter areas. This slightly higher temperature level, however, does not explain the relatively high temperature gradients.

Lateral variation of heat flow is the only factor, which remains to be considered. Such lateral variation of heat flow may be caused by a non uniform distribution of heat sources at great depths or by a lateral variation of thermal conductivities such as to constitute a "conduction chimney" (e.g. a salt dome). Otherwise there may be a local or regional transport of heat by groundwater, which rises through faults and fissures or simply through the interstices of primary rock porosity.

For the location with relatively high temperature gradients it cannot be inferred, from the temperature data only, which is the decisive mode of heat transfer: heat transport from great depths by groundwater, or a relatively high conductive heat flow. If there is an upward flow of groundwater, then its flow field should be such that somewhere vertical flow turns into a horizontal flow, which passes the observation well at some depths or underneath (Kappelmeyer and Haenel, 1974, p. 201). This restriction on the flow field stems from absence of convexity in the measured temperature profiles.

Some hydrochemical evidence of the rise of warm and gaseous mineral water through faults in the Alblasserwaard, in which observation well Bleskensgraaf (nr. 19) is located, is provided by Engelen (1969). This author supports his view with tectonic data published by Haanstra (1963) and with hydrothermal data published by Kimpe (1963). The latter describes the occurrence of warm mineral water passing along large faults at the southwestern side of the Central Graben at several points in the coal

mines of the Carboniferous district of Limburg. The temperature data of observation well Bleskensgraaf may be put forward as further evidence of the rise of warm water.
The relatively high temperature gradients in the other wells can, as yet, not be combined with relevant hydrochemical data. These wells, however, are located in areas with a pronounced tectonic activity (Van Staalduinen et al, 1980). The tectonic units are the Peel Horst with observation well Zoelen 1 at its northern tip and the shallow Venlo Graben with the observation wells Californië and Homberg. Here tectonic activity might have created a geohydrologic situation, in which warm water rises from great depths.

FIGURE 22 TEMPERATURE DISTRIBUTION AT 500 m BELOW GROUND SURFACE (AFTER ATLAS OF SUBSURFACE TEMPERATURES IN THE EUROPEAN COMMUNITY, 1980)

5. COMPARISON WITH TEMPERATURE DATA FOR GREATER DEPTHS

Data of temperatures at great depts in oil or gas wells were compiled and processed by Prins and compiled by Haenel (1980) in the Atlas of Subsurface Temperatures in the European Community. This Atlas contains isothermal maps of Europe, scale 1 : 5 000 000, for the depths of 500 m, 1000 m, 1500 m, 2000 m, 2500 m, 3000 m and 5000 m, an isothermal map of Belgium and The Netherlands at scale 1 : 1 500 000 for the depth of 1000 m and isothermal maps of the northeastern part of the province of Groningen, scale 1 : 75 000, for the depths of 1000 m, 2000 m and 3000 m below ground surface.

The results of the geothermal investigation in shallow observation wells, especially the isothermal map for the depth of 250 m (Fig. 17) and the temperatures at greater depths (Appendices 1 - 39), may be compared with the isothermal map for the depth of 500 m of the Atlas (Fig. 22). According to this, temperatures at 500 m range between 20 °C and 35 °C, divided in temperature intervals of 5 °C. More specifically the Atlas indicates that in more than half of The Netherlands temperatures range between 20 °C and 25 °C. Temperatures exceed the value of 25 °C in the eastern and southern part of the country. Two areas are indicated with temperatures in the range of 30 - 35 °C. One area covers Twente and the other the northern part of the province of Limburg.

Before any comparison is made, the comparability of the results of the investigation in shallow observation wells and the compilation of deep temperature data should be considered. The locations of the oil and gas wells, from which temperature data stem, have not been indicated in the Atlas. Therefore the isothermal contour-lines cannot be judged with respect to the distribution of data. Of course the oil and gas wells have other locations than the wells (Fig. 1) of the investigation reported here. Moreover the distributions of wells in both surveys are probably very dissimilar. For these very reasons one might expect a dissimilar isothermal contour-line pattern.

In spite of the above mentioned factors, which complicate a comparison, it seems to make sense to relate the two relatively high-temperature areas at depth of 250 m, the area north of Venlo and an area in Twente, to the high-temperature areas indicated at the map for the depth of 500 m. It is noted, however, that on the latter map the high temperature area in the province of Limburg has been centred north of the high temperature area on the map for depth of 250 m. The centres may have been scattered due to the absence of shallow subsurface temperature data in the north of Limburg and, conversely, the absence of oil and gas wells in the area south of it.

Apart from a certain similarity in the delineation of high-temperature areas, as indicated above, there arise also some discrepancies. If one extrapolates the temperature profiles (Appendices 33 - 35) of the rock salt exploitation wells (nrs. 207 - 209) in Twente, then at 500 m one obtains temperatures which are slightly higher than 25 ^{o}C, instead of exceeding 30 ^{o}C as indicated in the Atlas. It is not sure whether this discrepancy is a local phenomenon, due to rock salt exploitation at this site, or not. Extrapolation of the temperature profile (Appendix 39) in observation well Rouveen (nr. 243), in the province of Overijssel, does not lead to a temperature which exceeds 25 ^{o}C at depth of 500 m. Therefore it seems that the area with temperatures higher than 25 ^{o}C at depth of 500 m is smaller than delineated on the map. In The Veluwe there may even be an area where temperatures are lower than 20 ^{o}C.

Especially in respect to the areas with relatively low subsurface temperatures, identified in this investigation in shallow observation wells, a question should be raised. This question concerns the use of the ground surface as an isothermal upper boundary plane, at the construction of temperature profiles with temperature data from great depths in oil and gas wells, if the upper 200 m or so of the Earth acts as a heat sink due to infiltration. In such a case it seems to be preferable to use the temperature distribution at a level where groundwater fluxes are neglible as boundary values at the upper boundary plane. The temperature distribution at depth of 250 m, resulting from this investigation, may serve as such a boundary condition.

6. CONCLUSIONS AND RECOMMENDATIONS

The geothermal investigation in shallow observation wells, which has been described in some detail above, leads the author to the following conclusions and recommendations.

Conclusions

- Deep groundwater observation wells in The Netherlands provide a suitable opportunity to measure natural subsurface temperatures in a reliable way. In a number of wells, however, the probe may get stuck on its way down with a risk of losing the probe.

- Accurate temperature data - absolute inaccuracy less than 0,1 ^{o}C, inaccuracy in the difference of two data in the order of 0,01 ^{o}C - may be easily obtained, using an equipment with a platinum resistance thermometer. Thermal equilibrium at the transducer may be reached practically in 10 - 20 s. The connections of probe with cable at one end, and also at the other end of the cable with the measuring instrument may cause troubles, if they are not secured effectively.

- The shallow subsurface temperature field in The Netherlands, delineated to a depth of 250 m below ground surface, shows features which reflect several phenomena. These are (i) convection of heat by infiltrating meteoric water and by groundwater flowing in the hydrologic cycle, (ii) laterally varying thermal conductivities of sediments and (iii) laterally varying heat flow or heat transport at great depths.

- A comparison of the isotherm map for a depth of 250 m with the isotherm map for a depth of 500 m, derived from data of oil and gas wells, shows some similarity in the locations of the high-temperature areas at both depths. The temperatures indicated on the map for a depth of 500 m are probably too high for a number of locations.

Recommendations

- The delineated shallow subsurface temperature field should be verified by measurements, wherever recently completed deep observation, or other type, wells become available. This applies especially for the areas for which there are, as yet, few or no data.

- Available and observable evidence should be compiled to interprete temperature data in terms of the various heat transfer processes which may occur at depth. This evidence may comprise hydrologic, (hydro)geologic, tectonic, hydrochemical, isotope data .... etc.

- Numerical modeling should be stimulated to gain a quantitative insight into the influence of the hydrologic regime on the thermal regime. A realistic groundwater flow field should be supposed to obtain a realistic simulation of the subsurface temperature field on a regional scale. The simplest approach is to solve the heat balance equation with a two dimensional groundwater flow field.

- In deriving isotherm maps for great depths from temperature data of oil and gas wells, complications due to convection of heat in the shallow subsurface strata should be avoided. This is possible by taking the delineated temperature distribution at a depth of 250 m as a boundary condition for the upper boundary plane.

7. ACKNOWLEDGEMENTS

This investigation was made possible by the permission of numerous organisations (water supply companies; state, provincial and municipal services; industries; individuals) to measure temperatures in their wells. Many times they also provided personal and material help. I gratefully acknowledge their cooperation.

The measurements - totally about 45000 temperature/depth readings - were carefully made by Ko van Kuijk, Kim Rutten and Joost Herweijer, many times facing adverse circumstances. At many occasions, especially with artesian wells, J.P.J. van Maarseveen, head of field operations on observation wells at Groundwater Survey, provided invaluable assistance.

The construction, maintenance and repairs of the equipment were performed by Paul Dekker and Bill Bos, both at the instrumentation section of Groundwater Survey. They solved many difficulties with the equipment, which arose during the investigation.

The author is much indebted to W.A. Visser (chairman of the Geothermal Energy Discussion Group) for his continual encouragement, and stimulating discussions.

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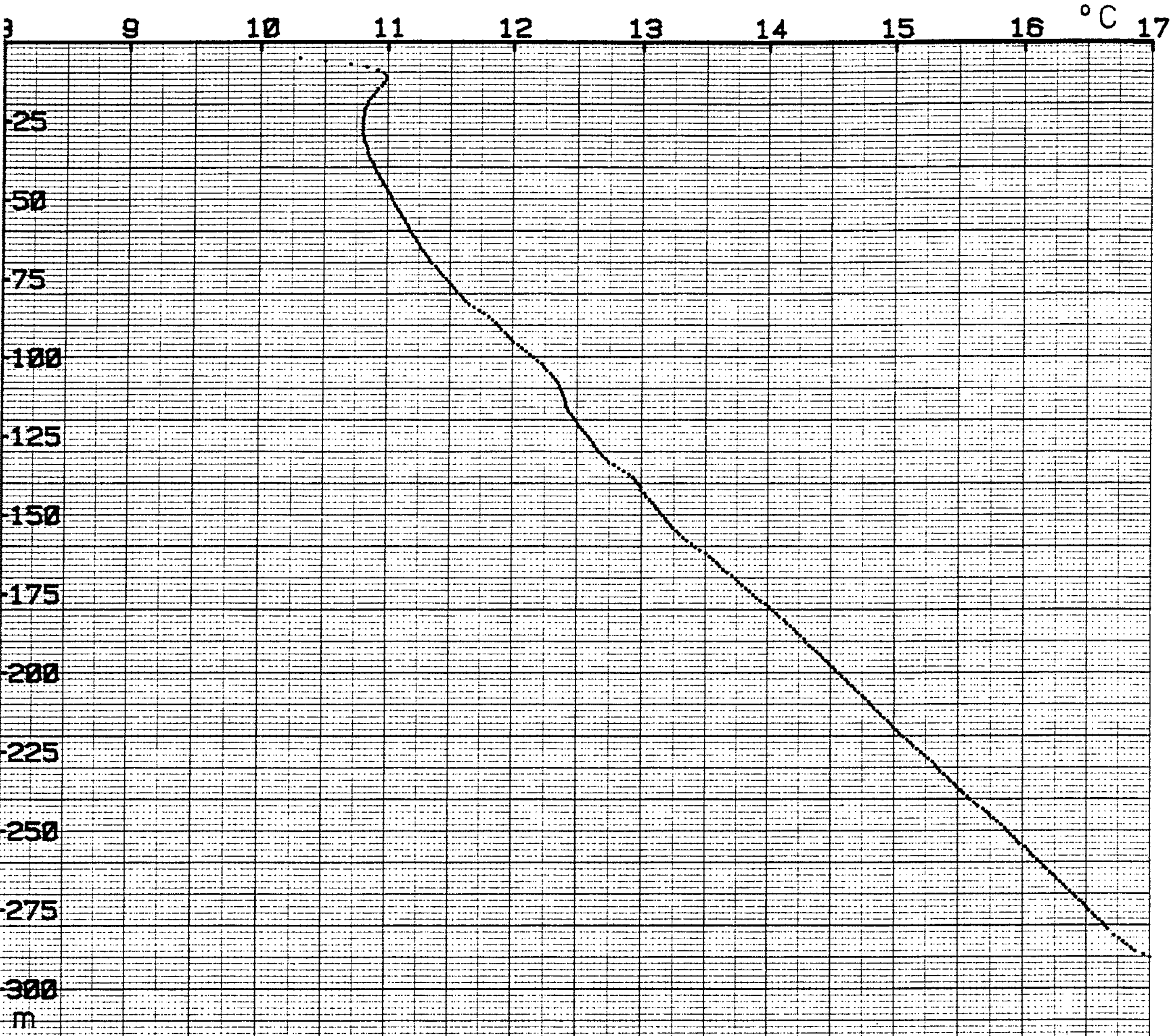
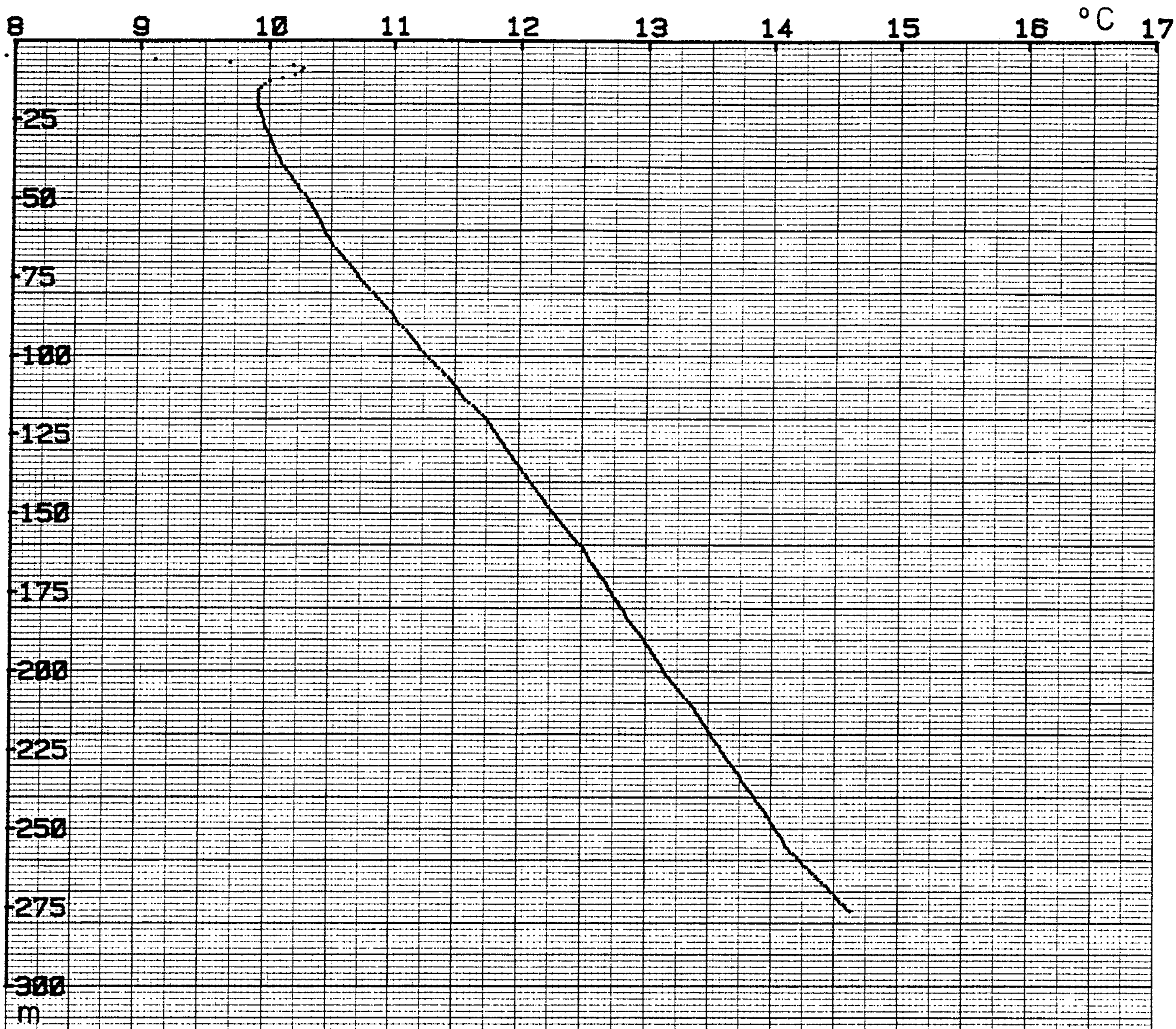


