WD/OS/77/13

A Digital Ground Water Model Of The Kakontwe Aquifer, Ndola, Zambia

- by -

B. Adams M.Sc.

CONTENTS

PAGE

PREFACE

PART 2 THE KAKONTWE AQUIFER

PART 3 THE GROUND WATER MODEL

PART 4 DATA INPUT

PART 5 THE PROGRAM

PART 6 CALIBRATION

APPENDICES

PREFACE

This report describes Phase II of studies carried out for the water supply to Ndola, Zambia. Phase I consisted of field investigations and collection of data to form the basis of the digital model described herein, and was carried out by Brian Colquohoun and Partners under assignment by the Ministry of Overseas Development. The results of Phase I studies are contained in a four volume report prepared by Brian Colquohoun and Partners. Phase III of the study will involve an assessment of the potential of the aquifer in the light of model investigations, and is to include recommendations for the economical exploitation and development of the Kakontwe aquifer in conjunction with the other sources of water available to Ndola.

PART I INTRODUCTION

The digital model described in this report uses a finite difference approximation and is based on a polygonal nodal system of the type first used by Tyson & Weber (1964) and Pliska (1968). The program is written in FORTRAN IV and the model is used for predicting ground water levels at fixed points throughout the Kakontwe outcrop area using meteorological and hydrogeological input data over fixed time periods of one month. This report describes the mathematical concepts involved the construction of the model, the method used in calibrating the model to measured field conditions and its use as a predictive tool in groundwater management of the Kakontwe basin.

PART 2 THE KAKONTWE AQUIFER

2.1. LOCATION

The Itawa-Mwateshi catchment forms the upper unit of the Kafubu catchment, above the Itawa dambo and is situated to the North-East of Ndola. Its long north-eastern boundary coinciding with the international boundary between Zambia and Zaire (see Fig 1).

2.2. HYDROGEOLOGY

The aquifer consists of the Kakontwe Formation which is part of the Lower Series of the Kundelungu System of the Pre-Cambrian Era. It occurs in this area as a major synclinal fold structure of dolomite and limestone beds plunging north-west across the border with Zaire. There is evidence of large transverse fissure systems and the limestone is generally karstic in nature - drilling having shown the presence of sub-surface caverns, and sink holes being evident at the surface. Perched water table conditions have been shown to exist at a few locations in the overburden which varies greatly in permeability over the area. There is no evidence of any major inflow across the boundaries of the northern or eastern watersheds, nor of any significant intrusion through the underlying Mwashia Shale. Recharge of the aquifer appears to be controlled by direct infiltration in areas of bare rock and shallow soils, and by horizontal recharge where the overburden is thicker.

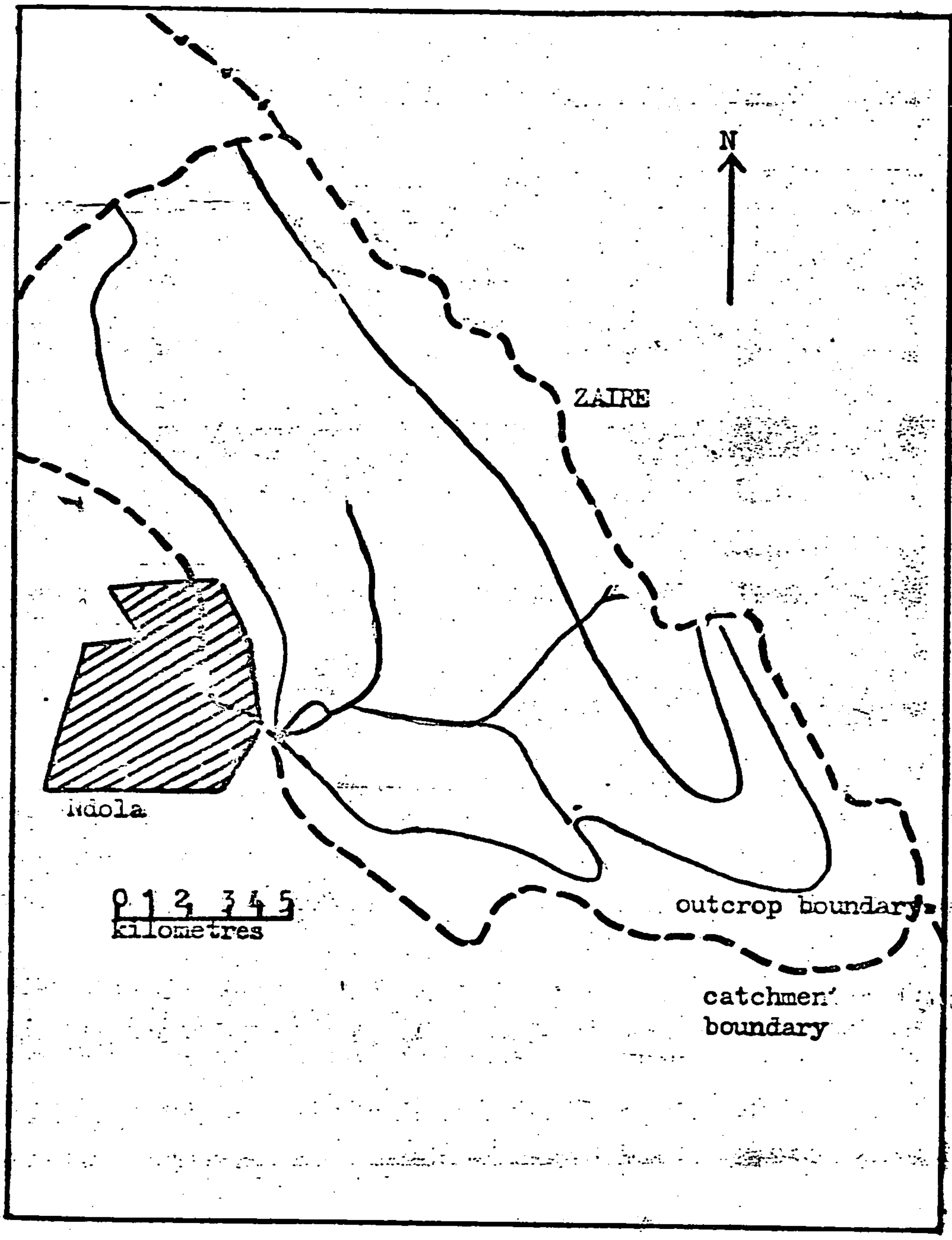


FIGURE 1. General Location Map

PART 3 THE GROUND WATER MODEL

3.1. THE NODAL NETWORK

It was obviously important to incorporate into the model the directional variation in Transmissivity indicated by the aquifer tests. For this reason a polygonal node system was used in preference to a rectangular one; the nodes were constructed by the "Thiessen polygon" method, the lines joining centres of adjacent nodes being considered as flowpaths. The boundary of the model is defined by the topographical catchment and approximated to by straight lines forming the sides of adjacent nodes - see Figure 2. As far as was possible the following considerations were included in the construction of the nodal net:

i) The node centres should coincide with data points

ii) The nodal boundaries should separate areas of differing hydraulic characteristics.

iii) No more than 40 nodes should be used because more nodes could not be warranted by the given data spread.

The resulting nodal network is shown in Figure 2.

To facilitate the use of the numerical intergration technique to be described later, it was necessary to assign numbers to the nodes; nodes were numbered consecutively in the approximate directions of flow from the north and south east ends of the catchment towards the dambo.

Initially nodes were set both outside and within the outcrop area to permit the modelling of flow across the catchment boundaries if this proved desirable. However, the "outcrop" nodes on the borders of the basin were later extended to include the catchment boundary "non-outcrop" nodes and the variables AREA(NODE) and CAREA(NODE) defined to contain the nodal outcrop area and nodal catchment area respectively. This is the reason for the nodes not being numbered consecutively.

As mentioned earlier the lines joining the centres of adjacent nodes are considered as flow paths and consequently values of Transmissivity are

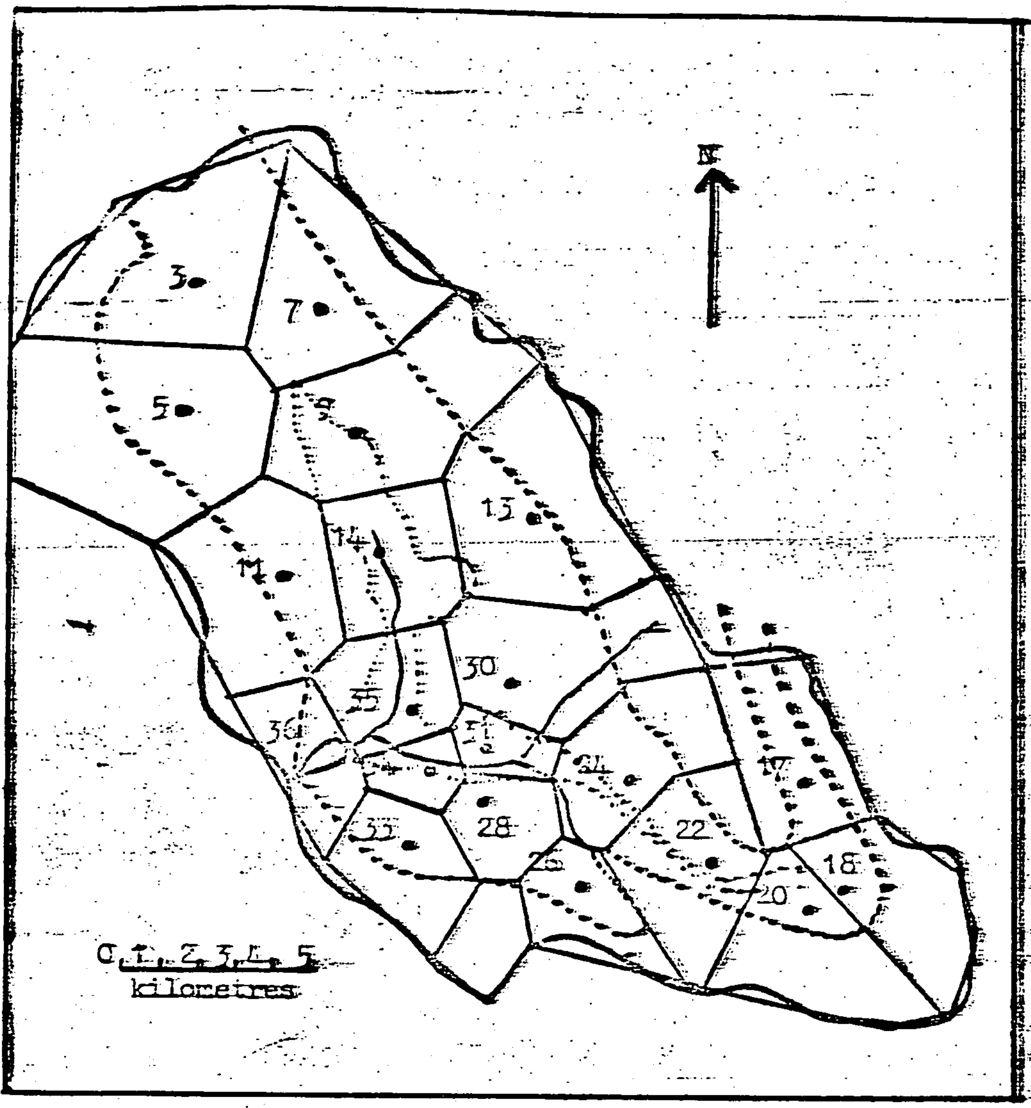


FIGURE 2. The Nodal Network

applied to these flow paths rather than the node, thus allowing variation in Transmissivity with direction to be modelled. Tyson and Weber (1964) numbered these flow paths consecutively and independently of the nodes, however, in the model under discussion it was decided to define each flow path by the nodes which it joined; thus the flow path between nodes 3 and 7 is labelled (3, 7), which will be equal to (7, 3).

Using this nodal system the ground water flow between two adjacent nodes can easily be calculated having assigned a Transmissivity to the flow path, knowing the water levels at each node, the width across which flow occurs (i.e. the length of the common side), the length of the flow path and the aquifer thickness.

3.2. THE GROUND WATER FLOW EQUATION

3.2.1. The Differential Equation for Ground Water Flow

The basic ground water flow equation, derived by combining Darcy's law and the law of conservation of Mass is expressed in partial differential form as :

$$\nabla T \nabla h - S \, {}^{\partial h}/_{\partial t} - Q = 0 \qquad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots(1)$$

Where T and S are respectively, the local transmissivity and storage coefficient of the aquifer, Q is the inflow/outflow and h is the head of water.

3.2.2. The Finite Difference Approximation

The basis of the finite difference approximation is to replace derivatives at a point by ratios of the changes in appropriate variables over a small but finite interval, thus.

$$\frac{dh}{dt} = \lim_{\Delta t \to 0} \frac{\Delta h}{\Delta t} \simeq \frac{\Delta h}{\Delta t}$$

The maximum allowable size of Δt for this approximation to hold will depend on the particular problem. This type of approximation made at a finite number of points will reduce a continuous boundary - value problem, such as hydraulic flow, to a set of algebraic equations. Thus, applying a backward difference approximation to equation (1) results in a system of finite difference equations (2) the simultaneous solution of which gives the required function h at each node.

$$\sum_i (h_i^{t+\Delta t} - h_N^{t+\Delta t}) C_{i,N} = \frac{A_N S_N}{\Delta t} (h_N^{t+\Delta t} - h_N^{t}) + Q_N^{t+\Delta t} \quad .....(2)$$

and $$C_{i,N} = \frac{J_{i,N} T_{i,N}}{L_{i,N}} \quad ....(3)$$

when subscripts t and t +Δt denote points along the time coordinate in days

subscript i denotes all nodes adjacent to node N.

subscript N denotes node N.

h denotes ground water level in metres.

A denotes area in square metres.

S denotes storage coefficient.

Q denotes the nodal discharge in cubic metres/day.

$J_{i,N}$ denotes the length of the perpendicular bisector associated with nodes i and N in metres.

$L_{i,N}$ denotes the length of the flow path between the centres of nodes i and N in metres.

$T_{i,N}$ denotes the transmissibility of the flow path between nodes i and N in cubic metres/day/metre.

$C_{i,N}$ denotes the conductance of the flow path between nodes i and N in cubic metres/day/metre.

t denotes the length of time step in days.

Figure 3 shows the above notation applied to a typical node.

