LABORATORIUM VOOR TOEGEPASTE GEOLOGIE EN HYDROGEOLOGIE

HYDROGEOLOGY OF THE BEDUGUL HIGH PLAINS AREA, BALI

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1. INTRODUCTION

The Bedugul High Plains area covers approximately 1250 ha (fig. 1). It is located in a caldera, in central Bali at an elevation between +1220 and +1275. It contains three lakes : Lake Bratan, Lake Buyan and Lake Tamblingan. The village of Candikuning is located near Lake Bratan, the village of Pancasari near Lake Buyan. The area has no surficial outlet. Hence the hydrological balance is only made by evapotranspiration and infiltration.

2. FIELD INVESTIGATIONS

The purpose of the field investigation was

- to collect all available hydrologic data
- to locate and evaluate the springs
- to collect information concerning the hydrogeology.

Field investigations were carried out from 13 October to 2 November 1988.

Several wells were identified and located at Pancasari and at Candikuning (fig. 2 and 3). All were leveled and located within the survey grid. Water levels were measured by tape (tab. 1 and 2).

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Table 1 - Groundwater levels at Pancasari

	October 1988	May 1989
P1	+1218,87	
P2	+1218,76	+1210,72
P3	+1218,80	+1220,74
P4	+1218,79	+1220,61
P5	+1218,75	+1220,57
P6	+1218,79	+1220,44
P7	+1218,77	+1220,93
P8	+1218,21	+1219,89
P9	+1219 ?	+1220,94
P10	+1218,83	+1220,79
P10A	dry	+1220,76
P11	+1218,79	+1220,74
P12	+1218,80	+1220,73
P13	+1217,81	+1229,67
P14	+1217,92	+1219,87
P15	+1218,78	+1220,71

Table 2 - Groundwater levels at Candikuning

	October 1988	May 1989
C1	+1229,52	+1232,05
C2	+1225,47	+1229,46
C3	+1226,52	+1230,16
C4	+1224,73	-
C5	+1229,56	+1231,65
C6	+1231,93	-

Levels in Lake Bratan were at +1233,50 (18.10.88), and +1234,27 (15.05.89), in Lake Buyan at +1217,66 (17.10.88) and +1219,18 (03.05.89).

According to the local population the highest level in Lake Bratan is +1235,20 and in Lake Buyan +1220,70.

In the same period the depths of both the lakes were measured. Several traverses were made by motorboat. Positions were marked by theodolite. Depths were measured by a weighted tape. The results are shown in figures 4, 5 and 6. The depth of Lake Tamblingan could not be measured. According to information from the villagers the depth may be estimated at 60 m in the deepest parts. Lake Tamblingan seems to have been separated from Lake Buyan by a lava flow. Since both lake levels (Lake Tamblingan 1217,04 m on 27.10.88) do not differ much, this separation wall may be very permeable. This would have a damping effect on the level drop of Lake Buyan in the case of pumping.

Springs were located as shown on the map (fig. 7). Because of the lack of reference marks, these locations are not very accurate.

Table 3 - Springs in the Bedugul High Plains Area

	Date	Elevation	Yield	Remarks
1	20.10.88	+1300	dry	
2a	24.10.88	+1170	750 l/h	perennial
b		+1150	3500 l/h	perennial
c		+1120	2050 l/h	perennial
3	27.10.88	+1035	very high	perennial
4	26.10.88	+1278	high	Lake Buyan perennial
5	25.10.88	+1450 ?	9000 l/h	perennial
6	27.10.88	+1340	480 l/h	dry in summer
7	27.10.88	+1190	345 l/h	perennial
8	28.10.88	+1570	1800 l/h	perennial

3. HYDROGEOLOGICAL MODELING

The mathematical model consists of a computing programme and a number of input data. The latter describe the geometry and the hydraulic parameters of the aquifer. For the present study the computer programme RMOQ3D has been used. It is a quasi-threedimensional flow model. It considers a number of aquifers separated by semi-pervious layers.
The model computes the head distribution and the horizontal flow in the aquifers and the vertical flow through the semi-pervious layers.

3.1. Location of modeled area

The area as modeled measures 16 km by 10 km (fig. 8). The limit was chosen at the highest spring level on the caldera wall. The model consists of 32 columns and 20 rows. Each cell measures 500 by 500 m.

3.2. Schematization

For the Bedugul area two aquifers separated by one semi-pervious layer are considered. The upper aquifer is supposed to be located above the level of the springs at the outer calera wall (+1200). This aquifer only occurs within the caldera.

The lower aquifer is located below +1200 m and has a thickness of 200 m.

3.3. Input data

3.3.1. Constraints

Since no hydrogeologic data were available the hydraulic parameters were estimated by calibrating the model on the head measurements. The parameters were gradually adapted until the head configuration as computed by the model was in agreement with the head distribution as measured in the field. Unfortunately only few and very narrowly localized level measurements are available. The calibration therefore is based mainly on the level measurements of the Bratan and Buyan Lakes. Hence the values of the hydraulic parameters must be considered as a very rough estimation. More information is needed to improve these values. At this end some deep wells should be drilled and pumping tests should be performed.

3.3.2. Hydraulic parameters

In the lower aquifer a constant value of 8 m/d has been accepted for the horizontal permeability. In the upper aquifer (fig. 9) outside the caldera a value of 0,001 m/d has been attributed to the horizontal permeability. Since this aquifer does not occur in this zone, there is no flow but the model requires the introduction of a value. Within the caldera a very large value of permeability (10.000 m/d) has been given to the cells containing the lakes. For the areas around the lakes, where alluvial deposits occur, the value of 500 m/d has been introduced. This is based on the fact that the water levels in the wells around Lake Buyan are almost at the same elevation as the lake level. The rest of the aquifer has been given a permeability of 20 m/d.

Outside the caldera the semi-pervious layer has a vertical hydraulic resistance (fig. 10) of 1 d. Here only the lower aquifer occurs. Because of the small hydraulic resistance, the heads in the lower and the upper aquifer are the same. Inside the caldera three values for the hydraulic resistance have been considered : in the west around Lake Tamblingan more than 3000 d, in the east around Lake Bratan 30.000 d and around Lake Buyan 1000 d.

Most of the boundaries have been considered as constant head boundaries (fig. 11). This means that here the heads remain unchanged. The constant heads coincide with the average spring level, located at +1200. The southern and southwestern boundary from column 6 to 16 are considered to be impermeable. They coincide with the water divide, so there is no flow across it.

The rim of the caldera is the water divide in the upper aquifer and is considered to be an impermeable boundary.

3.3.3. Alimentation

According to THORNTHWAITE the effective precipitation may be calculated for the period 1975-1983 from the values of precipitation and potential evapotranspiration (tables 4, 5.1, 5.2, 5.3 and 5.4). For the period considered the average precipitation was 2386,83 mm/year. The average surplus was 1329,26 mm/year which gives an infiltration coefficient of 55,7 %. These values were used for the whole area.

Table 4 - Yearly rainfall and surplus (mm/yr)

Year	Rainfall	Surplus
75	3631	2600
76	2216	1248
77	2050	1168
78	3235	1997
79	2498	1306
80	2371	1384
81	3235	1959
82	1295	564
83	2479	1376
84	2618	1380
85	1809	877
86	1817	715
87	1793	728
88	2354	1289 (jan-sep)
75-88	2387	1329

The average level in Lake Bratan in the period 1969-1978 was +1235,14. The variation was 1,89 m. In Lake Buyan the average level was +1215,24 in the period 1964-1978 (1972 not included). The variation was 1,73 m.

Table 5.1 - Hydrologic data

YR	MN	R	PET	RMP	ST	DST	AET	DEF	SUR
75	1	430.0	96.4	333.6	100.0	0.0	96.4	0.0	333.6
75	2	550.0	99.7	450.3	100.0	0.0	99.7	0.0	450.3
75	3	667.0	93.9	573.1	100.0	0.0	93.9	0.0	573.1
75	4	456.0	81.3	374.7	100.0	0.0	81.3	0.0	374.7
75	5	263.0	74.4	188.6	100.0	0.0	74.4	0.0	188.6
75	6	49.0	80.4	-31.4	73.1	-26.9	75.9	4.5	0.0
75	7	9.0	83.7	-74.7	34.6	-38.4	47.4	36.3	0.0
75	8	57.0	99.2	-42.2	22.7	-11.9	68.9	30.3	0.0
75	9	210.0	97.2	112.8	100.0	77.3	97.2	0.0	35.5
75	10	337.0	102.6	234.4	100.0	0.0	102.6	0.0	234.4
75	11	368.0	93.9	274.1	100.0	0.0	93.9	0.0	274.1
75	12	233.0	98.3	134.7	100.0	0.0	98.3	0.0	134.7
76	1	919.0	94.5	824.5	100.0	0.0	94.5	0.0	824.5
76	2	171.0	99.7	71.3	100.0	0.0	99.7	0.0	71.3
76	3	309.0	92.4	216.6	100.0	0.0	92.4	0.0	216.6
76	4	85.0	94.8	-9.8	90.7	-9.3	94.3	0.5	0.0
76	5	16.0	86.2	-70.2	44.9	-45.7	61.7	24.5	0.0
76	6	62.0	72.6	-10.6	40.4	-4.5	66.5	6.1	0.0
76	7	15.0	81.5	-66.5	20.8	-19.6	34.6	46.9	0.0
76	8	29.0	110.4	-81.4	9.2	-11.6	40.6	69.8	0.0
76	9	12.0	134.4	-122.4	2.7	-6.5	18.5	115.9	0.0
76	10	171.0	117.8	53.2	55.9	53.2	117.8	0.0	0.0
76	11	291.0	114.9	176.1	100.0	44.1	114.9	0.0	132.0
76	12	135.0	131.4	3.6	100.0	0.0	131.4	0.0	3.6
77	1	161.0	111.0	50.0	100.0	0.0	111.0	0.0	50.0
77	2	412.0	91.6	320.4	100.0	0.0	91.6	0.0	320.4
77	3	703.0	122.8	580.2	100.0	0.0	122.8	0.0	580.2
77	4	65.0	110.1	-45.1	63.7	-36.3	101.3	8.8	0.0
77	5	120.0	98.9	21.1	84.8	21.1	98.9	0.0	0.0
77	6	50.0	76.5	-26.5	65.1	-19.7	69.7	6.8	0.0
77	7	5.0	81.8	-76.8	30.2	-34.9	39.9	41.9	0.0
77	8	9.0	120.9	-111.9	9.9	-20.3	29.3	91.6	0.0
77	9	20.0	94.5	-74.5	4.7	-5.2	25.2	69.3	0.0
77	10	3.0	159.7	-156.7	1.0	-3.7	6.7	152.9	0.0
77	11	69.0	145.5	-76.5	0.5	-0.5	69.5	76.0	0.0
77	12	432.0	115.0	317.0	100.0	99.5	115.0	0.0	217.4
78	1	905.0	112.2	792.8	100.0	0.0	112.2	0.0	792.8
78	2	153.0	112.8	40.2	100.0	0.0	112.8	0.0	40.2
78	3	683.0	133.6	549.4	100.0	0.0	133.6	0.0	549.4
78	4	71.0	122.4	-51.4	59.8	-40.2	111.2	11.2	0.0
78	5	193.0	96.7	96.3	100.0	40.2	96.7	0.0	56.1
78	6	328.0	66.3	261.7	100.0	0.0	66.3	0.0	261.7
78	7	59.0	74.7	-15.7	85.5	-14.5	73.5	1.2	0.0
78	8	14.0	106.0	-92.0	34.1	-51.4	65.4	40.6	0.0
78	9	141.0	94.2	46.8	80.9	46.8	94.2	0.0	0.0
78	10	91.0	131.4	-40.4	54.0	-26.9	117.9	13.5	0.0
78	11	288.0	120.3	167.7	100.0	46.0	120.3	0.0	121.7
78	12	307.0	132.4	174.6	100.0	0.0	132.4	0.0	174.6

YR year
MN month
R precipitation
PET potential evapotranspiration
RMP rainfall minus potential evapotranspiration
ST storage
DST storage change
AET actual evapotranspiration
DEF deficit
SUR surplus