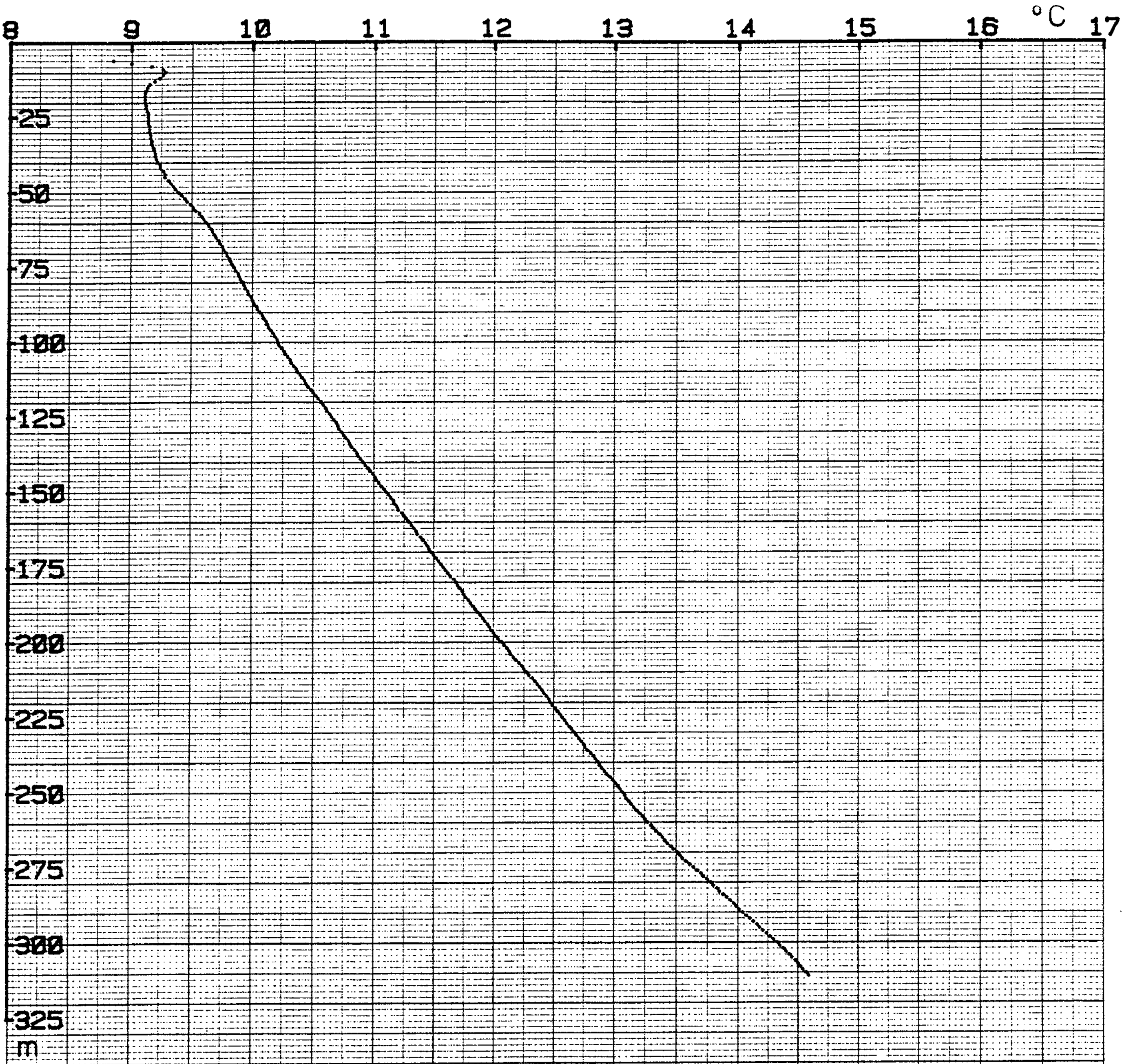
APPENDIX 1 TEMPERATURES (770624) IN OBSERVATION WELL NR. 1

LOCALITY DE MEERN



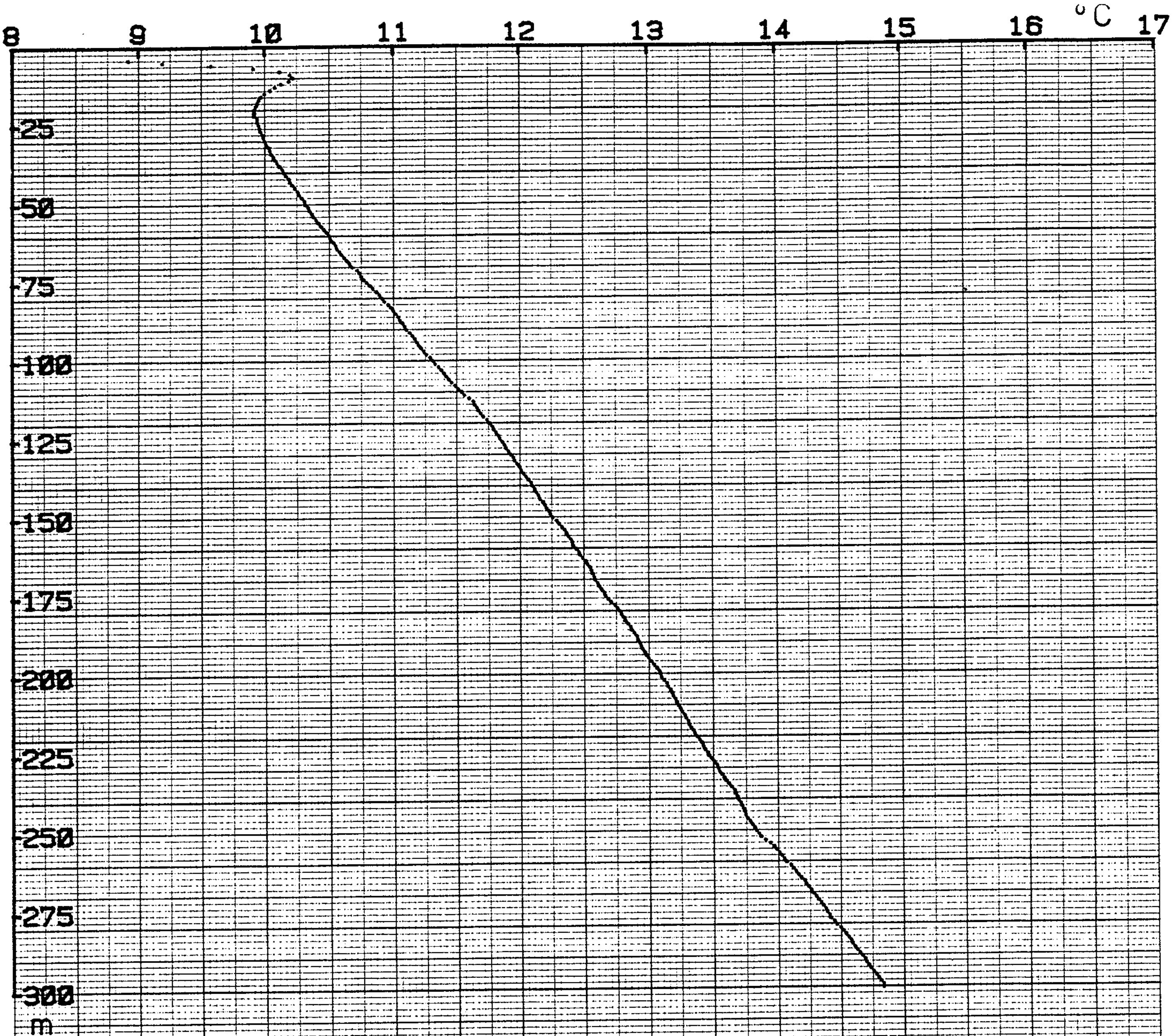
APPENDIX 2 TEMPERATURES (770302) IN OBSERVATION WELL NR. 31

LOCALITY NIEUWKUYK



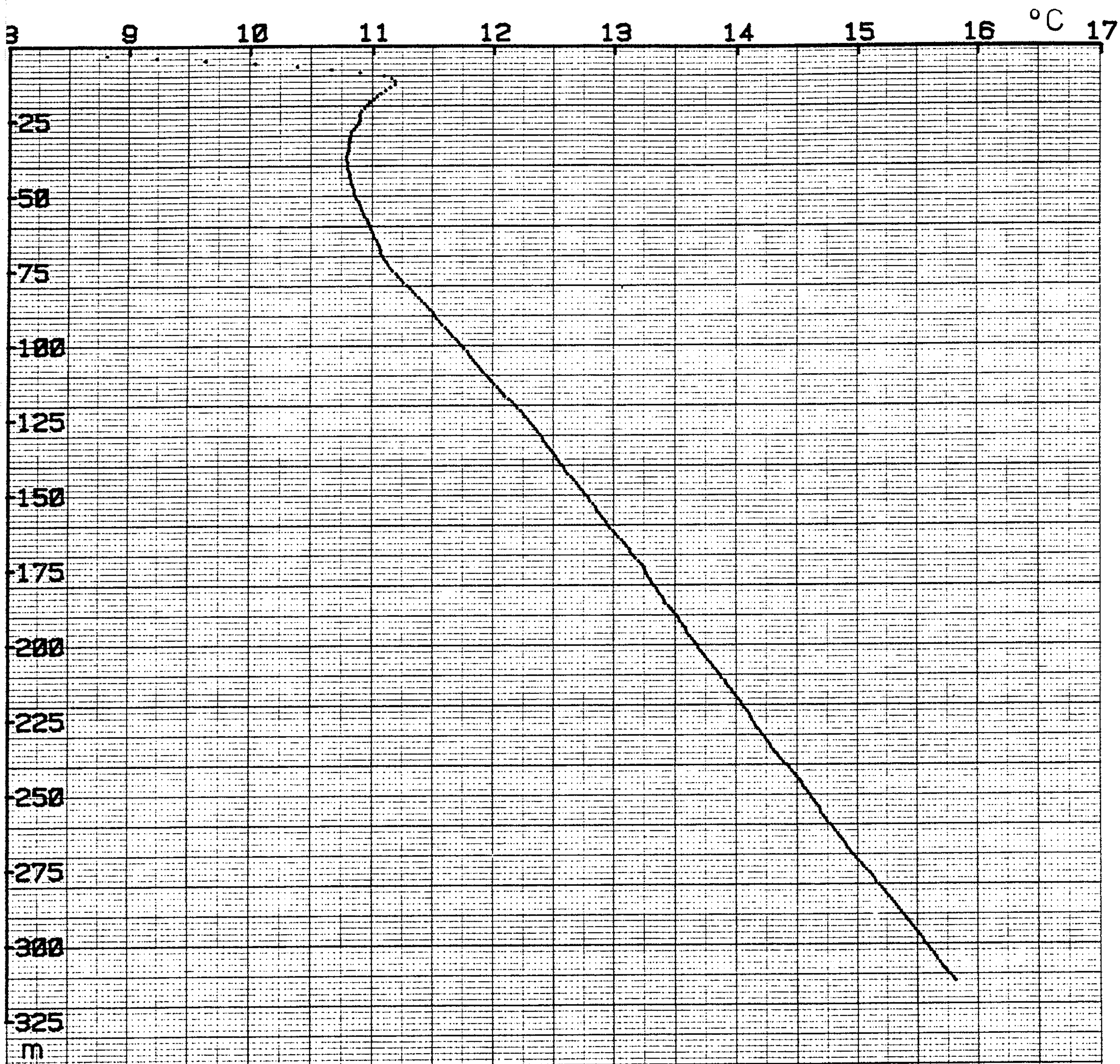
APPENDIX 3 TEMPERATURES (770304) IN OBSERVATION WELL NR. 32

LOCALITY LAGE VUURSCHE



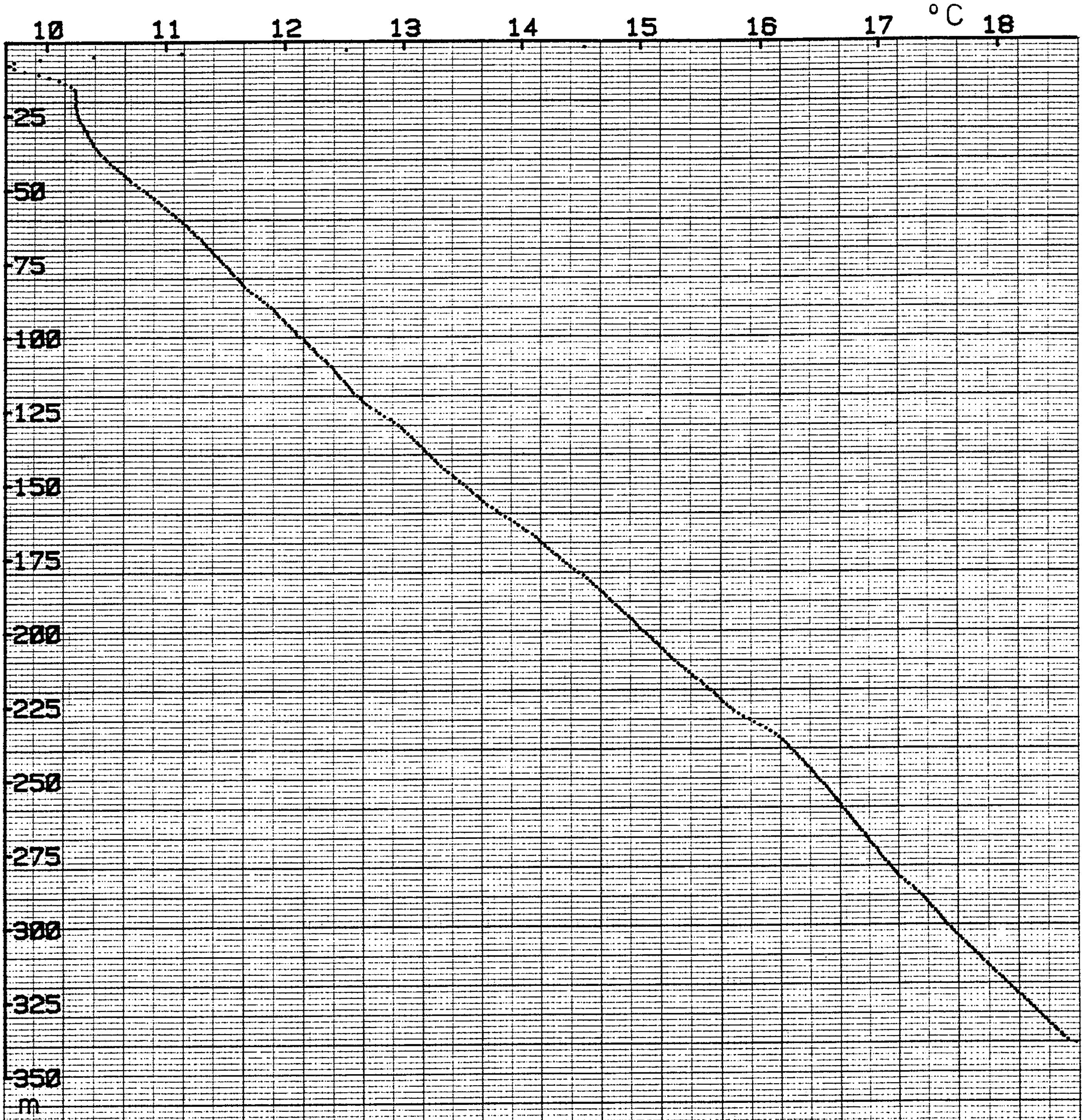
APPENDIX 4 TEMPERATURES (770316) IN OBSERVATION WELL NR. 34

LOCALITY HELVOIRT



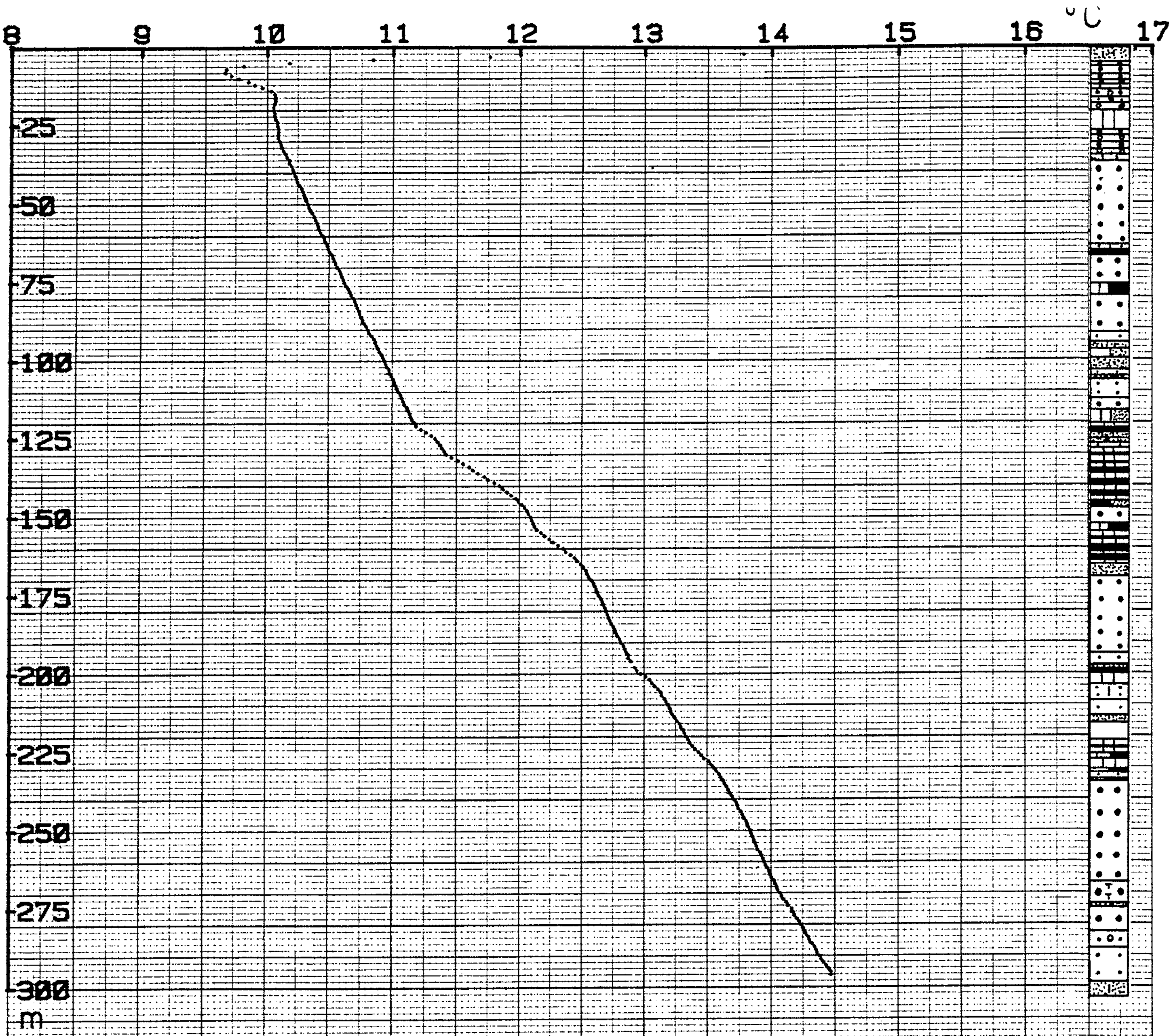
APPENDIX 5 TEMPERATURES (770330) IN OBSERVATION WELL NR. 35

LOCALITY VLYMEN



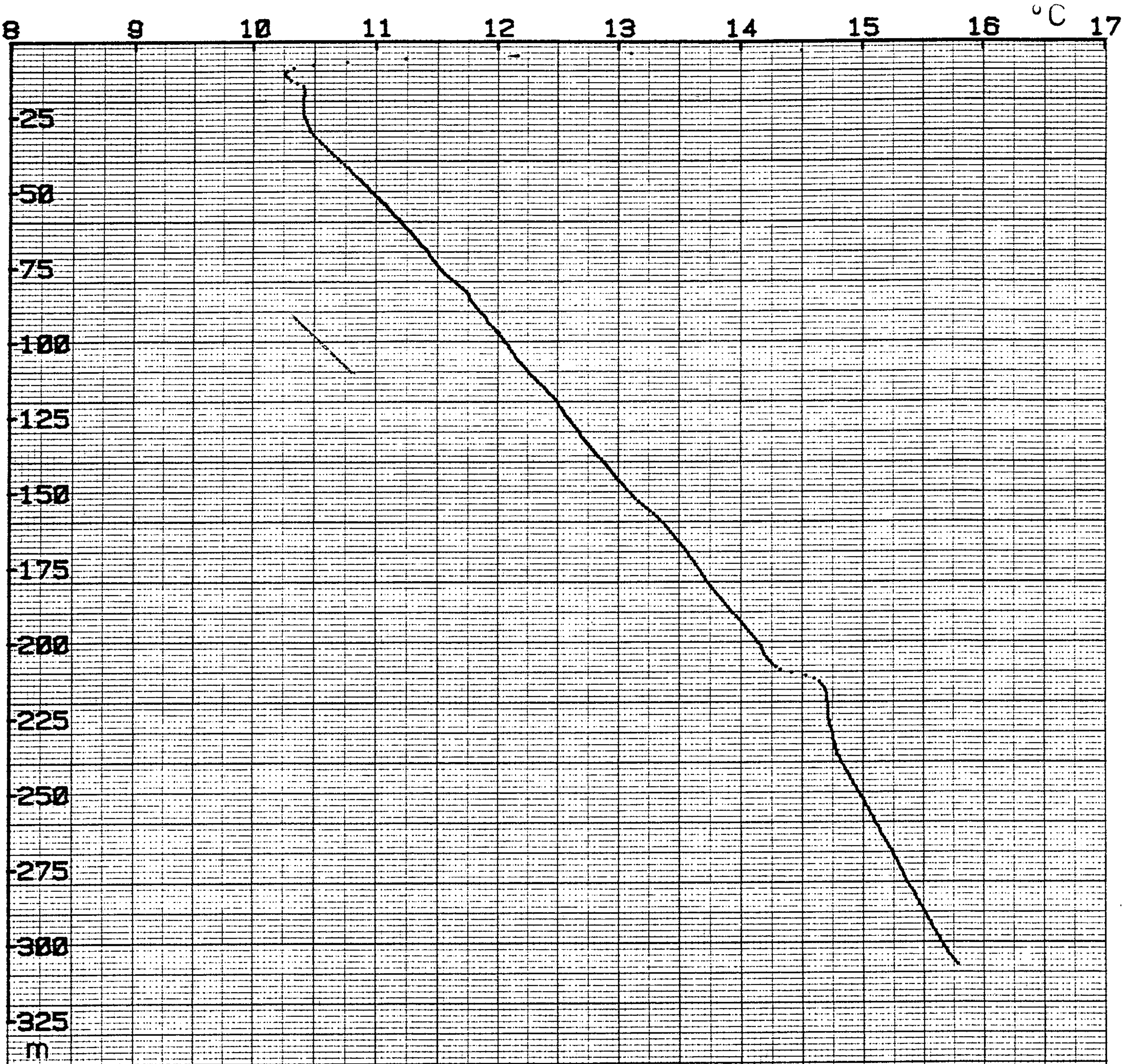
APPENDIX 6 TEMPERATURES (770714) IN OBSERVATION WELL NR. 47

LOCALITY ROGGEL



APPENDIX 7 TEMPERATURES (770715) IN OBSERVATION WELL NR. 48

LOCALITY TUNGELROY

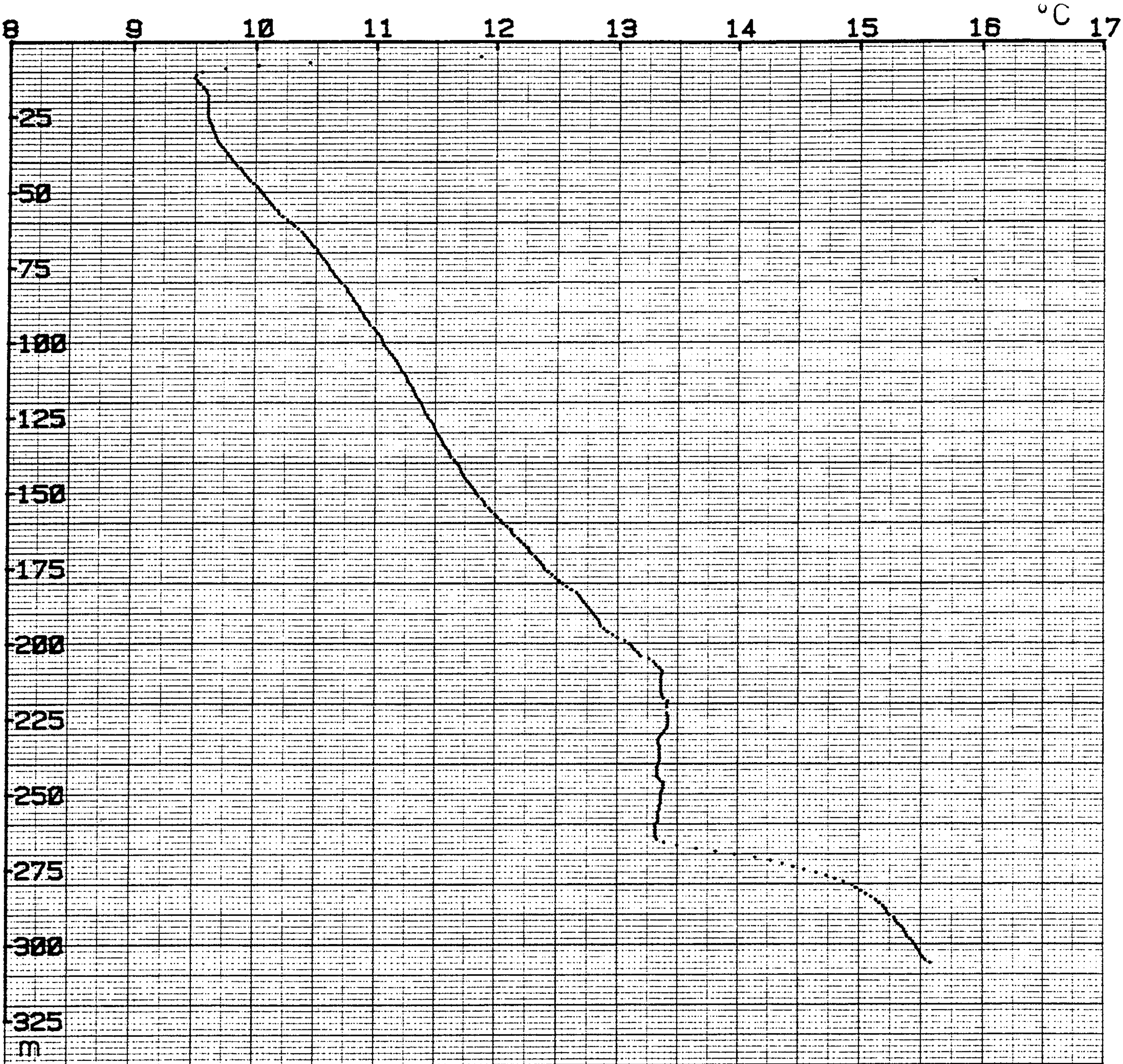