3.2.3. The Method of Solving the Finite Difference Approximation

One technique of solving the simultaneous equations would be to use the Gauss-Seidel Method which for linear symmetric systems of equations (such as the system representing the ground water problem) is known to be unconditionally convergent. This method also has the advantage that the length of time step does not depend on a stability criteria. The digital

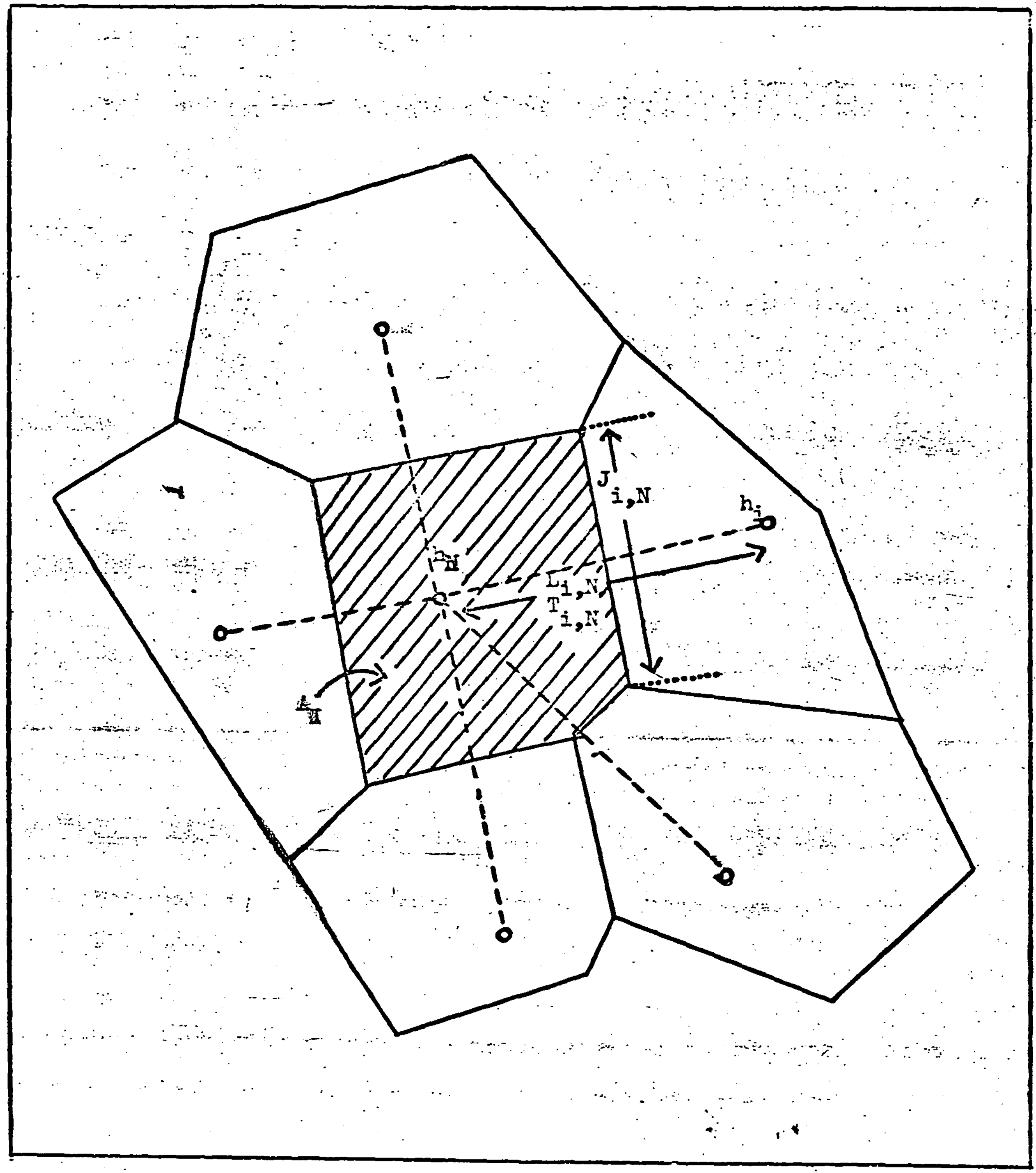


FIGURE 3. Nodal Geometry & Notation

model involves an equation in the form of equation (2) for each node of the network. By using the successive over-relaxation technique convergence can be achieved more rapidly than by the Gauss-Seidel method from which it was developed. The procedure is as follows:

Initial values of nodal water levels h_N^{t} are assigned to the nodes ($N = 1, 2 \ldots\ldots M$; M = no of nodes). Then for a given set of values of Q_N, $C_{i,N}$, A_N, S_N the values of the nodal water levels $h_N^{t+\Delta t}$ at the end of the timestep Δt are implicitly determined by an iteration process. The iteration process consists in using estimated values of $h_N^{t+\Delta t}$ to compute the ground water flows and storage flows for the network (for the first iteration $h_N^{t+\Delta t} = h_N^{t}$). Using equations (2) and (3) flow balances are calculated for each node and any errors or residuals attenuated by a relaxation coefficient are used to correct the estimated values of $h_N^{t+\Delta t}$. Iterations are repeated until the sum of absolute values of the nodal residuals becomes less than some predetermined error criteria.

By using a relaxation coefficient the number of iterations required to reach convergence is decreased. Because the product of the residual term and this relaxation coefficient results in a charge in water level and because the residual term is a flow rate, the relaxation coefficient is an impedance. The equation used for the impedance is

$$X_N = \frac{1.6}{\sum C_{i,N} + \frac{A_N S_N}{\Delta t}} \qquad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (4)$$

where X_N is the relaxation coefficient for the node in question and the other notation is as for equation (2).

PART 4 DATA INPUT

4.1. INTRODUCTION

The Data input of the model is of two main types, Climatic and Hydrogeologic. The following paragraphs discuss the separate factors of each type and an indication of the reliability of this data is given.

4.2. CLIMATIC FACTORS

4.2.1. Rain

There are a total of 16 meteorological stations within the area for which records over the calibration period (July 1973 - December 1974) exist. The average monthly rainfall over the Itawa catchment was compiled using the Thiessen polygon method. Because the distribution of recording stations is not even over the whole area, it was considered that there would be no gain in trying to assign individual monthly rainfall values to each node.

4.2.2. Potential Evaporation

Estimation of potential, and subsequently actual, evaporation is more complex than the estimation of precipitation. Several methods exist for the estimation of potential evaporation and a comparison of five different methods is shown in Table I (taken from table 3.3.1. of the Colquhoun report). As can be seen these estimates are mean monthly figures only taken from climatic records over a period of several years and not calculated specifically for the calibration period; the differences between the various estimates show the degree of uncertainty that exists in the calculation of potential evaporation. During calibration of the model it was found that the Turc values decreased by a factor of 0.75 gave the best overall results. Figure 4 shows the various estimates of potential evaporation plotted on a monthly basis. Further error must be involved in using monthly estimates of the potential evaporation which fluctuates widely even on a daily basis.

	Torrance (Penman)	Avne* (Pan)	Avne (Penman	Turc	Blaney-Criddle
July	126	145	121	104	124
August	149	182	152	123	137
September	161	206	186	156	147
October	174	212	211	152	165
November	151	166	168	124	160
December	135	125	149	124	163
January	135	107	152	134	160
February	123	101	126	112	142
March	135	136	149	120	153
April	144	142	144	125	142
May	132	145	127	115	135
June	116	127	108	99	122
Total (mm)	1681	1794	1793	1488	1750

2

*Corrected for reduced evaporation from large area

TABLE 1. Potential Evaporation Estimates for Ndola

(taken from table 3.3.1 Colquhoun and Ptnrs. 1975)

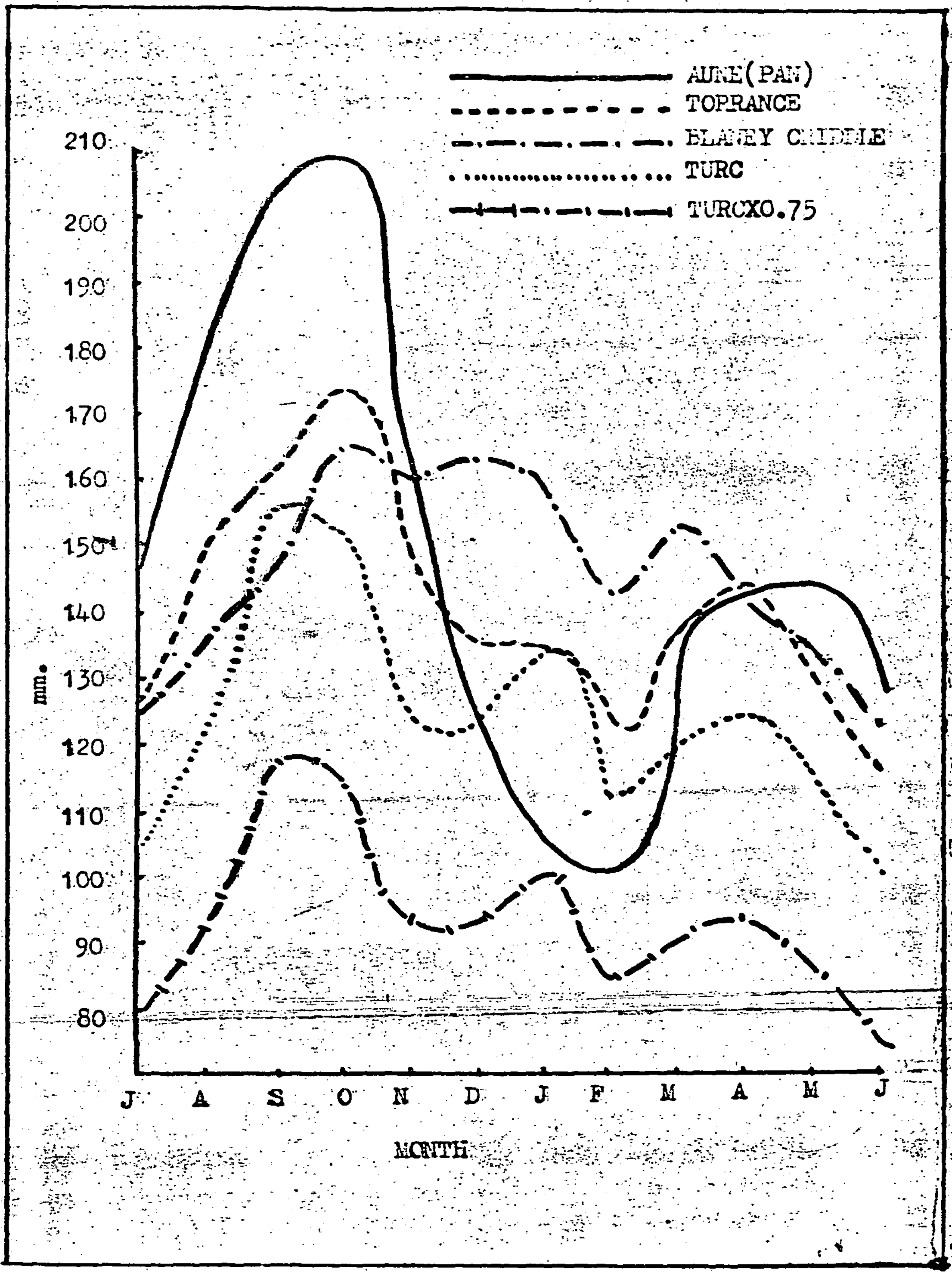


FIGURE 4. Monthly estimates of potential evaporation.

4.3. HYDROGEOLOGIC FACTORS

4.3.1. Transmissivity

Drilling and aquifer tests were carried out at several sites as shown on Figure 5. As can be seen the results of the tests indicate a variation of Transmissivity with direction and this variation was allowed for when Transmissivities were applied to the flow paths joining adjacent nodes. In areas where aquifer tests were inconclusive or were not carried out estimates of Transmissivities were made based on local hydrogeological conditions. It was found necessary during calibration of the model to introduce an effect of zonal transmissibility whereby transmissivities at high water levels may be considerably larger than those at low water levels. As the aquifer tests were all carried out at a time of low water levels no field values for the higher transmissivities are available and various values had to be tried during calibration (see section 6.2).

4.3.2. Storage Coefficient

The aquifer tests give fairly consistent storage coefficient values, generally typical of confined conditions except at sites Q12 and Q5. However, in order to match historical ground water levels it was necessary to use storage coefficients of the order of 0.1 and higher in several nodes; the justification for this is two fold:

i) Although aquifer tests show that locally confined conditions exist it is likely that unconfined conditions exist on the large scale. However, allowing for this factor alone does not justify the use of such high storage coefficients as proved necessary.

ii) At nodes which border the Kakontwe catchment the catchment area of individual nodes is generally a good deal larger than the outcrop area and so much of the precipitation will be stored in this overburden to be released later as horizontal recharge (cf Hadwin 1972). Use of high storage coefficients at these boundary nodes and nodes where large thicknesses of overburden occurr approximate to the effect of storage in the overburden.

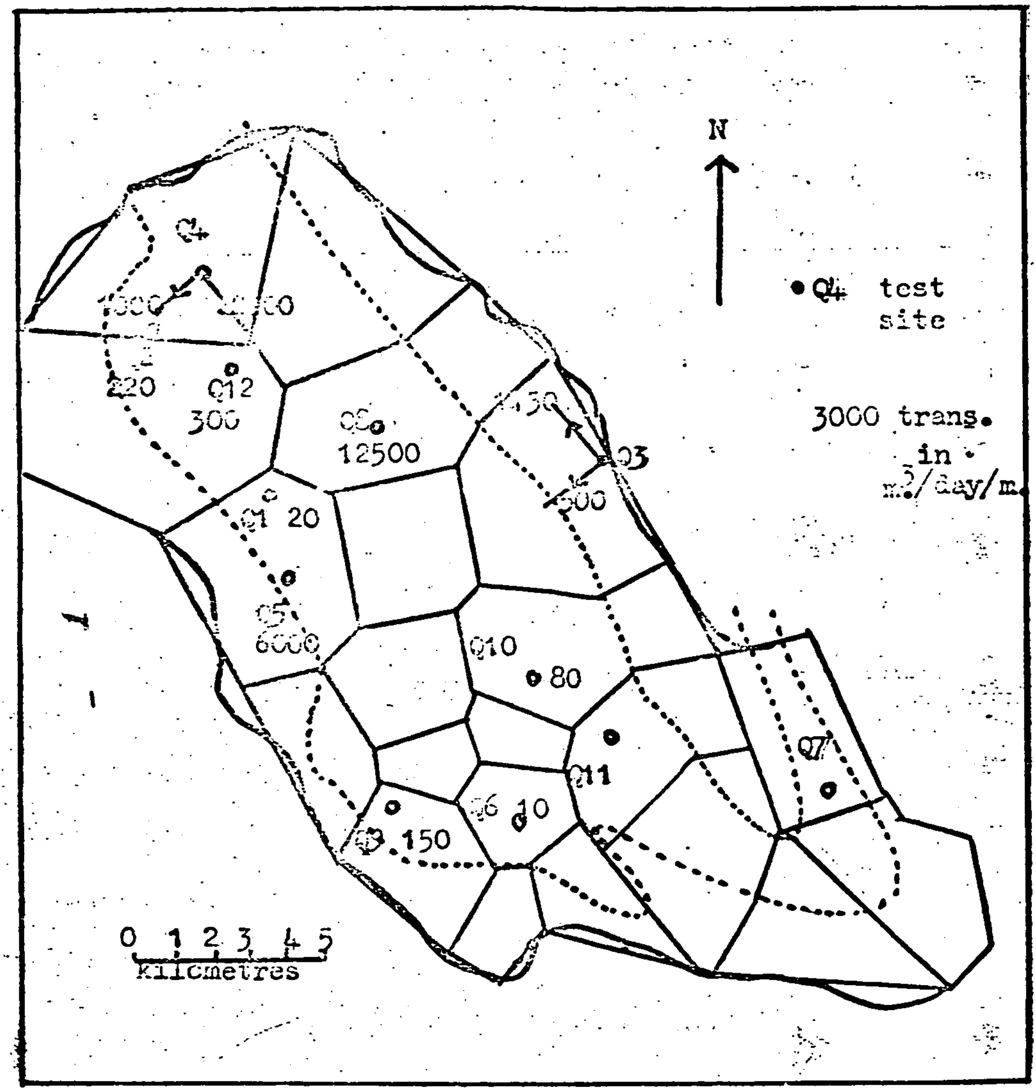


FIGURE 5. Aquifer Investigation sites, showing the Transmissivities determined from the aquifer tests

4.3.3. Ground Water Levels

Field measurements of water levels for all active nodes were required for the calibration period. Model ground water levels were set for July 1973 according to the field values and this was taken as the initial condition from which the response of the aquifer was calculated for the following 17 months. A network of observation points of 60 wells and boreholes was used to record ground water levels on a monthly basis from July 1973. Although the ground water level record is constant with time it does vary with area and where local data were not available, extrapolation was used to provide water levels. Data is particularly scarce in the south east of the area around nodes 17, 18 and 20 where there are only two boreholes which definitely penetrate the aquifer (W20 and W18 cf Colquhoun report). On this evidence alone it is possible that ground water flow in this area is from node 18 to 17 and out of the catchmemt.

4.3.4. Water Abstraction and Augmentation

The Colquhoun report gives detailed figures over the calibration period of water abstraction directly from surface and ground water and water augmentation via springs and effluent discharges.

4.3.5. Surface Runoff

The Itawa catchment drains south west into the Itawa Dambo where an embankment impounds water for the Council's Itawa waterworks. Discharge from the causeway is measured by totalling the discharge through 14 culverts with the discharge through four sluices. This information was recorded on a monthly basis from October 1973. No estimate of the quantity of underflow or seepage below the dam is available.

4.3.6. Permeability of Overburden

This factor is important in that it determines the percentage of precipitation entering the aquifer. The aquifer tests indicate a value of the order of 1 m/day for this parameter. Calibration runs indicate a critical value of approximately 0.005 m/day above which all rainfall, after evaporation and replenishment of soil moisture deficits, will infiltrate. Locally areas with vertical permeabilities lower than this critical must exist as shown by the evidence of perched water tables, however, on an overall scale a value of 1 m/day is used in the model.

4.3.7. Underflow

There is no definite field evidence for a major source of underflow into or out of the Kaknotwe aquifer under natural piezorietru conditions but the lack of data in the south eastern end of the catchment can not preclude this possibility.

PART 5 THE PROGRAM

5.1. PROGRAM DESCRIPTION

A listing of the program is given in Appendix I and Figure 6 shows a generalised flow diagram of the program showing how the finite difference flow equation is applied. All node-to-node subsurface flows are calculated first. Then all the storage flows are calculated. Next, all the flows (subsurface, storage and extraction) are balanced at each node by setting a variable named RES equal to their sum. The water elevation at the node is adjusted by the magnitude of the residual, attenuated by a relaxation coeffieient. Once all the ground water levels have been adjusted in this manner a sum is formed of the nodal residuals (in practice the sum of the absolute differences at each node between the ground water levels of the present and previous iteration). If this sum is less than or equal to a threshold value (contained in the variable, ERROR) the calculation is complete for that tiemstep, otherwise the calculation is pepeated.