Table 5.2 - Hydrologic data

YR	MN	R	PET	RMP	ST	DST	AET	DEF	SUR
79	1	263.0	103.5	159.5	100.0	0.0	103.5	0.0	159.5
79	2	311.5	108.6	202.9	100.0	0.0	108.6	0.0	202.9
79	3	678.0	117.8	560.2	100.0	0.0	117.8	0.0	560.2
79	4	90.0	111.0	-21.0	81.1	-18.9	108.9	2.1	0.0
79	5	110.0	83.1	26.9	100.0	18.9	83.1	0.0	8.0
79	6	146.0	60.6	85.4	100.0	0.0	60.6	0.0	85.4
79	7	110.0	90.2	19.8	100.0	0.0	90.2	0.0	19.8
79	8	29.0	104.8	-75.8	46.9	-53.1	82.1	22.6	0.0
79	9	24.0	107.4	-83.4	20.4	-26.5	50.5	56.9	0.0
79	10	112.0	140.4	-28.4	15.3	-5.0	117.0	23.4	0.0
79	11	289.0	139.2	149.8	100.0	84.7	139.2	0.0	65.1
79	12	334.5	129.6	204.9	100.0	0.0	129.6	0.0	204.9
80	1	538.0	99.5	438.5	100.0	0.0	99.5	0.0	438.5
80	2	288.0	93.8	194.2	100.0	0.0	93.8	0.0	194.2
80	3	269.0	105.4	163.6	100.0	0.0	105.4	0.0	163.6
80	4	324.0	87.0	237.0	100.0	0.0	87.0	0.0	237.0
80	5	54.0	91.1	-37.1	69.0	-31.0	85.0	6.1	0.0
80	6	0.0	75.0	-75.0	32.6	-36.4	36.4	38.6	0.0
80	7	44.0	86.8	-42.8	21.2	-11.3	55.3	31.5	0.0
80	8	89.0	114.4	-25.4	16.5	-4.8	93.8	20.6	0.0
80	9	15.0	117.6	-102.6	5.9	-10.6	25.6	92.0	0.0
80	10	74.0	139.2	-65.2	3.1	-2.8	76.8	62.4	0.0
80	11	285.0	126.9	158.1	100.0	96.9	126.9	0.0	61.2
80	12	389.5	100.4	289.1	100.0	0.0	100.4	0.0	289.1
81	1	1037.0	103.8	933.2	100.0	0.0	103.8	0.0	933.2
81	2	368.5	110.9	257.6	100.0	0.0	110.9	0.0	257.6
81	3	372.0	107.0	265.0	100.0	0.0	107.0	0.0	265.0
81	4	103.0	116.1	-13.1	87.7	-12.3	115.3	0.8	0.0
81	5	67.0	116.6	-49.6	53.4	-34.3	101.3	15.3	0.0
81	6	78.0	84.9	-6.9	49.9	-3.6	81.6	3.3	0.0
81	7	209.0	99.8	109.2	100.0	50.1	99.8	0.0	59.1
81	8	0.0	132.4	-132.4	26.6	-73.4	73.4	59.0	0.0
81	9	88.0	122.1	-34.1	18.9	-7.7	95.7	26.4	0.0
81	10	217.0	142.9	74.1	93.0	74.1	142.9	0.0	0.0
81	11	397.0	125.7	271.3	100.0	7.0	125.7	0.0	264.3
81	12	297.0	117.8	179.2	100.0	0.0	117.8	0.0	179.2
82	1	251.0	105.4	145.6	100.0	0.0	105.4	0.0	145.6
82	2	321.0	110.6	210.4	100.0	0.0	110.6	0.0	210.4
82	3	152.0	130.8	21.2	100.0	0.0	130.8	0.0	21.2
82	4	154.0	110.4	43.6	100.0	0.0	110.4	0.0	43.6
82	5	21.0	118.1	-97.1	37.9	-62.1	83.1	35.0	0.0
82	6	3.0	104.7	-101.7	13.7	-24.2	27.2	77.5	0.0
82	7	0.0	115.9	-115.9	4.3	-9.4	9.4	106.5	0.0
82	8	22.0	119.0	-97.0	1.6	-2.7	24.7	94.4	0.0
82	9	0.0	144.0	-144.0	0.4	-1.2	1.2	142.8	0.0
82	10	0.0	179.8	-179.8	0.1	-0.3	0.3	179.5	0.0
82	11	13.0	168.9	-155.9	0.0	-0.1	13.1	155.8	0.0
82	12	358.0	115.0	243.0	100.0	100.0	115.0	0.0	143.0

Table 5.3 - Hydrologic data

YR	MN	R	PET	RMP	ST	DST	AET	DEF	SUR
83	1	489.5	117.5	372.0	100.0	0.0	117.5	0.0	372.0
83	2	291.0	63.0	228.0	100.0	0.0	63.0	0.0	228.0
83	3	154.0	119.0	35.0	100.0	0.0	119.0	0.0	35.0
83	4	191.0	114.3	76.7	100.0	0.0	114.3	0.0	76.7
83	5	197.0	95.2	101.8	100.0	0.0	95.2	0.0	101.8
83	6	53.0	100.8	-47.8	62.0	-38.0	91.0	9.8	0.0
83	7	102.0	103.5	-1.5	61.1	-0.9	102.9	0.6	0.0
83	8	3.0	128.3	-125.3	17.4	-43.6	46.6	81.7	0.0
83	9	6.0	149.4	-143.4	4.2	-13.3	19.3	130.1	0.0
83	10	102.0	150.3	-48.3	2.6	-1.6	103.6	46.8	0.0
83	11	582.0	104.1	477.9	100.0	97.4	104.1	0.0	380.5
83	12	307.0	124.9	182.1	100.0	0.0	124.9	0.0	182.1
84	1	359.0	112.8	246.2	100.0	0.0	112.8	0.0	246.2
84	2	692.0	102.8	589.2	100.0	0.0	102.8	0.0	589.2
84	3	341.0	114.4	226.6	100.0	0.0	114.4	0.0	226.6
84	4	270.0	102.3	167.7	100.0	0.0	102.3	0.0	167.7
84	5	85.0	101.7	-16.7	84.6	-15.4	100.4	1.3	0.0
84	6	19.0	101.1	-82.1	37.2	-47.4	66.4	34.7	0.0
84	7	34.0	103.2	-69.2	18.6	-18.6	52.6	50.6	0.0
84	8	79.0	119.0	-40.0	12.5	-6.1	85.1	33.9	0.0
84	9	224.0	108.3	115.7	100.0	87.5	108.3	0.0	28.2
84	10	125.0	141.4	-16.4	84.9	-15.1	140.1	1.3	0.0
84	11	186.0	141.0	45.0	100.0	15.1	141.0	0.0	29.9
84	12	203.0	111.3	91.7	100.0	0.0	111.3	0.0	91.7
85	1	90.0	125.6	-35.6	70.1	-29.9	119.9	5.6	0.0
85	2	687.0	98.3	588.7	100.0	29.9	98.3	0.0	558.8
85	3	259.0	123.1	135.9	100.0	0.0	123.1	0.0	135.9
85	4	107.0	119.1	-12.1	88.6	-11.4	118.4	0.7	0.0
85	5	38.0	114.1	-76.1	41.4	-47.2	85.2	28.9	0.0
85	6	10.0	101.7	-91.7	16.5	-24.9	34.9	66.8	0.0
85	7	14.0	104.2	-90.2	6.7	-9.8	23.8	80.3	0.0
85	8	6.0	114.7	-108.7	2.3	-4.5	10.5	104.2	0.0
85	9	15.0	136.2	-121.2	0.7	-1.6	16.6	119.6	0.0
85	10	75.0	150.0	-75.0	0.3	-0.4	75.4	74.7	0.0
85	11	272.0	114.3	157.7	100.0	99.7	114.3	0.0	58.0
85	12	235.0	111.0	124.0	100.0	0.0	111.0	0.0	124.0
86	1	670.0	98.3	571.7	100.0	0.0	98.3	0.0	571.7
86	2	232.0	102.2	129.8	100.0	0.0	102.2	0.0	129.8
86	3	137.0	123.7	13.3	100.0	0.0	123.7	0.0	13.3
86	4	90.5	106.2	-15.7	85.5	-14.5	105.0	1.2	0.0
86	5	16.0	110.7	-94.7	33.2	-52.3	68.3	42.4	0.0
86	6	138.0	85.2	52.8	86.0	52.8	85.2	0.0	0.0
86	7	90.0	97.0	-7.0	80.1	-5.8	95.8	1.2	0.0
86	8	52.0	111.3	-59.3	44.3	-35.8	87.8	23.5	0.0
86	9	33.0	140.1	-107.1	15.2	-29.1	62.1	78.0	0.0
86	10	75.0	139.8	-64.8	7.9	-7.2	82.2	57.6	0.0
86	11	143.0	126.0	17.0	24.9	17.0	126.0	0.0	0.0
86	12	140.0	132.7	7.3	32.3	7.3	132.7	0.0	0.0

Table 5.4 - Hydrologic data

YR	MN	R	PET	RMP	ST	DST	AET	DEF	SUR
87	1	384.0	90.5	293.5	100.0	67.7	90.5	0.0	225.7
87	2	119.0	109.2	9.8	100.0	0.0	109.2	0.0	9.8
87	3	90.0	132.7	-42.7	65.3	-34.7	124.7	7.9	0.0
87	4	109.0	123.6	-14.6	56.4	-8.9	117.9	5.7	0.0
87	5	94.0	109.4	-15.4	48.3	-8.1	102.1	7.4	0.0
87	6	33.5	93.6	-60.1	26.5	-21.8	55.3	38.3	0.0
87	7	14.5	101.7	-87.2	11.1	-15.4	29.9	71.8	0.0
87	8	46.0	119.3	-73.3	5.3	-5.8	51.8	67.6	0.0
87	9	47.0	135.9	-88.9	2.2	-3.1	50.1	85.8	0.0
87	10	36.5	162.8	-126.3	0.6	-1.6	38.1	124.7	0.0
87	11	212.5	114.6	97.9	98.5	97.9	114.6	0.0	0.0
87	12	606.0	111.9	494.1	100.0	1.5	111.9	0.0	492.6
88	1	489.5	104.5	385.[illegible]	100.0	0.0	104.5	0.0	385.0
88	2	245.5	107.8	137.7	100.0	0.0	107.8	0.0	137.7
88	3	465.0	96.7	368.3	100.0	0.0	96.7	0.0	368.3
88	4	125.5	121.8	3.7	100.0	0.0	121.8	0.0	3.7
88	5	172.0	102.9	69.1	100.0	0.0	102.9	0.0	69.1
88	6	49.0	84.9	-35.9	69.8	-30.2	79.2	5.7	0.0
88	7	54.0	90.2	-36.2	48.6	-21.2	75.2	15.0	0.0
88	8	117.0	107.0	10.0	58.7	10.0	107.0	0.0	0.0
88	9	42.0	128.1	-86.1	24.8	-33.9	75.9	52.2	0.0

3.4. Ouput

3.4.1. Present situation

Some thirty ssimulations were made to calibrate the model. After calibration of the model the present situation was simulated. In Lake Buyan a level of +1215,39 and in Lake Bratan a level of +1234,72 was calculated. These values are in agreement with the measured ones.

In the upper aquifer (fig. 12) the model calculates the head contour lines, which indicate a flow from Lake Bratan to Lake Buyan. The gradient near Lake Bratan is much larger than the one near Lake Buyan. In the latter area levels in water wells do not differ much from the lake level. In the wells west of Lake Bratan water levels are several metres below the lake level, indicating an outward flow from the lake into the aquifer. However, since the flow pattern depends very much on the permeability, a smaller value in the area in between would result in a water divide between both lakes. Since no measurements in that area are available, it is impossible to check whatever presumption.

In the lower aquifer (fig. 13) the flow is directed radially outward.