APPENDIX 8 TEMPERATURES (770824) IN OBSERVATION WELL NR. 59

LOCALITY SCHYNDEL

REMARKS WATER BEARING STRATA SHORT-CIRCUITED DUE TO AN IMPROPERLY COMPLETED OBSERVATION WELL

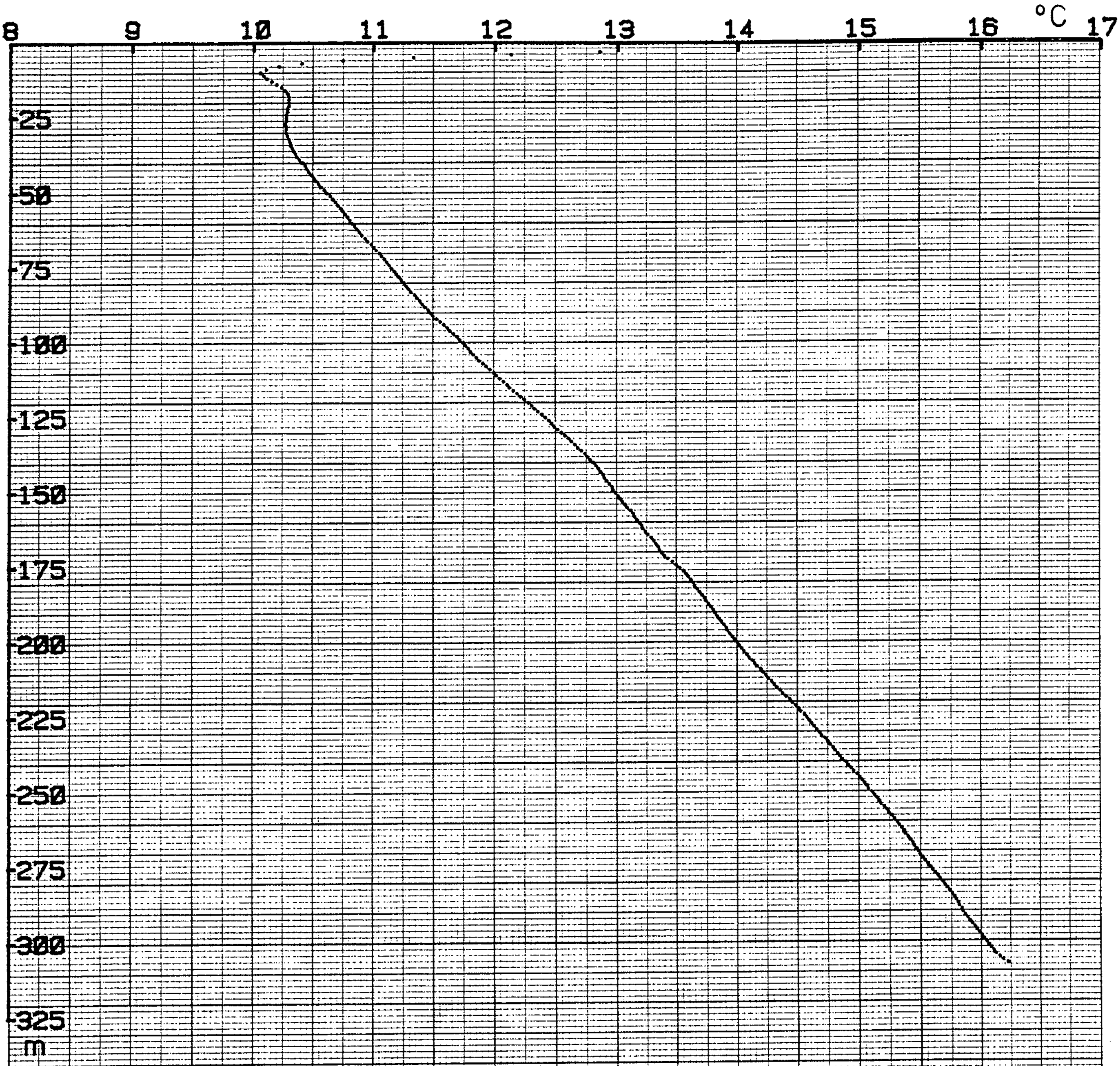
GROUNDWATER FLOWS FROM STRATA AT 240-225 M, THROUGH THE BOREHOLE, INTO STRATA AT 220-210 M



APPENDIX 9 TEMPERATURES (770825) IN OBSERVATION WELL NR. 61

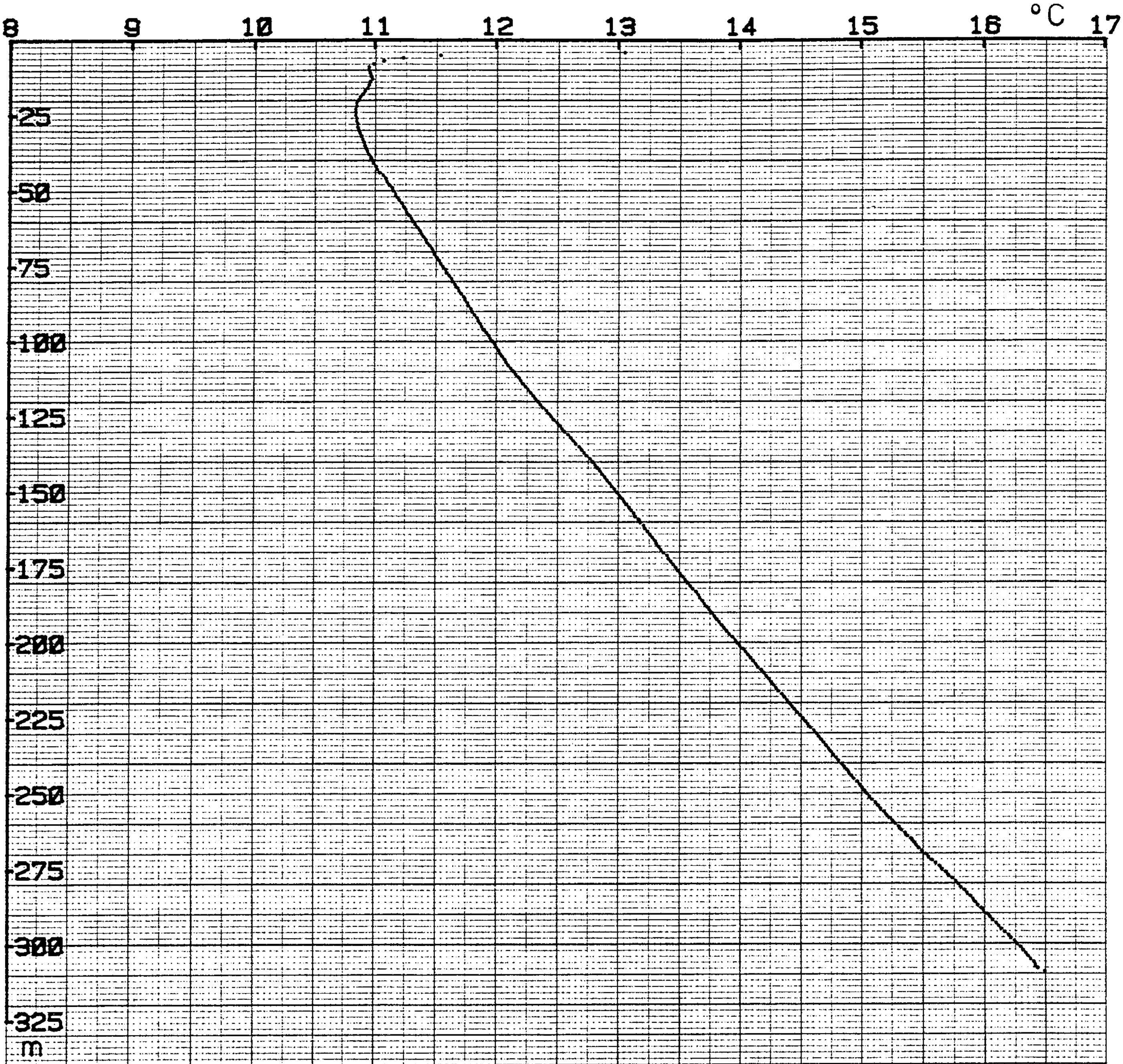
LOCALITY SOMEREN 1

REMARKS TEMPERATURE PROFILE IN A PIEZOMETER IN A PUMPING WELL, WHICH HAD NOT BEEN IN ACTIVE OPERATION YET
BOREHOLE SHORT-CIRCUITS WATER BEARING STRATA
FLOW FROM STRATA AT ABOUT 210 M INTO STRATA AT 230-285 M



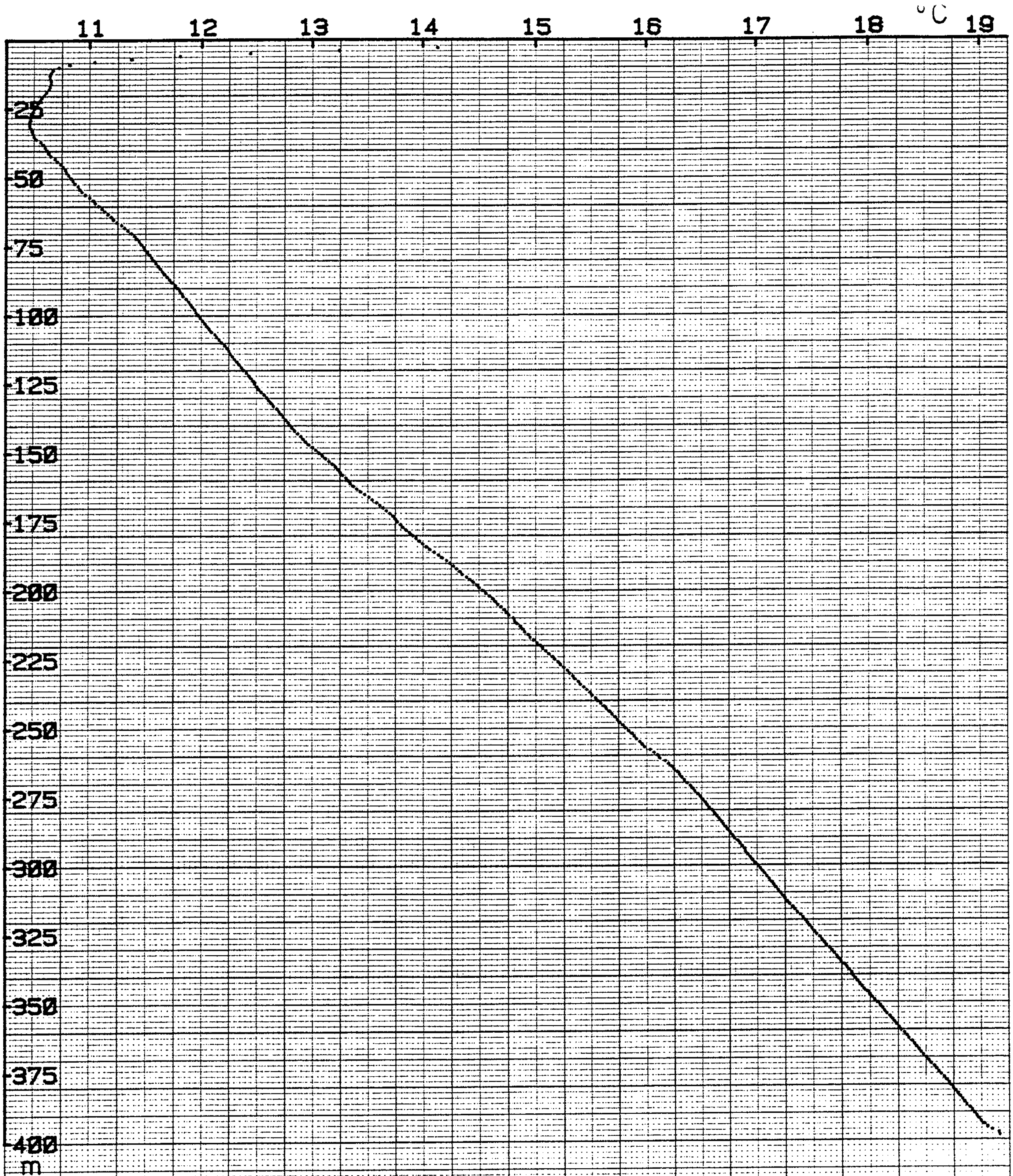
APPENDIX 10 TEMPERATURES (770826) IN OBSERVATION WELL NR. 63

LOCALITY VEGHEL



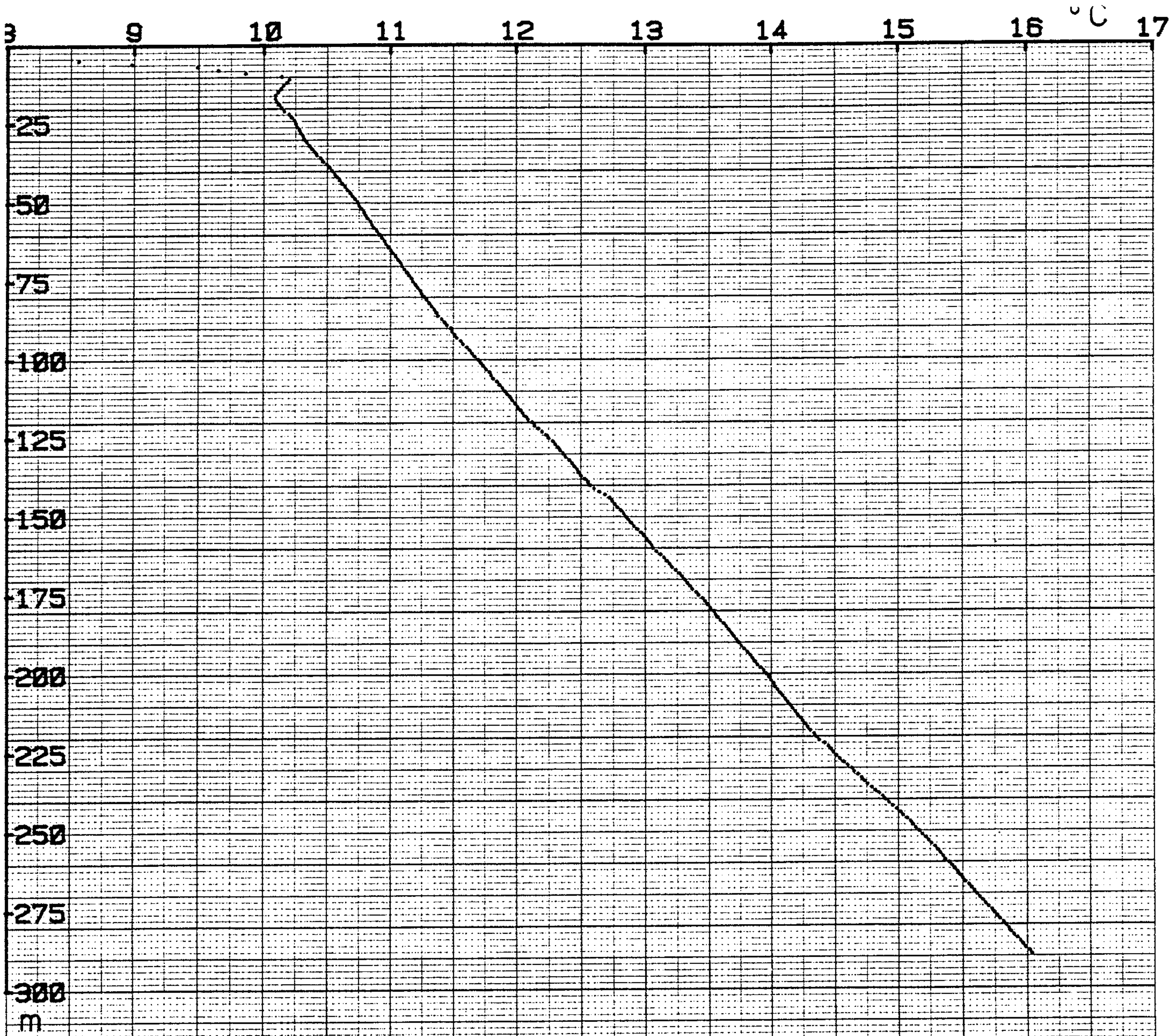
APPENDIX 11 TEMPERATURES (770907) IN OBSERVATION WELL NR. 66