As stated previously this method is essentially that of successive over-relaxation for linear symmetric systems of equations is known to be unconditionally convergent. This method also has the advantage that the length of timestep does not depend on a stability criteria.

As can be seen from the listing of the program in Appendix I, the program is subdivided into several numbered sections by comment cards, for example section 13 is labelled

C 13   EVAP AND INF CALCULATIONS

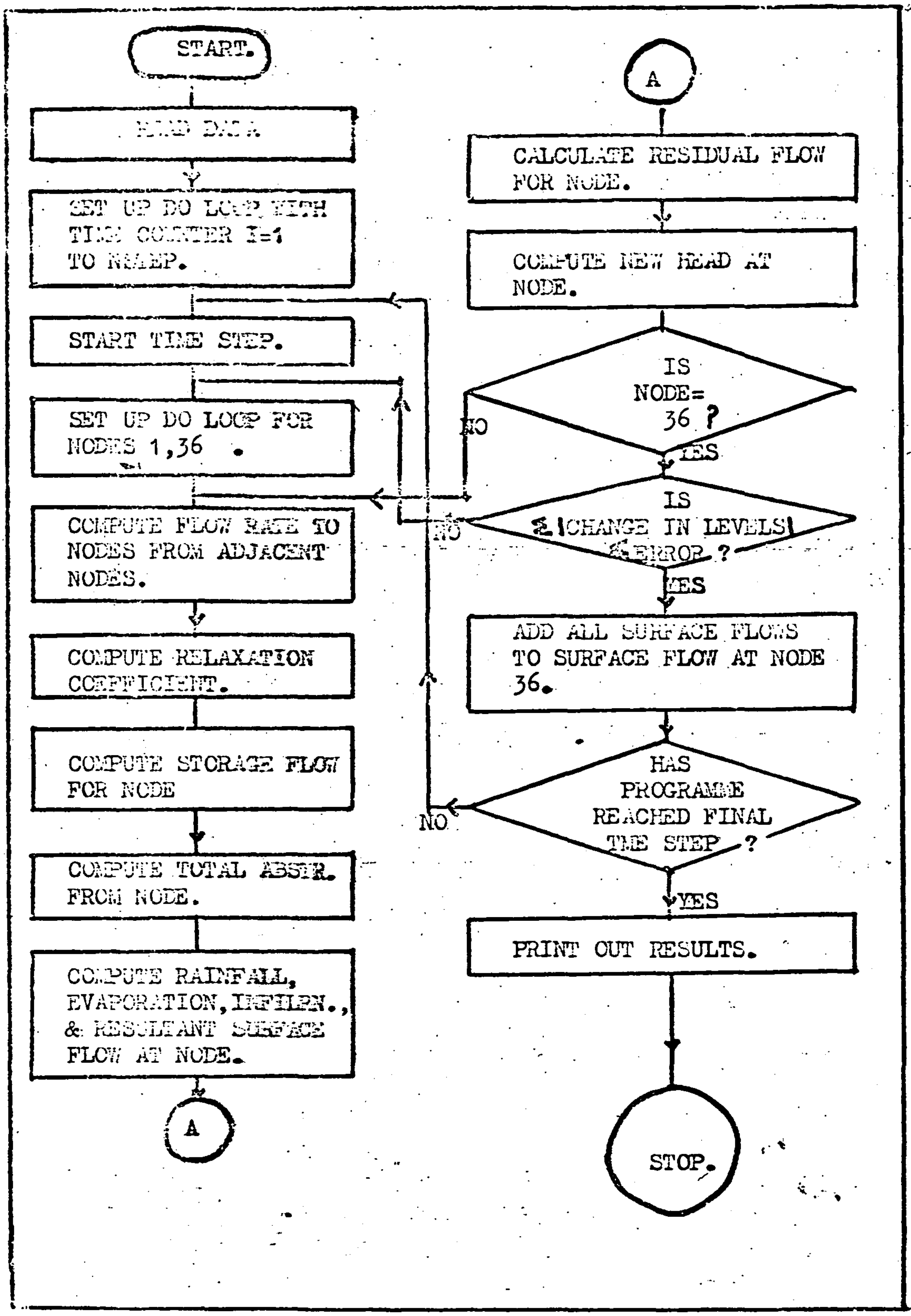
There follows a brief description of each section and where necessary these description will be amplified in a later section of the report.

1, 2 & 3 Reception and preparation of input data and display of same.

4 The introduction of root constant which affects the rate of actual evapotranspiration, this factor is discussed more fully in section 6.2.3.

5 Setting up of the monthly time cycle. During calibration model values are compared to field values at the end of every month.

FIGURE 6. Generalised Flow Diagram of the Programme.



6 Setting up of the time steps within the monthly cycle over which the iterative calculations are carried out.

7 The Do Loop for the iterative process.

8 The Do Loop for all nodes adjacent to the node under consideration as specified by section 7.

9 The calculation of Transmissivity and conductance of flow paths between the node under consideration and its adjacent nodes. The nature of the Transmissivity function is discussed more fully in section 6.2.1.

10 Calculation of the Relaxation Coefficient - as mentioned in section 3.2.3.

11 Calculation of storage flows by difference in level at node between current and previous timesteps.

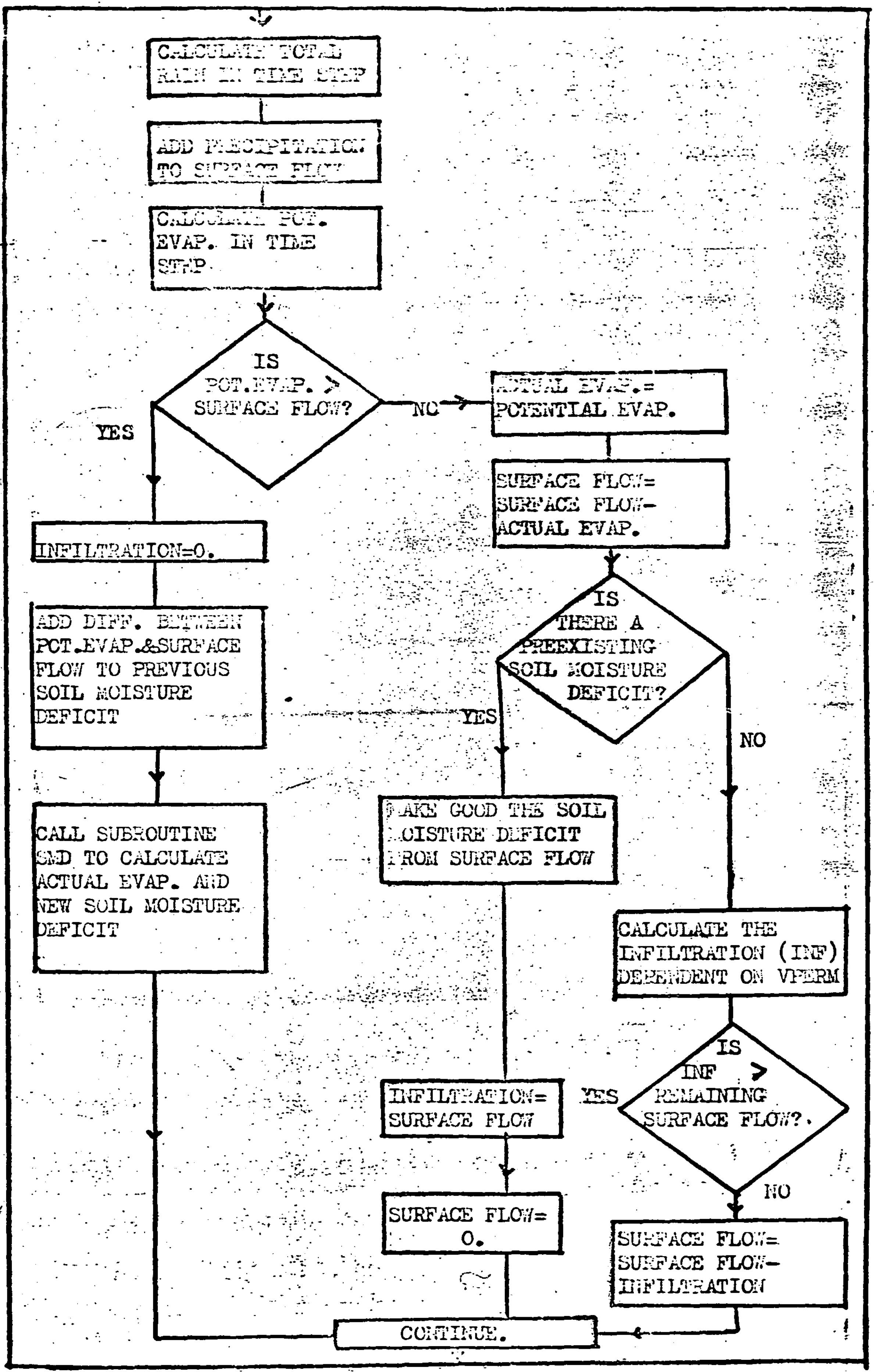
12 Calculation of Recharge/Abstraction.

13 This section involves the calculation of Nodal Rainfall, Evaporation, Soil Moisture Deficits and Infiltration. Figure 7 shows a generalised flow diagram of this particular section. Briefly the difference, if any, between rain and potential evaporation is added to surface flow. The resulting surface flow is then used to make good any soil moisture deficit remaining from the previous timestep and any surface flow then remaining is allowed to infiltrate to ground water.

14 The total of all flows into and out of the node are balanced to give a residual term RES.

15 The value of RES is used to adjust the nodal ground water level calculated during the previous iteration. If this calculation results in a ground water level greater than surface elevation then the level is restricted to the nodal surface elevation and the nodal rate of rising water, EXCSS, is set equal to RES.

FIGURE 7. Generalised flow diagram of section 13 of the program, the precipitation and evaporation calculatins.



16 The absolute difference in levels at each node between the current and previous time step is summed. If the resulting value is less than or equal to the threshold value ERROR the calculation of ground water levels is complete for the current time step - otherwise a further iteration is commenced.

17 If necessary the facility exists to allow a change in storage coefficient should conditions change from unconfined to confined. At present this has not proved necessary.

18 All nodal surface flows are added to the dambo surface flow at node 36 where surface water abstraction is carried out.

19 This section merely calculates the change in surface flow over the time step.

20 Printing of results.

PART 6 CALIBRATION

6.1. INTRODUCTION

The calibration of the digital model consisted of comparing model behaviour with field observations of ground water and surface water fluctuations over a fixed time period and making appropriate adjustments to the model input parameters. Such adjustments are recurring due to the limitations of input data, e.g. the uncertainty in potential evaporation estimates and root constant. Calibration is obviously a very lengthy process due to the number of alternative combinations of adjustments which can be made to the various parameters.

Generally the method used was to select T and S values based on analyses of the aquifer tests and examination of local hydrogeological conditions, and selecting trial potential evaporation figures the nodel was run - abstraction figures were considered to be accurate and no attempt was made to vary this parameter. On completion of a run comparison of model and field ground water levels and surface water flows were compared and adjustments made to bring the model into line with the field values. The nature of these adjustments depended on the type and degree of discrepancy between the field and model values.

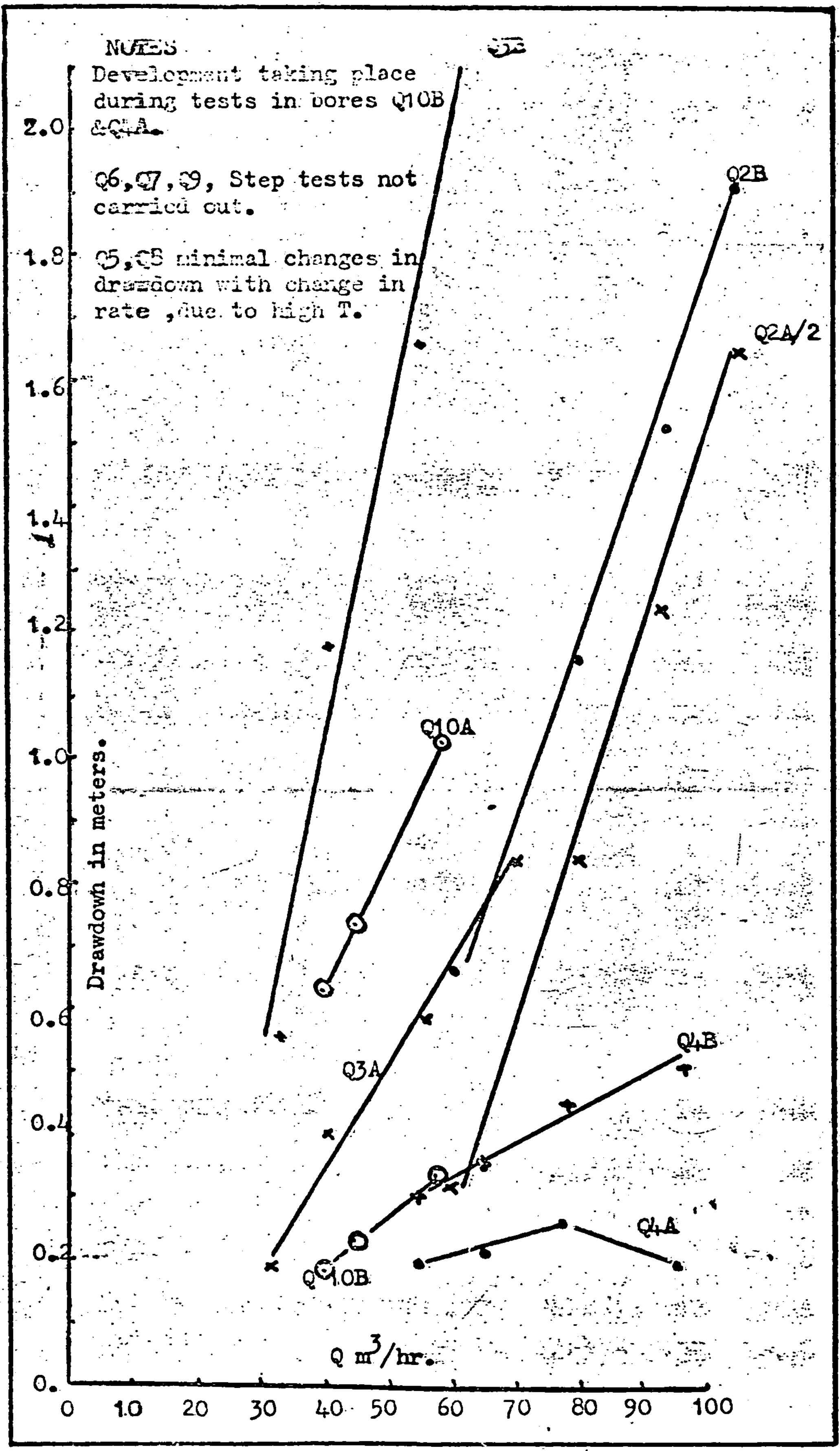
6.2. THE GROUND WATER REGIME

On field evidence the Kakontwe dolomite and limestone appears to be a non-porous and tightly bedded formation, the ground water movement within this formation predominantly occuring along open fissures and through caverns developed along joints and faults in the rock mass. Such conditions are generally considered to cause turbulent flow locally (i.e. in single fissures or caverns) but on a larger scale, as a greater number of fissures are considered, flow approximates to laminar conditions. It is partly for this reason that a finer nodal grid than the one used was rejected.

Turbulent flow conditions are normally expected to be set up close to a production well under these conditions during an aquifer test. However, the results of the step tests show that the relationship between discharge and drawdown in the observation bores was linear (see Figure 8) except in those bores where development was apparently continuing during the test. This linear relationship confirms laminar flow at the corresponding distances from the point of abstraction under the hydraulic gradients associated with the tests; an important point since it establishes that conventional groundwater hydraulics and pumping test analyses may be applied (Foster and Milton 1974). Thus under test conditions laminar flow exists at a distance of at least 8 m from the production bore, which indicates that Darcian flow theory may be safely used in the model under even greater gradients than those set up during the tests using the size of node shown in Figure 2, i.e. of the order of 2.5 km across.

Although the fissures in the aquifer do not apparently set up turbulent flow on a large scale they do affect the direction of flow. For example at all the test sites the local ground water gradients are deflected from 23° to as much as 174° from the anticipated direction of the regional gradient. The fissuring also gives rise to the compartmentalisation of the aquifer into distinct zones. For example the water table in the formation underlying Lake Chirengwa fluctuates seasonally by less than 1.5 metres, at an average elevation of 1262 metres whereas the short period on record of borehole Q7A at a distance of less than 1.5 kilometres away indicates a similar elevation but with greater variation in water level.

During calibration of the model reappraisal of field ground water levels was necessary in cases where difficulty was encountered in obtaining agreement between model and field values. Generally where a node centre coincided with a field observation well the monthly levels obtained from that well were initially used as nodal field levels to be calibrated against. However, further examination of field observations showed that the "central" well was not necessarily representative of the whole node. Figure 9 shows the relative positions of wells situated within node 11. Well 103 coincides



NOTES

Development taking place during tests in bores Q10B &Q4A.