3.4.2. Simulation of water extraction from Lake Buyan

Three possibilities of extraction have been simulated. The quantities withdrawn correspond with a maximal, a minimal, and a yearly average irrigation volume for an area of 300 ha, respectively 3980, 1707, and 2573 m^3/ha or a total yearly volume of 2.573.100, 512.100, and 1.194.000 m^3/yr. The results of the simulations are shown in figs. 14, 15 and 16. The expected water-level drop is indicated in cm. The level drop in Lake Buyan is respectively 16, 3, and 7 cm. The influence in Lake Bratan is less than 1 cm. These values are valid for permanent conditions with an average rainfall. A succession of dry years may result in larger level drops.

5. CONCLUSIONS AND RECOMMENDATIONS

Springs are very difficult to locate. The springs outside the caldera seem to occur below +1200 m. The higher springs only have a small yield. A few piezometric data were obtained in the vicinity of the lakes. The depth of the lakes Bratan and Buyan were measured. No information concerning the geology or the hydraulic parameters of the area were available. A threedimensional two-layer model has been applied to simulate the groundwater conditions. The calibration had to be based on very few piezometric data. The simulations show that the influence of a maximal withdrawal corresponding with 3980 m^3/ha will be very small. Near Lake Bratan the level would drop by less than 1 cm.

However, if implemented and especially if larger quantities will be withdrawn the operating scheme should be accompanied or preceded by a thorough hydrogeologic investigation of the area. This investigation would comprise at least one pumping test on a deep well (70 to 80 metres) drilled in the area between the two lakes. At least ten to twenty observation wells, reaching 5 m below the lowest water level should be installed. They will provide the information required for a better calibration of the model. At the same time they will have to be used to monitor the evolution of the piezometry in the future. They will also serve to collect samples at regular intervals to control the evolution of the groundwater quality. To ensure a proper functioning of these wells precautions will have to be taken to avoid all contamination risks.

If the area will be developed as a tourist resort a proper sewage system and a waste treating plant will be a absolute necessity. Otherwise the lake water but also the groundwater will irremediably be deteriorated.

26 July, 1989.

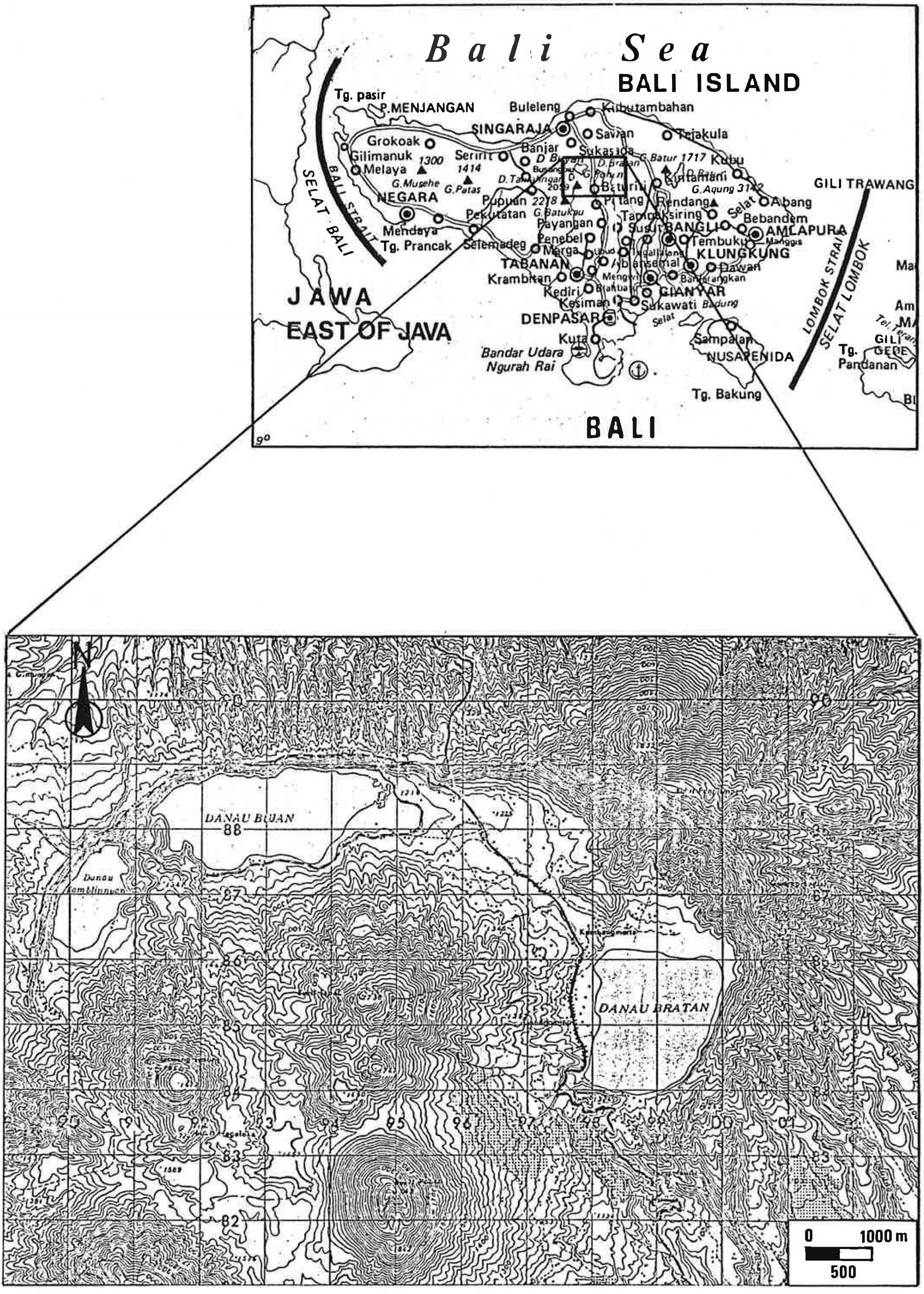

Fig. 1 - General map.

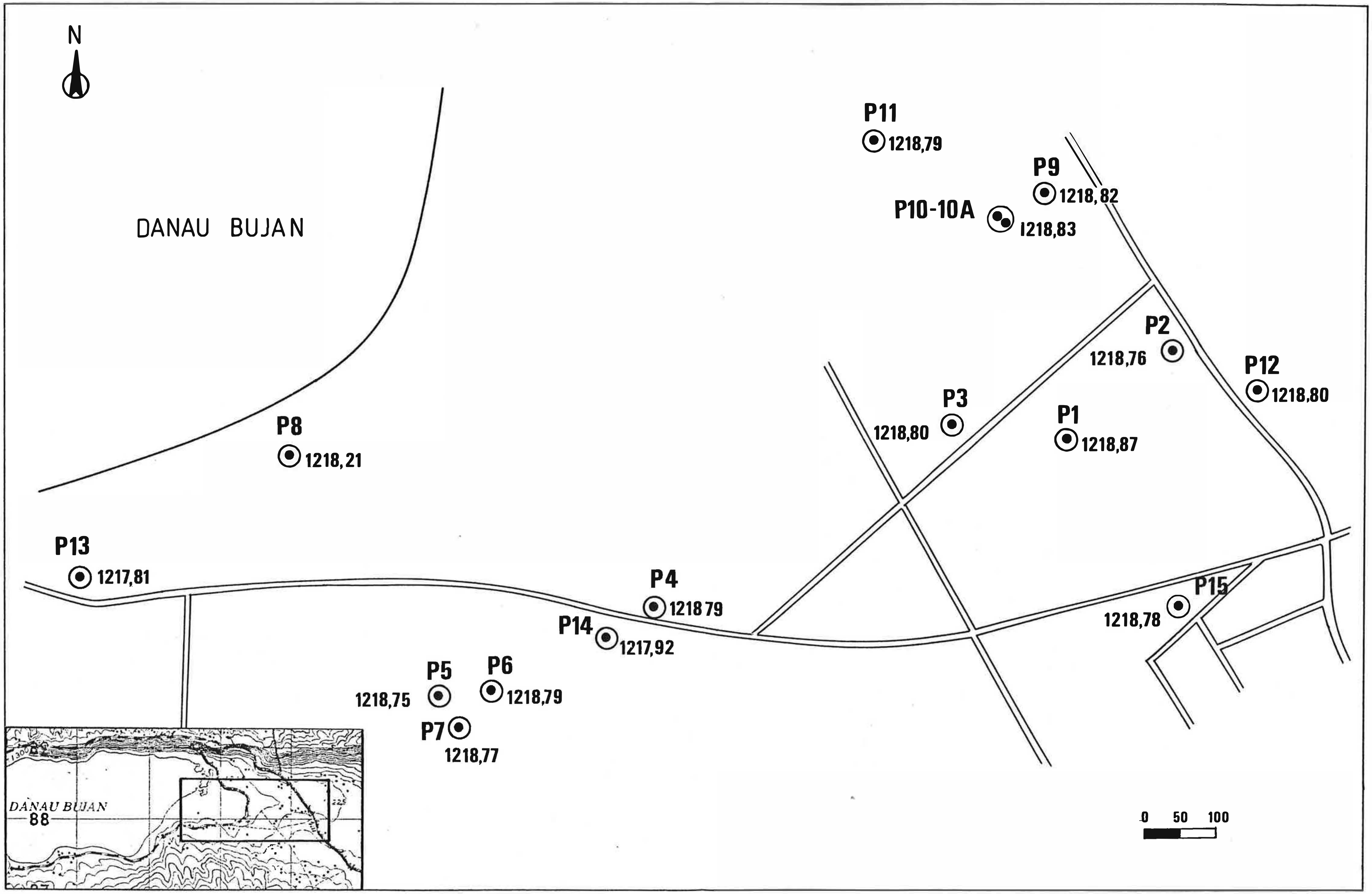

Fig. 2 - Groundwater levels at Pancosari.

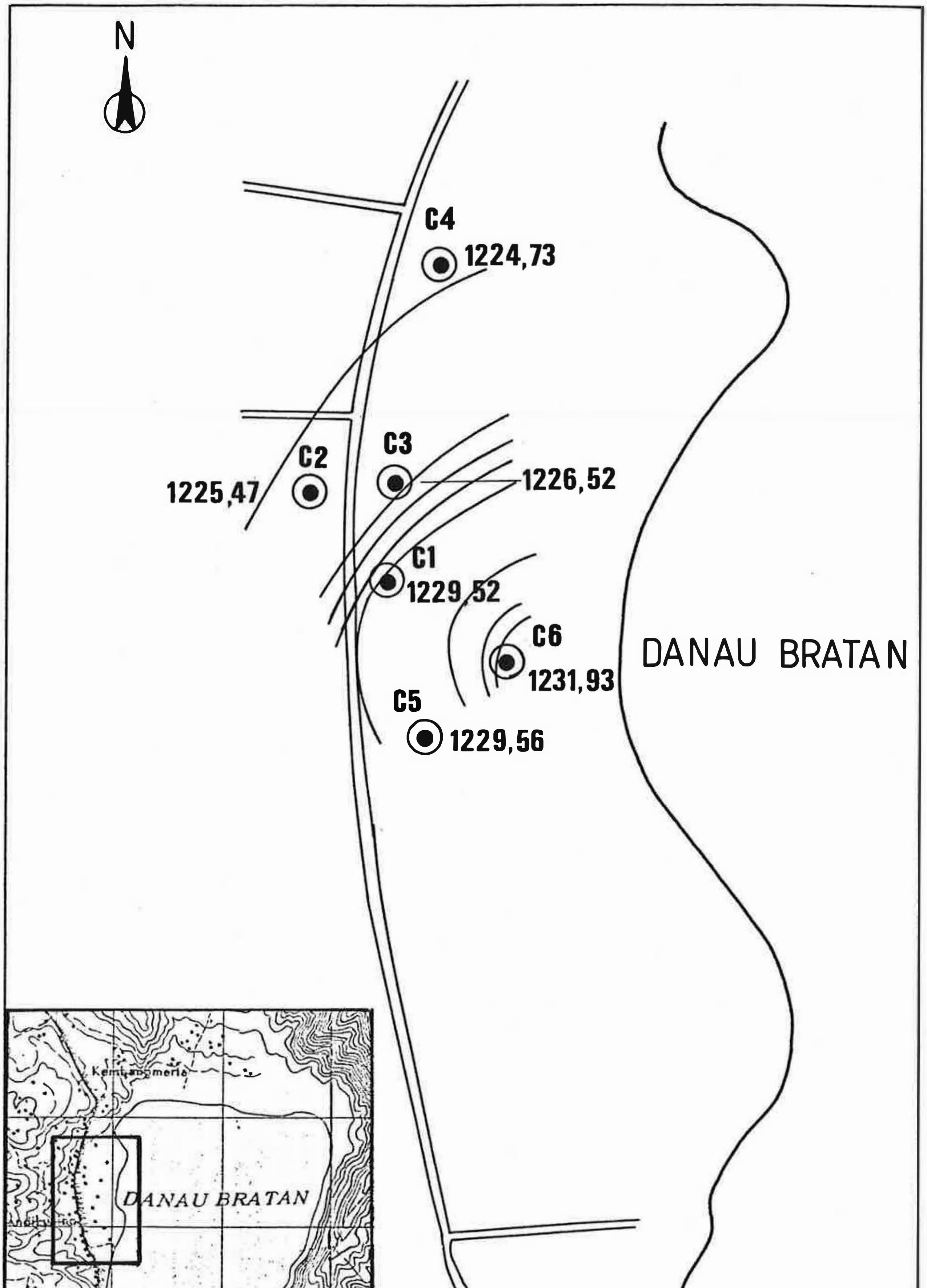

Fig. 3 - Groundwater levels at Candikuning.