LOCALITY KLUNDERT



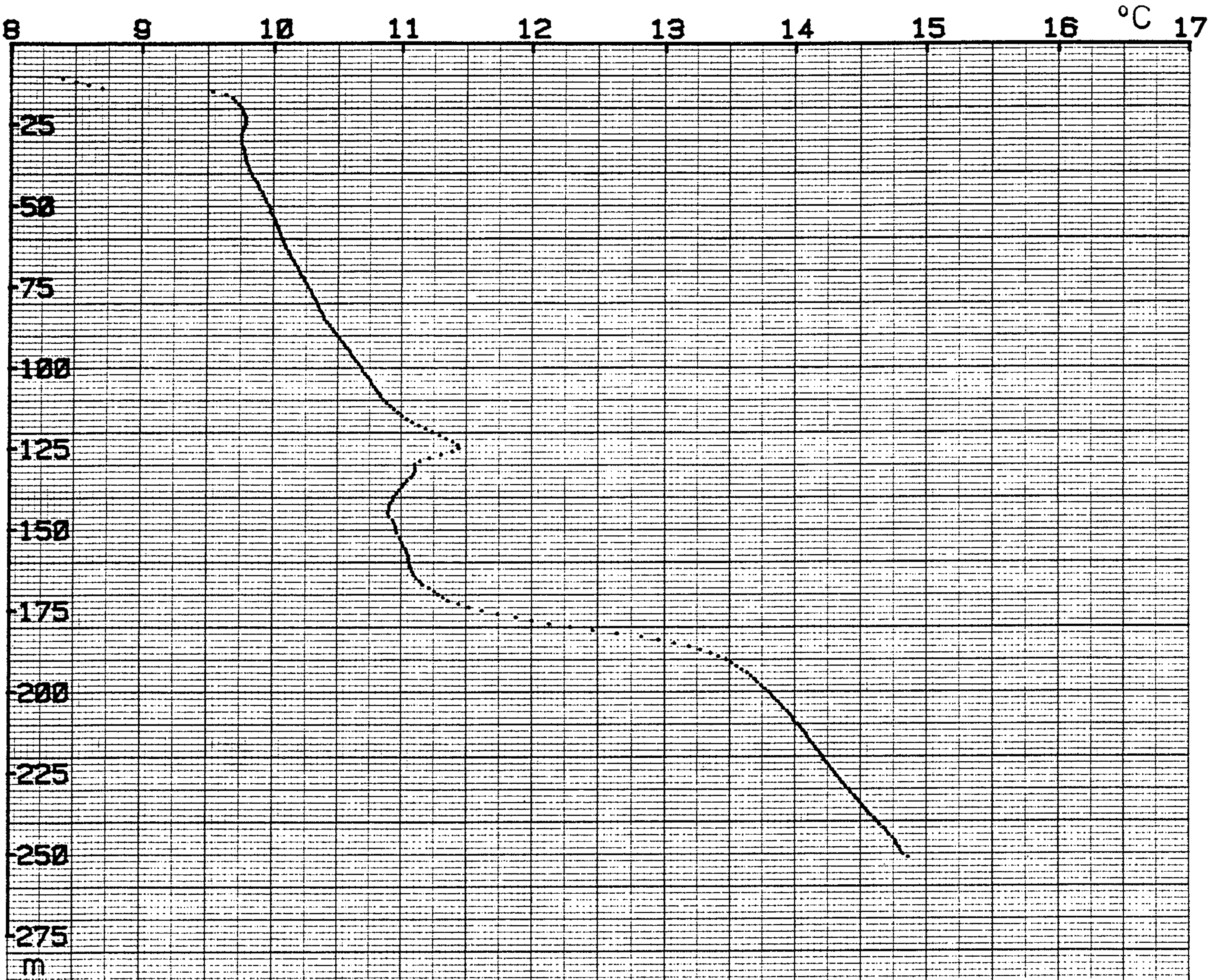
APPENDIX 12 TEMPERATURES (770910) IN OBSERVATION WELL NR. 69

LOCALITY LEVEROY



APPENDIX 13 TEMPERATURES (780228) IN OBSERVATION WELL NR. 70

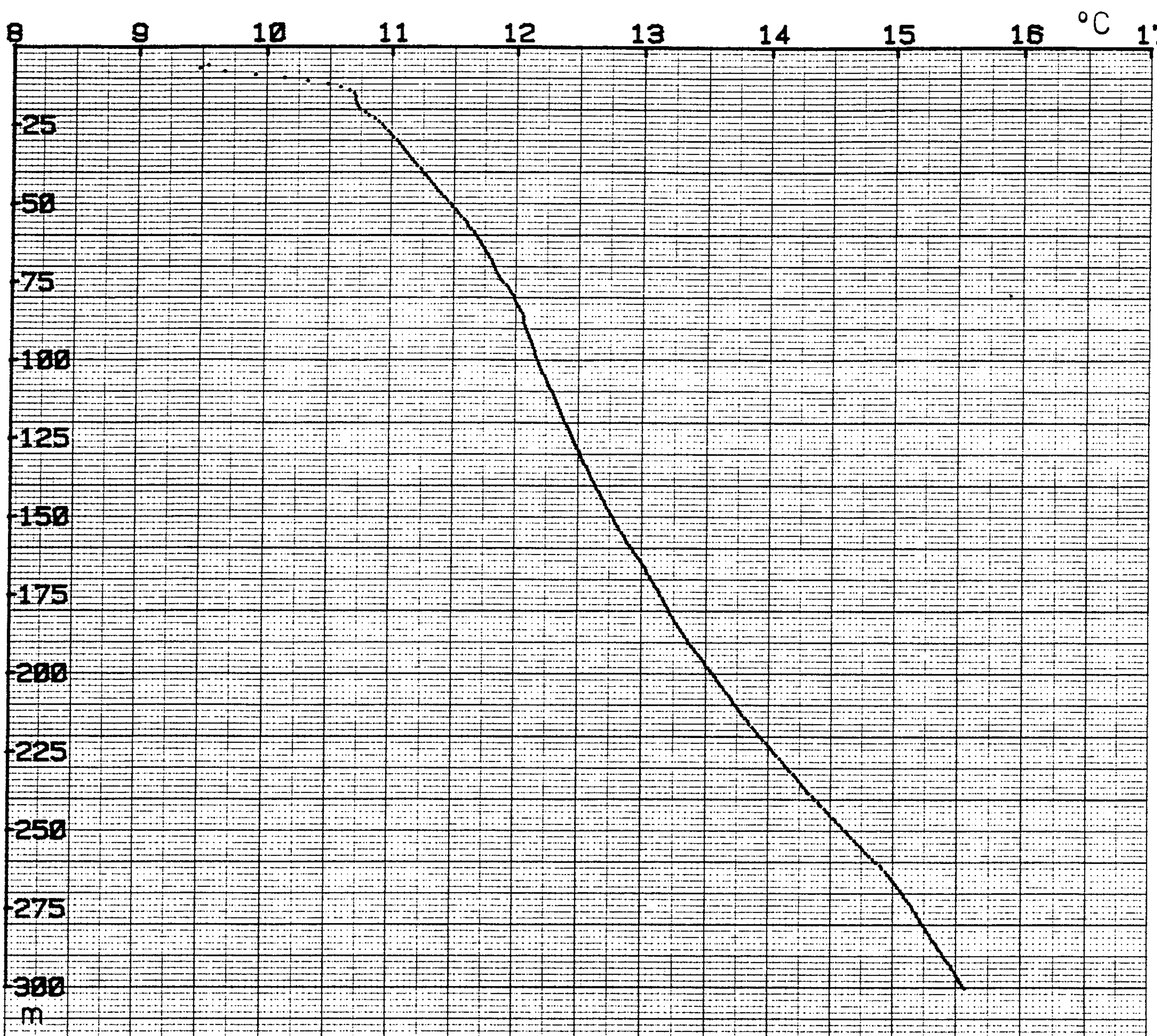
LOCALITY GLINDHORST 2



APPENDIX 14 TEMPERATURES (780405) IN OBSERVATION WELL NR. 79

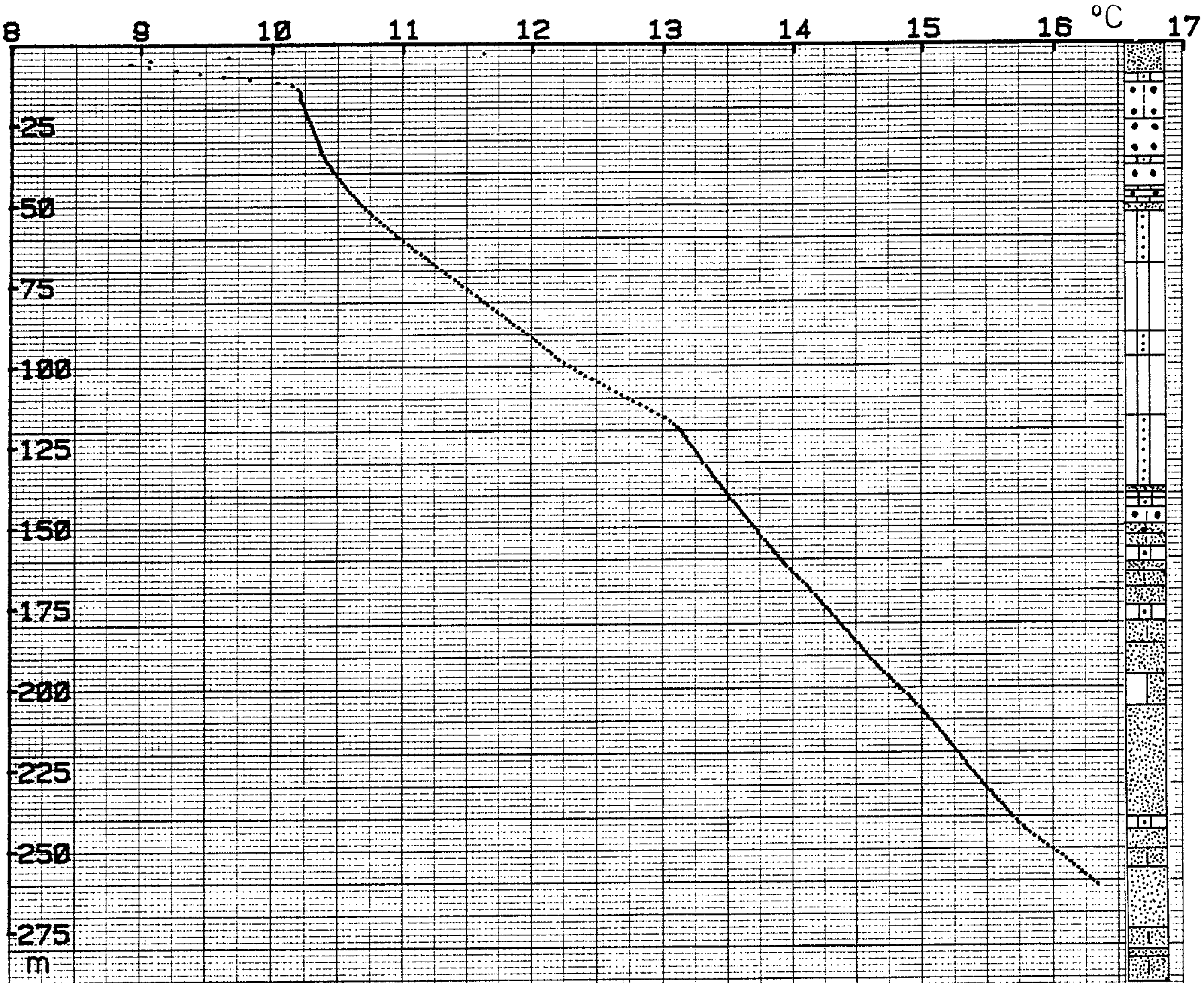
LOCALITY SEPPE

REMARKS TEMPERATURE ANOMALY BETWEEN 115 M AND 195 M
CAUSE OF ANOMALY IS PROBABLY GROUNDWATER FLOW.
DETAILS OF FLOW, HOWEVER, ARE NOT CLEAR