Q6,Q7,Q9, Step tests not carried out.

Q5,Q8 minimal changes in drawdown with change in rate ,due to high T.

FIGURE 8 Plots of Discharge vs. Drawdown from observation bores during step tests.Straight line plots indicate laminar flow.

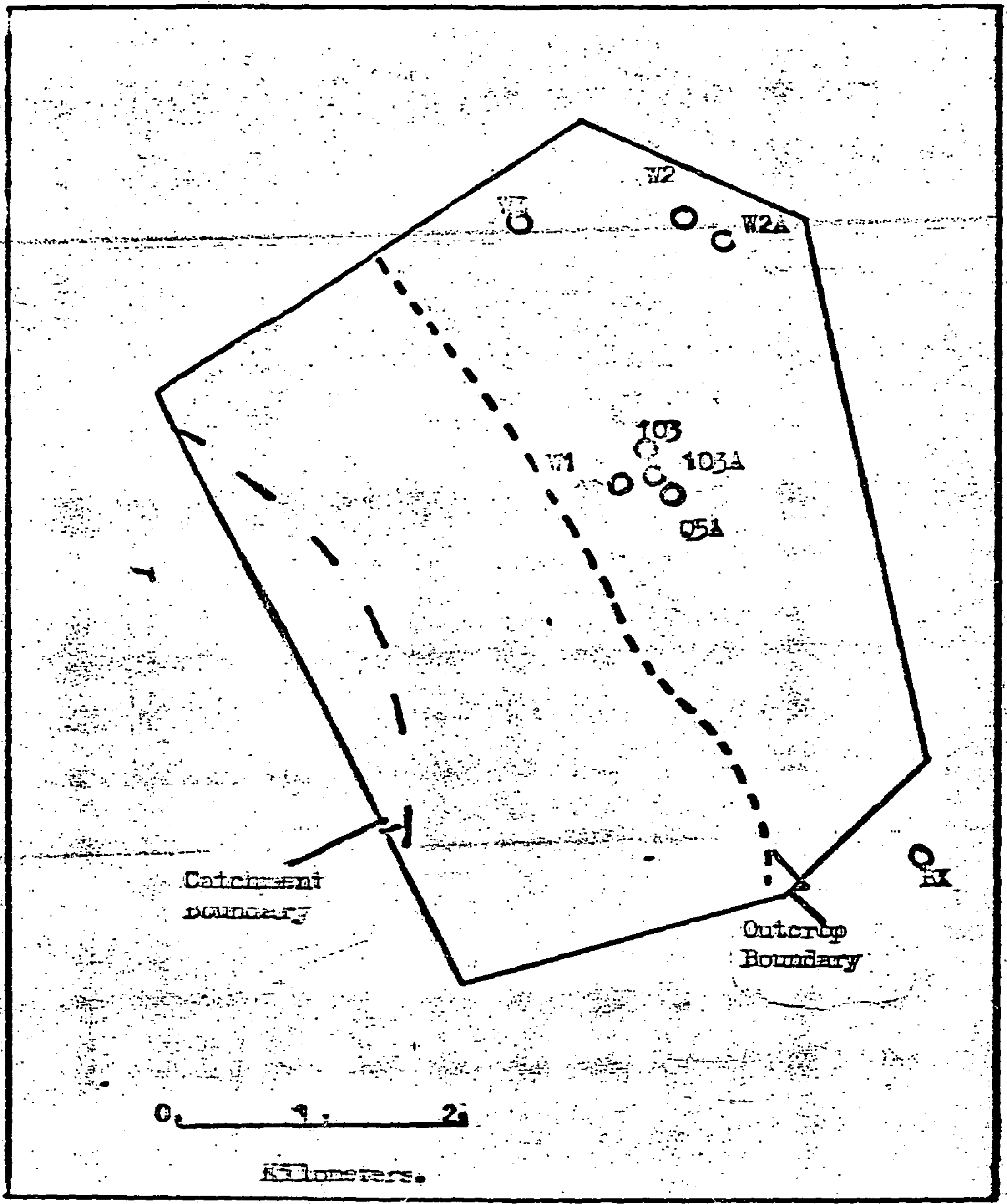


FIGURE 9. , Distribution of bore holes within Node 11.

with the node "centre" and was initially taken as the data point for that node. Figure 10 however, shows the variation between water levels in the various wells within node 11 and during calibration the model ground water levels for this node were found to correlate better with the levels of W2 and W3 rather than W103. This apparent variation is response of the aquifer over a relatively small distance can be explained in two ways. It is either the effect of shallow wells monitoring perched water tables rather than the aquifer's true piezometric surface or it is the effect of fissures resulting in compartmentalisation of the aquifer or even a combination of the two effects.

Apparent compartmentalisation of the aquifer is more pronounced in the south-eastern part of the catchment, the example of Lake Chirengwa has already been given. Another example is found in the region of nodes 28 and 33 where water level data from Lake Ishiku is very different to that from bore Q6A (both data points occurring in node 28). Whilst realising that the only well occurring in node 33, i.e. W34, is not representative of the piezometric surface of the Kakontwe (W34 probably being fed by upward percolation through the Mwashia Shales from the Roan Formation) it was originally assumed that the general direction of flow would follow the topographic surface, i.e. from node 33 towards node 28. However, the later evidence from bores Q6A and Q9A indicate that the reverse is probably true. Thus during the calibration period the field water level for node 28 was set at 6 m below that of node 26 (i.e. W32) as early data was not available for Q6A but later data showed Q6A to be approximately 6 m less than W32.

A more extreme effect of their compartmentalisation of the aquifer has been modelled by introducing an impermeable barrier boundary between nodes 22 and 24. The field indication of this boundary is given by the higher standing water levels observed at Lake Chirengwa and Q7 (nodes 22 and 17) over W17 (node 24). In the Colquhoun report it is suggested that such a barrier could be formed by belts of massive (unfissured) dolomite, dyke intrusions or local folds in the rock formation. If such a barrier is not modelled water levels in node 24 build up to values much greater than the

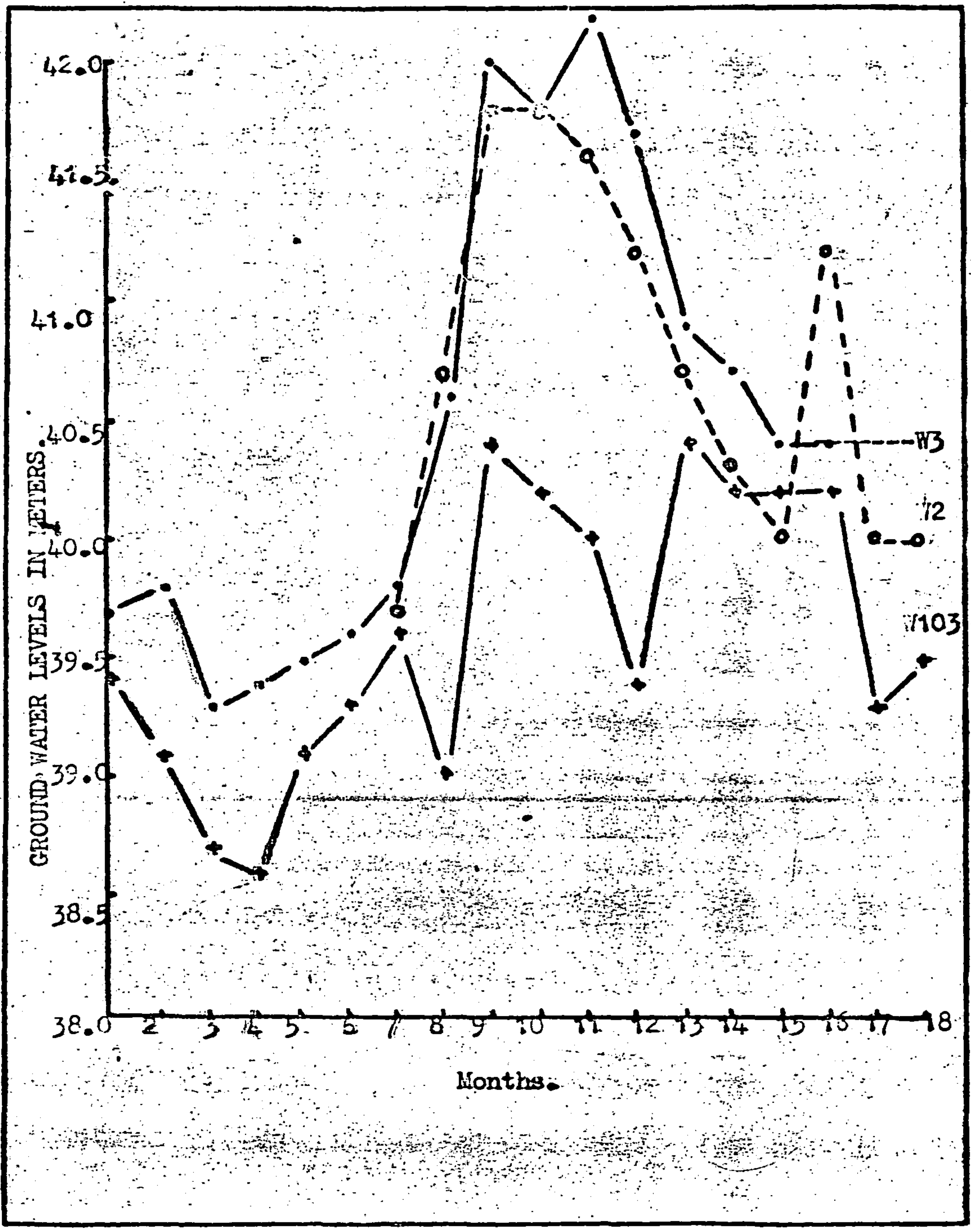
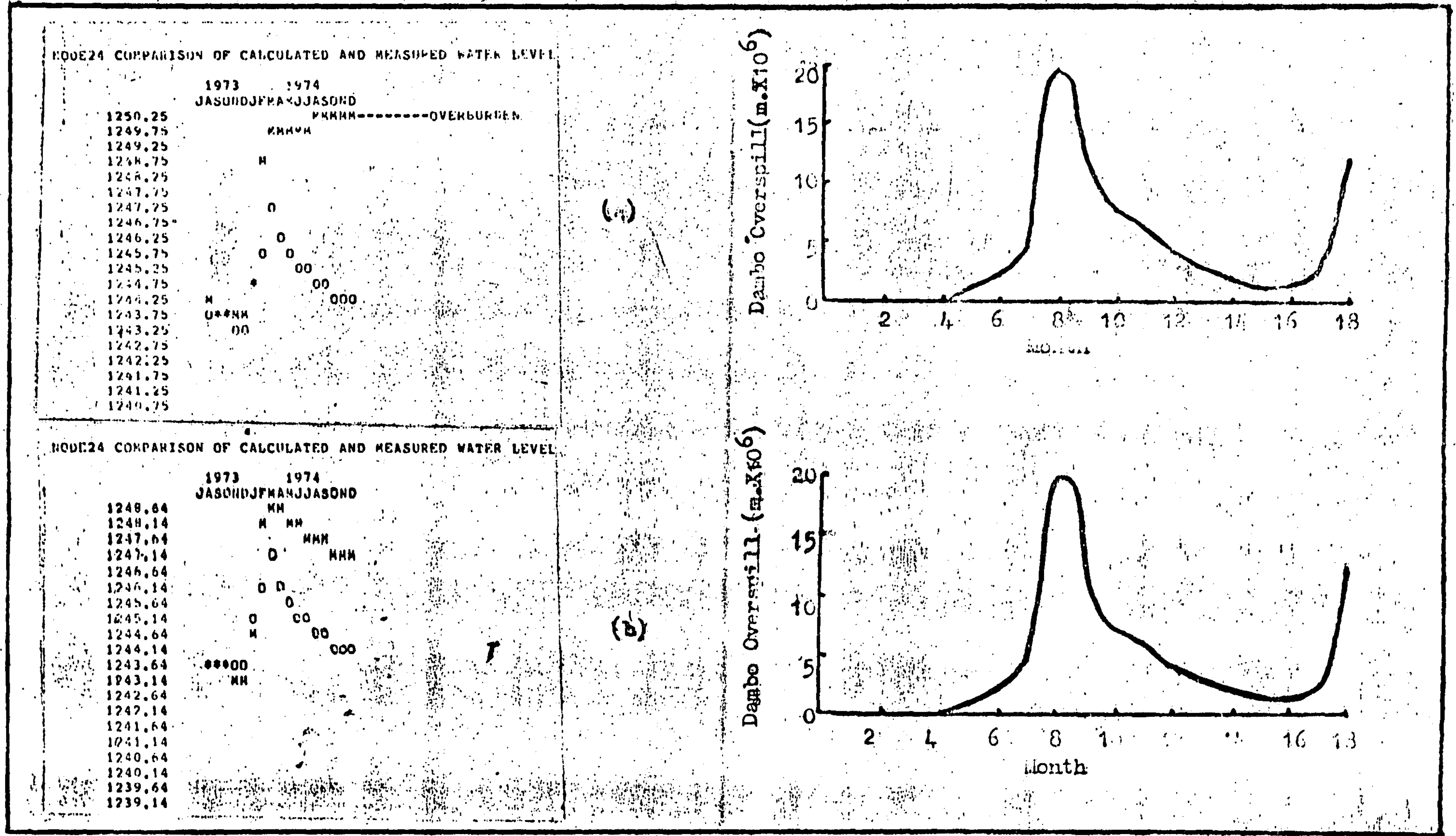


FIGURE 10. Ground Water Levels for selected bores within Node 11.

field values see Fig 11; such high levels can then only be controlled by introducing high nodal Transmissivity and storage values which are not justified by field tests. In spite of the large catchment area upstream of this barrier (approximately 20% of the total) very little effect on the surface flow and ground water levels downstream of this barrier (except for node 24) resulted from its introdüction. To the east of this boundary (nodes 22, 20, 18 and 17) there is very little ground water level information; only Lake Chirengwa and wells in node 17 definately penetrate the dolomite other wells reflecting water levels within the adjacent shales. On this evidence alone it is impossible to determine the direction of groundwater flow but previously both Hadwin and the Colquhoun report assumed the ground water contours followed topographic ones. However, with the introduction of a barrier between nodes 22 and 24 it is necessary to postulate flow in the reverse direction (modelled by a sink at node 17 or 18) to prevent ground water build up in node 22. The quantity of water involved is of the order of 1 000 000 m^3/month but on the data available it is difficult to determine the destination of this flow; probably the majority flows into Zaire but some no doubt feeds the seasonal swamp which occurs on the south eastern catchment boundary.

Nodes 14, 31, 34, 35 and 36 are all centred on areas of perennial swamp and so the ground water level input is given as being equal to surface elevation for all months of the calibration period.

Previous mention has been made of the fact that nodal outcrop area (AREA) is less than nodal catchment area (CAREA) for boundary nodes (c.f. section 3.1) and so although precipitation and evaporation are calculated using CAREA, changes in ground water level and ground water storage involve the use of AREA. However, for nodes on the north eastern border of the catchment (i.e. 3, 7, 9, 13, 30, 24, 22 and 17) AREA is put equal to CAREA although outcrop area is less than catchment area for these nodes. The reason for this is that the Border Formation is not a true acquiclude boundary being merely a "capping" of rocks on the Kakontwe and so the groundwater fluctuations will occur over CAREA and not AREA.



```
NODE24 COMPARISON OF CALCULATED AND MEASURED WATER LEVEL

                 1973     1974
                JASONDJFMAMJJASOND
      1250.25                MMMM---------OVERBURDEN
      1249.75           MMMMM
      1249.25
      1248.75          M
      1248.25
      1247.75
      1247.25           0
      1246.75
      1246.25            0
      1245.75          0  0
      1245.25              00
      1244.75         *      00
      1244.25     M             000
      1243.75     0**MM
      1243.25        00
      1242.75
      1242.25
      1241.75
      1241.25
      1240.75
```

```
NODE24 COMPARISON OF CALCULATED AND MEASURED WATER LEVEL

                 1973     1974
                JASONDJFMAMJJASOND
      1248.64           MM
      1248.14          M  MM
      1247.64                MMM
      1247.14           0      MMM
      1246.64
      1246.14          0 0
      1245.64             0
      1245.14         0    00
      1244.64         M      00
      1244.14                  000
      1243.64     ***00
      1243.14        MM
      1242.64
      1242.14
      1241.64
      1241.14
      1240.64
      1240.14
      1239.64
      1239.14
```

FIGURE 11. Ground water level plots for Node 24 and Dambo overspill plots for Model runs 679 &680,(a) & (b) respectively. Barrier boundary between Nodes 22&24 present in (b) only. Note surface flow not changed.