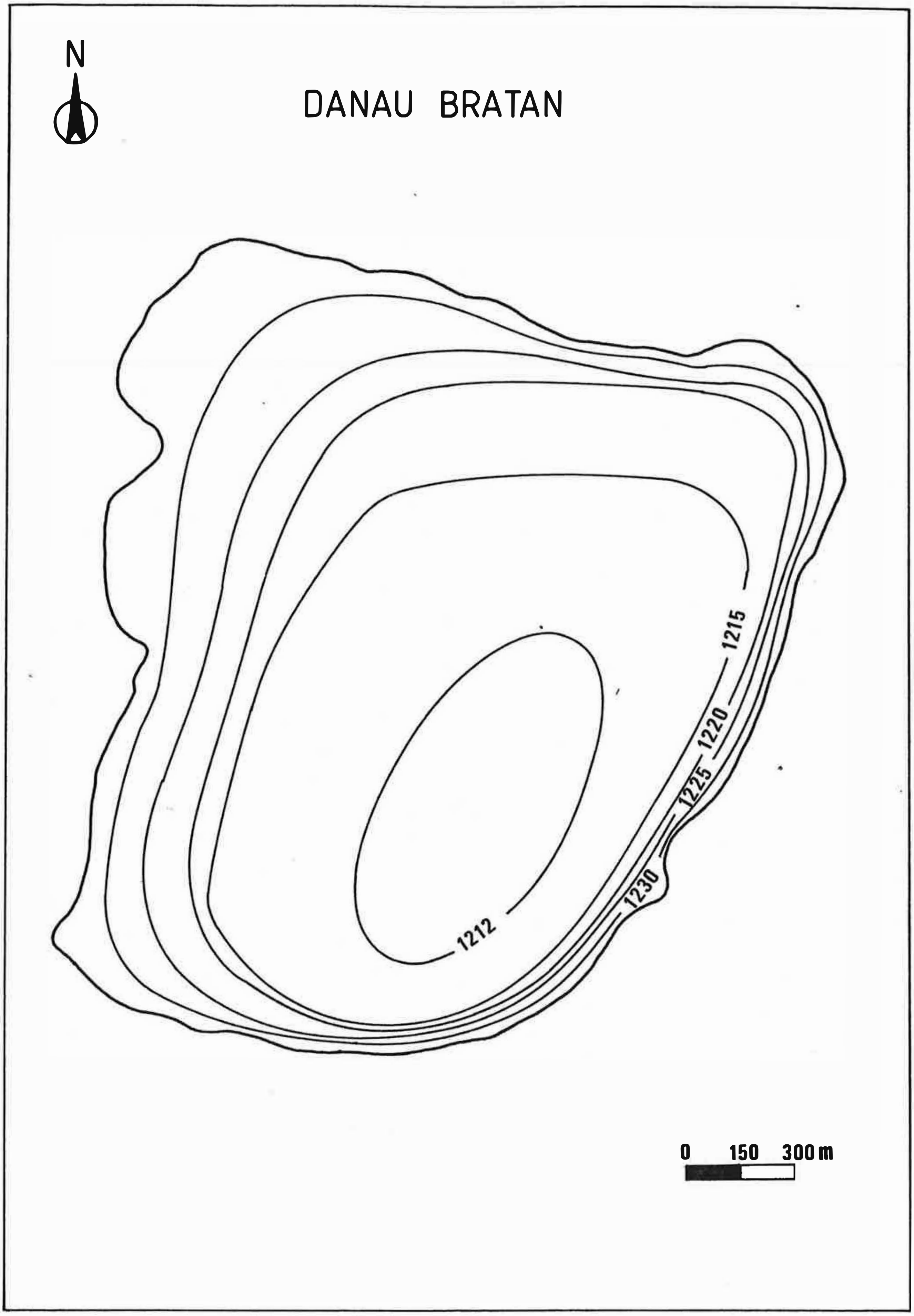

Fig. 4 - Bottom levels of Lake Bratan.

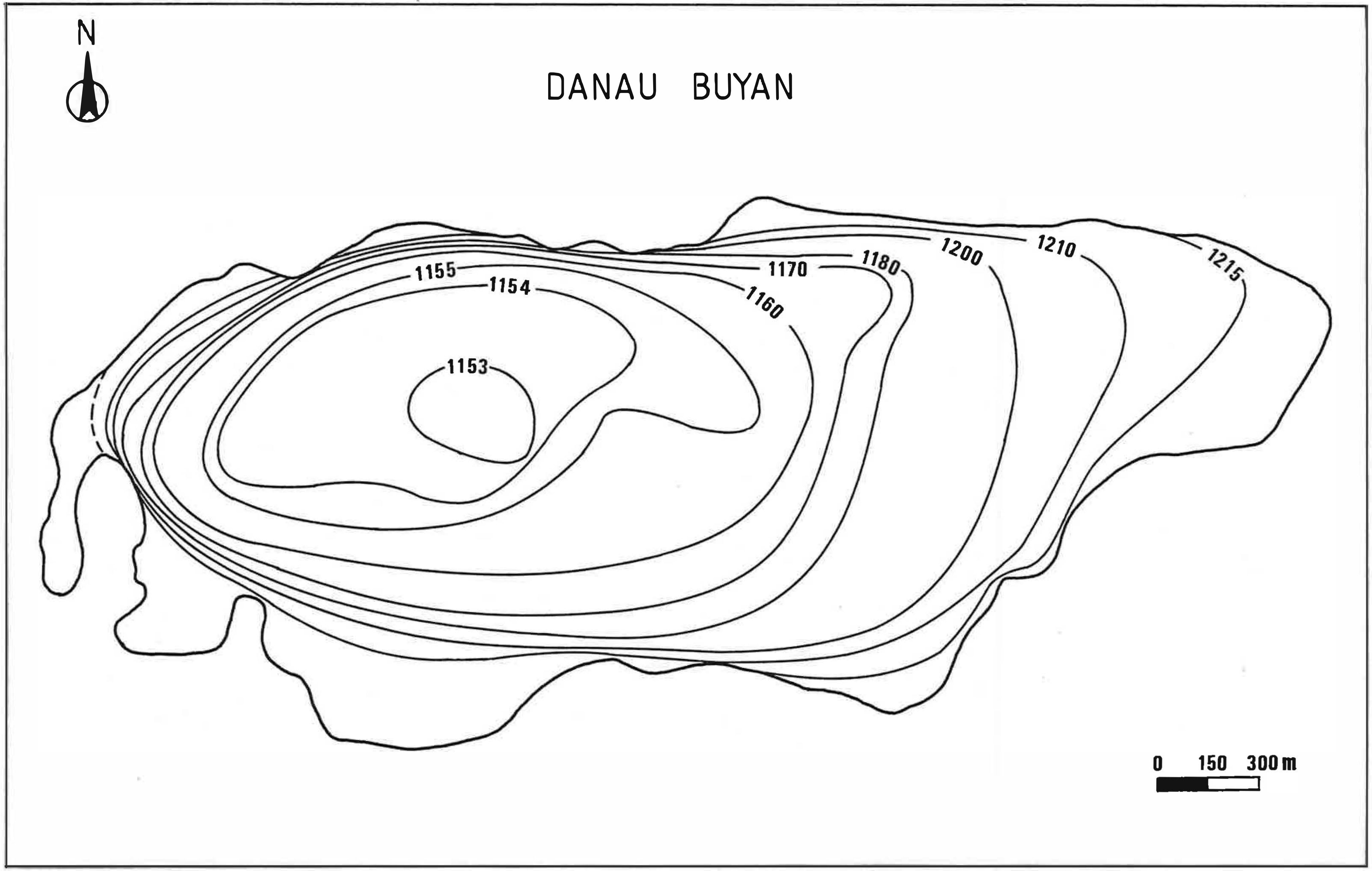

Fig. 5 - Bottom levels of Lake Buyan.

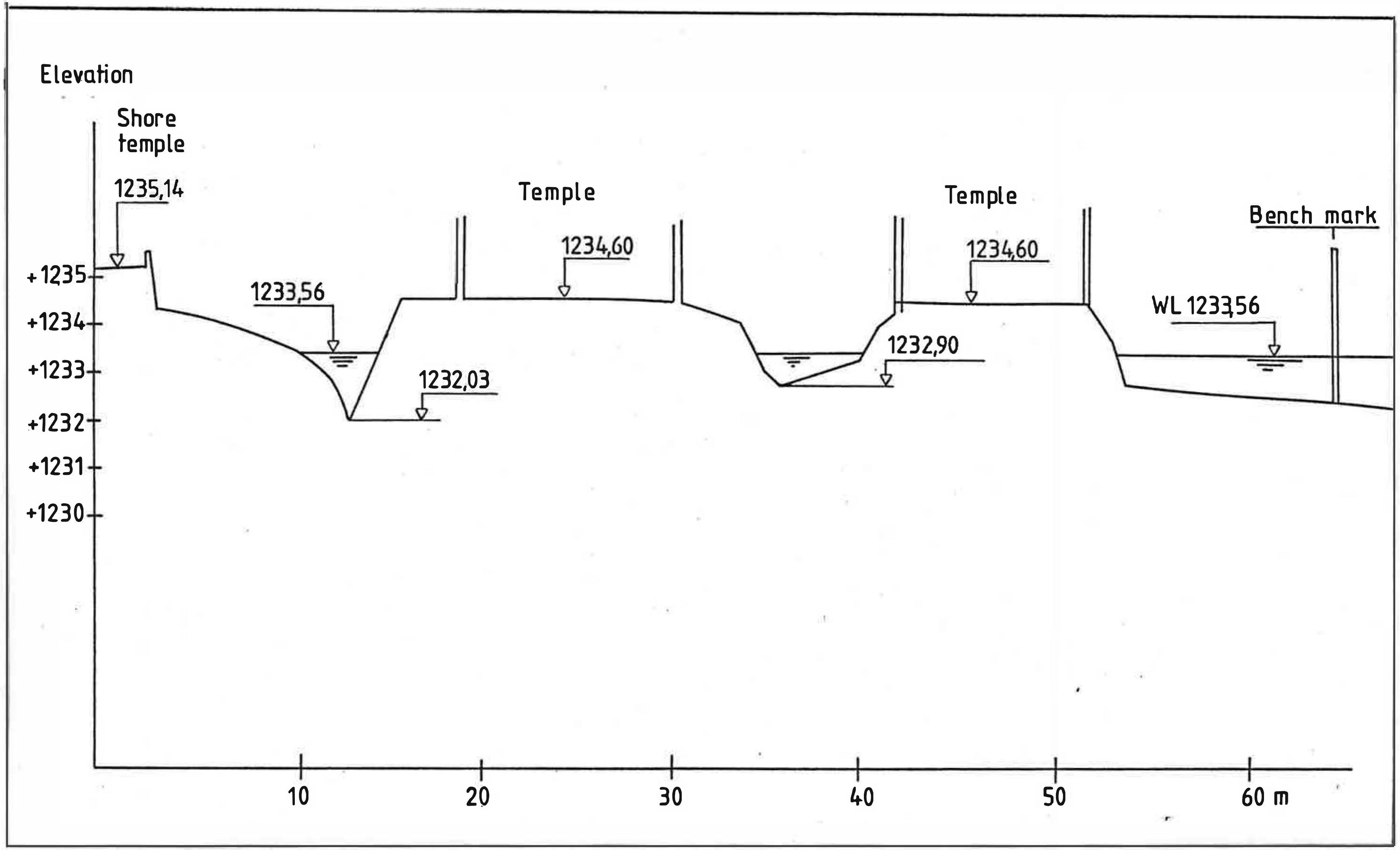

Fig. 6 - Bottom level profile of Lake Bratan at temple site.