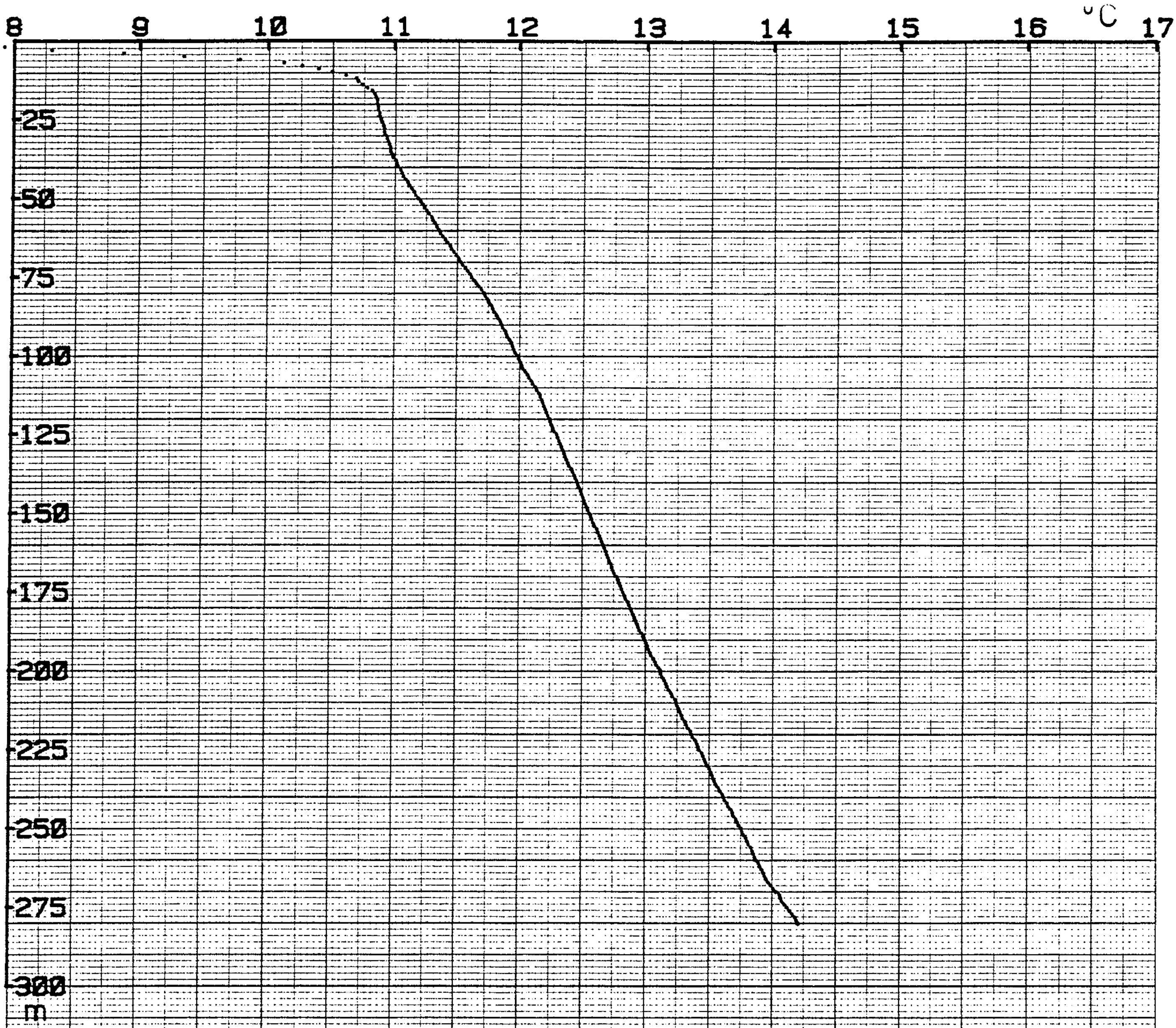
APPENDIX 15 TEMPERATURES (780605) IN OBSERVATION WELL NR. 104

LOCALITY KNARDYK



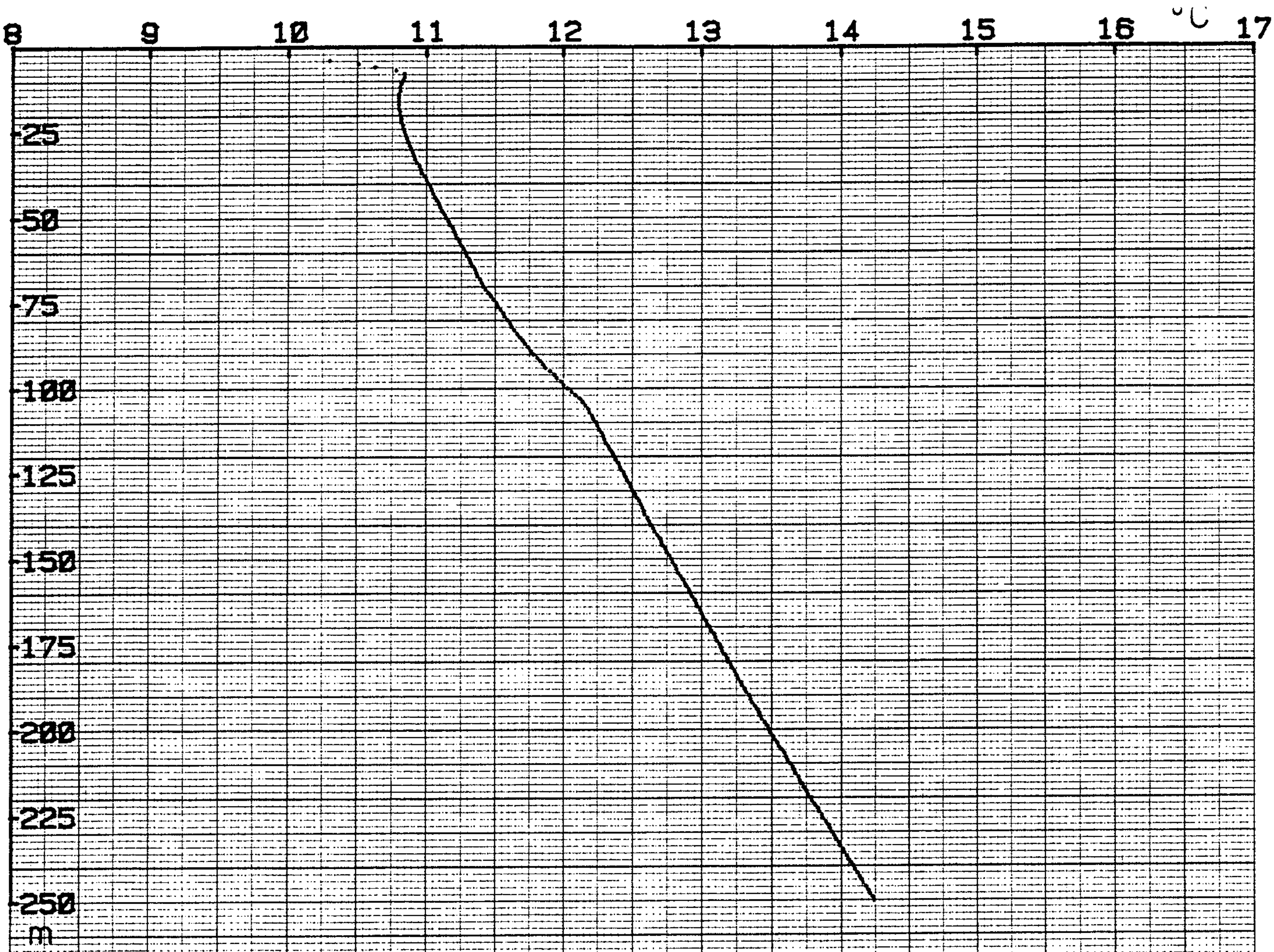
APPENDIX 16 TEMPERATURES (780606) IN OBSERVATION WELL NR. 105

LOCALITY VAASSEN 2



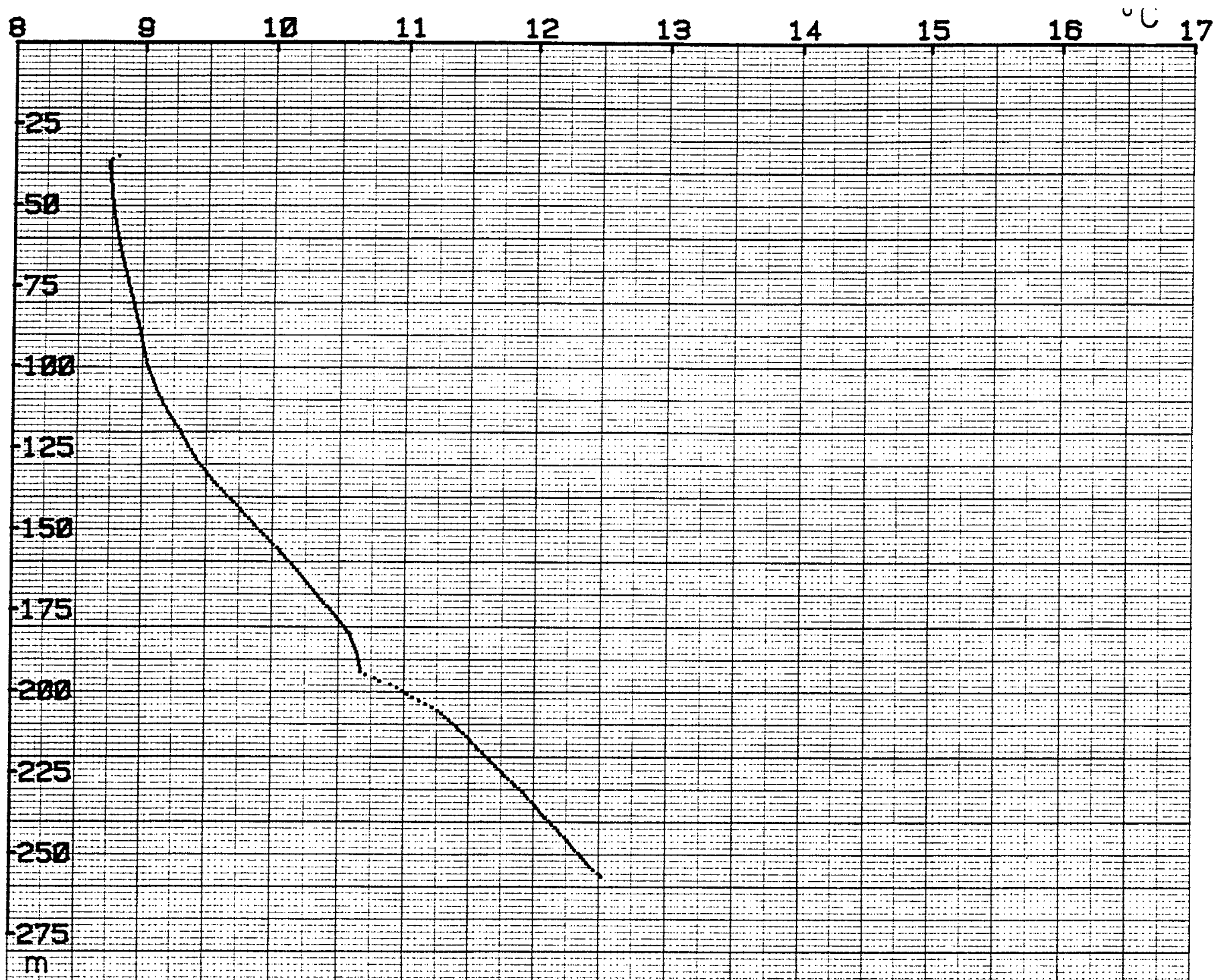
APPENDIX 17 TEMPERATURES (790409) IN OBSERVATION WELL NR. 115

LOCALITY SCHARWOUDE



APPENDIX 18 TEMPERATURES (780621) IN OBSERVATION WELL NR. 116

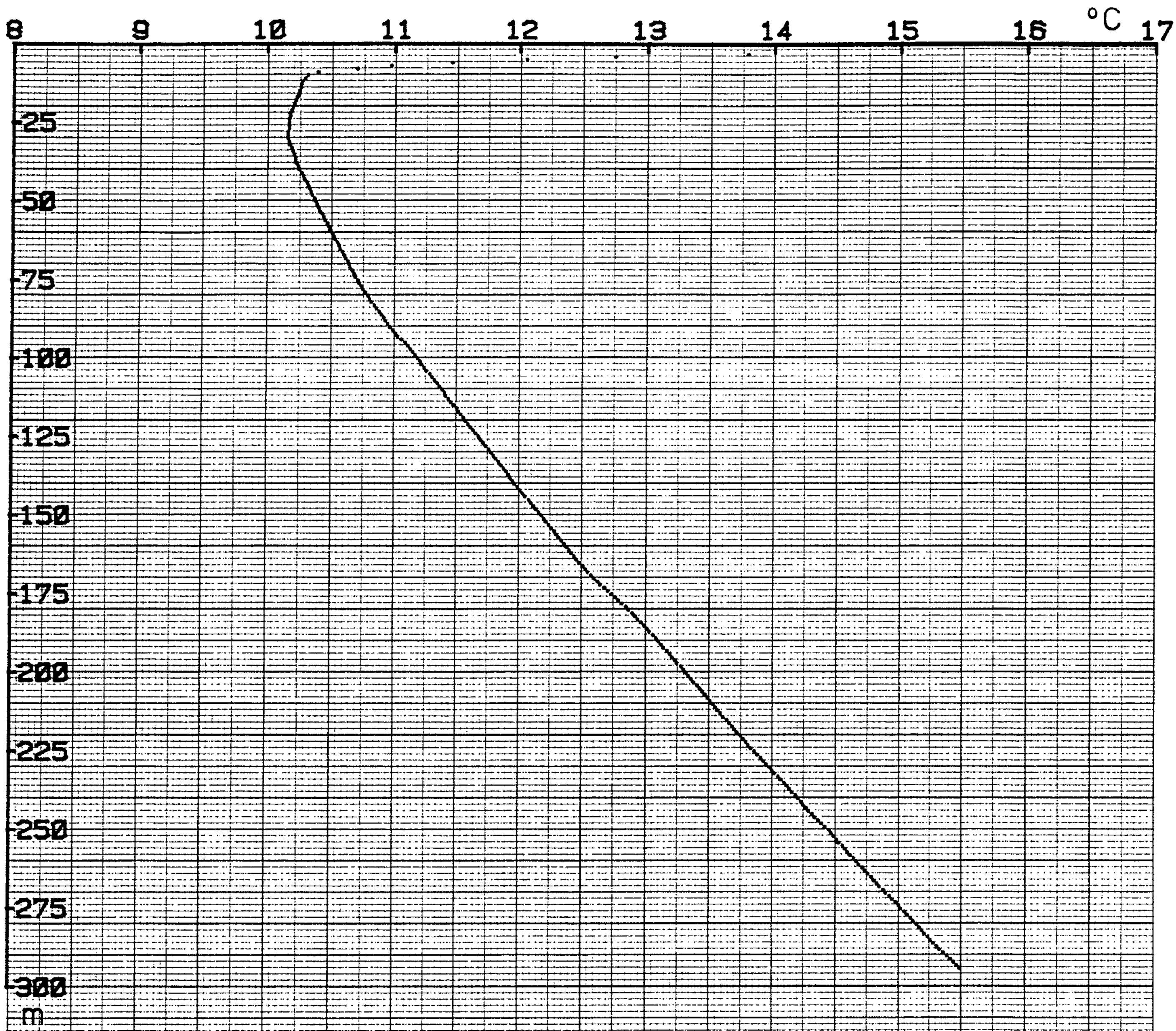
LOCALITY BROEK IN WATERLAND



APPENDIX 19 TEMPERATURES (780705) IN OBSERVATION WELL NR. 119

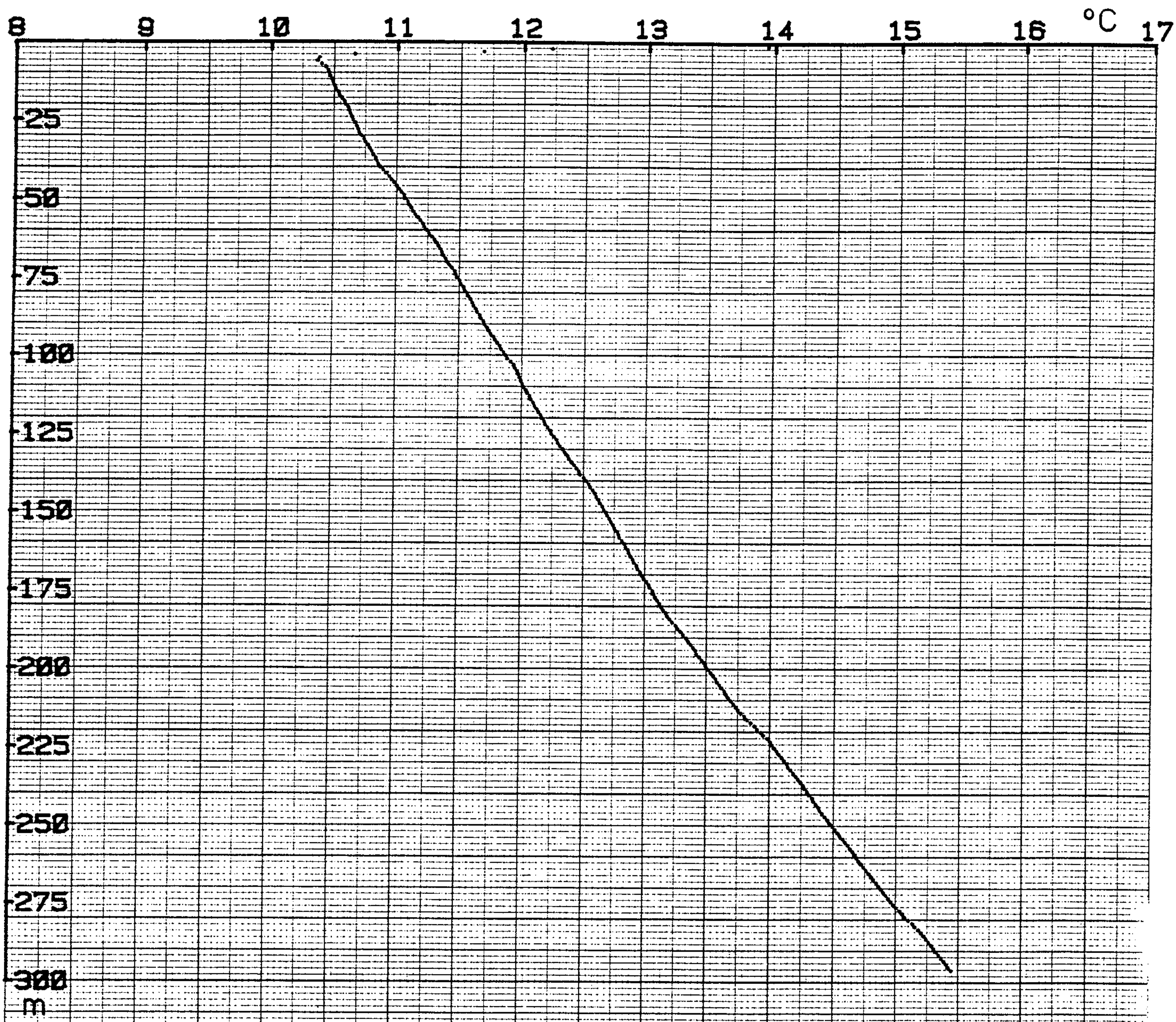
LOCALITY HOENDERLOO

REMARKS CUSP-SHAPED TEMPERATURE ANOMALY AT ABOUT 194 M
CAUSE OF ANOMALY IS PROBABLY GROUNDWATER FLOW.
DETAILS OF FLOW, HOWEVER, ARE NOT CLEAR