6.3. DEVELOPMENTS DURING CALIBRATION

6.3.1. Transmissivity Function

In the early stages of calibration a constant transmissivity value was applied to each flow path which was later modified to give linear variation with water level. However, it was found necessary to modify this function further. Using a linear increase in T with water level tended to result in the model giving high peak surface flows in months of high rainfall and surface flows below field values in months of low rainfall. It was necessary to delay the rate at which water was leaving the system as surface flow in month 8 and allow it to leave during the succeeding dryer months where model surface flows were low i.e. it was necessary to alter the model's basic response to precipitation. A solution to this problem was found in the concept of zonal transmissibility.

From field evidence (chiefly the borehole logs) and the results obtained during calibration of the model it would appear that the transmissivity in the upper part of the aquifer, i.e. the zone of fluctuation of the water level, is higher than in that part of the aquifer below this zone. Figure 12 indicates the probable shape of transmissibility function and the way in which it has been approximated in the model. As this function is no longer smooth non-convergence of water levels can result with oscillations occuring during successive iterations about the points of inflection. Such oscillations can be prevented by several means:

(i) decreasing the time step

(ii) decreasing the contrast between the max. and min. T values

(iii) increasing the SPRED factor such that the function gives a closer approximation to a smooth function.

Figure 12 shows that a definition of a Base line is critical for the operation of this function. A generalised plot of field nodal water levels is shown in Figure 13; it can be seen that ground water levels rise rapidly in months 7 and 8 when the rainfall reaches a peak and then drop as recharge to the aquifer decreases. The positioning of the base line was chosen to be

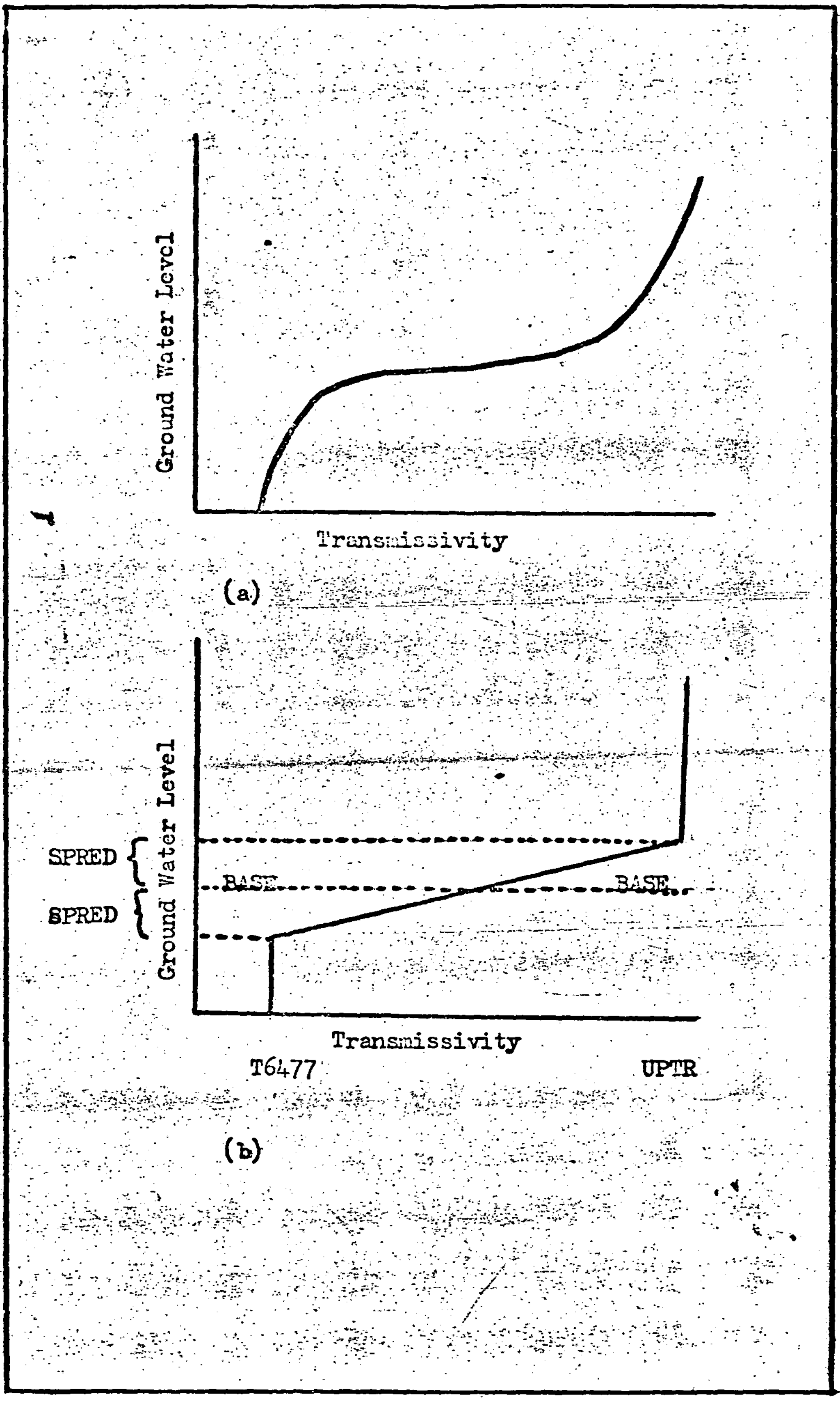


FIGURE 12. (a) Probable aquifer Transmissivity function

(b) Model Transmissivity function (in final model SPRED=1m.)

higher than the ground water level at about month 6 and 18. The justification of the function is that in karstic limestones the portion of the aquifer in the zone of ground water level fluctuation generally has a higher permeability than the lower zones due to solution processes and also from the drilling logs of the area there is evidence of decreased fissuring with depth.

Use of this transmissibility function in the model has achieved improved correlation between model and field values of ground water levels and surface flows. However, the aquifer tests which formed the basis of initial Transmissivity estimates for the model were carried out between October 1974 and March 1975 whereas the maximum ground water levels were reached in Many and June of 1975 for that particular water year. Thus if the concept of zonal transmissivity is correct the aquifer test results only give estimates for the lower transmissivity values and not the higher ones. To ascertain the validity of this concept aquifer tests would need to be carried out during a period of high ground water levels. Table 2 shows the internodal transmissivity values used in the final model run.

6.3.2. Storage Function

The concept of zonal storage follows from the idea of zonal transmissibility in karstic aquifers i.e. in the zone of ground water level fluctuation, solution cavities and widened fissures will increase the effective storage of this zone. In the model the facility exists for the storage coefficient to be increased once the nodal ground water level rises above the BASE level of Figure 13. (The programming of this function differs slightly from the transmissivity function in that transmissivity is applied on an inter-nodal basis and storage on a nodal basis).

Table 3 shows the upper and lower storage coefficients used in modelling the zonal storage effect. As mentioned in section 4.3.2. the very high storage coefficients ~~used~~ for some nodes are used as a simple means of modelling the storage of the overburden at boundary nodes.

TABLE 2(A)

16477.LOWER INTERNODAL ZONAL TRANSMISSIVITY VALUES. I.E. VALUES BELOW BASE. (m^3/day/m)

NODE	ADJ1	ADJ2	ADJ3	ADJ4	ADJ5	ADJ6
1	(3).0	(0).0	(0).0	(0).0	(0).0	(0).0
2	(3).0	(0).0	(0).0	(0).0	(0).0	(0).0
3	(10).0	(2).0	(5).0	(7).10000E+04	(0).0	(0).0
4	(5).0	(0).0	(0).0	(0).0	(0).0	(0).0
5	(3).0	(4).0	(7).0	(11).10000E+03	(9).20000E+03	(0).0
6	(7).0	(0).0	(0).0	(0).0	(0).0	(0).0
7	(3).10000E+04	(5).0	(6).0	(9).50000E+04	(0).0	(0).0
8	(9).0	(0).0	(0).0	(0).0	(0).0	(0).0
9	(5).20000E+03	(7).50000E+04	(11).0	(8).0	(14).50000E+04	(13).0
10	(11).0	(0).0	(0).0	(0).0	(0).0	(0).0
11	(5).10000E+03	(10).0	(9).0	(14).80000E+04	(35).10000E+04	(0).0
12	(13).0	(0).0	(0).0	(0).0	(0).0	(0).0
13	(9).0	(14).10000E+04	(12).0	(30).0	(0).0	(0).0
14	(11).80000E+04	(9).50000E+04	(13).10000E+04	(35).10000E+04	(30).0	(0).0
15	(17).0	(0).0	(0).0	(0).0	(0).0	(0).0
16	(22).0	(20).0	(17).0	(0).0	(0).0	(0).0
17	(16).0	(18).50000E+02	(15).0	(0).0	(0).0	(0).0
18	(20).50000E+02	(17).50000E+02	(0).0	(0).0	(0).0	(0).0
19	(20).0	(0).0	(0).0	(0).0	(0).0	(0).0
20	(22).50000E+02	(16).0	(19).0	(18).50000E+02	(0).0	(0).0
21	(22).0	(0).0	(0).0	(0).0	(0).0	(0).0
22	(24).0	(21).0	(16).0	(20).50000E+02	(0).0	(0).0
23	(24).0	(0).0	(0).0	(0).0	(0).0	(0).0
24	(30).0	(31).50000E+02	(28).0	(23).0	(22).0	(0).0
25	(26).0	(0).0	(0).0	(0).0	(0).0	(0).0
26	(28).50000E+02	(25).0	(0).0	(0).0	(0).0	(0).0
27	(28).0	(0).0	(0).0	(0).0	(0).0	(0).0
28	(33).0	(34).20000E+02	(31).20000E+02	(24).0	(27).0	(26).50000E+02
29	(30).0	(0).0	(0).0	(0).0	(0).0	(0).0
30	(14).0	(13).0	(35).50000E+02	(29).0	(31).50000E+02	(24).0
31	(35).50000E+02	(30).50000E+02	(34).50000E+02	(28).20000E+02	(24).50000E+02	(0).0
32	(33).0	(0).0	(0).0	(0).0	(0).0	(0).0
33	(36).50000E+02	(32).0	(34).50000E+02	(28).0	(0).0	(0).0
34	(36).10000E+04	(35).10000E+03	(33).50000E+02	(31).50000E+02	(28).20000E+02	(0).0
35	(11).10000E+04	(14).10000E+04	(36).92000E+03	(30).50000E+02	(34).10000E+03	(31).50000E+02
36	(35).92000E+03	(33).50000E+02	(34).10000E+04	(0).0	(0).0	(0).0

UPTR. UPPER INTERNODAL ZONAL TRANSMISSIVITY VALUES, I.E. VALUES ABOVE BASE. (m^3/day/m)

```
NODE       ADJ1                ADJ2                ADJ3                ADJ4                ADJ5                ADJ6
   1 ( 3).0              ( 0).0              ( 0).0              ( 0).0              ( 0).0              ( 0).0
   2 ( 3).0              ( 0).0              ( 0).0              ( 0).0              ( 0).0              ( 0).0
   3 (10).0              ( 2).0              ( 5).0              ( 7).18000E+05/( 0).0              ( 0).0
   4 ( 5).0              ( 0).0              ( 0).0              ( 0).0              ( 0).0              ( 0).0
   5 ( 3).0              ( 4).0              ( 7).0              (11).70000E+03 ( 9).25000E+04 ( 0).0
   6 ( 7).0              ( 0).0              ( 0).0              ( 0).0              ( 0).0              ( 0).0
   7 ( 3).18000E+05 ( 5).0              ( 6).0              ( 9).33000E+05 ( 0).0              ( 0).0
   8 ( 9).0              ( 0).0              ( 0).0              ( 0).0              ( 0).0              ( 0).0
   9 ( 5).25000E+04 ( 7).33000E+05 (11).0              ( 8).0              (14).33000E+05 (13).0
  10 (11).0              ( 0).0              ( 0).0              ( 0).0              ( 0).0              ( 0).0
  11 ( 5).70000E+03 (10).0              ( 9).0              (14).20000E+05 (35).10000E+04 ( 0).0
  12 (13).0              ( 0).0              ( 0).0              ( 0).0              ( 0).0              ( 0).0
  13 ( 9).0              (14).60000E+04 (12).0              (30).0              ( 0).0              ( 0).0
  14 (11).20000E+05 ( 9).33000E+05 (13).60000E+04 (35).10000E+04 (30).0              ( 0).0
  15 (17).0              ( 0).0              ( 0).0              ( 0).0              ( 0).0              ( 0).0
  16 (22).0              (20).0              (17).0              ( 0).0              ( 0).0              ( 0).0
  17 (16).0              (18).20000E+04 (15).0              ( 0).0              ( 0).0              ( 0).0
  18 (20).20000E+04 (17).20000E+04 ( 0).0              ( 0).0              ( 0).0              ( 0).0
  19 (20).0              ( 0).0              ( 0).0              ( 0).0              ( 0).0              ( 0).0
  20 (22).50000E+04 (16).0              (19).0              (18).20000E+04 ( 0).0              ( 0).0
  21 (22).0              ( 0).0              ( 0).0              ( 0).0              ( 0).0              ( 0).0
  22 (24).0              (21).0              (16).0              (20).50000E+04 ( 0).0              ( 0).0
  23 (24).0              ( 0).0              ( 0).0              ( 0).0              ( 0).0              ( 0).0
  24 (30).0              (31).40000E+04 (28).0              (23).0              (22).0              ( 0).0
  25 (26).0              ( 0).0              ( 0).0              ( 0).0              ( 0).0              ( 0).0
  26 (28).35000E+04 (25).0              ( 0).0              ( 0).0              ( 0).0              ( 0).0
  27 (28).0              ( 0).0              ( 0).0              ( 0).0              ( 0).0              ( 0).0
  28 (33).0              (34).40000E+03 (31).40000E+03 (24).0              (27).0              (26).35000E+04
  29 (30).0              ( 0).0              ( 0).0              ( 0).0              ( 0).0              ( 0).0
  30 (14).0              (13).0              (35).40000E+04 (29).0              (31).40000E+04 (24).0
  31 (35).40000E+04 (30).40000E+04 (34).15000E+04 (28).40000E+03 (24).40000E+04 ( 0).0
  32 (33).0              ( 0).0              ( 0).0              ( 0).0              ( 0).0              ( 0).0
  33 (36).30000E+03 (32).0              (34).30000E+03 (28).0              ( 0).0              ( 0).0
  34 (36).15000E+04 (35).15000E+04 (33).30000E+03 (31).15000E+04 (28).40000E+03 ( 0).0
  35 (11).10000E+04 (14).10000E+04 (36).15000E+04 (30).40000E+04 (34).15000E+04 (31).40000E+04
  36 (35).15000E+04 (33).30000E+03 (34).15000E+04 ( 0).0              ( 0).0              ( 0).0
```

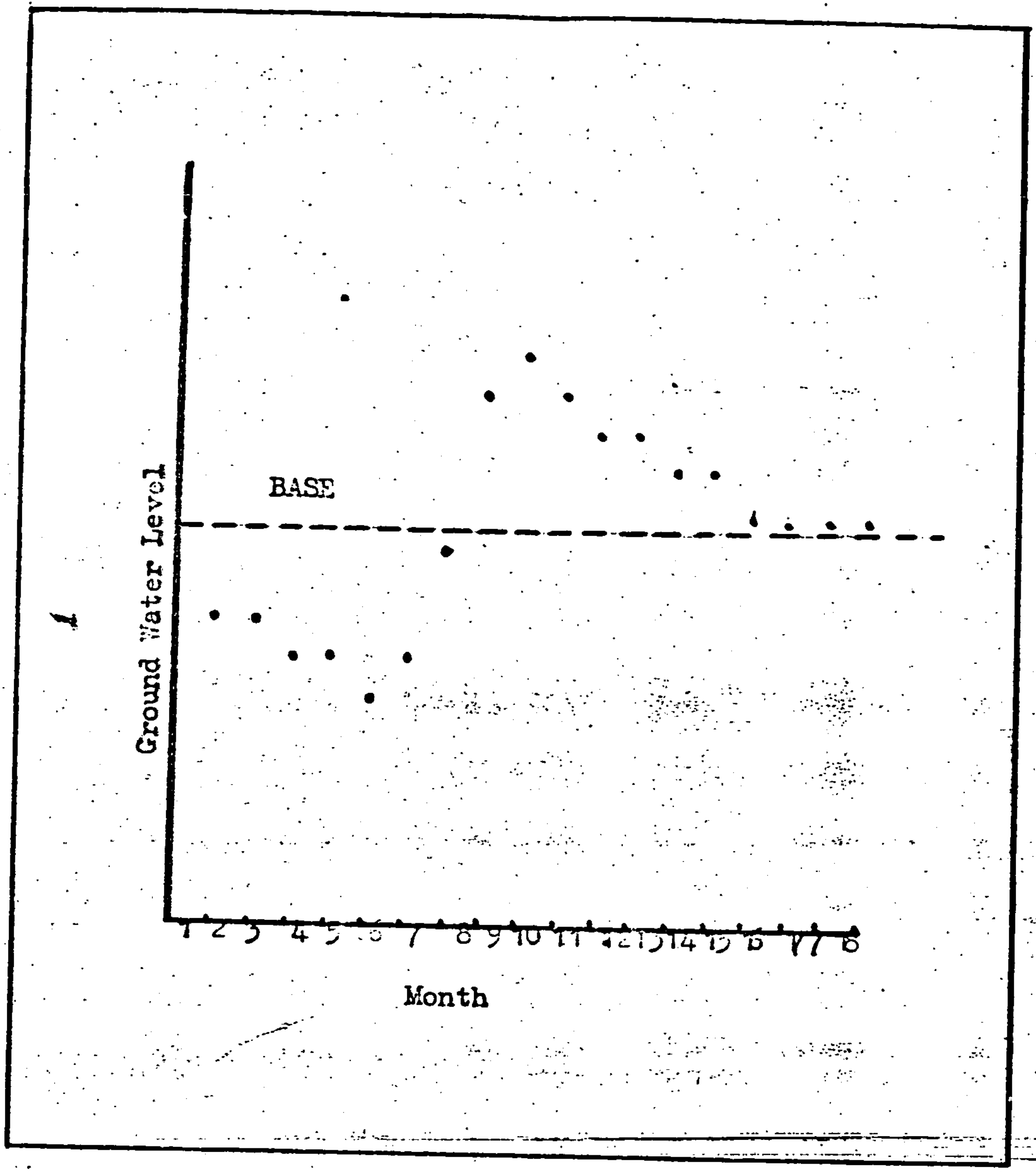


FIGURE 13. Generalised plot of field ground water level data showing position of BASE, the point of change of T and S.