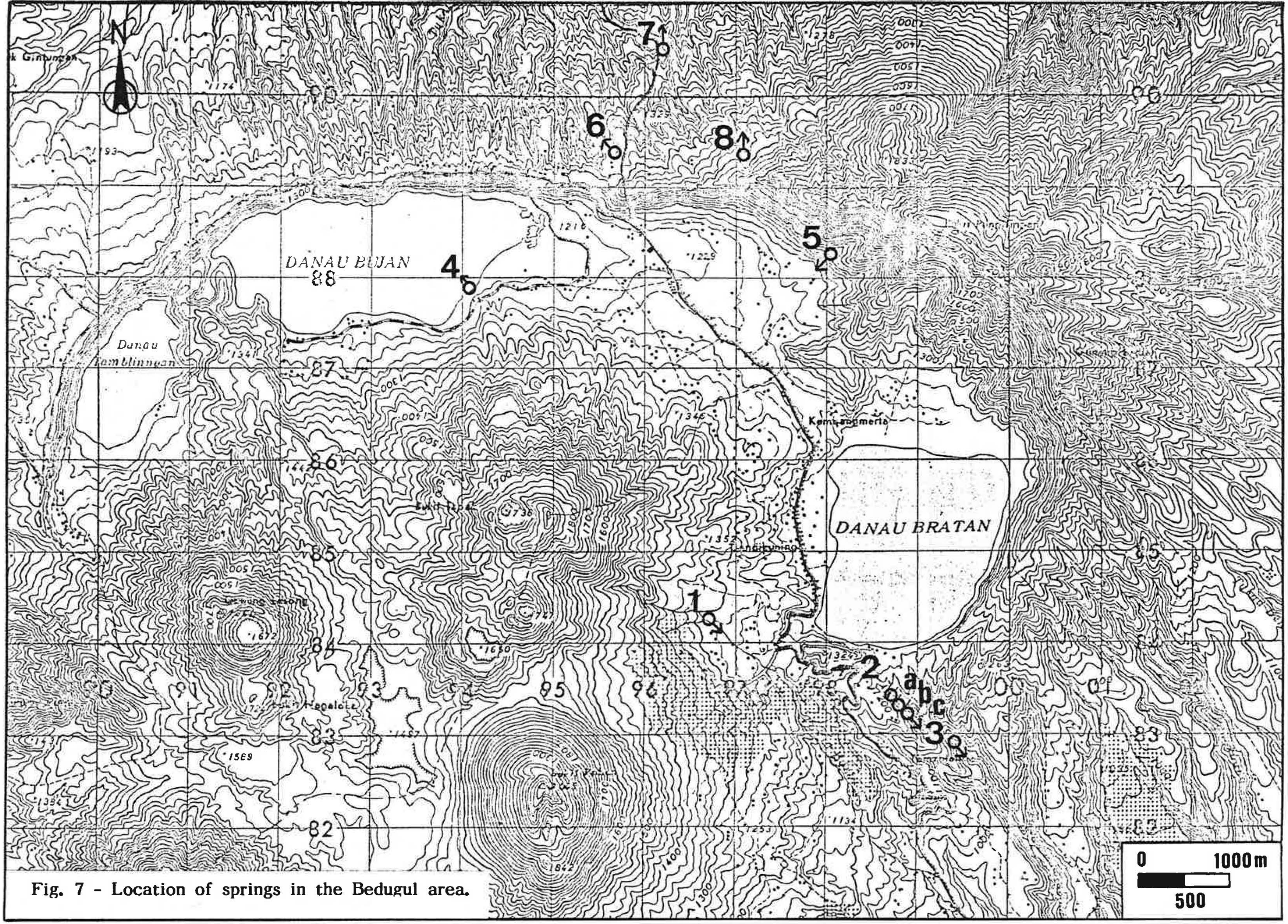

Fig. 7 - Location of springs in the Bedugul area.

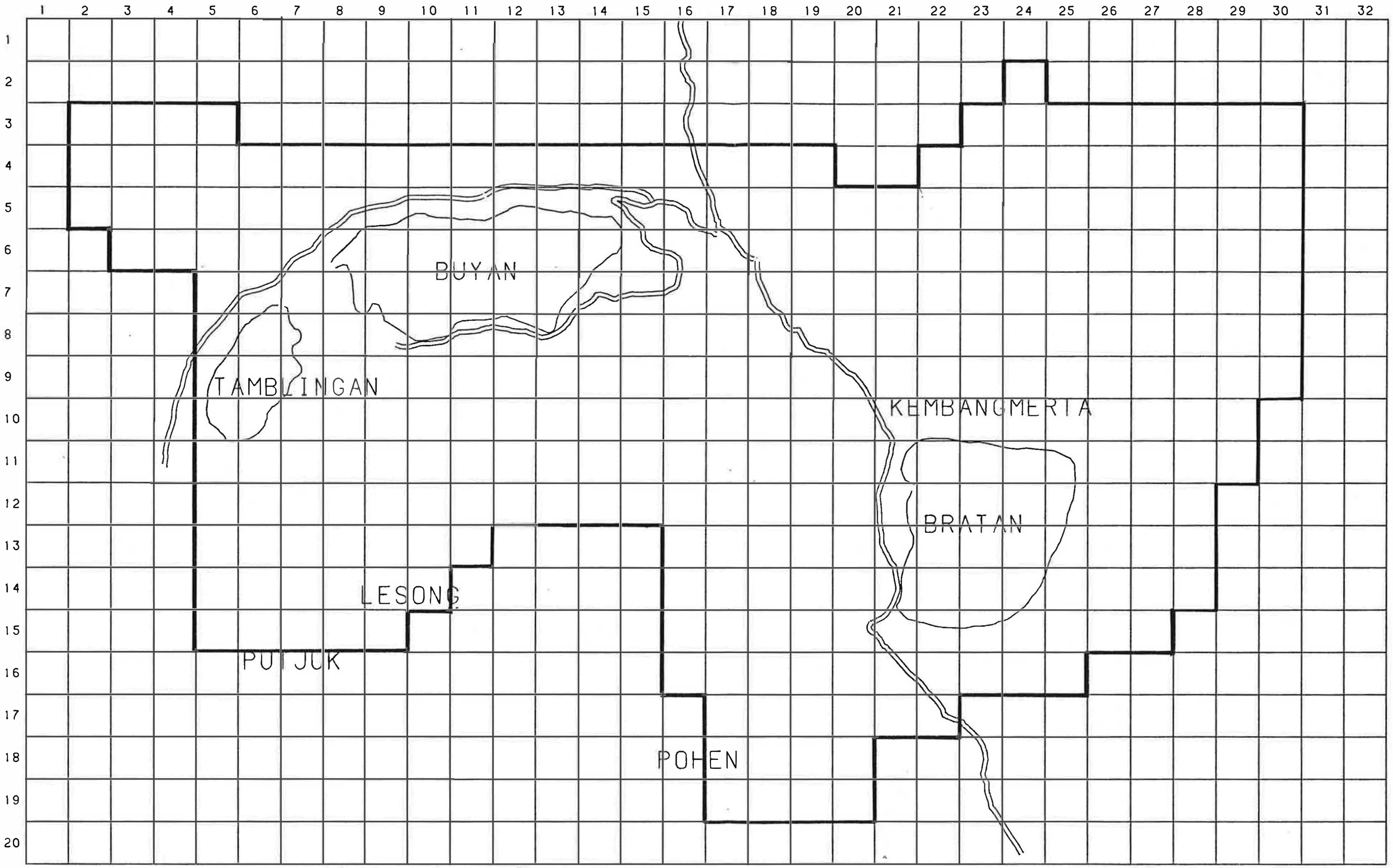

Fig. 8 - Model area.

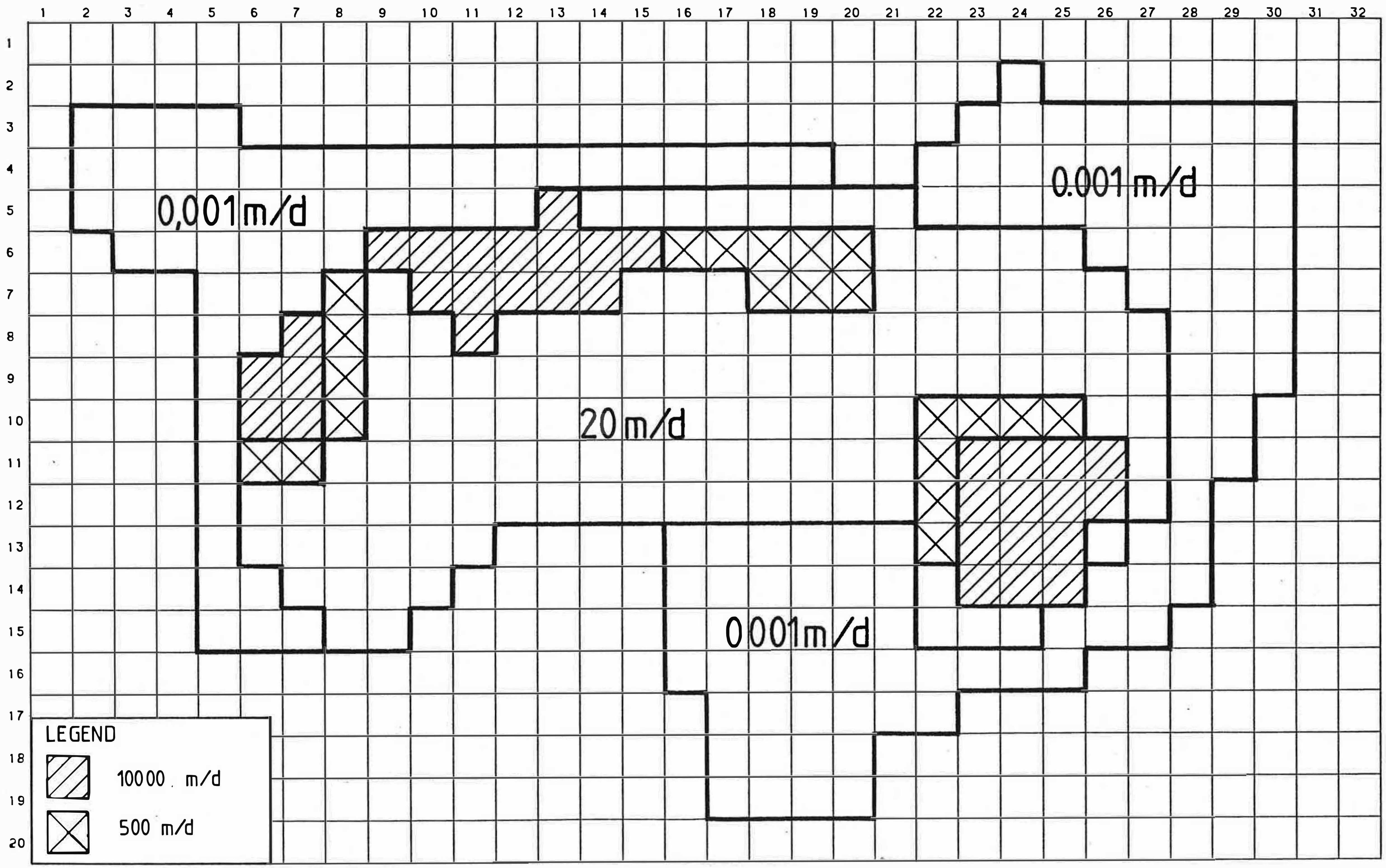

Fig. 9 - Permeability values of the upper aquifer.

