**ATLANTIC ZONE PROGRAMME**

**Report No. 39**
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# DRAINAGE OBSERVATIONS IN POORLY DRAINED SOILS IN THE ATLANTIC ZONE

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[illegible] Location of the study area.

# PREFACE

## General description of the research programme on sustainable Landuse.

The research programme is based on the document "elaboration of the VF research programme in Costa Rica" prepared by the Working Group Costa Rica (WCR) in 1990. The document can be summarized as follows:
To develop a methodology to analyze ecologicaly sustainable and economically feasible land use, three hierarchical levels of analysis can be distinguished.
1. The Land Use System (LUS) analyses the relations between soil type and crops as well as technology and yield.
2. The Farm System (FS) analyses the decisions made at the farm household regarding the generation of income and on farm activities.
3. The Regional System (RS) analyses the agroecological and socio-economic boundary conditions and the incentives presented by development oriented activities.

Ecological aspects of the analysis comprise comparison of the effects of different crops and production techniques on the soil as ecological resource. For this comparision the chemical and physical qualities of the soil are examined as well as the polution by agrochemicals. Evaluation of the groundwater condition is included in the ecological approach. Criterions for sustainability have a relative character. The question of what is in time a more sustainable land use will be answered on the three different levels for three major soil groups and nine important land use types.

Combinations of crops and soils

|  | Maiz | Yuca | Platano | Piña | Palmito | Pasto | Forestal I II III |
|---|---|---|---|---|---|---|---|
| Soil I | x | x | x |  | x | x | x |
| Soil II |  |  |  |  |  | x | x |
| Soil III | x |  |  | x | x | x | x |

As landuse is realized in the socio-economic context of the farm or region, feasibility criterions at corresponding levels are to be taken in consideration. MGP models on farm scale and regional scale are developed to evaluate the different ecological criterions in economical terms or visa-versa.

Different scenarios will be tested in close cooperation with the counter parts.

The Atlantic Zone Programme (CATIE-AUW-MAG) is the result of an agreement for technical cooperation between the Centro Agronómico Tropical de Investigación y Enseñanza (CATIE), the Agricultural University Wageningen (AUW). The Netherlands and the Ministerio de Agricultura y Ganadería (MAG) of Costa Rica. The Programme, that was started in April 1986, has a long-term objective multidisciplinary research aimed at rational use of the natural resources in the Atlantic Zone of Costa Rica with emphasis on the small landowner.

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# ABSTRACT

The high annual rainfall (± 4000 mm per year) and the relatively flat topography of the Atlantic Zone of Costa Rica are reasons for a problematic drainage in about half the area.

To allow land use planning in the Atlantic Zone an inventory of the drainage problems and possible solutions is required.

This report presents the first evaluation of the problemacy, based on observations in a transect between to natural drains. The work was carried out between March and July 1992.

# Drainage observations in the bad drained soils.

## 1. Introduction.

During a period of more than 4 months, groundwater levels were observed in piezometers located in a crossection between two rivers, nl. the Río Palacios and the Río Tortuguero, close to Quatro Esquinas, located 40 km north of Guápiles. This area consists mainly of bad drained soils. The location of the different piezometers is given in map 1.

## 2. Geology.

Most of the deposits in this area are relatively young Holocene alluvial deposits with different textures ranging from coarse sand (old river beds) to clayey and silty textures, but the finer textures are predominating.The detrital material has a volcanic origin. Most of the soils are relatively fertile. Also some older Neguev soils, which are deeply weathered, very clayey and unfertile are present in the area. To which depth these alluvial deposits extend is not clear, but from some descriptions of deeper groundwater abstraction wells in the area (Anon., 1992), it can be concluded that the alternation of more sandy and more clayey alluvial sediments could extend to more than 40 meters deep.

For a more detailed description of the upper 1.5m to 2m, in the crossection, we refer to the report of Stefan Mantel, 1992. For the piezometers, a brief textural description of the borehole is given in appendix 2. From the descriptions, we can conclude that most of the predominating textural classes are in the neighbourhood of sandy loam. Most of the time, a less permeable silty layer with grey color and without oxidation spots was found at a depth of around 2m. Very often, above this layer (between 150 - 200), coarser sand was found. Finally, we should emphasise that the deposits are very heterogeneous, as well as in horizontal as in vertical direction. To illustrate the heterogenity in the horizontal direction, we can mention that close to piezometer #3 (150 m west of it), an old river bed was found consisting mainly of darkcolored coarse sand with even some gravel at 5m depth.

## 3. Hydrogeology.

The water levels observed in the different piezometers are given in table 1a. All the levels are relative to the bottom of the Río Tortuguero. For each piezometer, the elevation of the groundsurface (not the top of the tube) is also given in this table. These waterlevels are also presented in Fig. 1 to Fig. 4.

Precipitation data from the bananaplantation Banagro of Cobal, which is situated 8 km away from the investigation site are given in table 1b.

If we consider a water balance, we can write that:

$$Q_g = P - E - Q_s - \Delta S$$

with $Q_s$ : surface runoff
$Q_g$ : groundwater runoff
$P$ : precipitation
$E$ : evapotranspirtion
$\Delta S$ : change in groundwaterstorage (=change in groundwaterlevel times specific yield)

We see now that there are two values missing to calculate $Q_g$ : evapotranspiration and surface runoff. The evapotranspiration can be estimated roughly but the surface runoff not. For a short period with a high precipitation we can assume that the groundwater runoff during that period is neglectible in the water balance to calculate the surface runoff for that period. It is clear that the surface runoff calculated in this way will highly depend on the amount of precipitation and the storage capacity of the soil at that moment. A problem for these calculations is that the precipitation was not measured exactly on the site of observation. This can explain why f.e. between day 02/7 and 03/7 the waterlevel in the piezometers rised a lot (between 0.5 and 0.9 m) although there was almost no precipitation observed ( = 12.7 mm).

On the other hand, when there is no precipitation at all during a period, we can calculate the groundwater runoff because there is no surface runoff in that period. This last type of calculation is illustrated in the following section.

At some periods, a drawdown curve in the piezometer without or with very little precipitation can be distinguished. From these drawdown curves, it should be possible to estimate the groundwater runoff for that period, if specific yield (drainable porespace) and evapotranspiration are known, and if there was no precipitation at all. The specific yield was taken equal to 0.25 for the loamy soils and equal to 0.30 for the sandy sediments. The evapotranspiration was set equal to 4 mm/day (only in the first outflow curves, from 24/3 to 23/4, this value was set to 3 mm/day because of the low groundwatertable position). The values for the different selected outflow curves are given in Table 2a to 2c. From table 2c, it can be concluded that the outflows in well #1, #2, #3, and #5 are relatively similar and that the groundwater outflow for low water table position is around 2 mm/day, for a medium water table position around 5 - 7 mm/day and for a high position around 20 mm/day. Negative values in this table can be due to the fact that the water table rised, that the evapotranspiration was overestimated or that there was some precipitation. In table 2c, also the mean daily precipitation measured in the bananaplantation of Banagro during the respective outflow periods is given. We should emphasize that we did not correct the calculated outflowrates with these precipitation values.

In the next section, we will verify if this amount of groundwater can be drained perpendicular to the two rivers.
From the soil observations, we can conclude that close to the rivers (in a zone of 200 to 300 m) the deposits are mainly sand (often coarse) and are relatively thick (more than 3m). The hydraulic conductivities in this zone are high (10 to 20 m/day). In the rest of the section, we distinguished mostly a low permeable silty layer at a depth of 2m or more. Above this layer, we had some loamy or sandy deposits with a hydraulic conductivity ranging mostly between 1 and 5 m/day. The topography of the cross-section and the position of the piezometers are given in Fig. 5 and appendix 2 and the observed waterlevels in the cross-section are given for 4 different dates in Fig.6.