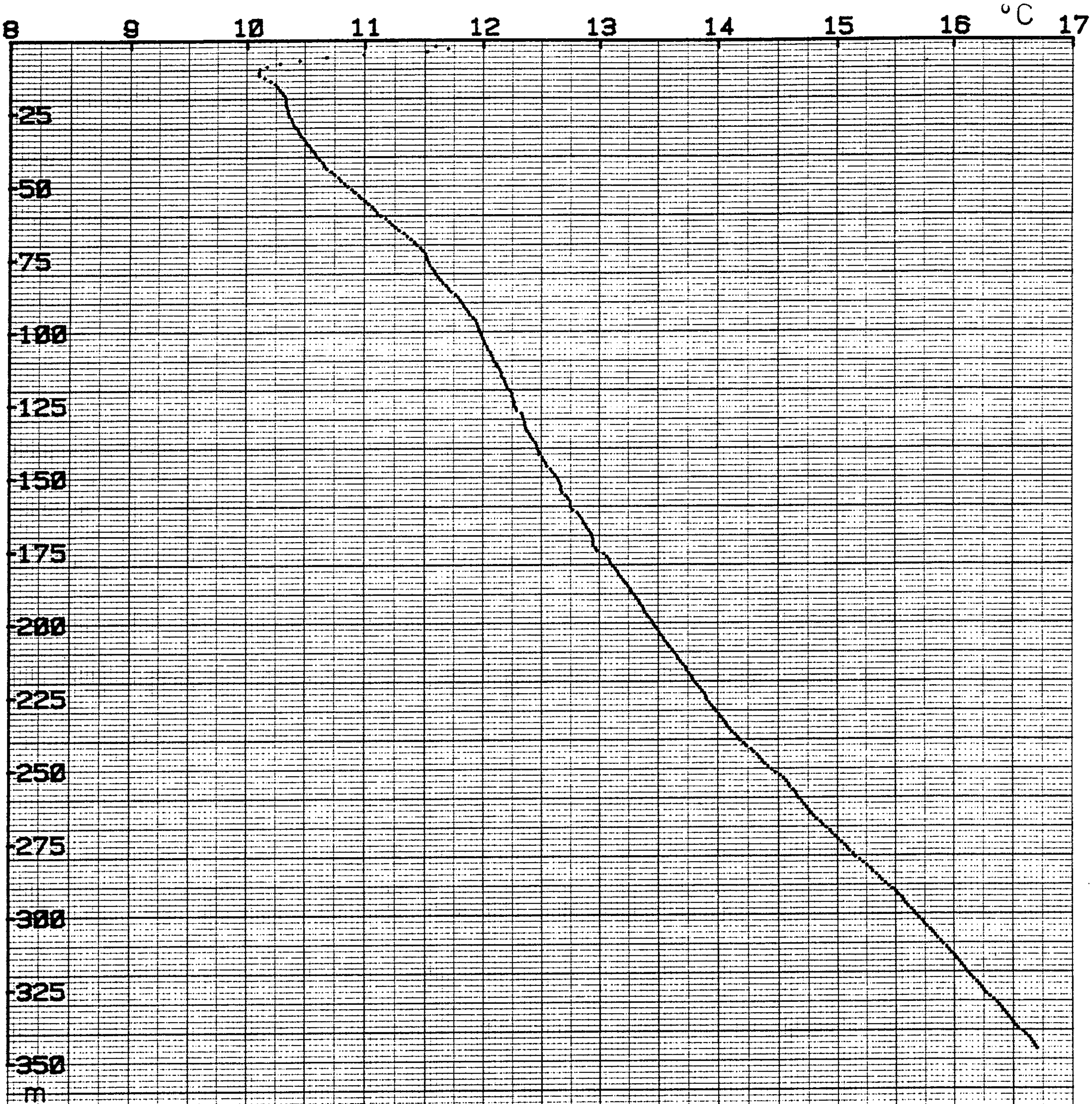
APPENDIX 20 TEMPERATURES (780906) IN OBSERVATION WELL NR. 148

LOCALITY WAGENINGEN



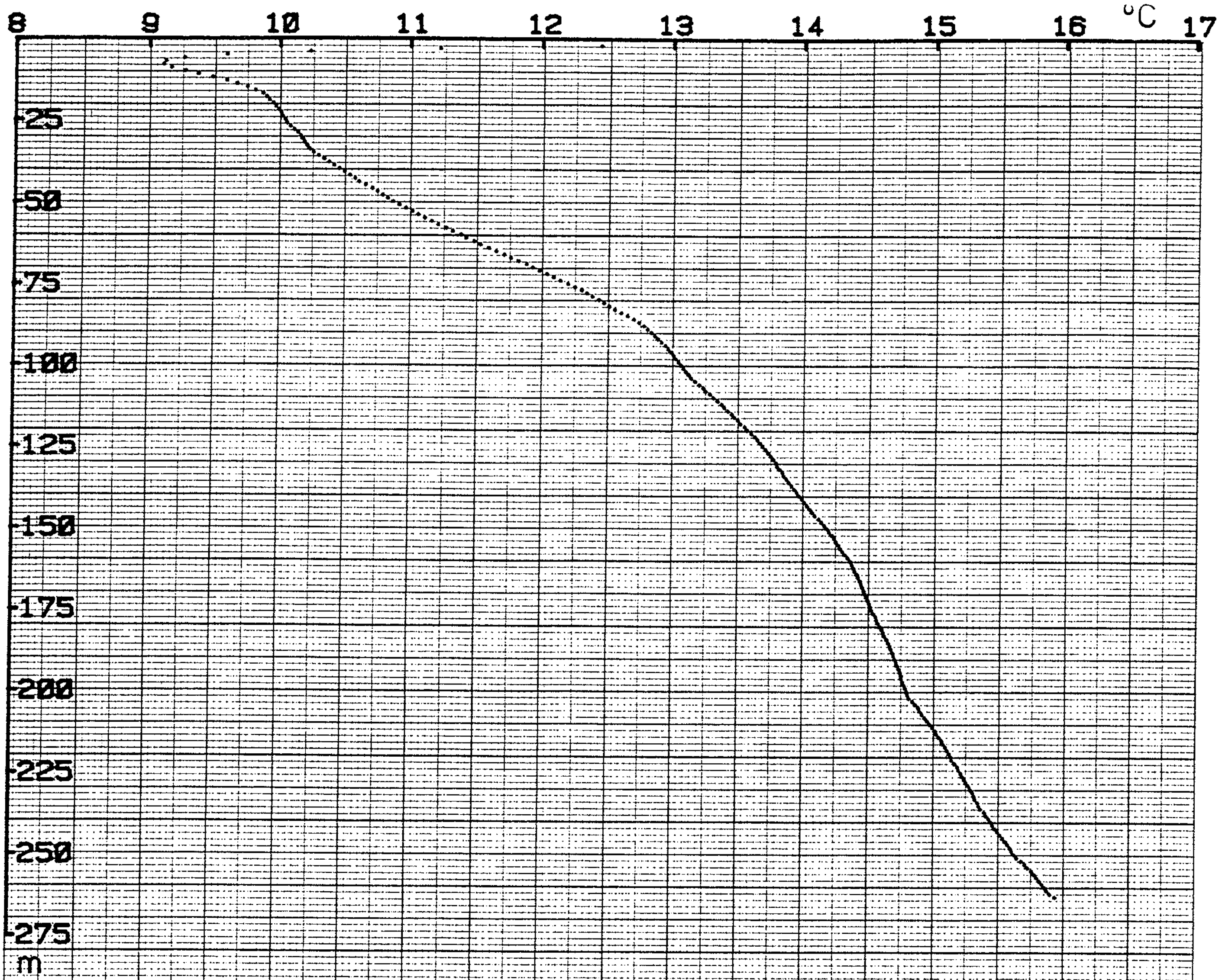
APPENDIX 21 TEMPERATURES (780912) IN OBSERVATION WELL NR. 158

LOCALITY EEMNES



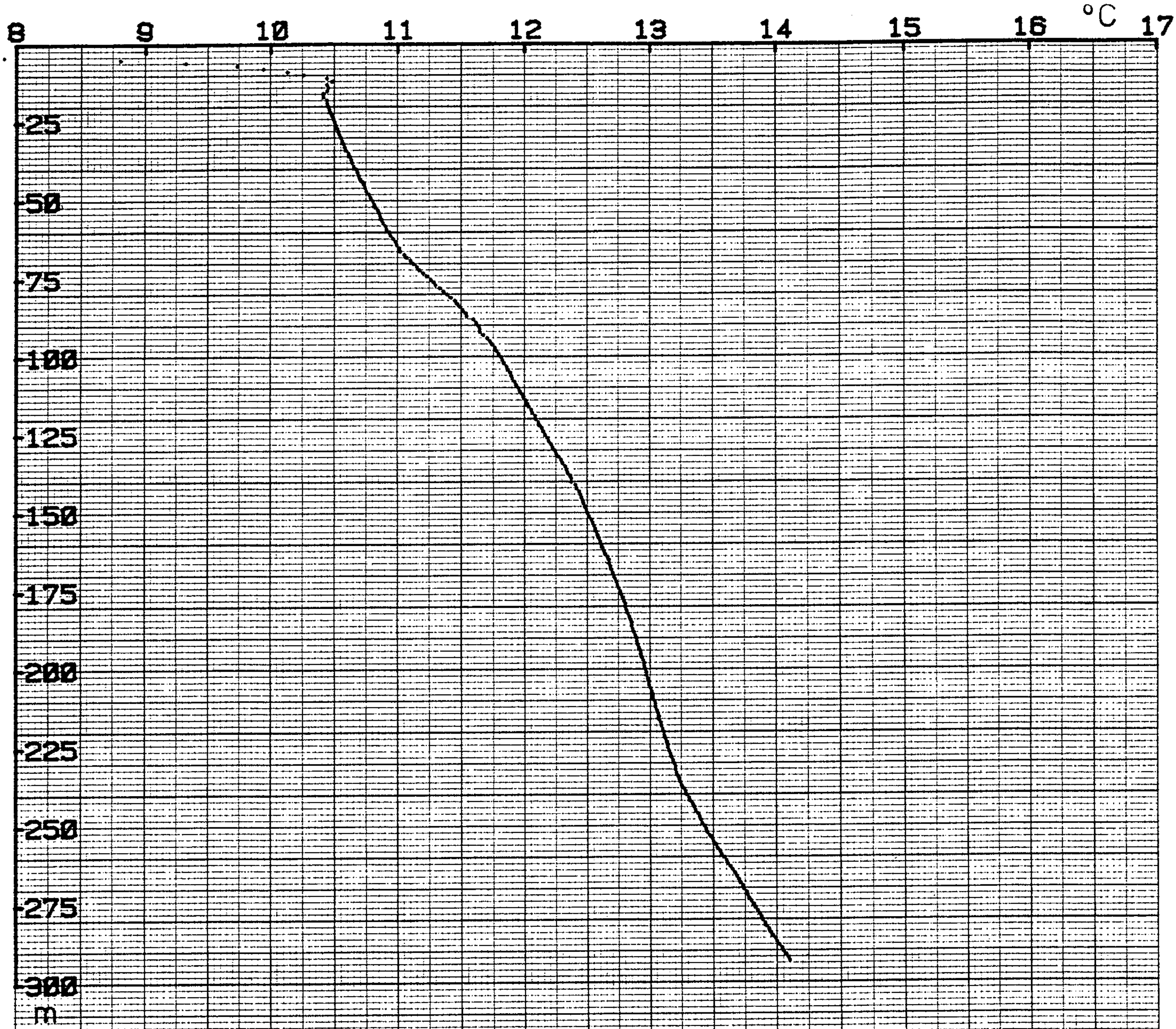
APPENDIX 22 TEMPERATURES (781013) IN OBSERVATION WELL NR. 178

LOCALITY ZUIDELYK FLEVOLAND



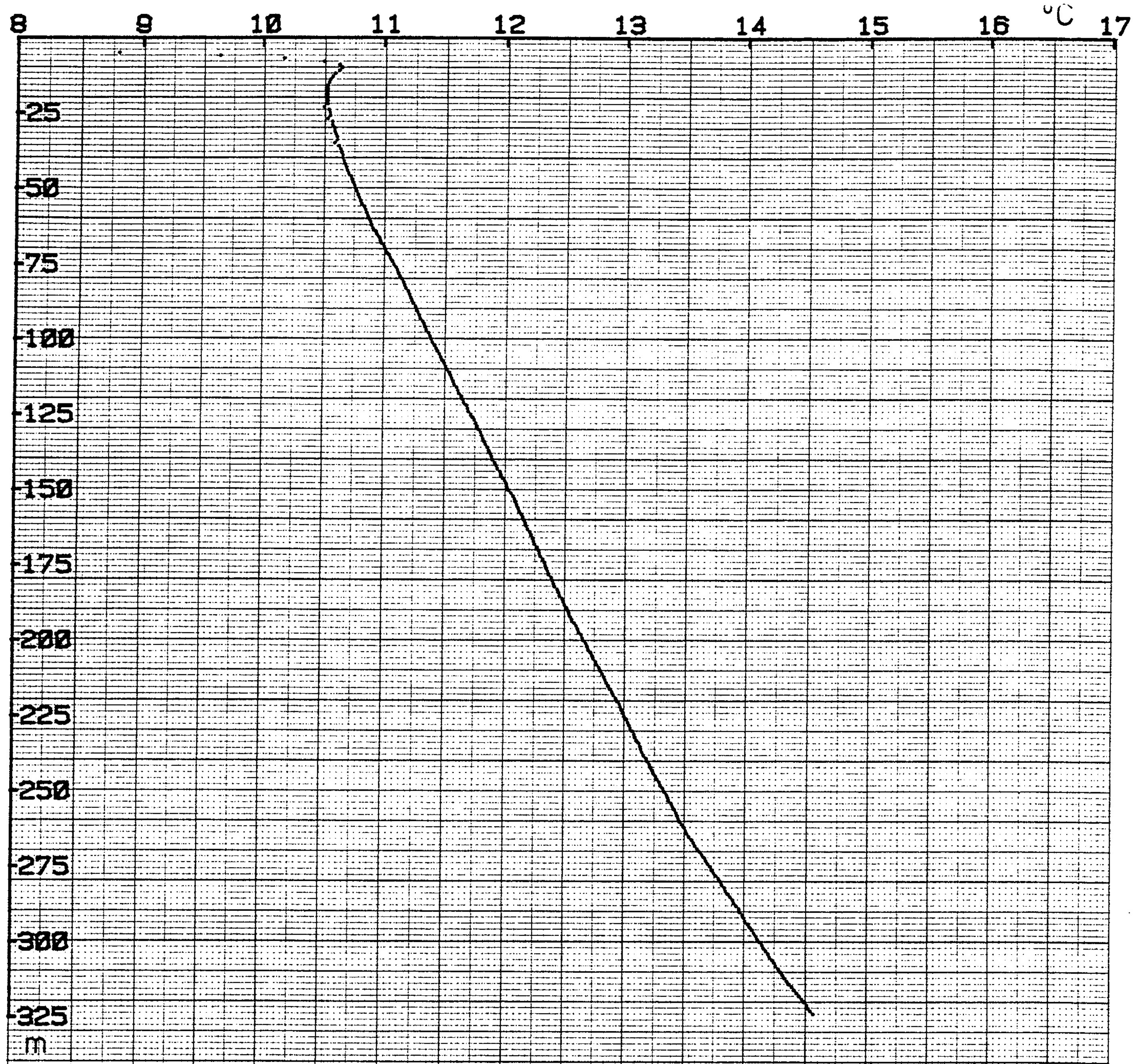
APPENDIX 23 TEMPERATURES (790727) IN OBSERVATION WELL NR. 182

LOCALITY NOORDBERGUM 4



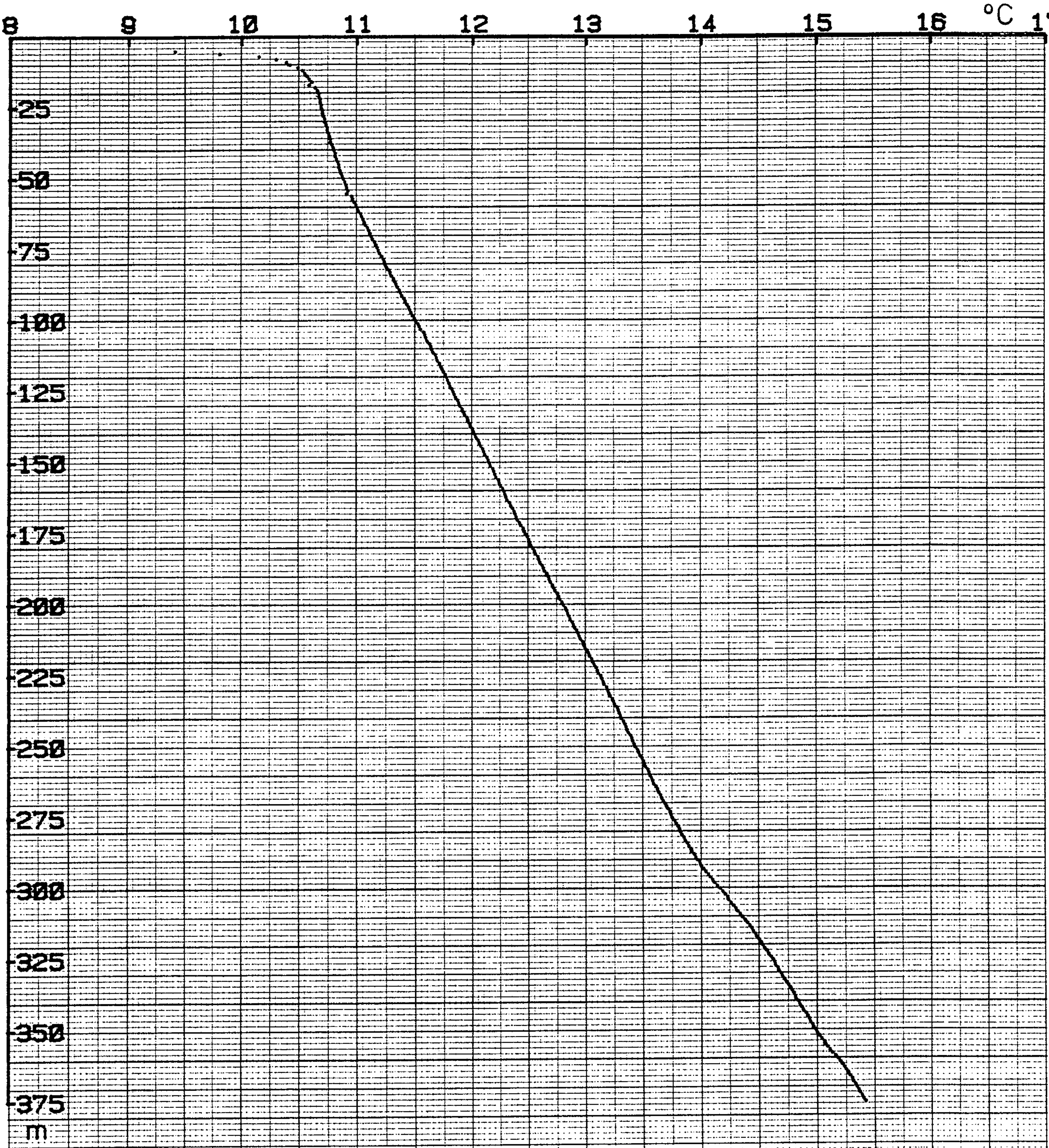
APPENDIX 24 TEMPERATURES (790314) IN OBSERVATION WELL NR. 184

LOCALITY DEN HELDER



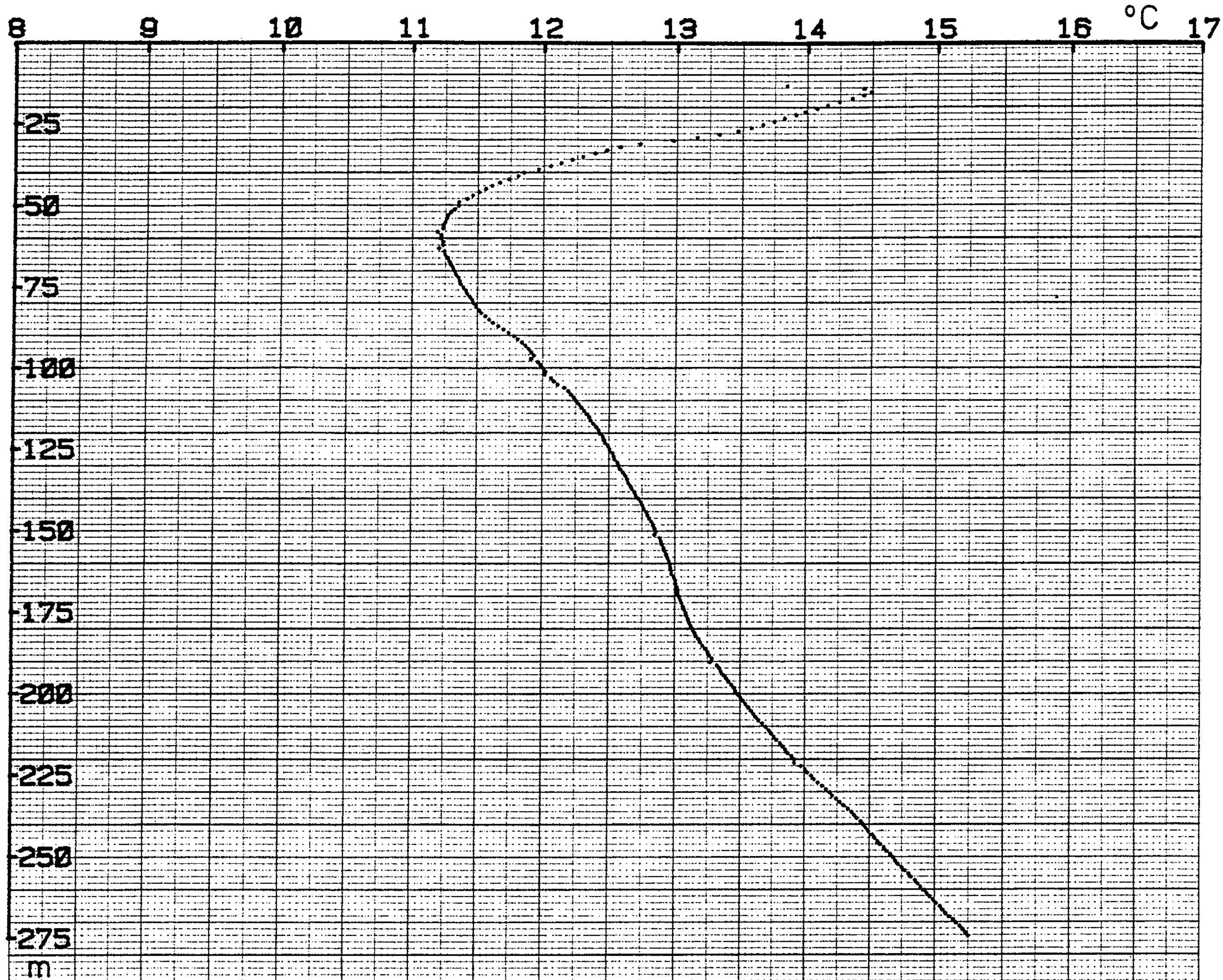
APPENDIX 25 TEMPERATURES (790322) IN OBSERVATION WELL NR. 185