TABLE 3

ZONAL STORAGE COEFFICIENTS

NODE	STOR.COEFF.ABOVE BASE (SCON)	STOR.COEFF.BELOW BASE (SCK)
1	.0800	.0500
2	.0800	.0500
3	.3000	.0500
4	.0800	.0500
5	.1500	.0200
6	.0800	.0500
7	.1000	.0500
8	.0800	.0500
9	.2000	.0700
10	.0800	.0500
11	.2000	.0500
12	.0800	.0500
13	.0300	.0100
14	.0800	.0500
15	.0800	.0500
16	.0800	.0500
17	.0800	.0020
18	.5000	.5000
19	.0800	.0500
20	.2000	.0500
21	.0800	.0500
22	.2000	.0500
23	.0800	.0500
24	.1500	.0500
25	.0800	.0500
26	.2000	.0500
27	.0800	.0500
28	.0600	.0500
29	.0800	.0500
30	.2000	.0500
31	.0600	.0500
32	.0800	.0500
33	.1000	.0100
34	.0800	.0500
35	.0800	.0500
36	.0800	.0500

6.3.3. Actual Evapotranspiration

All of the methods of estimating potential evaporation shown in Table 1 assume that water is freely available whereas of course actual evapotranspiration losses are dependent on soil type and type of cover. In the Colquhoun report only two categories of cover were distinguished in calculation of the water balance; open water and perrenial swamp being considered separate from all other cover. The ratio of actual evapotranspiration to potential was taken as a uniform 1.0 over the whole year for open water and swamps and the monthly ratios for other areas were, "assumed approximating to water availability". Although this method will of course achieve a good water balance such monthly coefficients for calculating actual evapotranspiration are difficult to justify and as the Colquhoun report admits such estimates do suffer "lack of precision".

Examination of the evapotranspiration losses calculated by this method as shown in Tables 8.4.1. and 2. of the Colquhoun report indicate the nature of the error involved. For example, during the month of October 1974 when precipitation was only 0.6 $m^3 \times 10^6$, ground losses of -43.2 $m^3 \times 10^6$ are calculated following four months of zero rainfall. It should also be noted that during those four preceeding months ground losses totalled 45.2 $m^3 \times 10^6$ indicating that a reasonably large soil moisture deficit would have built up. It is difficult to see in this case the relationship between the "Average Coefficient" and ground water availability. The error of this method is also seen by comparing the evapotranspiration losses given in Tables 8.4.1. and 2. of the Colquhoun report with the mean values calculated by Hadwin (1972) for the same catchment. Figure 14, in comparing the two sets of values, shows an error in the phase of the Colquhoun figures. In order to overcome such problems in the calculation of actual evapotranspiration it was found necessary to introduce a Soil Moisture Deficit facility. Soil Moisture Deficits are considered to have been set up when evapotranspiration exceeds precipitation and vegetation has to draw on reserves of water in the soil to satisfy transpiration requirements. The facility for estimating soil

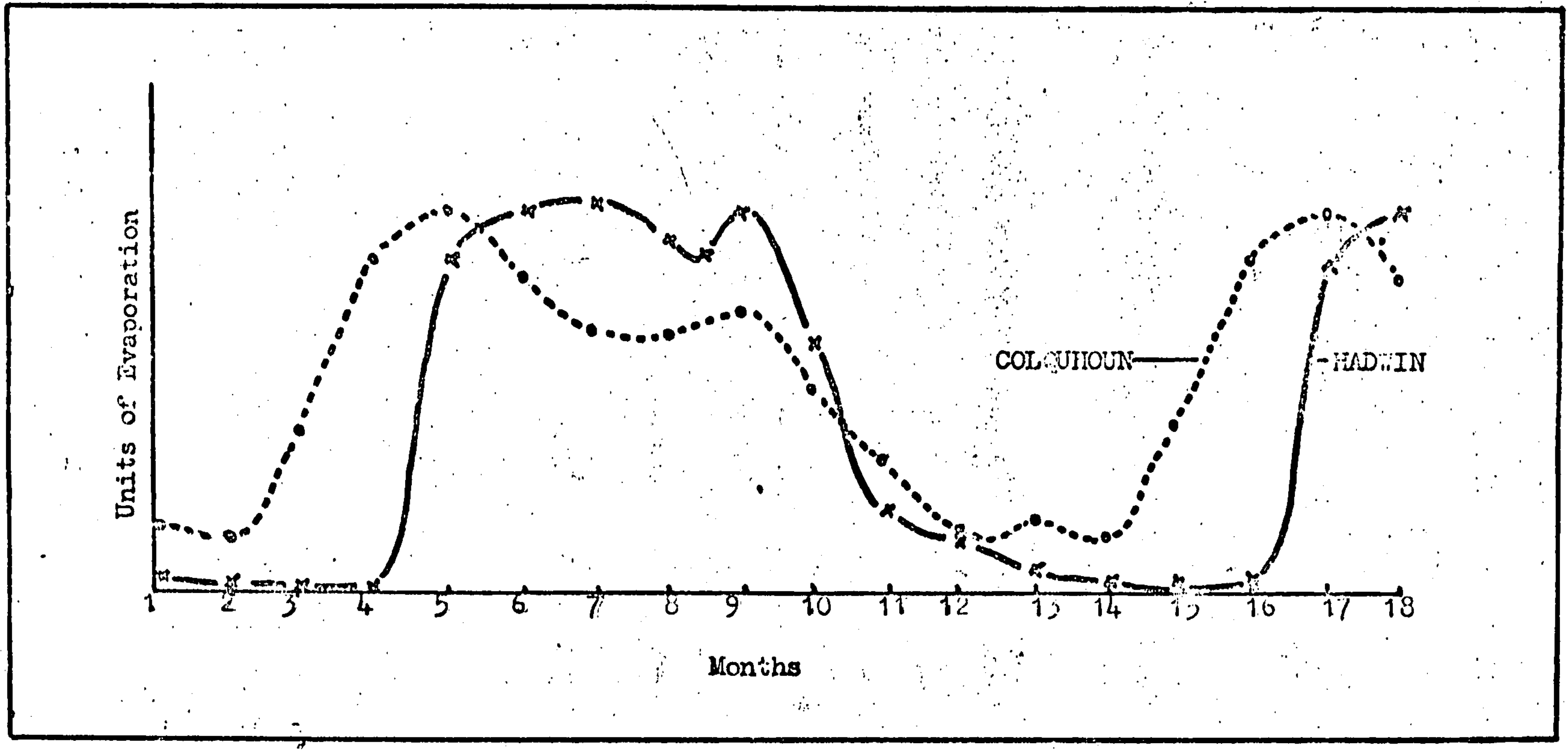


FIGURE 14. Comparison of Hadwin's and the Colquhoun estimates of actual evaporation showing a phase difference between the two (N.B. vertical scale of plots not equal)

moisture deficits takes into account the fact that vegetation has increasing difficulty in extracting moisture from the soil as accumulated potential evapotranspiration becomes greater than accumulated rainfall. The Meteorological Office (1971) state, "the point at which actual evapotranspiration starts to fall below potential and the rate at which the discrepency increases presents one of the most controversial aspects of soil physics". The point at which actual evapotranspiration falls below potential is called the Root Constant; once the root constant has been exceeded the rate at which the discrepancy increases is based on the scheme proposed by Penman (1949) and explained by the Met Office (1971) - this rate, as applied in the model is shown in Table 4.

Potential Evapotrans	4/3R	5/3R	2R	7/3R	10/3R
Actual Evapotrans	.96P	.68P	.52P	.40P	.28P

where R = Root Constant and P = Potential Evapotranspiration

Table 4

The effect of the soil moisture deficit facility is briefly this:

(a) In months when rainfall is greater than potential evaporation, model evapotranspiration is equal to potential.

(b) In months when rainfall is less than potentail evapotranspiration model evapotranspiration differs from potential according to Table 4.

(c) When rainfall once more exceeds potential evaporation the excess rain restores the soil moisture deficit in preference to either infiltrating the ground water or increasing the surface flow.

Figure 15 shows that using this facility gives comparable phasing of evapotranspiration losses as compared to Hadwin.

6.4. SENSITIVITY ANALYSES

6.4.I. Introduction

In the course of calibration sensitivity analyses clearly showed the

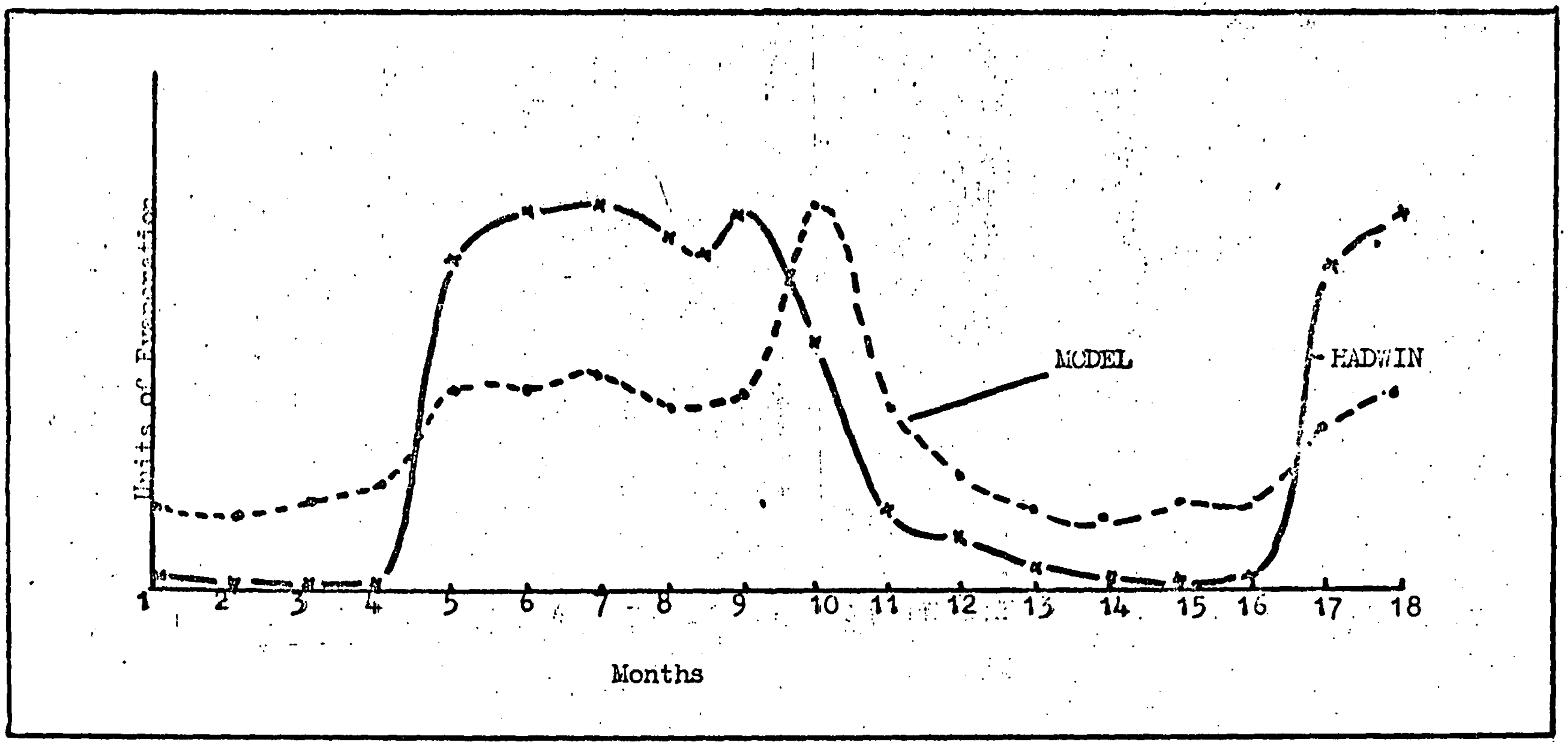


FIGURE 15. Comparison of Hadwin's and the model's values of actual evaporation, showing the same phasing (N.B. vertical scale of plots not equal)

effect of varying the various parameters on both ground water levels and surface flows - whether over the whole area or for individual nodes. The several parameters which can justifiably be altered during calibration are obviously interactive with each other but briefly their effects on the model can be summarised as follows:

(i) Transmissivity. Increased T reduced mean model water level and vice versa.

(ii) Storage Coefficient. Increased S reduced the amplitude of seasonal ground water level fluctuation and vice versa.

(iii) Root Constant. Increased root constant allowed actual evaporation to become nearer potential and therby increase soil moisture deficits. Thus in months where rainfall was greater than evaporation the excess rain initially made good soil moisture deficits before recharging ground water and/or surface flow.

(iv) Vertical Permeability. By varying the vertical permeability of the overburden the percentage of precipitation which infiltrates can be controlled.

(v) Evaporation. The Colquhoun report given several estimates of potential evaporation; obviously the actual evaporation is directly dependent on the potential.

6.4.2. Results

The following discussion refers to Figures 16 - 42 which show:

(i) the model surface flows over the causeway (Figures 16 - 24)

(ii) the model ground water levels for each node compared to the field values (Figures 25 - 42). Nodes 17, 18, 20 and 22 are not included as not enough field data is available to allow successful modelling of this area. On these plots 'M' represents the model value, 'O' the observed and an '*' is printed where the two coincide.

These plots indicate the effect of varying the different parameters. Figures 16, 25 and 26 show the plots of surface flow and ground water levels taken from the final calibration run which is taken as the standard. The

Transmissivity and Storage Coefficient values are as shown in Tables 2 and 3 respectively, a root constant of 100 mm is used and the potential evaporation figures used are those of Turc (see Table 1) decreased by a factor of 0.75.

Figures 17, 18, 27, 28, 29 and 30 show the effect of varying the root constant. By decreasing the root constant to 75 mm (Figs 17, 27 and 28) actual evaporation during times of zero or low rainfall is decreased thus increasing both surface flow and ground water levels. The reverse of this effect is shown in Figures 18, 29 and 30 where the root constant has been increased to 200 mm.

By having no zonal increase in storage (i.e. by putting the variable SCON equal to the variable SEK) the aquifers response to rainfall will be increased and thus both surface flows and ground water levels during months of high rainfall (e.g. Feb – May 1973) will be increased, see Figures 19, 31 and 32. By increasing the zonal increase in storage by a factor of 2 over the standard run shown in Figure 16 more water is taken into storage in the aquifer during months of high rainfall thus decreasing the peaks shown in Figures 19, 31 and 32 - see Figures 20, 33 and 34.

The effect of having no zonal increase in Transmissivity (i.e. by putting the variable UPTR equal to the variable T6477) is shown in Figures 21, 33 and 34. This decrease in transmissivity coupled with no alteration in zonal storage effectively increases ground water levels. The program was run with the upper value of zonal transmissivity (see Table 2B) increased by a factor of 10 but this did not result in convergence with the time step used.