To make the calculations easy, we will assume that there is only horizontal flow, that the waterpotential of the river is extending down to the impermeable layer and that the aquifer is homogeneous. Furthermore, we will assume that this impermeable layer is located at the same depth all over the crossection and lower than the bottom of the Río Tortuguero. In the case of steady state, we can use then the following equation to calculate the groundwatertable position between the two rivers:

$$H^2=\frac{x}{L}(H_2^2-H_1^2)+H_1^2+\frac{N}{K}x(L-x)$$

with L : distance between the two rivers (m);
N : natural recharge over the cross-section (m/day);
K : hydraulic conductivity of the aquifer-system (m/day);
x : distance from any point in the cross-section to the first river (m);
$H_1$: waterpotential at the first river, x=0 (m);
$H_2$: waterpotential at the second river, x=L (m);
H : waterlevel at any point x (m).

We calculated the theoretical watertable position for the case that the natural recharge N is equal to 0.003 m/day and the hydraulic conductivity K is equal to 5 m/day. The waterdepth in both rivers was set equal to 0.3 m. These calculations were repeated for three different cases: the impermeable layer is 1 m lower than the bottom of the Tortuguero (D +1), 5 m lower (D +5) or 10 m lower (D +10). This means that for the first case $H_1$=3.42 and $H_2$=1.3m, for the second case $H_1$=7.42 and $H_2$=5.3m, and for the third case $H_1$=12.42 and $H_2$=10.3m. The fact that we took this layer so low (in reality, the silty layer with a low permeability is not so low) will result in a better draining capacity than there exist in reality. The results of these calculations are given in Fig.7.

A second simulation was done with considering also a fixed potential (= 1.9m+1, +5 or +10) at x equal to 1300 m. This was done because we had observed that the waterlevel at piezometer #4 was always lower than in the two surrounding piezometers indicating that there was always groundwaterflow towards this piezometer. Indeed, close to this piezometer there is a small gully in which there is always water standing and slowly flowing. The results of these calculations are given in Fig. 8.

All the calculated water table profiles are higher than the topography indicating that the aquifer system cannot drain 3 mm/day under the given assumptions. On the contrary, the outflow curves in the piezometers are showing that the mean ground water discharge is at least 3 mm/day, probably even around 6 mm/day. Finally, this means that a relative important amount of the groundwater discharge is not flowing perpendicular to the two rivers. Different possibilities exist: or an amount of the groundwater is infiltrating through the silty layer to a deeper laying aquifer (this is not very probable because we already considered that the thickness of the upper aquifer is much more thicker than in reality is) or an amount of the groundwater recharge is flowing parallel with the rivers (because the slope of the topography in this direction is small, ± 7m/5km, this amount will certainly not be more than what is flowing perpendicular to the river system) or an amount is flowing to small gullies laying between the two rivers and this would mean that the distance between two drains is much more smaller. In some way, this last possibility is already illustrated in Fig. 8, for the section between the intermediate point at 1300m and the Río Tortuguero. When the impermeable layer is 10 m lower than the Río Tortuguero, the watertable profile is partly lower than the topography indicating that in this case the section of 655m could drain ±3 mm/day. In Fig.9, the waterprofile is fitted as good as possible with the observed piezometerlevels during a wet period (see day 103). The impermeable layer is supposed to be 5 m lower than the Río Tortuguero and the hydraulic conductivity is set equal to 5 m/day. In this case, the calculated value of the natural recharge N is equal to 0.25 mm/day to fit with the levels in the section with 1300 m distance and equal to 0.8 mm/day to fit with the levels in the section with 645 m distance.

## 4. Conclusions.

From the previous calculations, we can conclude that even under optimal conditions (the hydraulic conductivity is equal to 5 m/day, the impermeable layer is laying 5 m lower than the bottom of the Río Tortuguero and a fixed water level is set also at a distance of 1300m to simulate a gully) only a small amount of water can be drained towards the rivers. If we would take the groundwater discharge equal to 0.8 mm/day, we would get the following annual water balance:

mean precipitation : 4000 mm
mean evapotranspiration: 95 mm/month * 12 = 1140 mm
mean gr.water runoff: .8 mm/day * 365 = 292 mm
mean surf. water runoff: 4000-1140-292 = 2568 mm

The value for the mean annual precipitation is based on values for the meteorologic station La Mola (mean annual precipitation = 3500 mm) and Tortuguero (mean annual precipitation = 5440 mm). The investigation area is located between these two stations. We considered to take 4000 mm instead of the arithmetic mean of the two stations, because the annual value for the Tortuguero station is probably extremely high due to the vicinity of the sea. In the case that there would be a mean daily groundwater runoff of 0.8 mm/day, about 90 % of the net precipitation is surface runoff.
If the mean daily groundwater runoff would be equal to 6 mm/day, the surface runoff would be equal to 670 mm/year which is 23 % of the net precipitation.

The observed lowering of groundwater levels during drier periods, indicates that the true mean groundwater runoff could be in the neighbourhood of 6 mm/day. Also, there was no indication in the field of high surface runoff volumes.
The question is now, how does the groundwater drains away. Most probably, an important amount of groundwater drains to gullies which are carrying this water slowly to the river system. This means that in this case the mean distance between the different gullies will affect the drainage conditions.
For a better estimation, new observations between such gullies should be done. Another possibility is to do observations between drainage channels on a plantation. This is more attractive because of the nice boundary conditions, but the infiltrationcapacity of the soil can be changed compared to the natural condition due to human activities.

Reference:

Anon, 1992. Extracto del inventario de pozos de
SENARA, mayo 1992.
intern. document programa Zona Atlantica (0547 S)

# APPENDIX 1*

Piezometer #1: 0 - 55 cm : loamy, brown color with red oxidation spots.
55 - 80 cm : sandy loam, grey color with red oxidation spots.
80 - 115 cm : loamy sand, grey color with red oxidation spots.
115 - 170 cm : medium to coarse sand, with dark to black color.
170 - 200 cm : silty, grey color with dark green concrations.

Piezometer #2: 0 - 20 cm : loamy, brown color.
20 - 35 cm : clay loam, grey color.
35 - 65 cm : fine sand, black color.
65 - 90 cm : medium to coarse sand, black color.
90 - 140 cm : loamy sand, grey with red oxidation spots
140 - 280 cm : silty with grey color.

Piezometer #3: 0 - 60 cm : clay loam.
60 - 120 cm : sandy clay.
120 - 180 cm : clay.

Piezometer #4: 0 - 60 cm : loam, brown color.
60 - 100 cm : clay loam, grey with oxidation spots.
100 - 190 cm : clay, grey color with some oxidation spots.
Piezometer #5: 0 - 80 cm : clay, grey color.
80 - 100 cm : clay, brown color.
100 - 180 cm : sandy clay, grey color.

Piezometer #6: 0 - 10 cm : loam, light brown.
10 - 50 cm : sandy loam, light brown.
50 - 75 cm : loamy sand, light brown.
75 - 120 cm : loamy sand, grey with many oxidation spots.
120 - 180 cm : sandy clay loam, light brown.
180 - 230 cm : loamy sand, light brown.
230 - 310 cm : medium to coarse sand, dark brown to black.

Piezometer #7: 0 - 60 cm : loam, light brown with oxidation spots.
60 - 110 cm : sandy clay loam, light brown with oxidation spots.
110 - 170 cm : fine sand, grey color.
170 - 325 cm : medium to coarse sand, dark brown to black.

Piezometer #8: no description was made, but the sediments were clayey over the whole profile (3m).

* : the profiles of these wells were described very briefly, so that the textural classes and colors are only a rough indication.