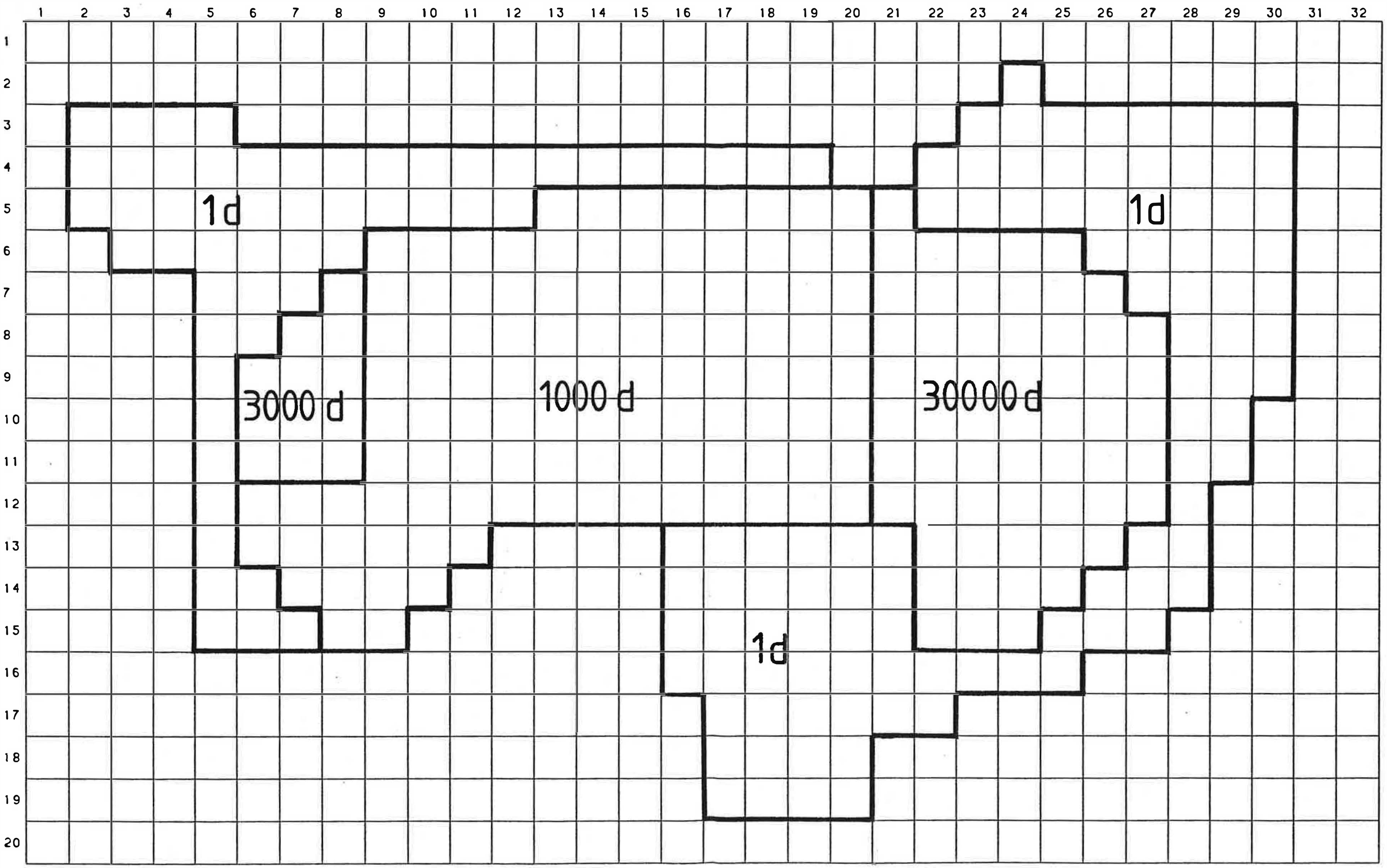

Fig. 10 - Hydraulic resistance values of the semi-pervious layer.

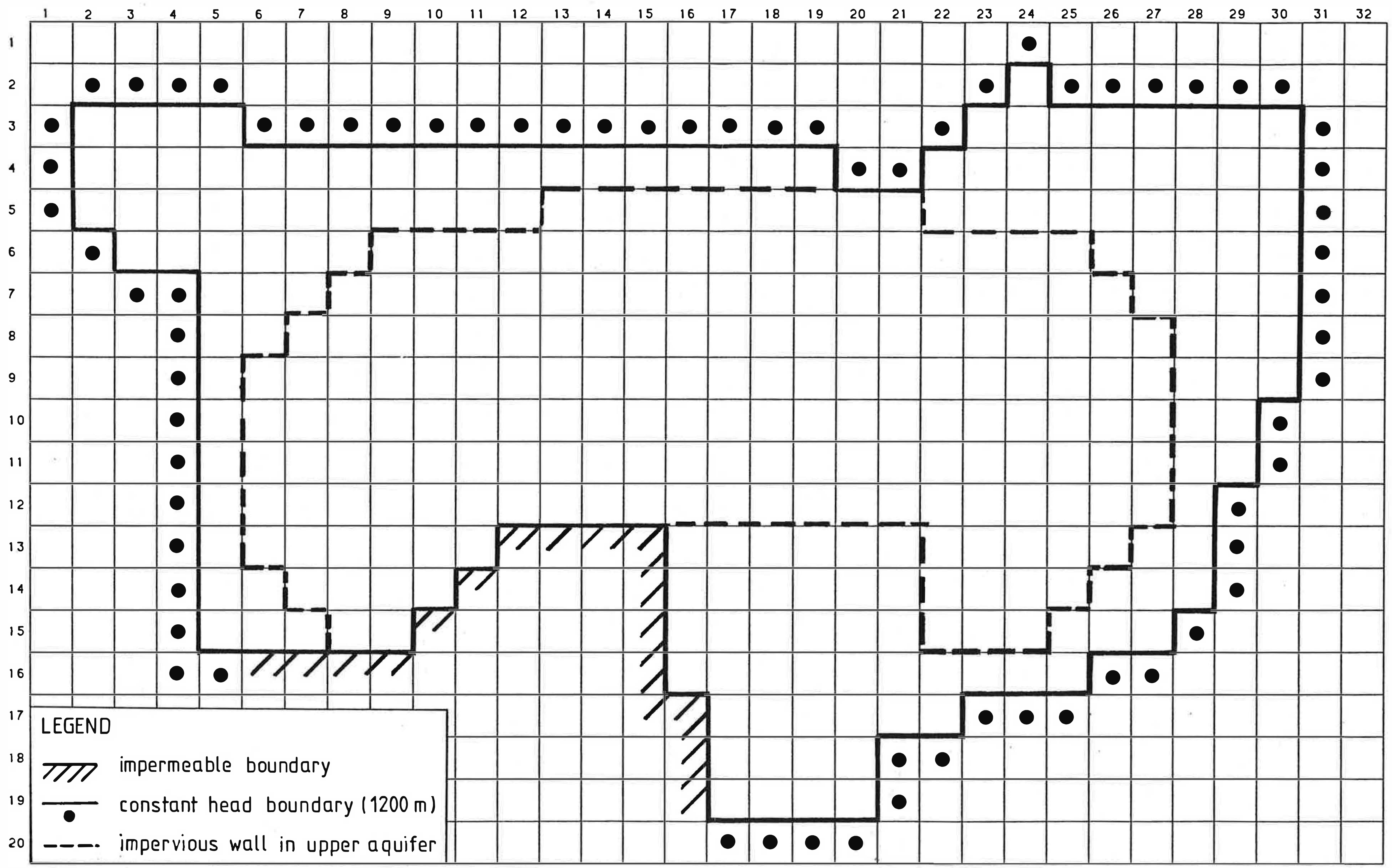

Fig. 11 - Boundary conditions of the model.

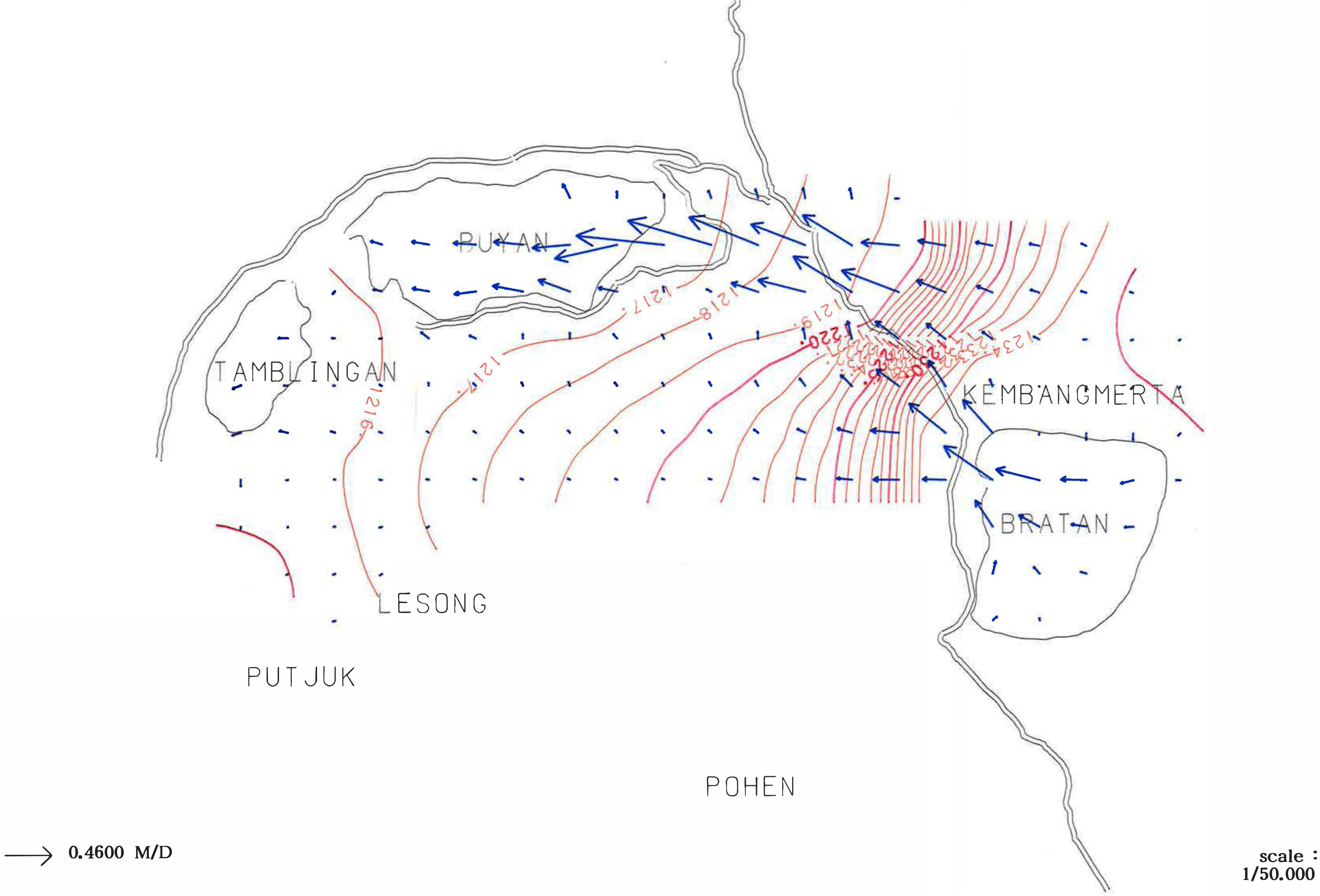

Fig. 12 - Simulation of the present head contour lines (in m) and Darcy velocities (in m/day) in the upper aquifer