Figures 22, 37, 38, 23, 39, 40, 24, 41 and 42 show the effect of using the Turc, Aune and Blaney Criddle estimates of potential evaporation (see Table 1). As is to be expected an increase in evaporation decreases both surface flows and ground water levels.

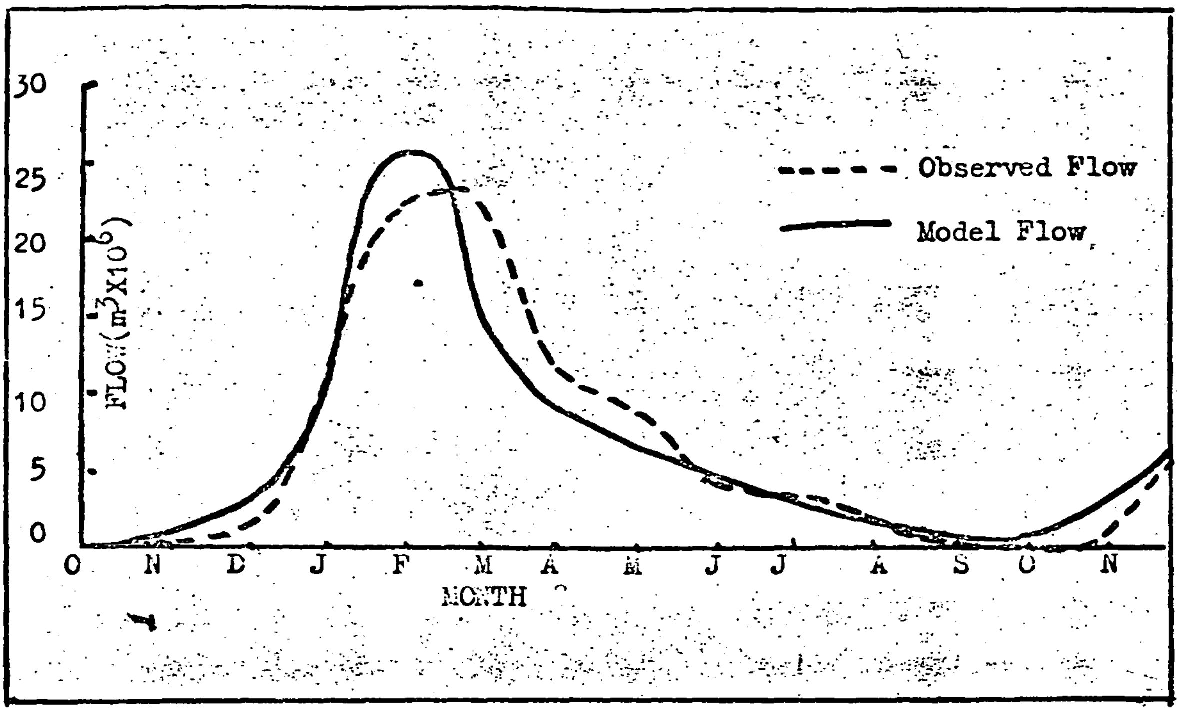


FIGURE 16. Comparison of model and field values of surface flow over the causeway for the standard run.

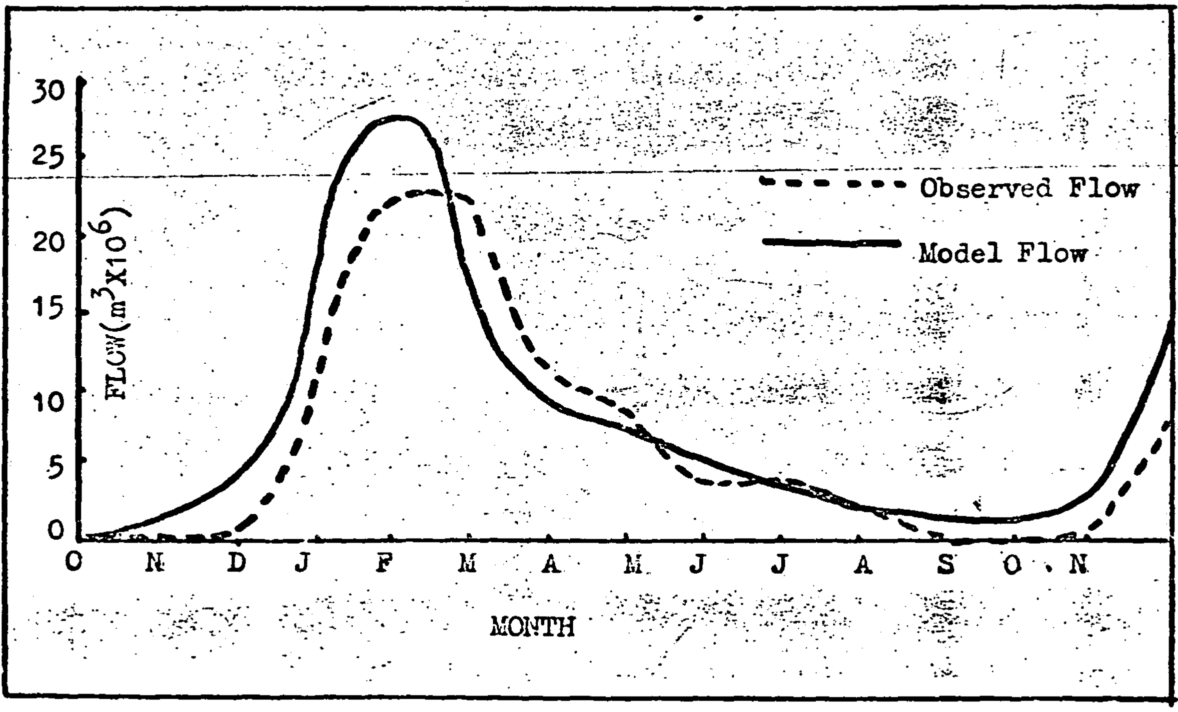


FIGURE 17. Comparison of model and field values of surface flow over the causeway using a Root Constant of 75mm.

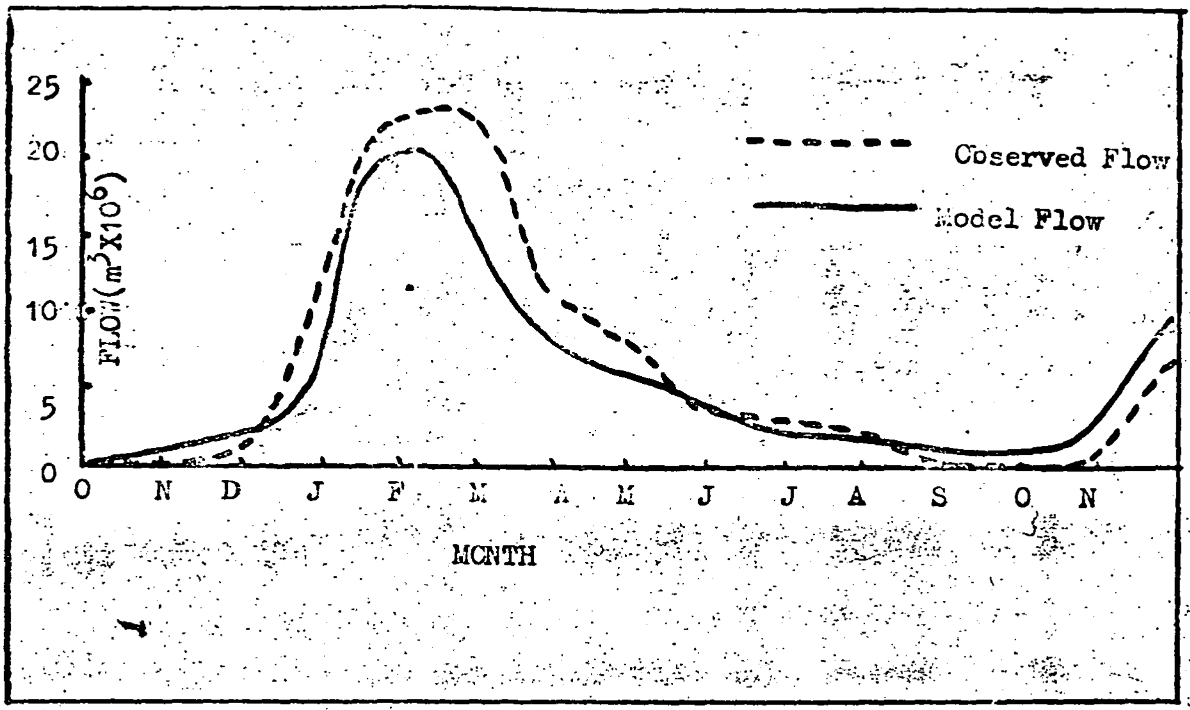


FIGURE 18. Comparison of model and field values of surface flow over the causeway using aRoot Constant of 200mm.

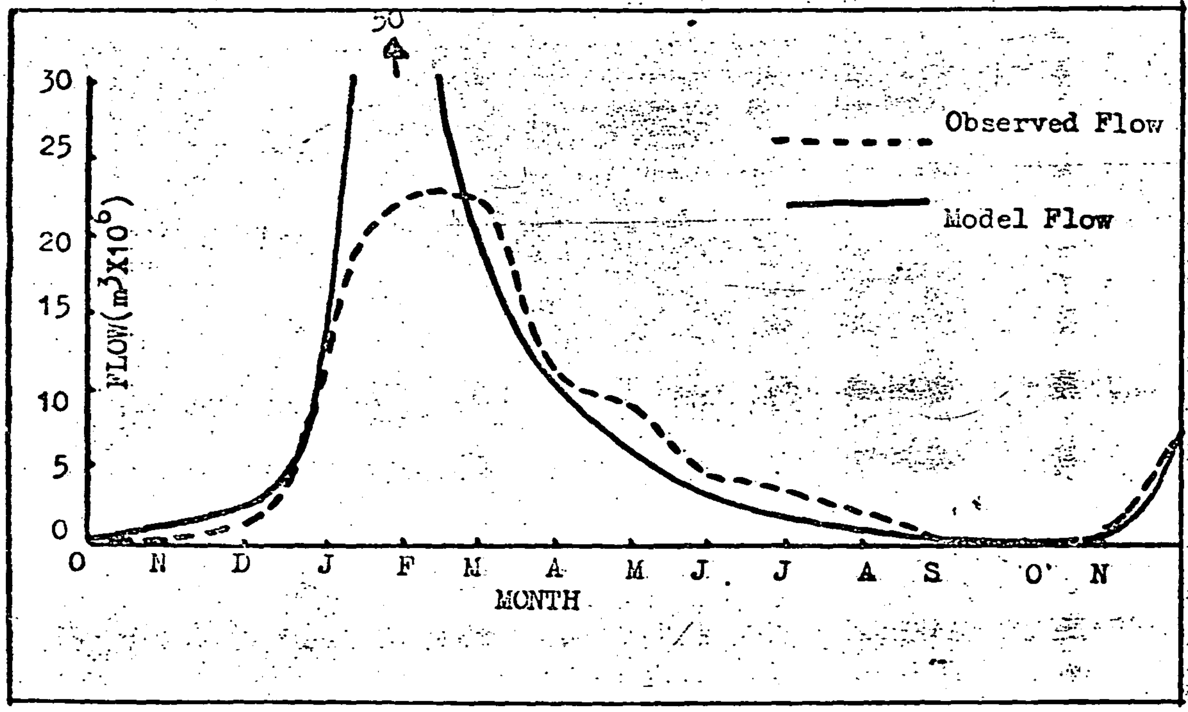


FIGURE 19. Comparison of model and field values of surface flow over the causeway with no increase in storage above 'BASE' level.

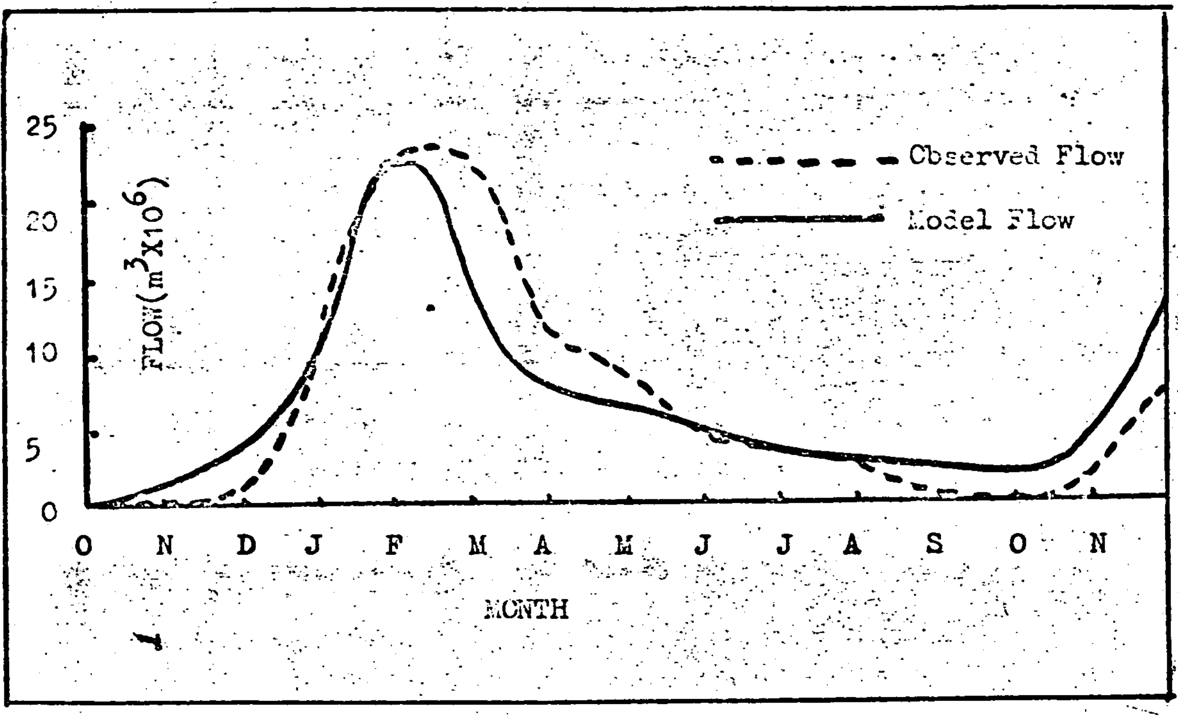


FIGURE 20. Comparison of model and field values of surface flow over the causeway with the zonal increase in storage above 'BASE' level doubled over the standard run.

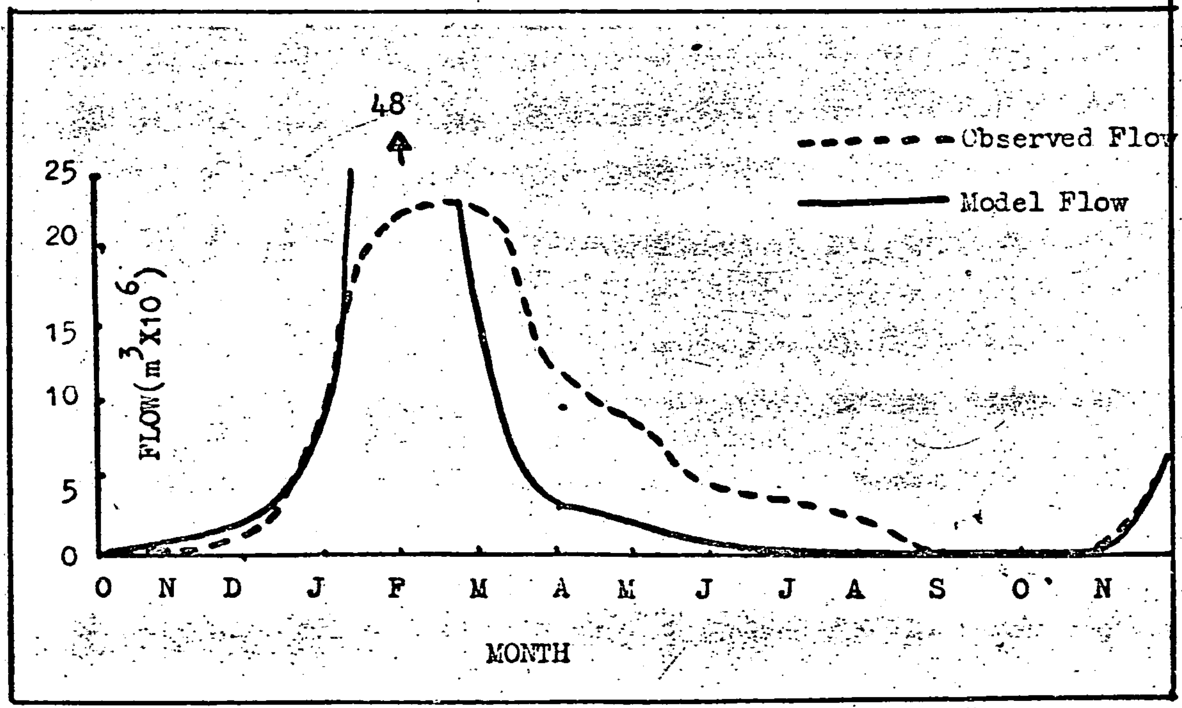


FIGURE 21, Comparison of model and field values of surface flow over the causeway with no increase in Transmissivity or Storage above 'BASE' level.