# APPENDIX 2

| | distance x (m) | elevation (m) |
|---|---|---|
| Río Palacios | 0 | 2.12 |
| | 200 | 4.52 |
| piezo #1 | 430 | 4.01 |
| piezo #2 | 476 | 3.75 |
| | 515 | 4.09 |
| | 715 | 4.08 |
| | 1015 | 3.61 |
| piezo #3 | 1202 | 2.92 |
| piezo #4 | 1295 | 3.05 |
| | 1474 | 3.84 |
| piezo #5 | 1620 | 2.74 |
| | 1690 | 3.26 |
| piezo #6 | 1819 | 4.16 |
| | 1908 | 2.84 |
| piezo #7 | 1935 | 2.57 |
| piezo #8 | 1940 | 2.16 |
| Río Tortuguero | 1945 | 0 |

Table 1a: Observed waterlevels in the wells located between Río Palacios and Río Tortuguero (section in bad drained soils).

| Well no | #1 | #2 | #3 | #4 | #5 | #6 | #7 | #8 |
|---|---|---|---|---|---|---|---|---|
| Surf. (m) | 4.01 | 3.75 | 2.92 | 3.05 | 2.74 | 4.16 | 2.57 | 2.16 |
| Date(D/M) | | | | | | | | |
| 24/3 | | 3.20 | 2.27 | | 2.14 | | | |
| 10/4 | | 2.85 | 1.97 | | 1.79 | | | |
| 23/4 | | 2.75 | 1.94 | | 1.77 | | | |
| 28/4 | | 3.75 | 2.92 | | 2.74 | | | |
| 29/4 | | 3.75 | 2.92 | | 2.74 | 2.75 | 1.14 | |
| 06/5 | 3.77 | 3.75 | 2.92 | | 2.64 | 2.77 | 1.02 | |
| 07/5 | 3.88 | 3.75 | 2.92 | 2.49 | 2.74 | 2.77 | 0.86 | |
| 14/5 | 3.77 | | | 2.39 | 2.63 | 2.85 | 1.23 | |
| 21/5 | 3.54 | 3.60 | 2.42 | 2.06 | 2.38 | 2.12 | 0.50 | |
| 22/5 | 3.49 | 3.60 | 2.36 | 2.05 | 2.35 | 2.07 | 0.56 | |
| 26/5 | 3.64 | | 2.63 | 2.18 | 2.55 | 2.04 | 0.51 | |
| 28/5 | 3.44 | | 2.42 | 2.07 | 2.36 | 1.96 | | |
| 01/6 | 3.30 | 3.45 | 2.27 | 1.98 | 2.21 | 1.79 | | |
| 04/6 | 3.38 | 3.50 | 2.47 | 2.08 | 2.38 | 1.83 | | |
| 08/6 | 3.22 | 3.41 | 2.28 | 1.98 | 2.22 | 1.71 | | |
| 10/6 | 3.20 | 3.40 | 2.25 | 1.96 | 2.26 | 1.64 | | 0.57 |
| 11/6 | 3.24 | 3.43 | 2.27 | 1.97 | 2.31 | 1.66 | | 0.79 |
| 17/6 | 3.23 | 3.46 | 2.37 | 2.05 | 2.30 | 1.63 | | 0.73 |
| 19/6 | 3.25 | 3.49 | 2.46 | 2.08 | 2.43 | 1.62 | | 0.58 |
| 22/6 | 3.13 | 3.36 | 2.34 | 2.04 | 2.26 | 1.61 | | 0.77 |
| 24/6 | 3.05 | 3.29 | 2.24 | 1.96 | 2.15 | 1.56 | | 0.80 |
| 25/6 | 3.07 | 3.32 | 2.27 | 1.96 | 2.13 | 1.56 | | 0.76 |
| 02/7 | 2.94 | 3.15 | 2.29 | 1.96 | 2.26 | 1.45 | | 0.58 |
| 03/7 | 3.83 | | 2.92 | 2.55 | 2.74 | 1.75 | | 0.66 |
| 04/7 | 3.69 | | 2.89 | 2.41 | 2.66 | 1.87 | | 0.63 |
| 14/7 | 3.66 | 3.75 | 2.62 | 2.20 | 2.57 | 2.41 | | 1.05 |
| 16/7 | 3.58 | 3.75 | 2.50 | 2.13 | 2.50 | 2.25 | | 1.10 |
| 22/7 | 3.79 | 3.75 | 2.83 | 2.47 | 2.68 | 2.69 | | 1.14 |
| 29/7 | 3.80 | 3.75 | 2.92 | 2.67 | 2.74 | 2.91 | | 1.08 |

Table 1b: Daily precipitation (mm/day) observed at the bananaplantation Banagro.

| day | March | April | May | June | July | August |
|---|---|---|---|---|---|---|
| 1 | 12.70 | .00 | .00 | 7.62 | .00 | .00 |
| 2 | 58.42 | .00 | .00 | .00 | .00 | 38.10 |
| 3 | 12.70 | .00 | 5.08 | .00 | 12.70 | 63.50 |
| 4 | .51 | .00 | 55.88 | .00 | 76.20 | .00 |
| 5 | .00 | .00 | 25.40 | .00 | .00 | 21.59 |
| 6 | 2.03 | .00 | 5.08 | .00 | 10.16 | 55.88 |
| 7 | .00 | .00 | 34.29 | 7.62 | 66.04 | .00 |
| 8 | 12.70 | .00 | 114.30 | .00 | 12.70 | .00 |
| 9 | .00 | .00 | 25.40 | 10.16 | 27.94 | .00 |
| 10 | .00 | 1.27 | 48.26 | 10.16 | .00 | .00 |
| 11 | .00 | 1.52 | 30.48 | 21.59 | .00 | 63.50 |
| 12 | .00 | 18.80 | 17.78 | .00 | .00 | 5.08 |
| 13 | .00 | 5.08 | .00 | .00 | 3.56 | .00 |
| 14 | 1.52 | 2.03 | .00 | .00 | 19.05 | .00 |
| 15 | .00 | .00 | .00 | 15.24 | 18.29 | 38.10 |
| 16 | .00 | .00 | .00 | .00 | .00 | .00 |
| 17 | .00 | .00 | .00 | .00 | .00 | 2.54 |
| 18 | 1.78 | .00 | .00 | 16.51 | 25.40 | .00 |
| 19 | 1.78 | .00 | 17.78 | .00 | 76.20 | 12.70 |
| 20 | 2.54 | .00 | 2.54 | .00 | 7.62 | 25.40 |
| 21 | .00 | .00 | .00 | .00 | 7.62 | 45.72 |
| 22 | 2.54 | .00 | 21.59 | .00 | 5.08 | 19.05 |
| 23 | .00 | 11.18 | 12.70 | .00 | 2.54 | .00 |
| 24 | .00 | 15.24 | 15.24 | .00 | 7.62 | 13.97 |
| 25 | .00 | 58.42 | 2.54 | .00 | 25.40 | 10.16 |
| 26 | .00 | 13.97 | .00 | .00 | 38.10 | .00 |
| 27 | .00 | 68.58 | .00 | .00 | 17.78 | 19.05 |
| 28 | .00 | 22.86 | .00 | 12.70 | 6.10 | 12.70 |
| 29 | 2.54 | 2.54 | .00 | .00 | 25.40 | 19.05 |
| 30 | 1.27 | .00 | .00 | .00 | .00 | |
| 31 | .00 | .00 | .00 | .00 | 12.70 | |

Table 2a Outflow rates for the different wells in the cross-section of Quatro Esquinas for some periods with few precipitation.

lev.: waterlevel in the piezometer at the specified date
diff. : change in waterlevel for the specified period expressed in mm/day, negative for lowering and positive for rising watertable.

Well #1:

| date | lev.(m) | diff. | date | lev. (m) | diff. |
|---|---|---|---|---|---|
| 26/5 | 3.635 | | 19/6 | 3.25 | |
| 28/5 | 3.44 | -97.5 | 22/6 | 3.13 | -40.0 |
| 01/6 | 3.295 | -36.3 | 24/6 | 3.05 | -40.0 |
| | | | 25/6 | 3.07 | +20.0 |
| | | | 02/7 | 2.94 | -18.6 |

Well #2:

| date | lev. (m) | diff. | date | lev. (m) | diff. |
|---|---|---|---|---|---|
| 24/3 | 3.20 | | 19/6 | 3.49 | |
| 10/4 | 2.85 | -20.6 | 22/6 | 3.36 | -43.0 |
| 23/4 | 2.75 | - 7.7 | 24/6 | 3.29 | -35.0 |
| | | | 25/6 | 3.32 | +30.0 |
| | | | 02/7 | 3.15 | -24.3 |

Well #3:

| date | lev. (m) | diff. | date | lev. (m) | diff. |
|---|---|---|---|---|---|
| 24/3 | 2.27 | | 26/5 | 2.63 | |
| 10/4 | 1.97 | -17.6 | 28/5 | 2.42 | -105. |
| 23/4 | 1.94 | - 2.3 | 01/6 | 2.265 | -38.8 |