LOCALITY 'T VELD



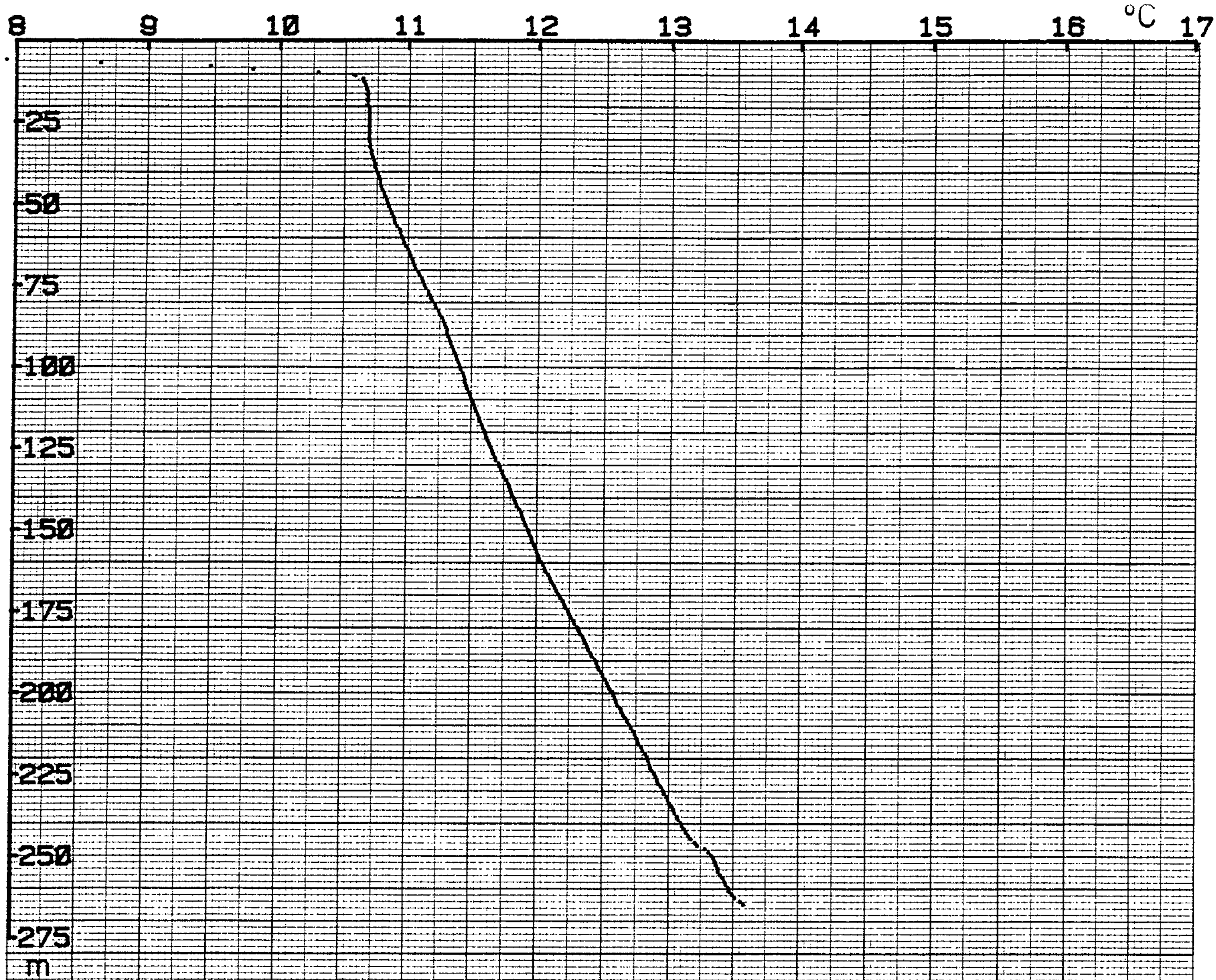
APPENDIX 26 TEMPERATURES (790323) IN OBSERVATION WELL NR. 187

LOCALITY SYBEKARSPEL



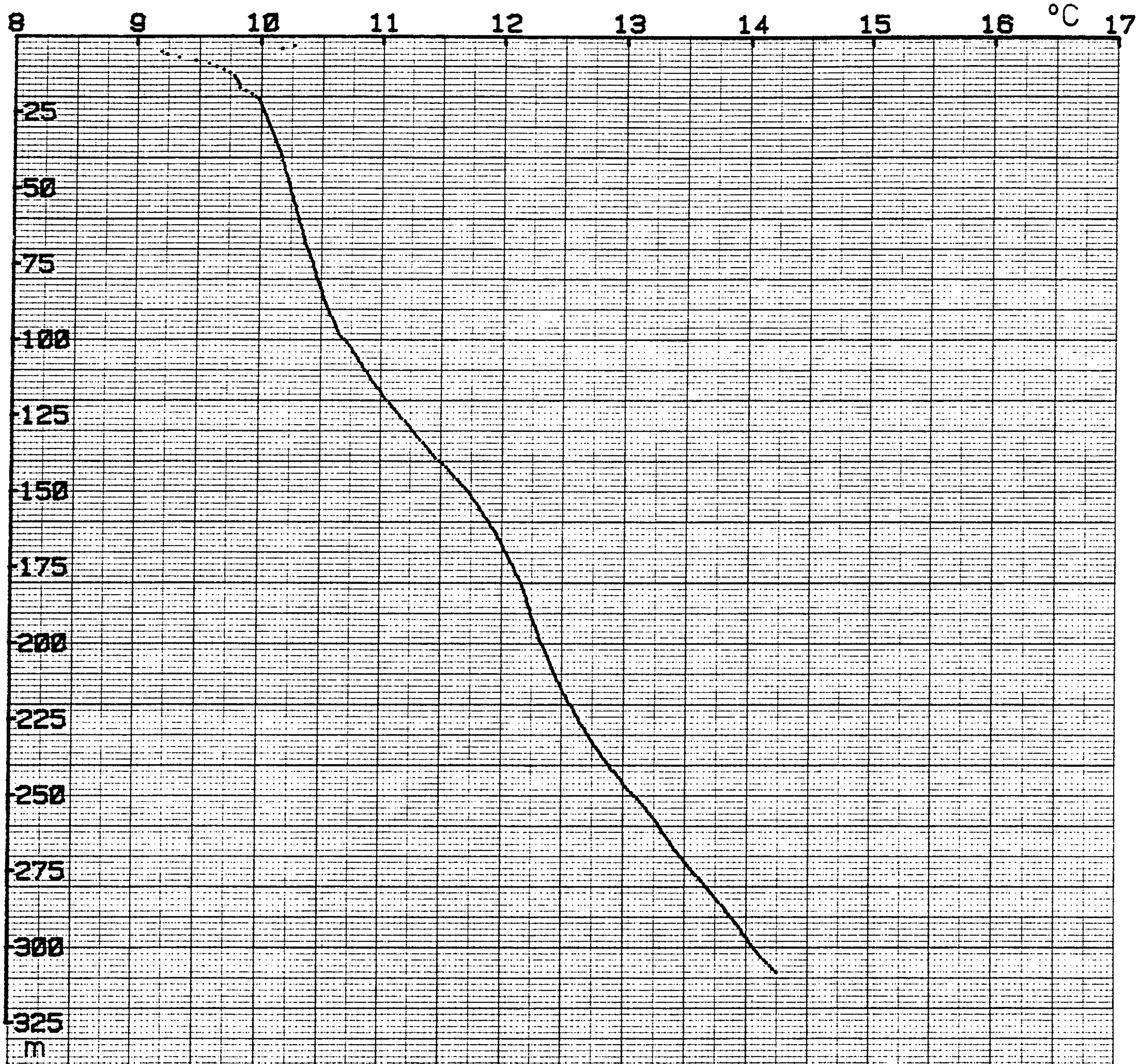
APPENDIX 27 TEMPERATURES (790330) IN OBSERVATION WELL NR. 190

LOCALITY VELSEN



APPENDIX 28 TEMPERATURES (790409) IN OBSERVATION WELL NR. 193

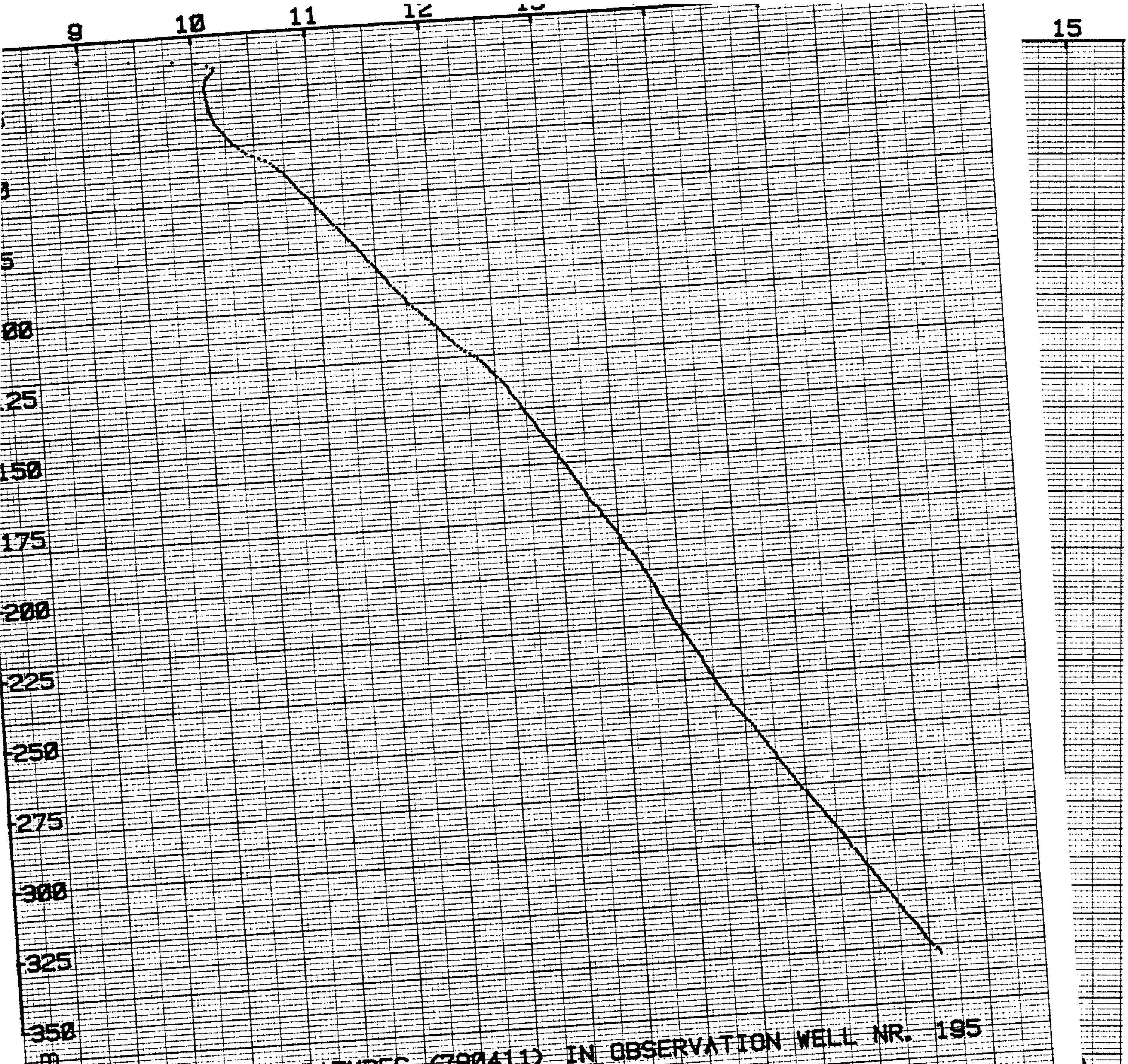
LOCALITY MEDEMBLIK



APPENDIX 29 TEMPERATURES (790411) IN OBSERVATION WELL NR. 194

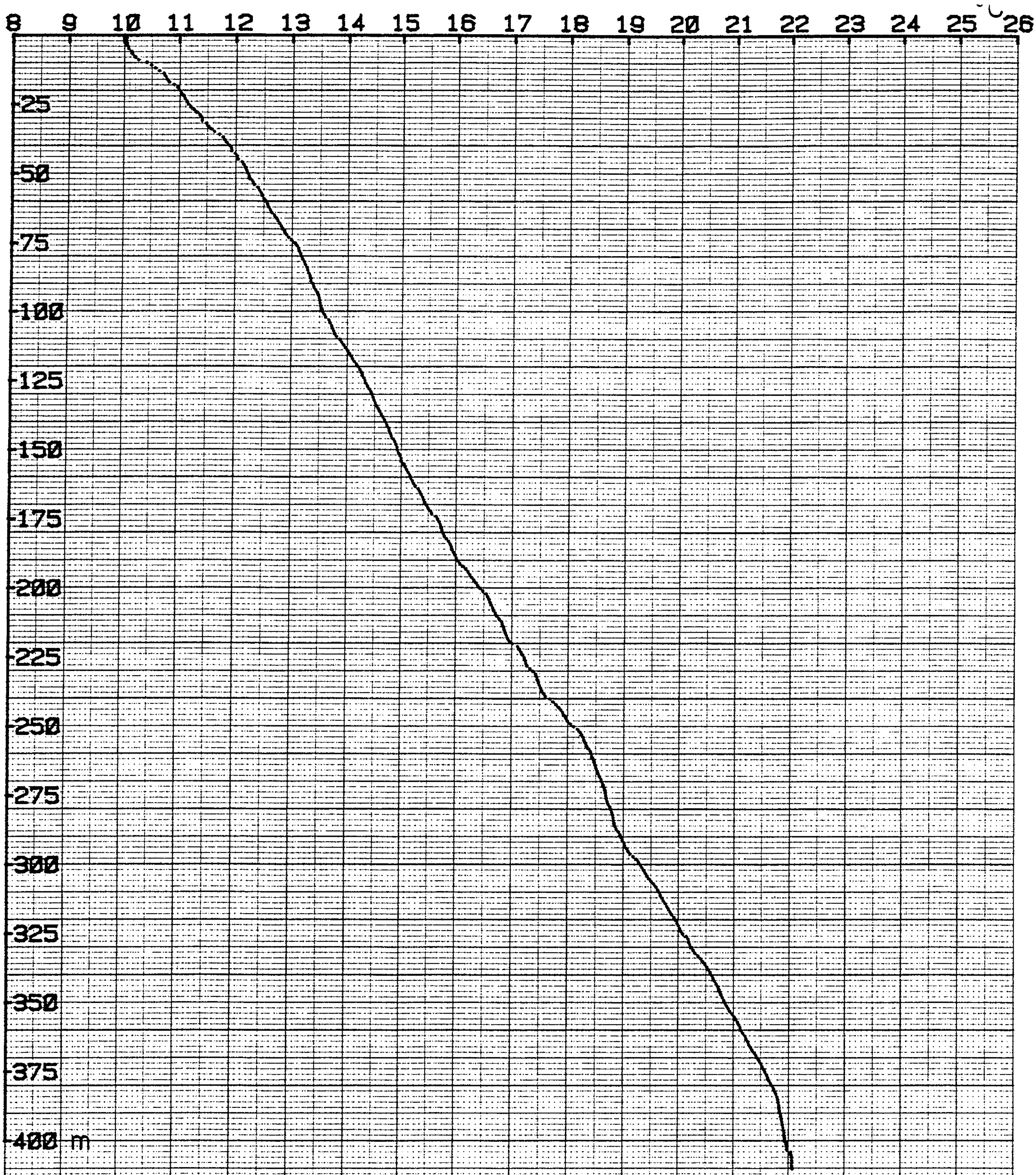
LOCALITY SCHOORL

REMARKS PIEZOMETERS IN THIS OBSERVATION WELL ARE OF STAINLESS STEEL PIPE



APPENDIX 30 TEMPERATURES (790411) IN OBSERVATION WELL NR. 195

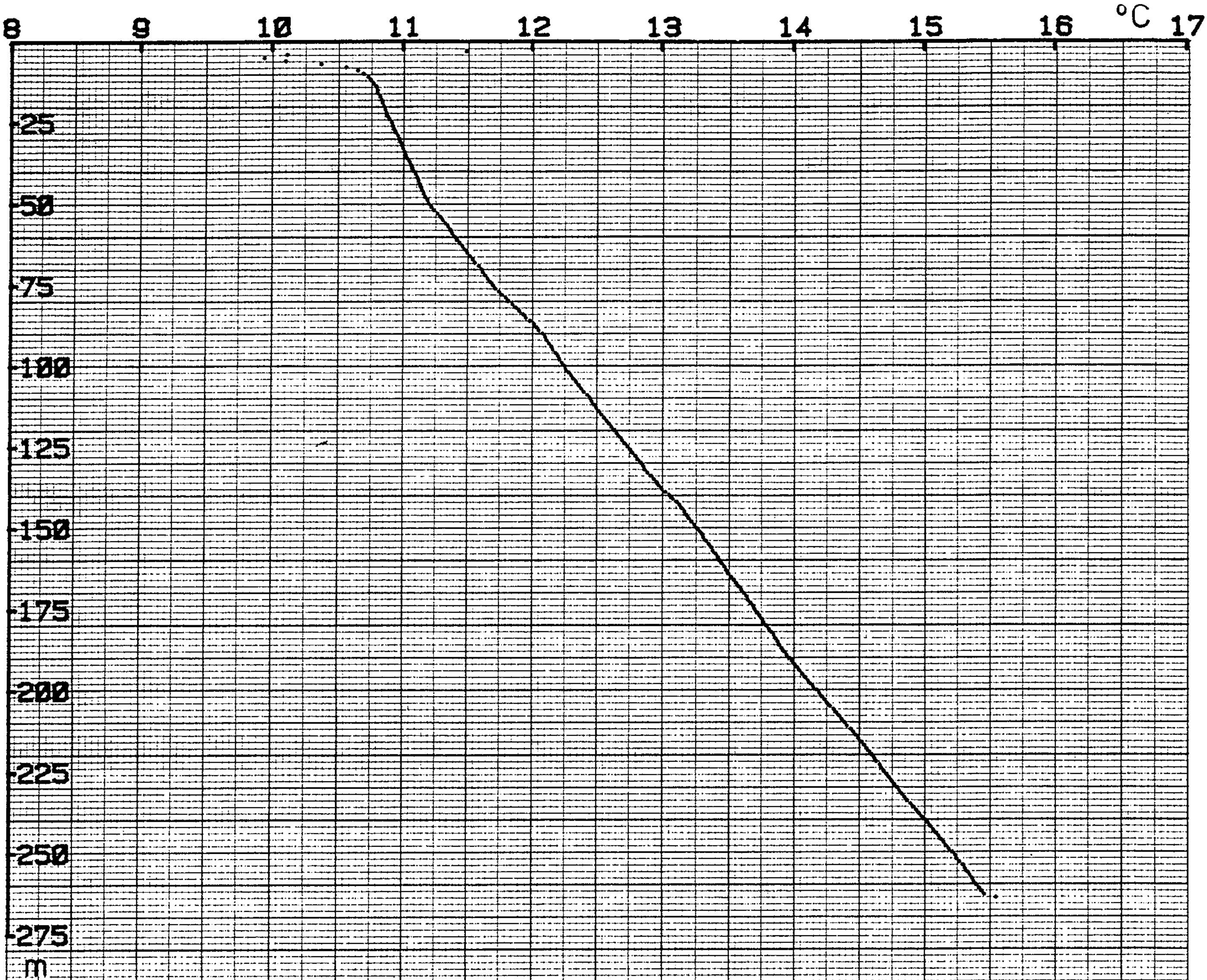
LOCALITY EGMOND-BINNEN



APPENDIX 35 TEMPERATURES (790511) IN OBSERVATION WELL NR. 209

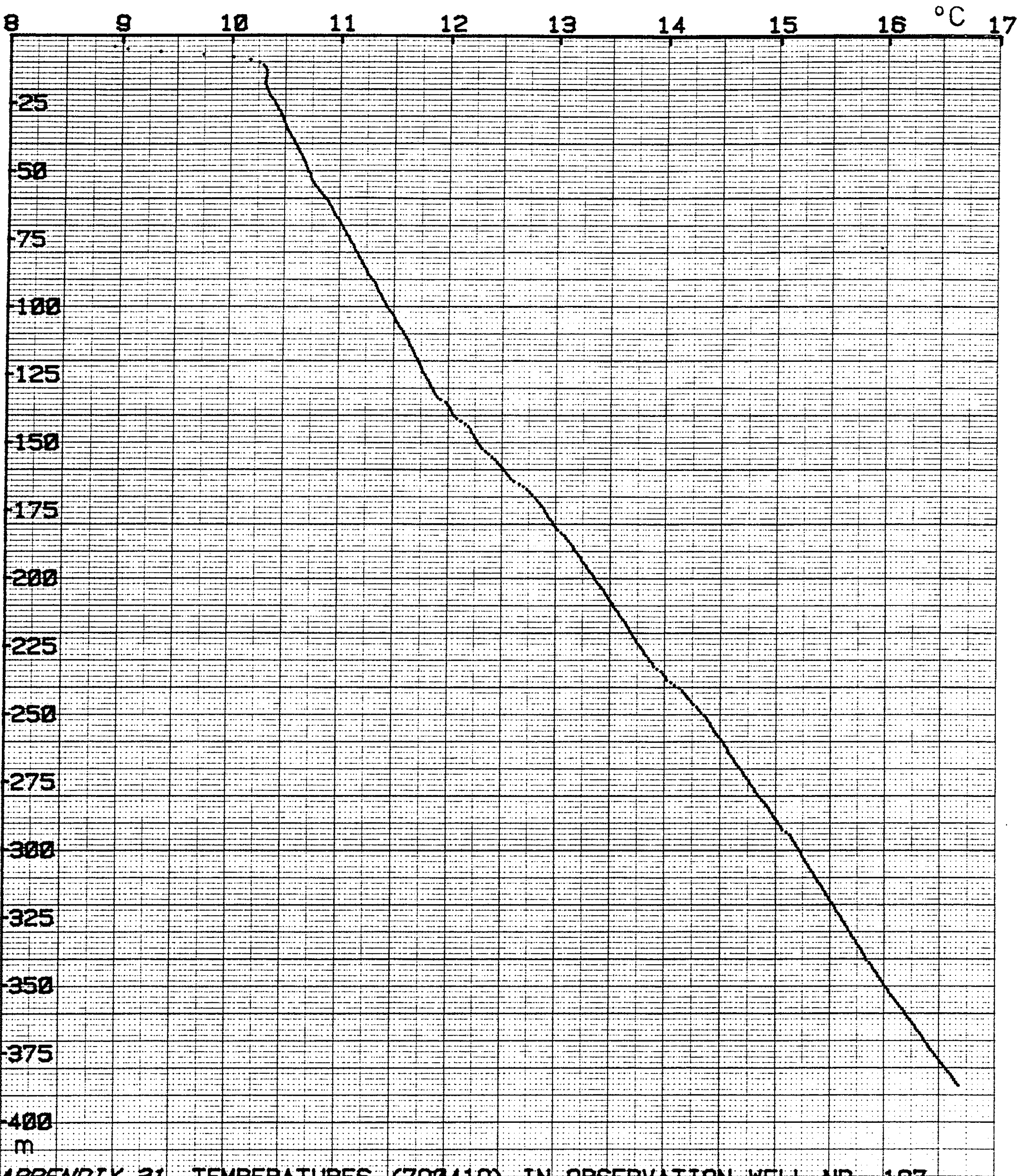
LOCALITY TWEKKELO 3

REMARKS TEMPERATURE PROFILE IN A ROCK SALT EXPLOITATION WELL, WHICH WAS TAKEN OUT OF ACTIVE OPERATION IN FEBR. 1973
TOP OF ROCK SALT FORMATION AT 369 M, BASE AT 433 M
TOP OF CAVERN AT 406 M, BOTTOM AT 424 M