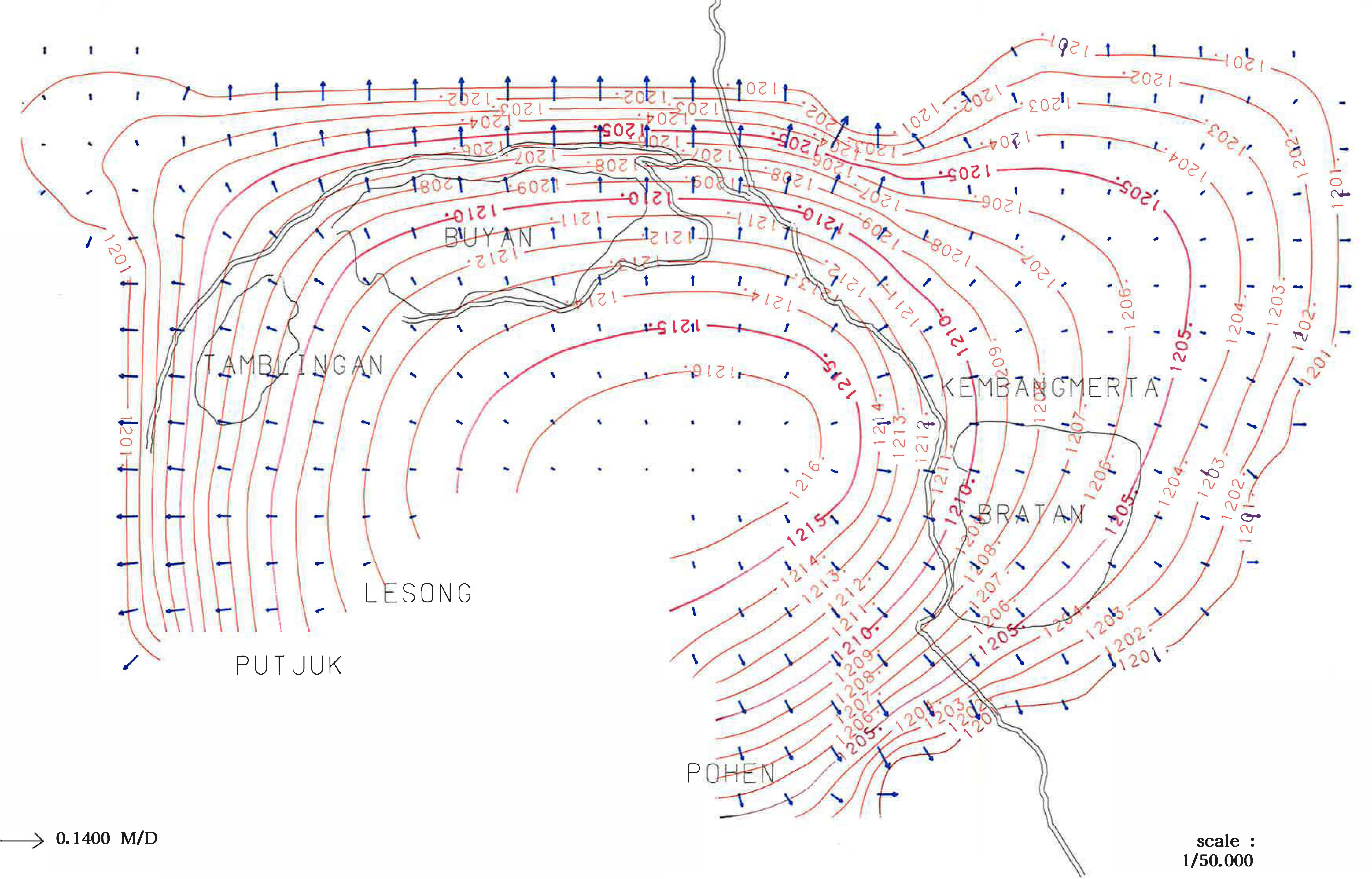

Fig. 13 - Simulation of the present head contour lines (in m) and Darcy velocities (in m/day) in the lower aquifer

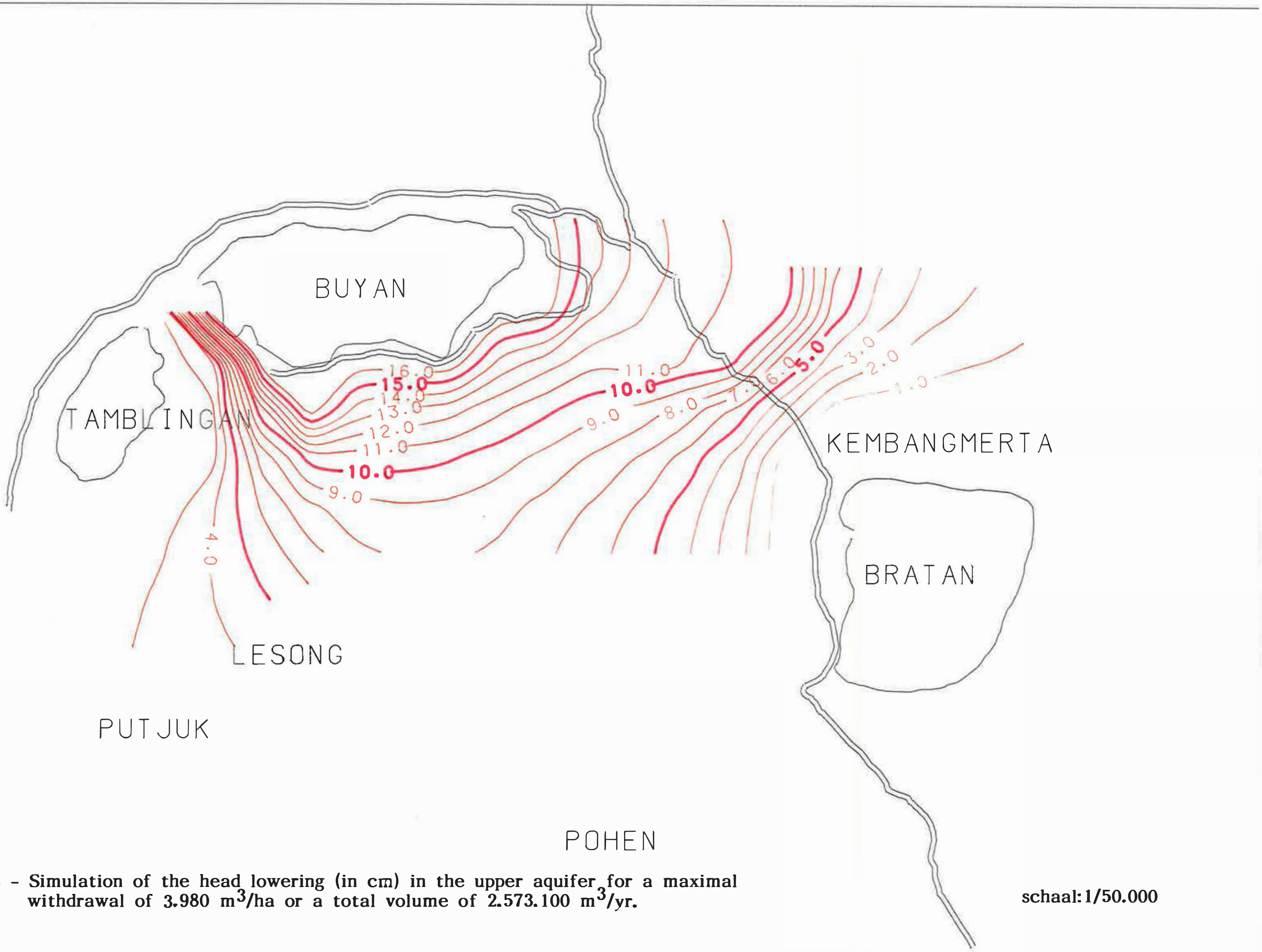

Fig. 14 - Simulation of the head lowering (in cm) in the upper aquifer for a maximal withdrawal of 3.980 m^3/ha or a total volume of 2.573.100 m^3/yr.

schaal: 1/50.000

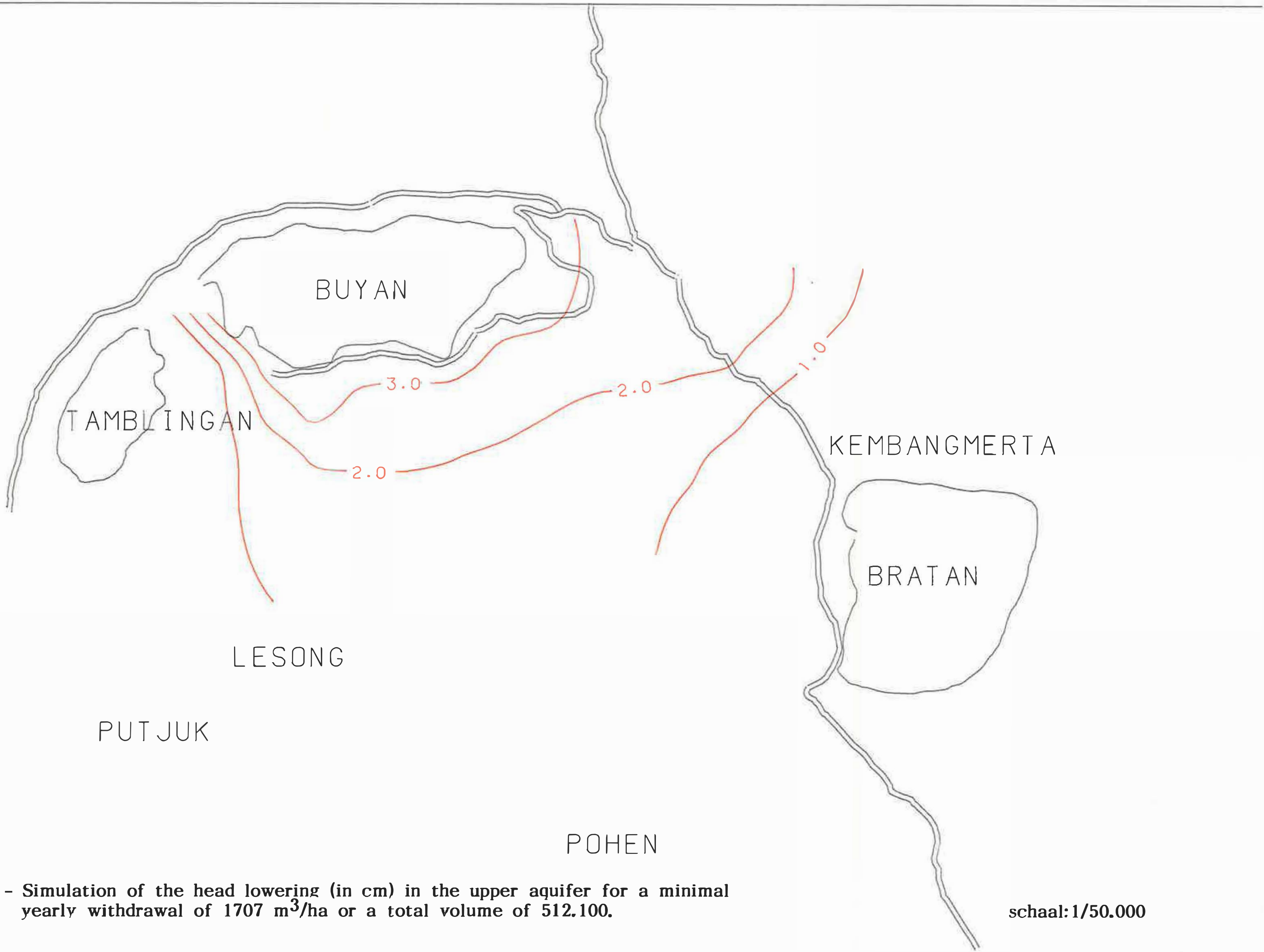

Fig. 15 - Simulation of the head lowering (in cm) in the upper aquifer for a minimal yearly withdrawal of 1707 m^3/ha or a total volume of 512.100.