Table 2a : continuation.

| date | lev. (m) | diff. |
|---|---|---|
| 19/6 | 2.46 | |
| 22/6 | 2.335 | -41.7 |
| 24/6 | 2.24 | -47.5 |
| 25/6 | 2.27 | +30.0 |
| 02/7 | 2.285 | + 2.1 |

Well #4:

| date | lev. (m) | diff. | date | lev. (m) | diff. |
|---|---|---|---|---|---|
| 26/5 | 2.18 | | 19/6 | 2.075 | |
| 28/5 | 2.07 | -55.0 | 22/6 | 2.035 | -13.3 |
| 01/6 | 1.98 | -22.5 | 24/6 | 1.96 | -13.3 |
| | | | 25/6 | 1.96 | 0.0 |
| | | | 02/7 | 1.96 | 0.0 |

Well #5:

| date | lev. (m) | diff. | date | lev. (m) | diff. |
|---|---|---|---|---|---|
| 24/3 | 2.14 | | 26/5 | 2.55 | |
| 10/4 | 1.79 | -20.6 | 28/5 | 2.36 | -95.0 |
| 23/4 | 1.77 | - 1.5 | 01/6 | 2.21 | -37.5 |

Table 2a : continuation.

| date | lev. (m) | diff. |
|---|---|---|
| 19/6 | 2.43 | |
| 22/6 | 2.26 | -56.7 |
| 24/6 | 2.15 | -55.0 |
| 25/6 | 2.13 | -20.0 |
| 02/7 | 2.25 | +17.8 |

Table 2b: Outflow rates for the different wells corrected for specific yields and evaporation.

Outflow in well #1 :

| mean level | corrected outflow rates |
|---|---|
| 3.54m | 97.5 * 0.25 - 4 = 23 mm/d |
| 3.37m | 36.3 * 0.25 - 4 = 5 mm/d |
| 3.15m | 40.0 * 0.25 - 4 = 6 mm/d |
| 3.00m | 18.6 * 0.25 - 4 = 0.6 mm/d |

Outflow in well #2 :

| | |
|---|---|
| 3.02m | 20.6 * 0.30 - 3 = 3.2 mm/d |
| 2.80m | 7.7 * 0.30 - 3 = -0.7 mm/d |
| 3.42m | 43.0 * 0.25 - 4 = 7 mm/d |
| 3.32m | 35.0 * 0.25 - 4 = 5 mm/d |
| 3.24m | 24.3 * 0.25 - 4 = 2 mm/d |

Outflow in well #3 :

| | |
|---|---|
| 2.12m | 17.6 * 0.25 - 3 = 1.4 mm/d |
| 1.95m | 2.3 * 0.25 - 3 = -2.4 mm/d |
| 2.52m | 105. * 0.25 - 4 = 22.5 mm/d |
| 2.34m | 38.8 * 0.25 - 4 = 5.7 mm/d |
| 2.40m | 41.7 * 0.25 - 4 = 6.4 mm/d |
| 2.30m | 47.5 * 0.25 - 4 = 7.9 mm/d |

Outflow in well #4 :

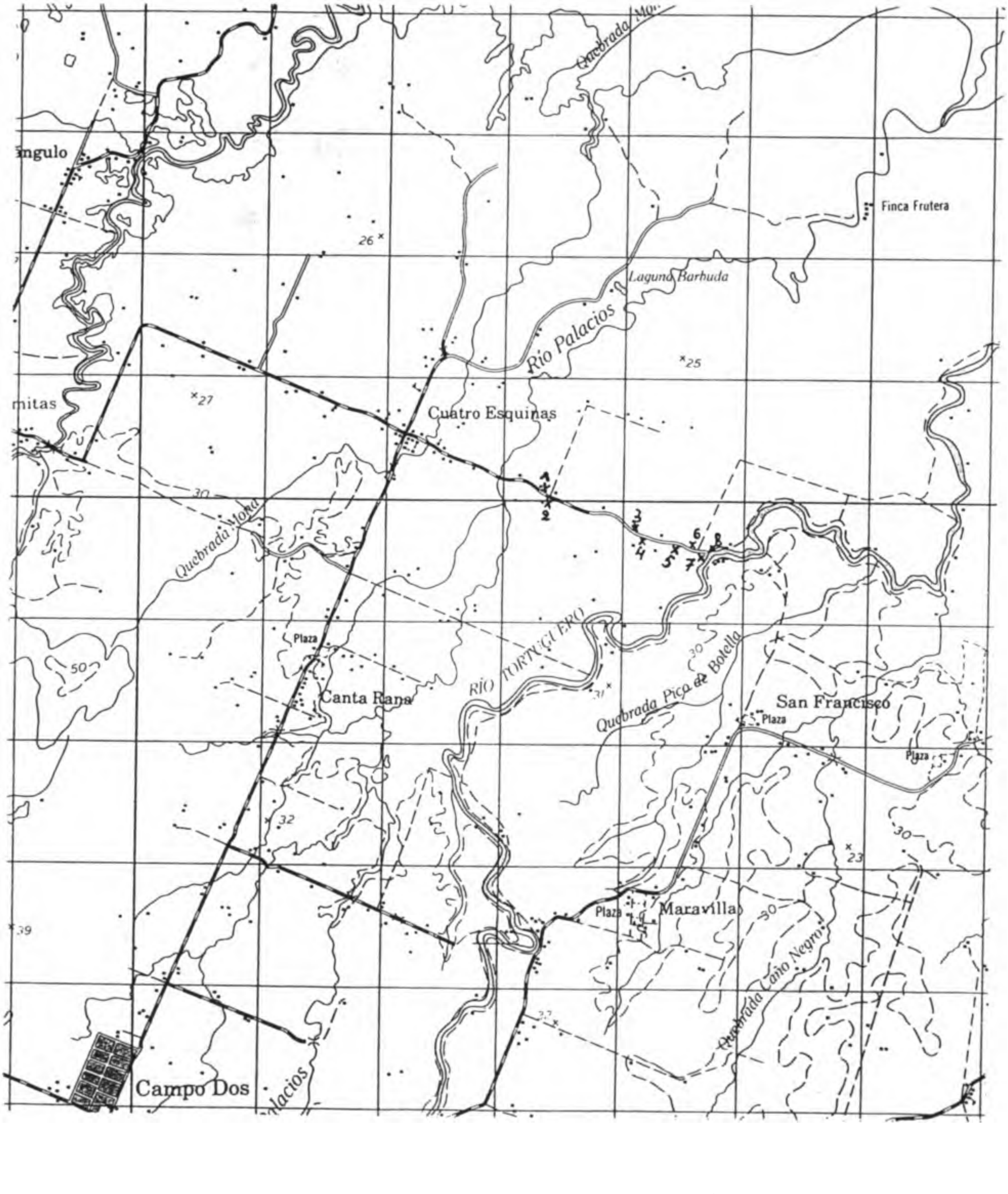
| | |
|---|---|
| 2.12m | 55.0 * 0.25 - 4 = 9.8 mm/d |
| 2.02m | 22.5 * 0.25 - 4 = 1.6 mm/d |
| 2.02m | 13.3 * 0.25 - 4 = -0.7 mm/d |

Outflow in well #5 :

| | |
|---|---|
| 1.96m | 20.6 * 0.25 - 3 = 2.2 mm/d |
| 1.78m | 1.5 * 0.25 - 3 = -2.6 mm/d |
| 2.45m | 95.0 * 0.25 - 4 = 19.8 mm/d |
| 2.28m | 37.5 * 0.25 - 4 = 5.4 mm/d |
| 2.26m | 56.0 * 0.25 - 4 = 10.0 mm/d |
| 2.14m | 20.0 * 0.25 - 4 = 1.0 mm/d |

Table 2c: Corrected outflow rates (mm/day) for the different wells listed per end-date of the outflowperiod, the corresponding mean water level (m) in piezometer 3 and the mean daily precipitation P (mm/day), measured in the bananaplantation of Banagro, for the corresponding outflowperiod.