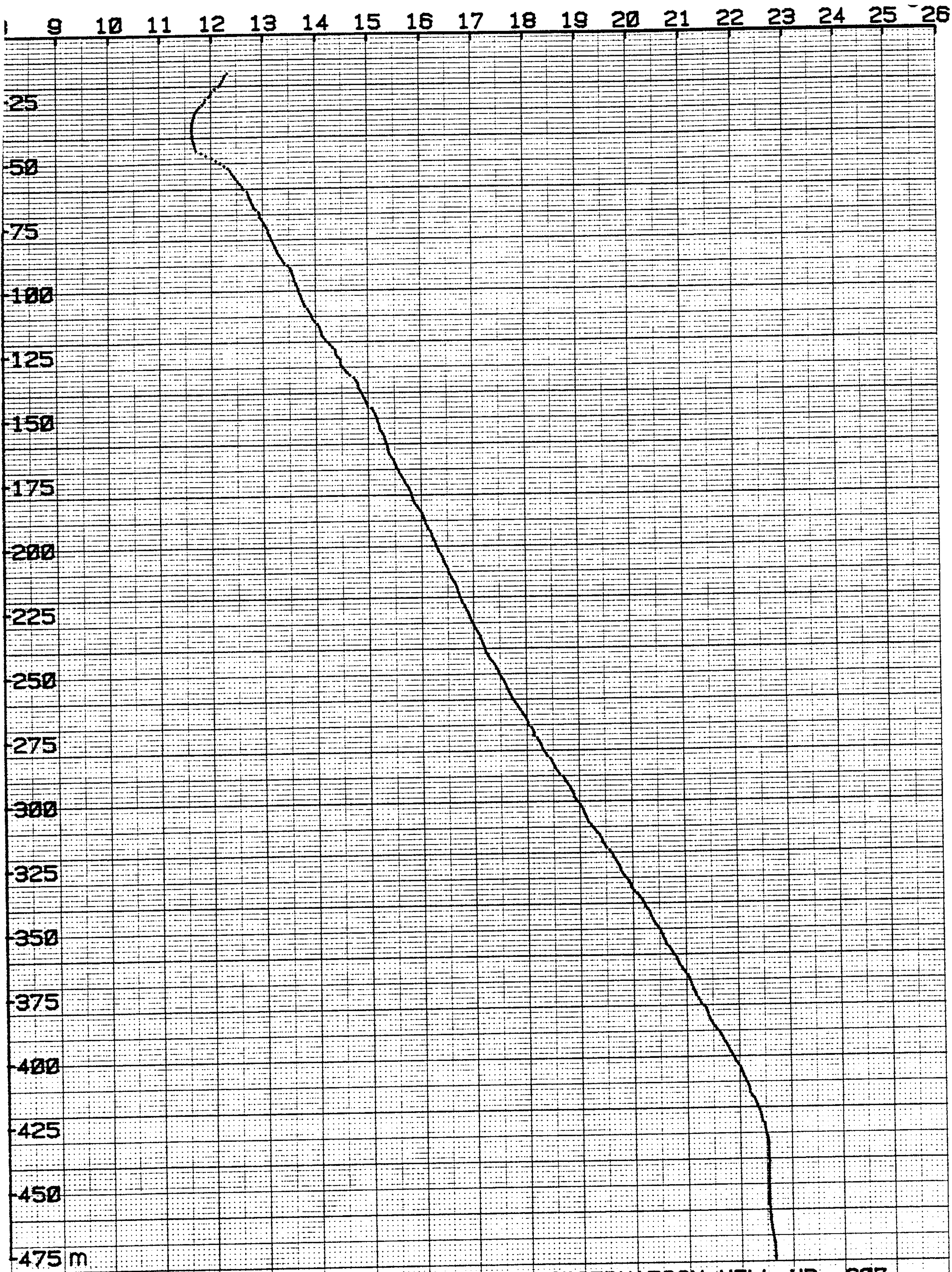
APPENDIX 32 TEMPERATURES (790724) IN OBSERVATION WELL NR. 202

LOCALITY ASPEREN



APPENDIX 31 TEMPERATURES (790419) IN OBSERVATION WELL NR. 197

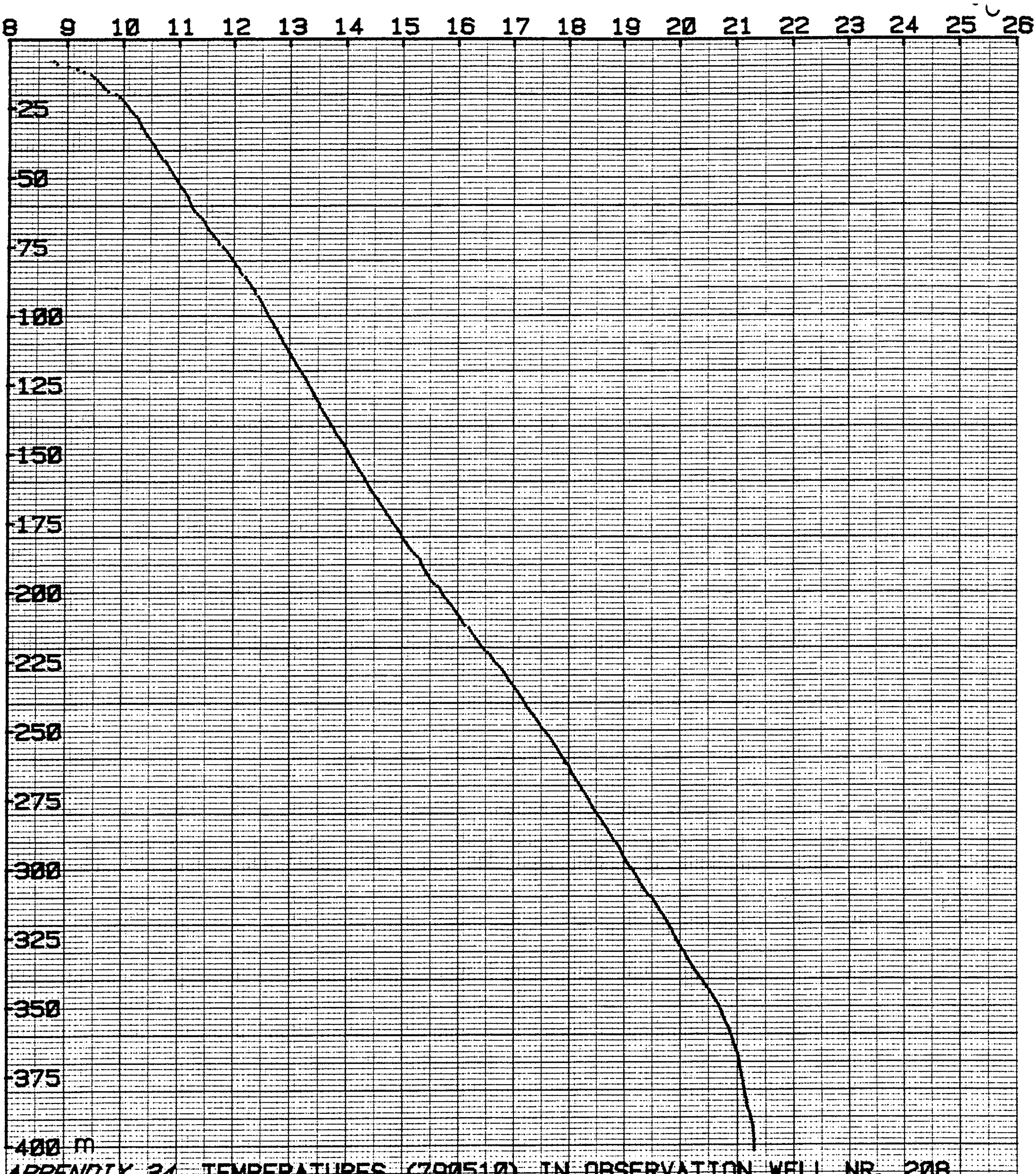
LOCALITY HEEZE



APPENDIX 33 TEMPERATURES (790510) IN OBSERVATION WELL NR. 207

LOCALITY TWEKKELO 1

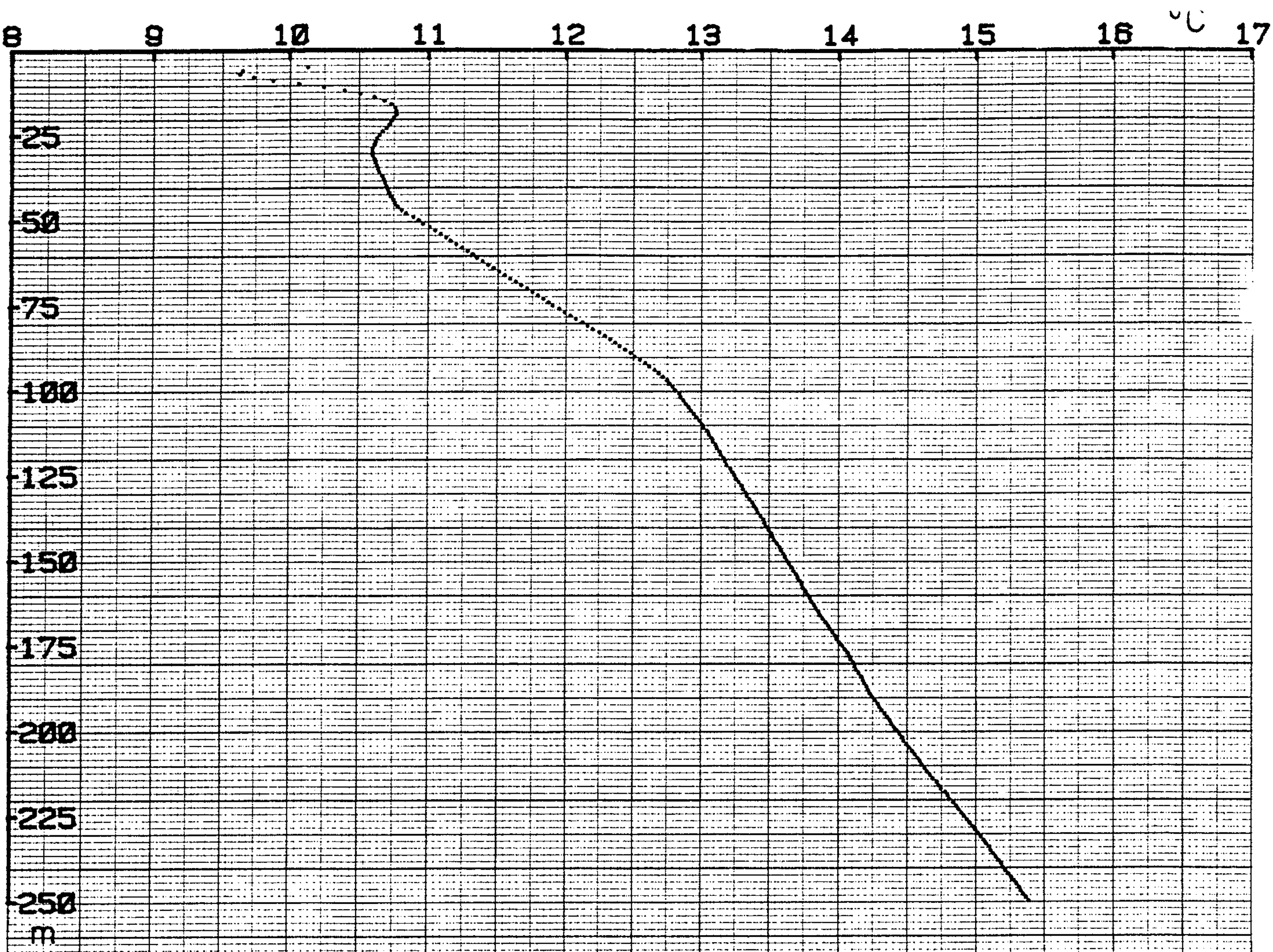
REMARKS TEMPERATURE PROFILE IN A ROCK SALT EXPLOITATION WELL, WHICH WAS TAKEN OUT OF ACTIVE OPERATION IN AUGUST 1976
TOP OF ROCK SALT FORMATION AT 437 M, BASE AT 483 M
TOP OF CAVERN AT 469 M, BOTTOM AT 480 M



APPENDIX 34 TEMPERATURES (790510) IN OBSERVATION WELL NR. 208

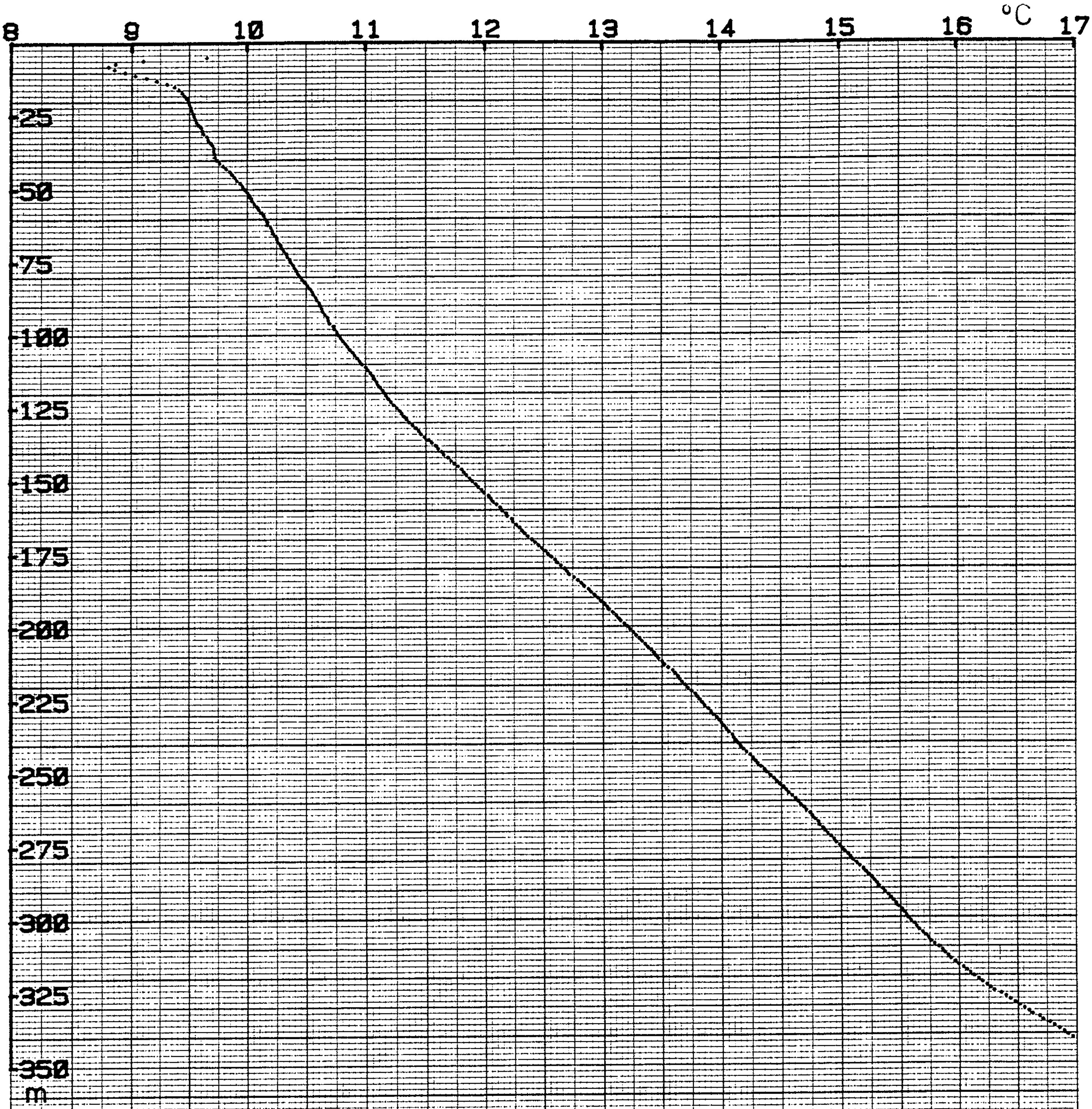
LOCALITY TWEKKELO 2

REMARKS TEMPERATURE PROFILE IN A ROCK SALT EXPLOITATION WELL, WHICH, AFTER ITS COMPLETION IN SEPTEMBER 1976, HAD NOT BEEN IN ACTIVE OPERATION YET
TOP OF ROCK SALT FORMATION AT 357 M, BASE AT 419 M



APPENDIX 37 TEMPERATURES (790727) IN OBSERVATION WELL NR. 229

LOCALITY NOORDBERGUM 5



APPENDIX 38 TEMPERATURES (790804) IN OBSERVATION WELL NR. 241

LOCALITY LUYKSGESTEL