schaal: 1/50.000

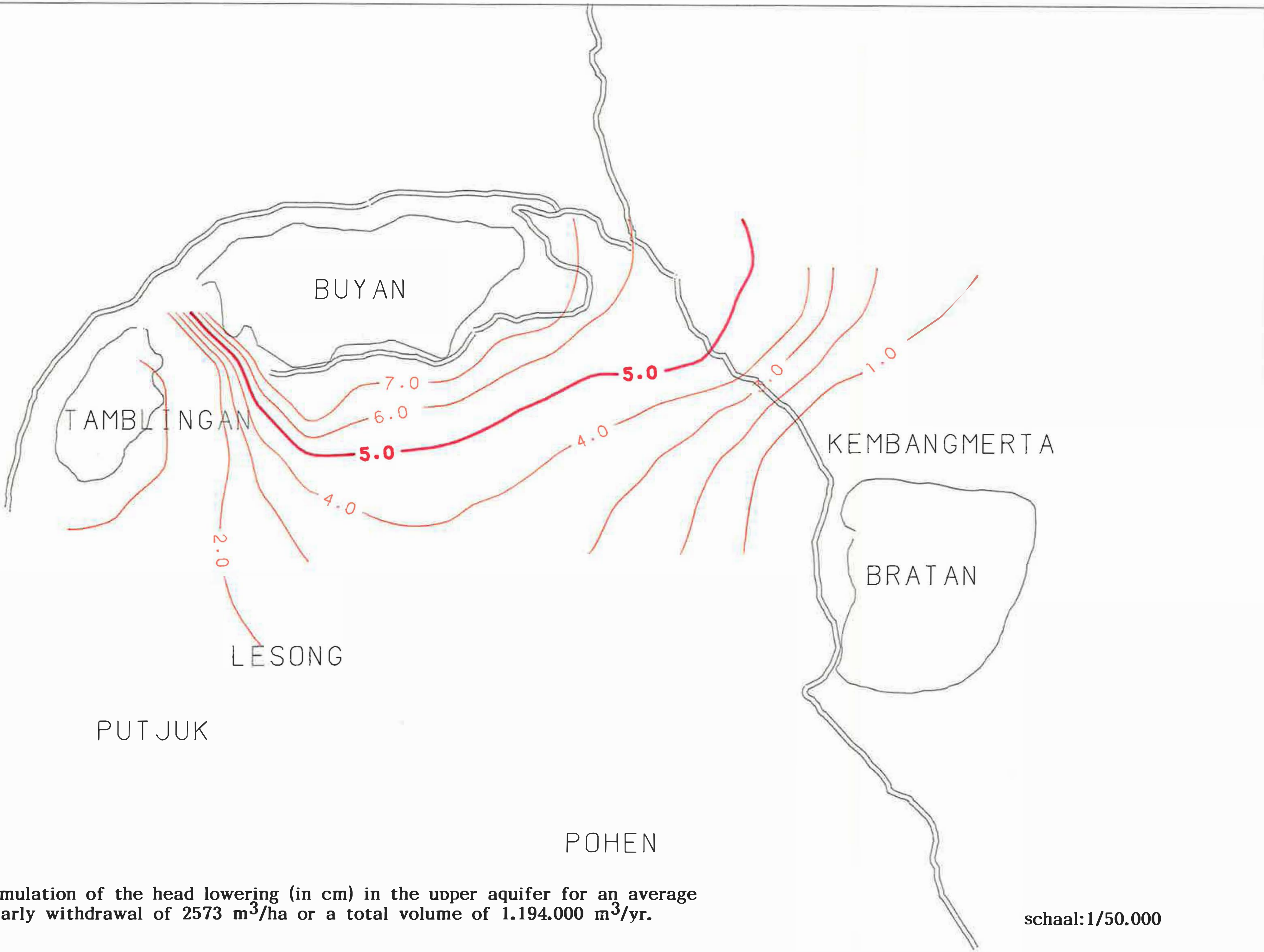

Fig. 16 - Simulation of the head lowering (in cm) in the upper aquifer for an average yearly withdrawal of 2573 m^3/ha or a total volume of 1.194.000 m^3/yr.

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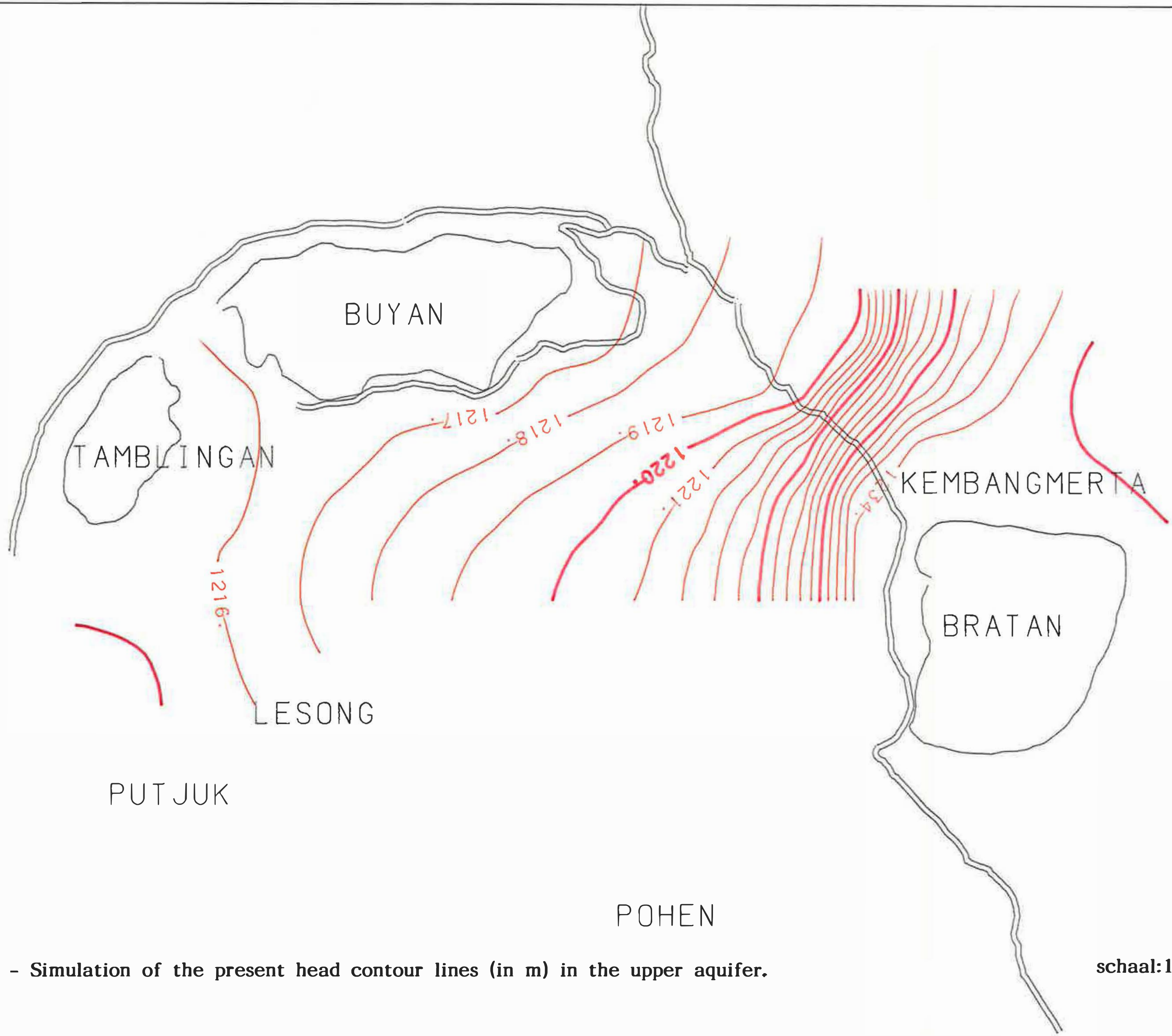

Fig. 12 - Simulation of the present head contour lines (in m) in the upper aquifer.

schaal:1/50.000

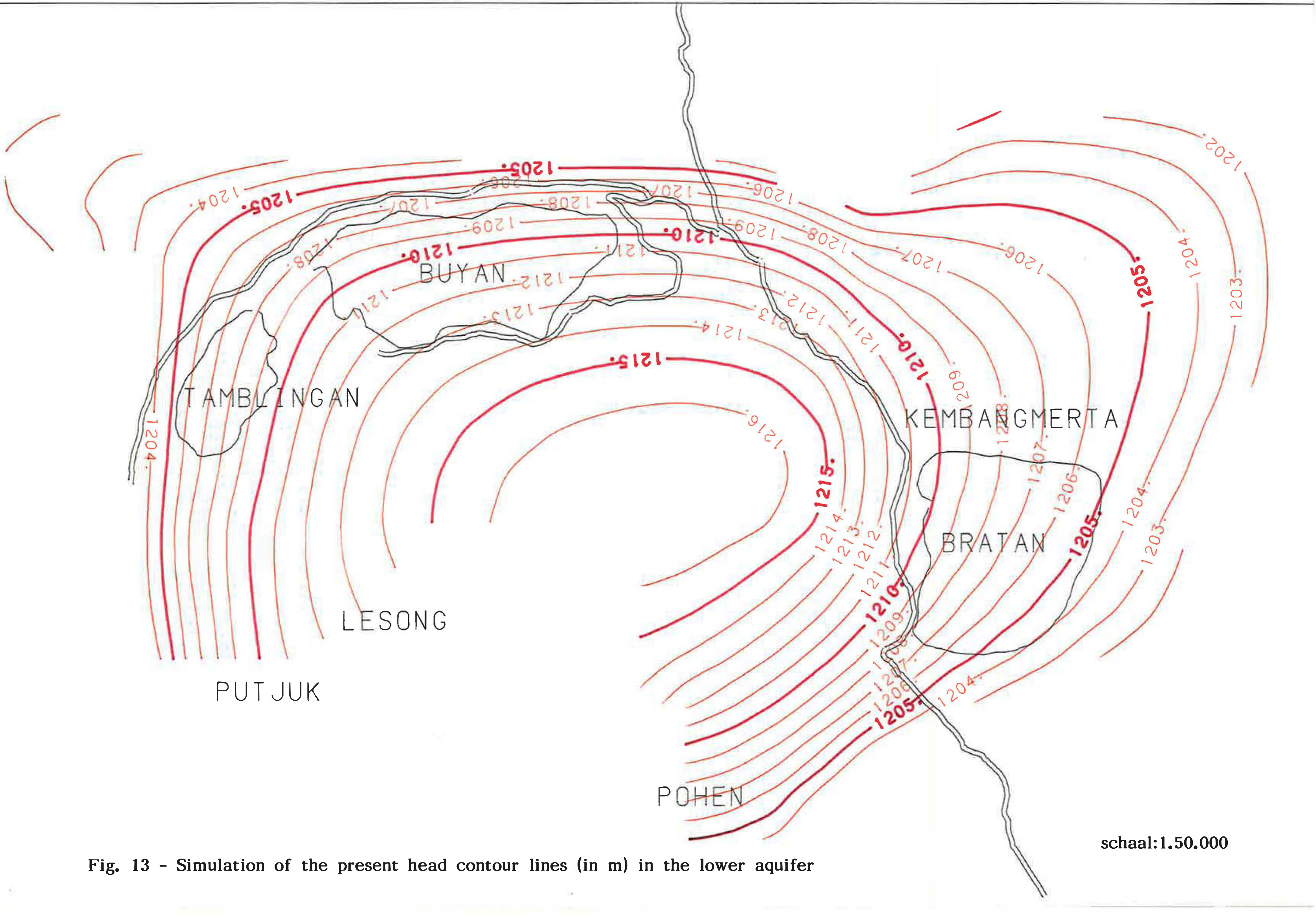

Fig. 13 - Simulation of the present head contour lines (in m) in the lower aquifer