| date | well 1 | well 2 | well 3 | well 4 | well 5 | depth #3 | P |
|---|---|---|---|---|---|---|---|
| 10/4 | - | 3.2 | 1.4 | - | 2.2 | 2.12 | 0.2 |
| 23/4 | - | -0.7 | -2.4 | - | -2.6 | 1.95 | 2.2 |
| 28/5 | 23 | - | 22.5 | 9.8 | 19.8 | 2.52 | 0 |
| 01/6 | 5 | - | 5.7 | 1.6 | 5.4 | 2.34 | 0 |
| 22/6 | 6 | 7 | 6.4 | -0.7 | 10.0 | 2.40 | 0 |
| 24/6 | 6 | 5 | 7.9 | -0.7 | 10.0 | 2.30 | 0 |
| 02/7 | 0.6 | 2 | -4.5 | -4.0 | -8.4 | 2.28 | 1.8 |



Map 1: Location of the piezometers (1 to 8) on the cross-section between Río Palacios and Río Tortuguero. (Abstract from "Hoja 3447 II, Agua Fria; Lambert-coordinate of the lower left corner: latitude 2.65 and longitude 5.69)

Fig. 1: Waterlevels observed in piezometer 1 and 2 (day 1 = 24/03/92)

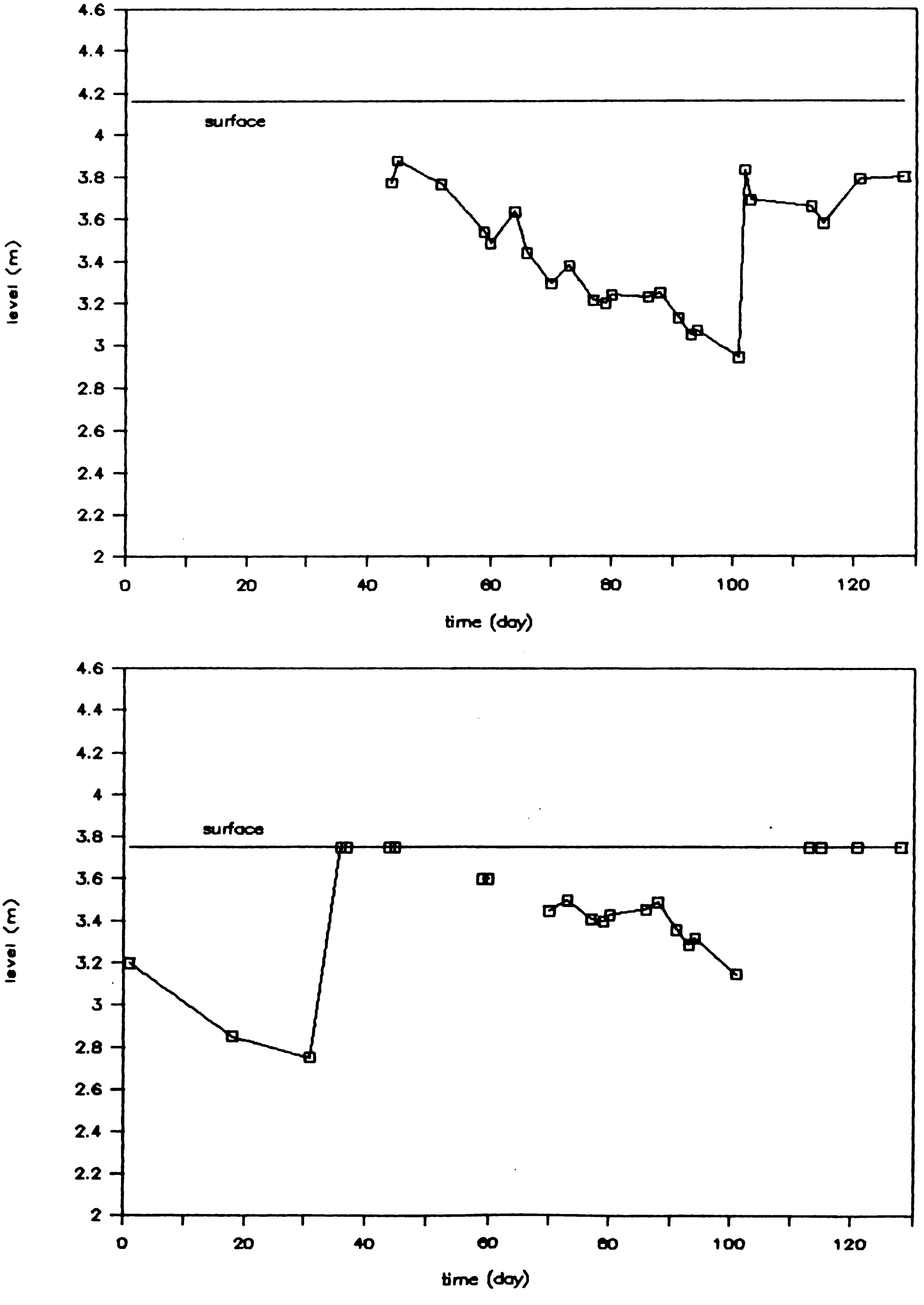
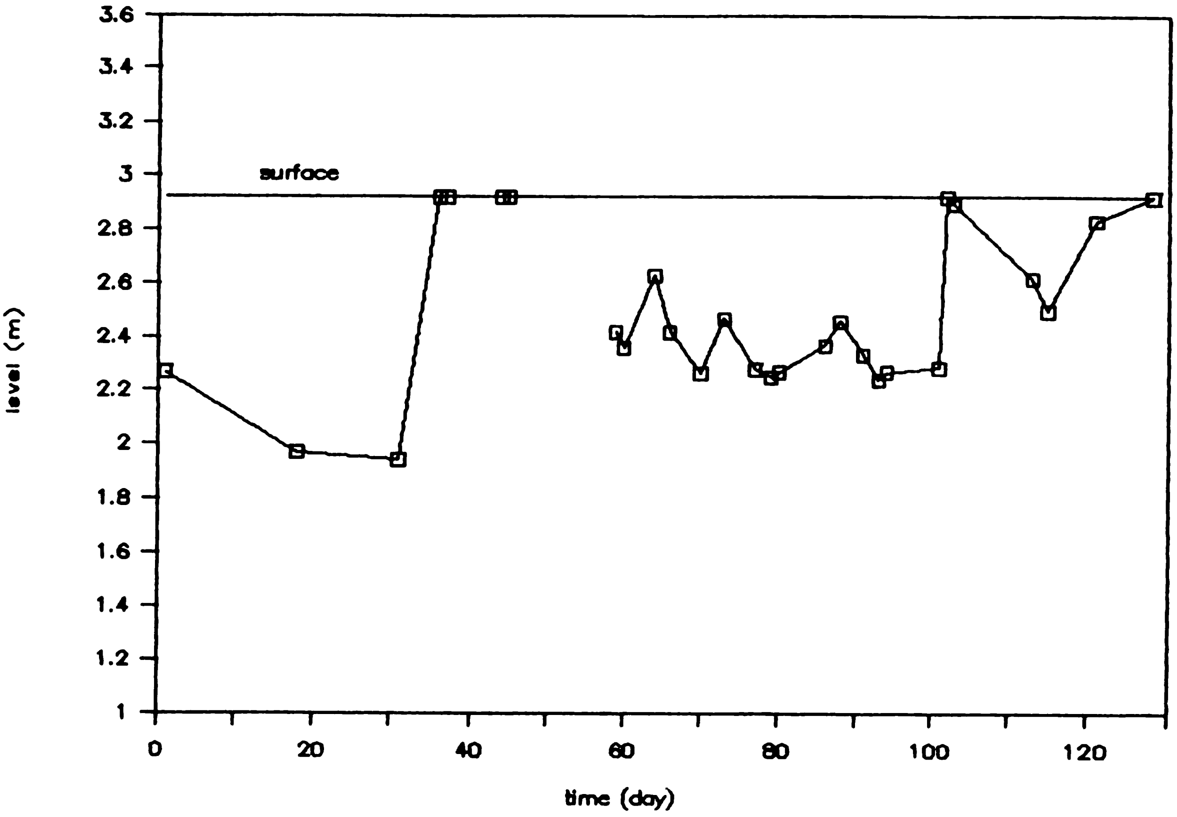


Fig. 2: Waterlevels observed in piezometer 3 and 4 (day 1 = 24/03/92)



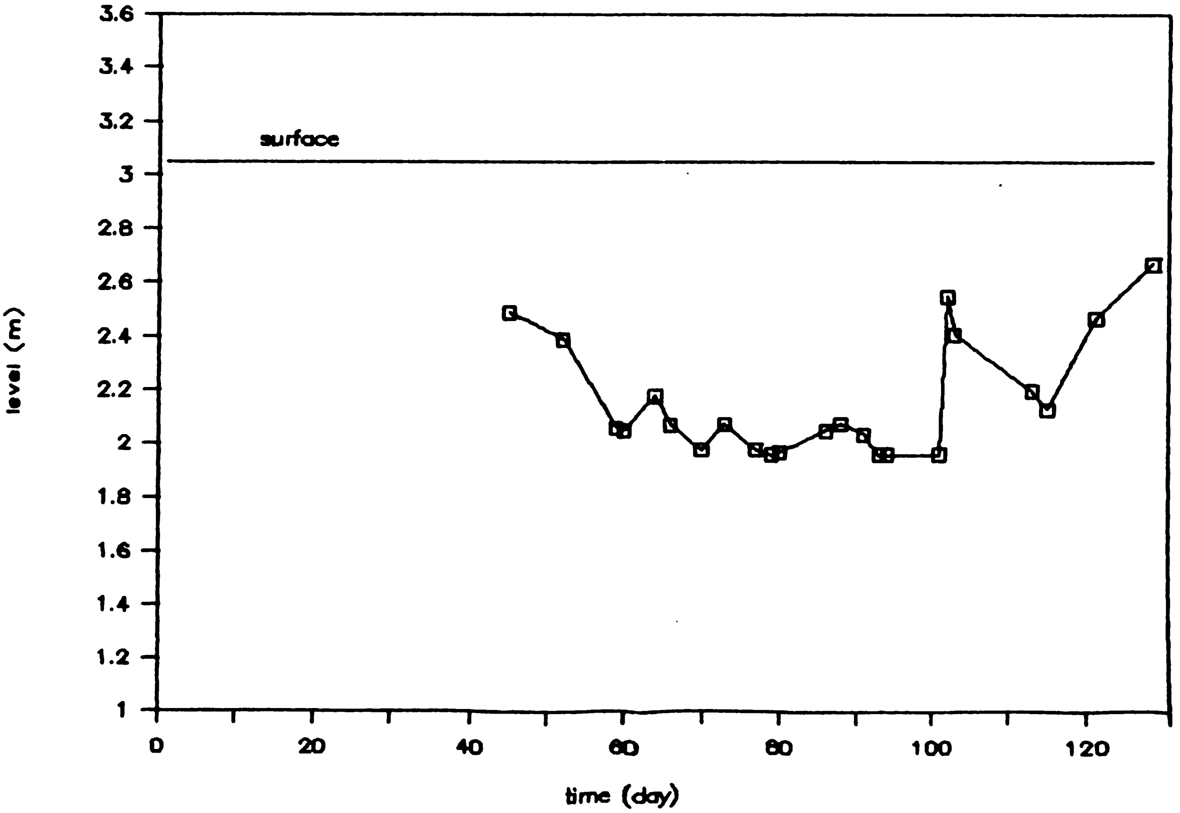


Fig. 3: Waterlevels observed in piezometer 5 and 6 (day 1 = 24/03/92)

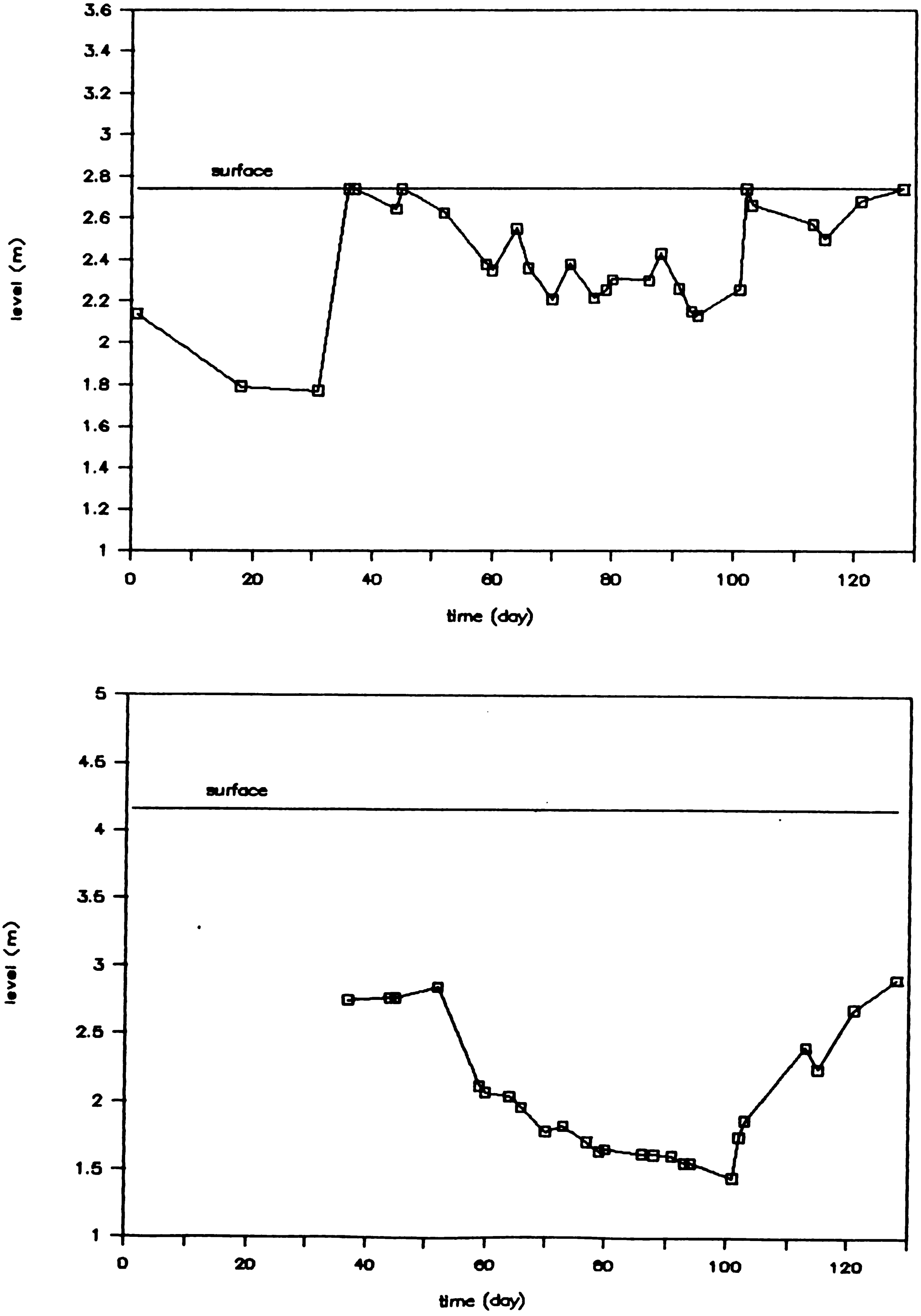


Fig. 4: Waterlevels observed in piezometer 7 and 8 (day 1 = 24/03/92)

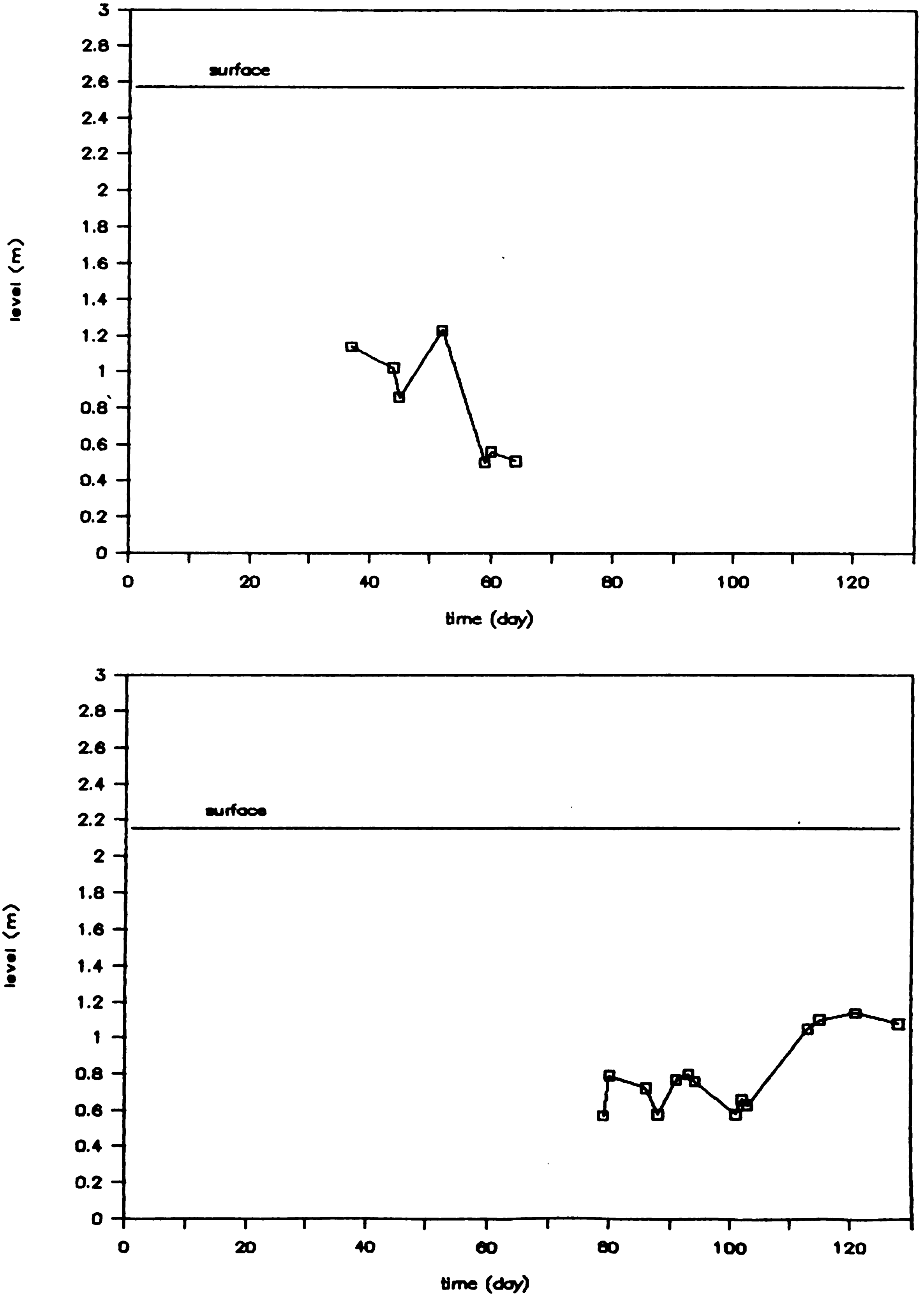


Fig. 5: Topography and location of the piezometers in the cross-section between Río Palacios and Río Tortuguero.

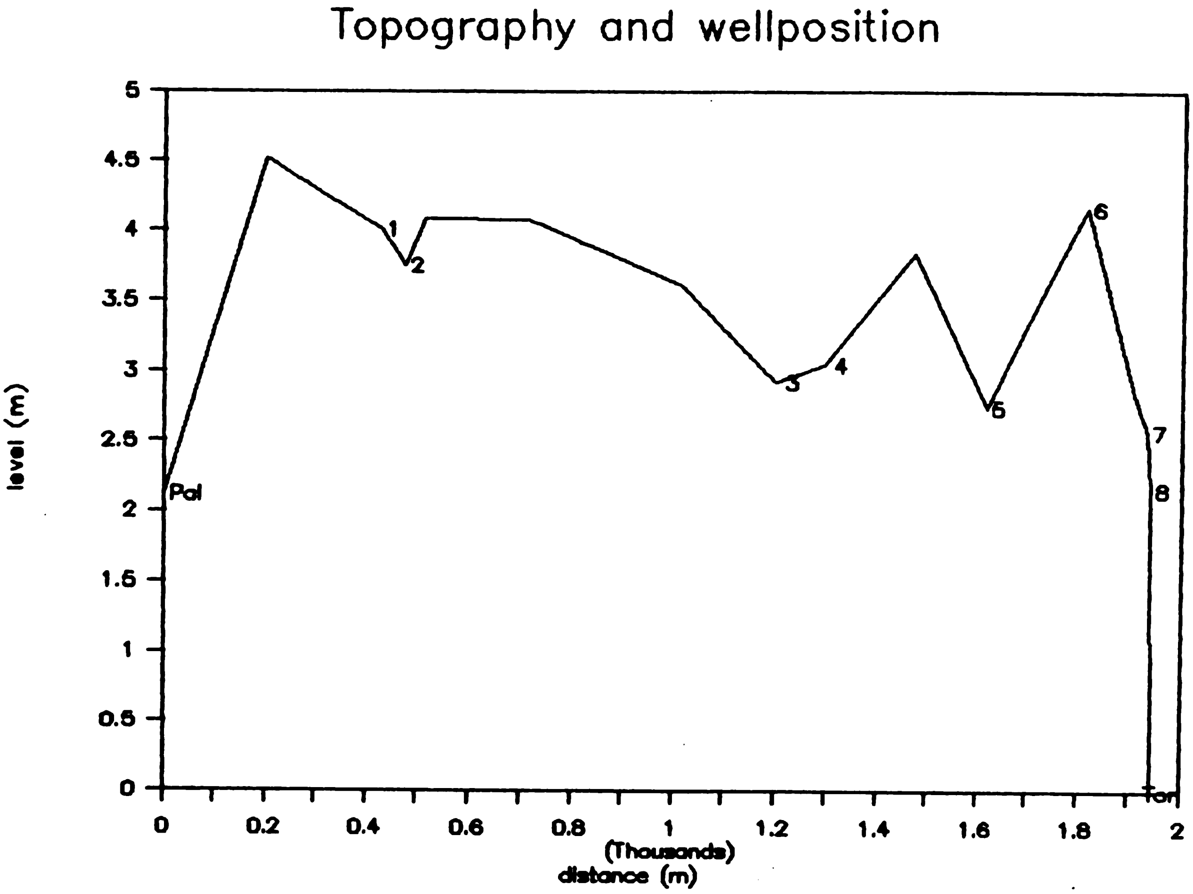


Fig. 6 : Four watertable profiles under different conditions (very dry, dry, moderate and wet).

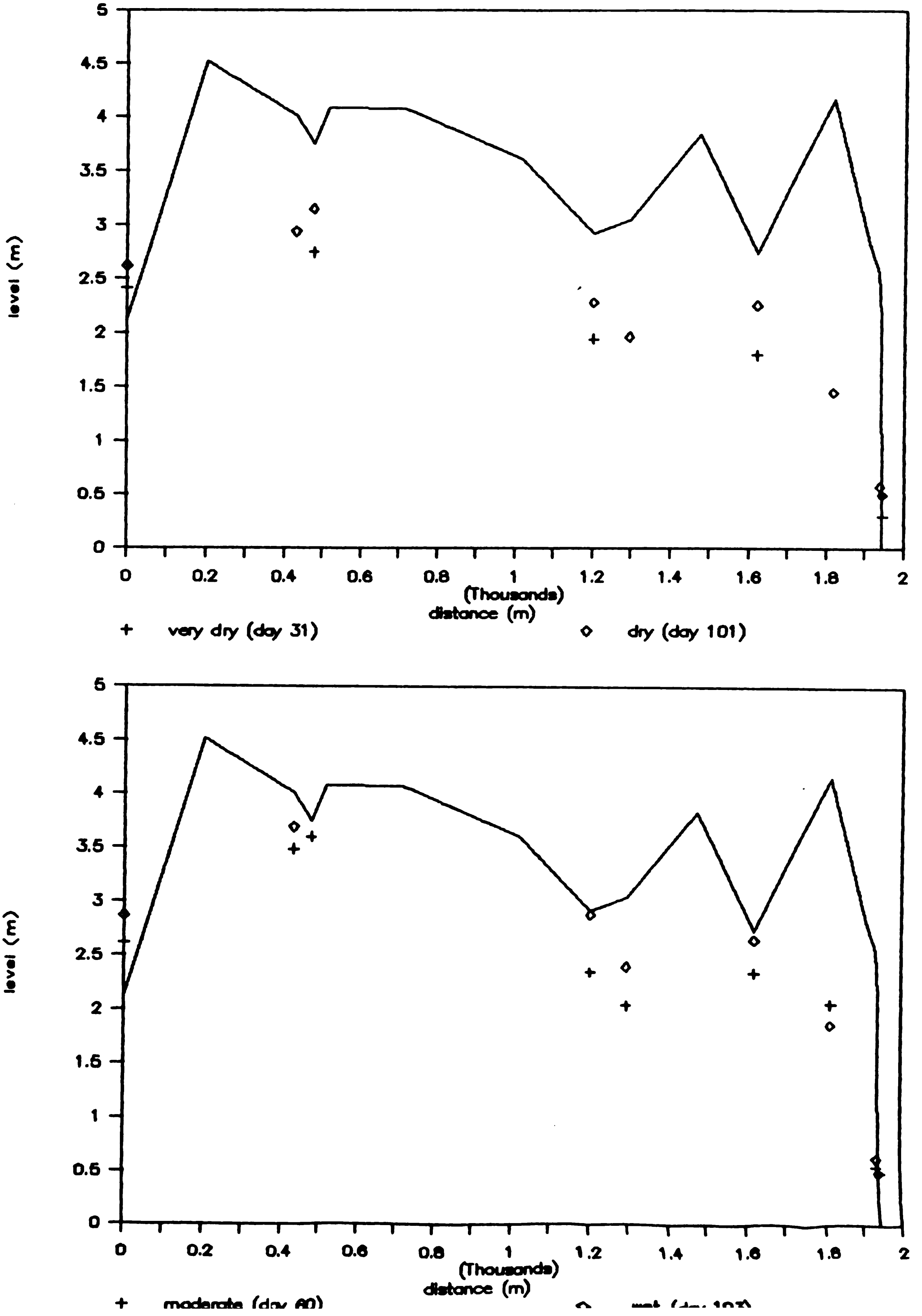


Fig. 7. Theoretical waterprofiles calculated for a natural recharge equal to 3 mm/day and with a hydraulic conductivity equal to 5m/day and the impervious layer 1m, 5m or 10 m below the bed of the Tortuguero

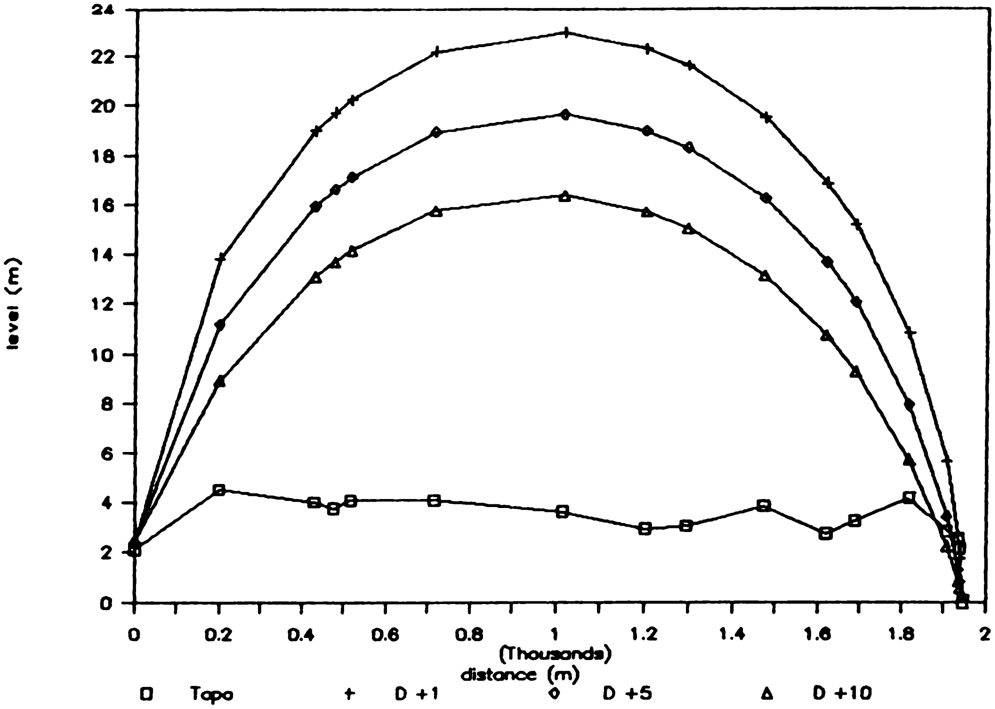


Fig. 8. Theoretical waterprofiles calculated for a natural recharge equal to 3 mm/day and with a hydraulic conductivity equal to 5m/day and the impervious layer 1m, 5m or 10 m below the bed of the Tortuguero and a fixed potential of 1.9m at 1300m.

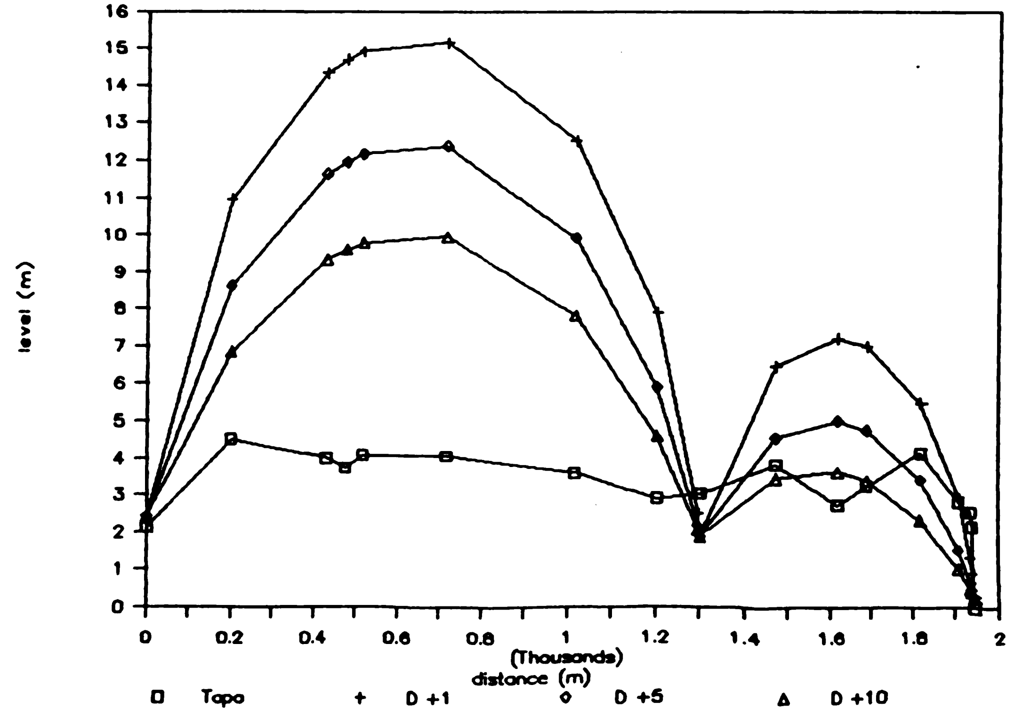


Fig. 9 : Theoretical waterprofile fitted with the observed waterlevels of 04/07/92 (day 103); the impervious layer is taken 5 m lower than the bed of the Tortuguero and K is equal to 5 m/day; a fixed potential equal to 2.4 m is set at 1300m; the natural recharge N was found to be equal to .25 mm/day to fit with the observed levels in the left side and found to be equal to .8 mm/day to fit with the observed levels in the right side.