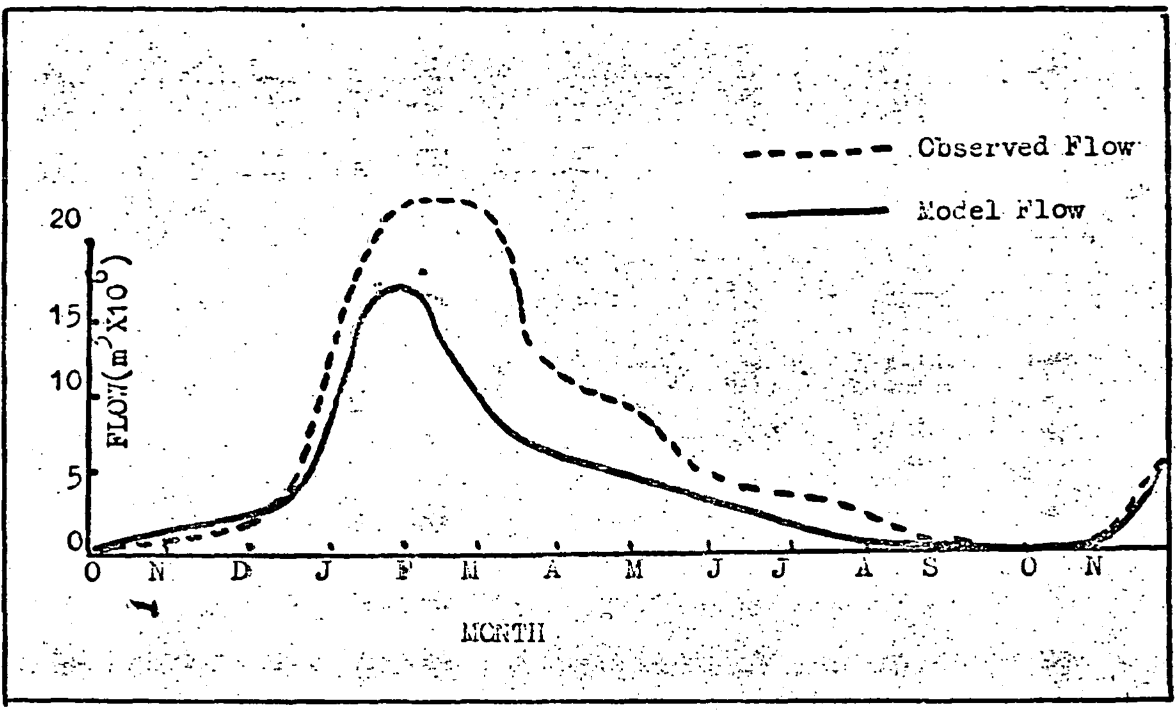


FIGURE 22. Comparison of the model and field values of surface flow over the causeway using the Turc estimate of potential evaporation.

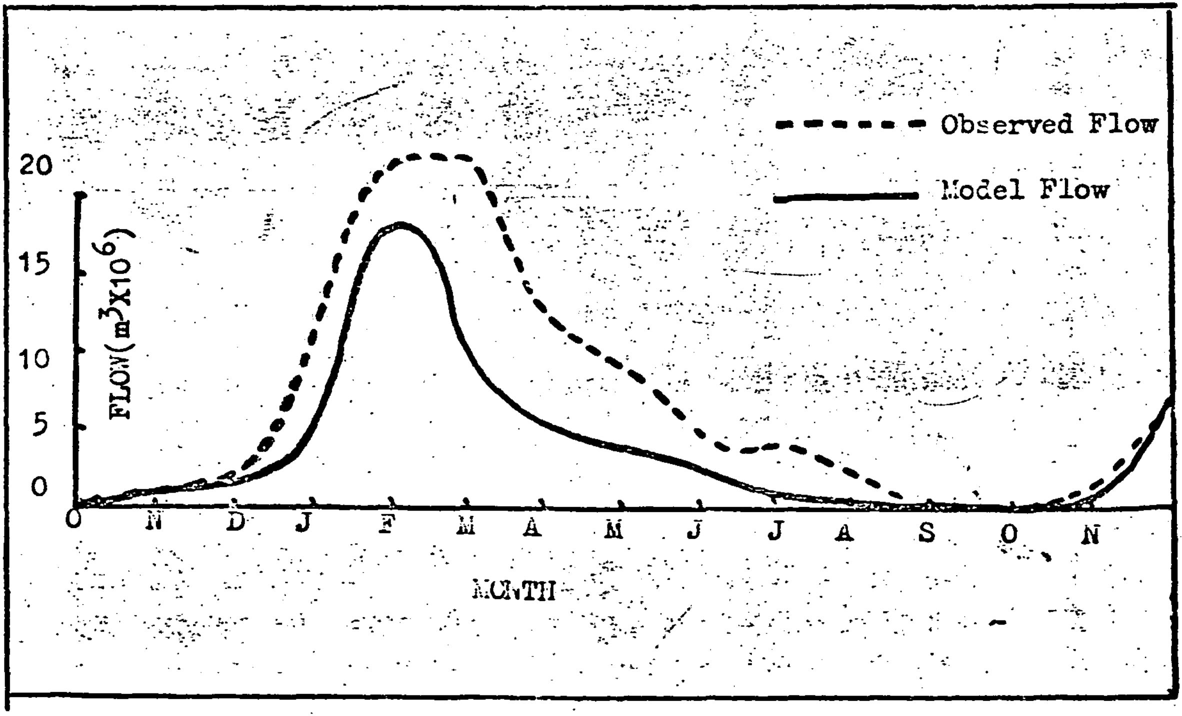


FIGURE 23. Comparison of the model and field values of surface flow over the causeway using the Aune (pan) estimate of potential evaporation.

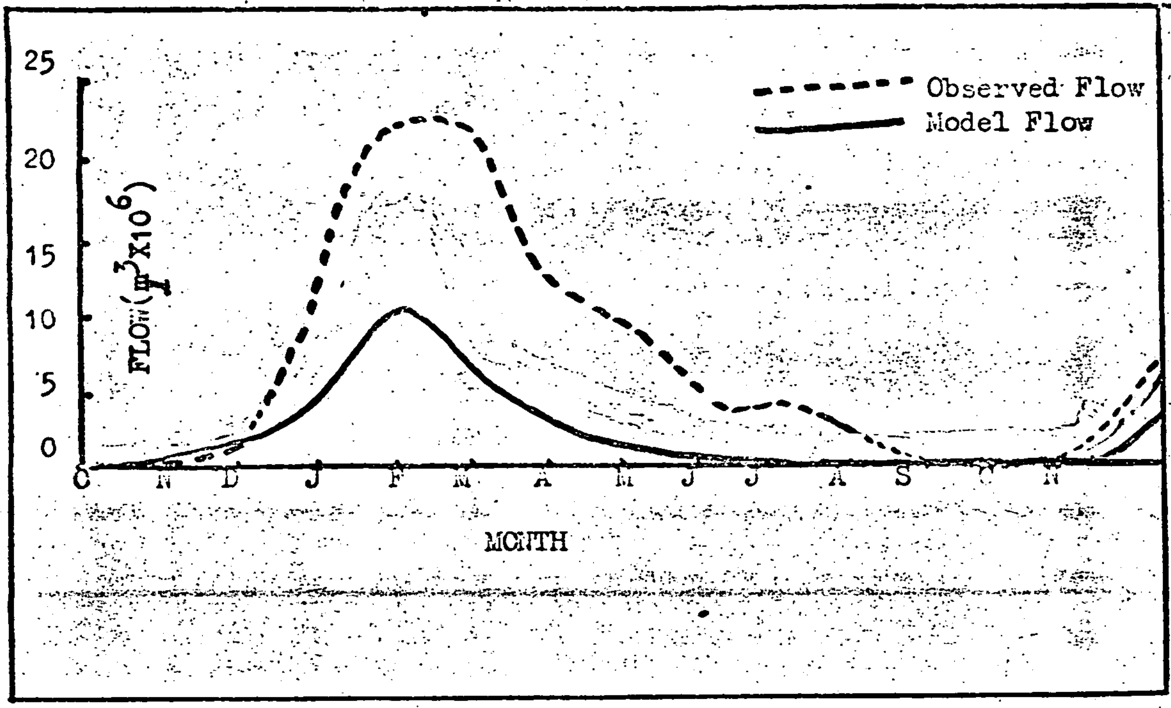
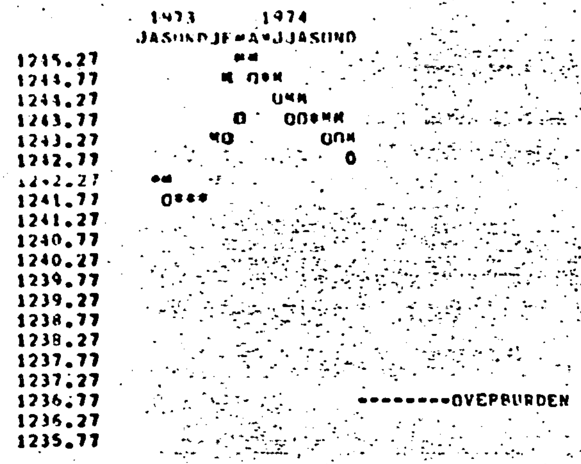
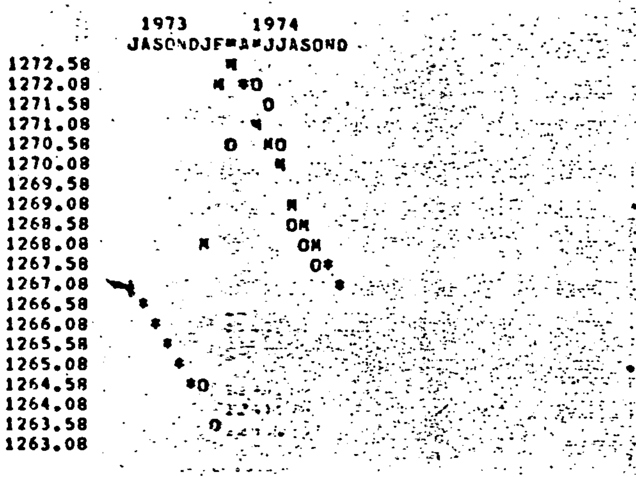


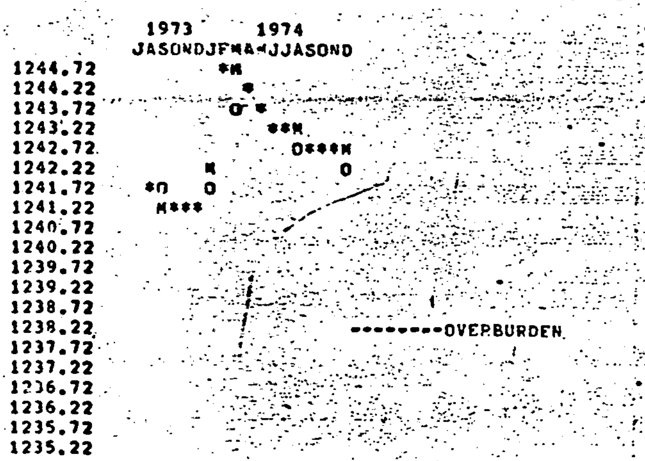
FIGURE 24. Comparison of model and field values of surface flow over the causeway using the Blaney Criddle estimate of potential evaporation.



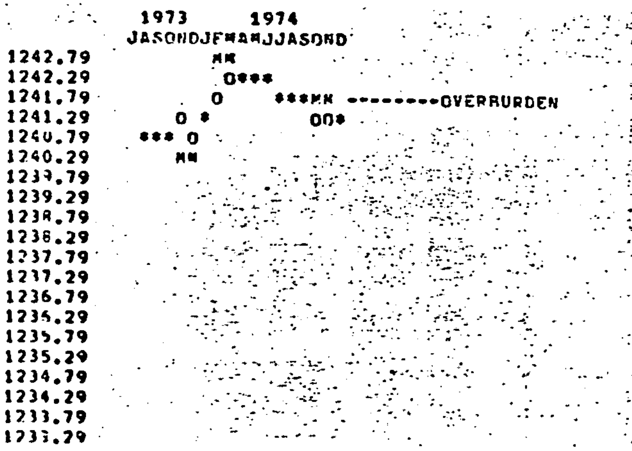
NODE 5 COMPARISON OF CALCULATED AND MEASURED WATER LEVELS

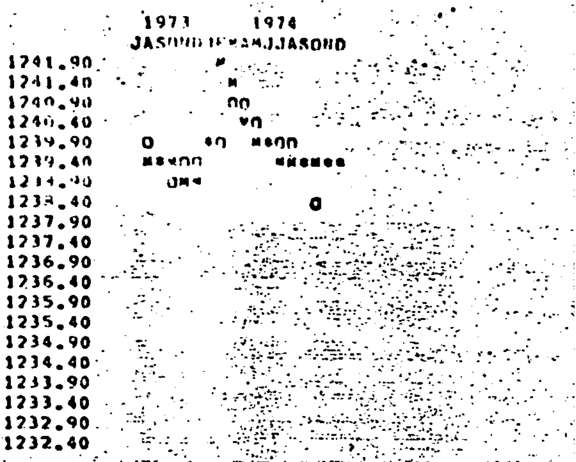


NODE 7 COMPARISON OF CALCULATED AND MEASURED WATER LEVELS

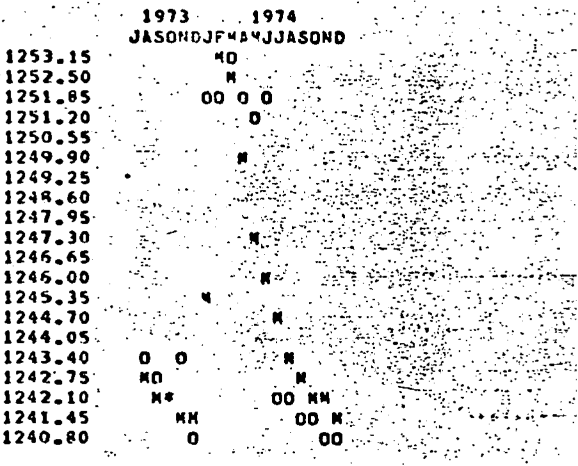


NODE 9 COMPARISON OF CALCULATED AND MEASURED WATER LEVELS

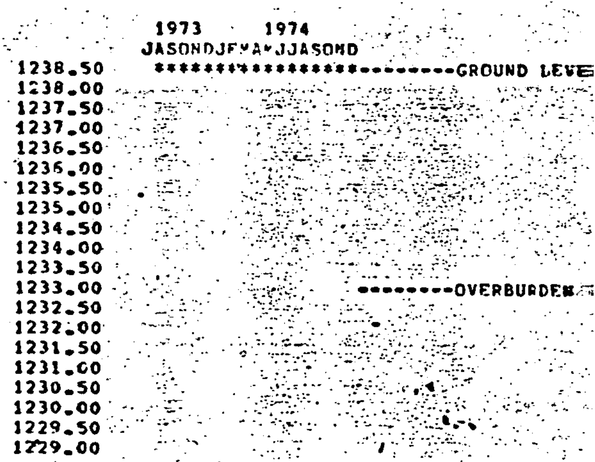




NODE13 COMPARISON OF CALCULATED AND MEASURED WATER



NODE14 COMPARISON OF CALCULATED AND MEASURED WATER



NODE24 COMPARISON OF CALCULATED AND MEASURED WATER

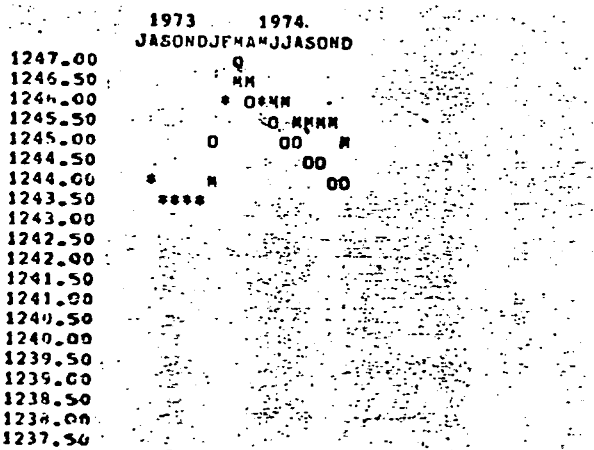


FIGURE 25. Comparison of model and field nodal ground water levels for the final calibration run-standard.

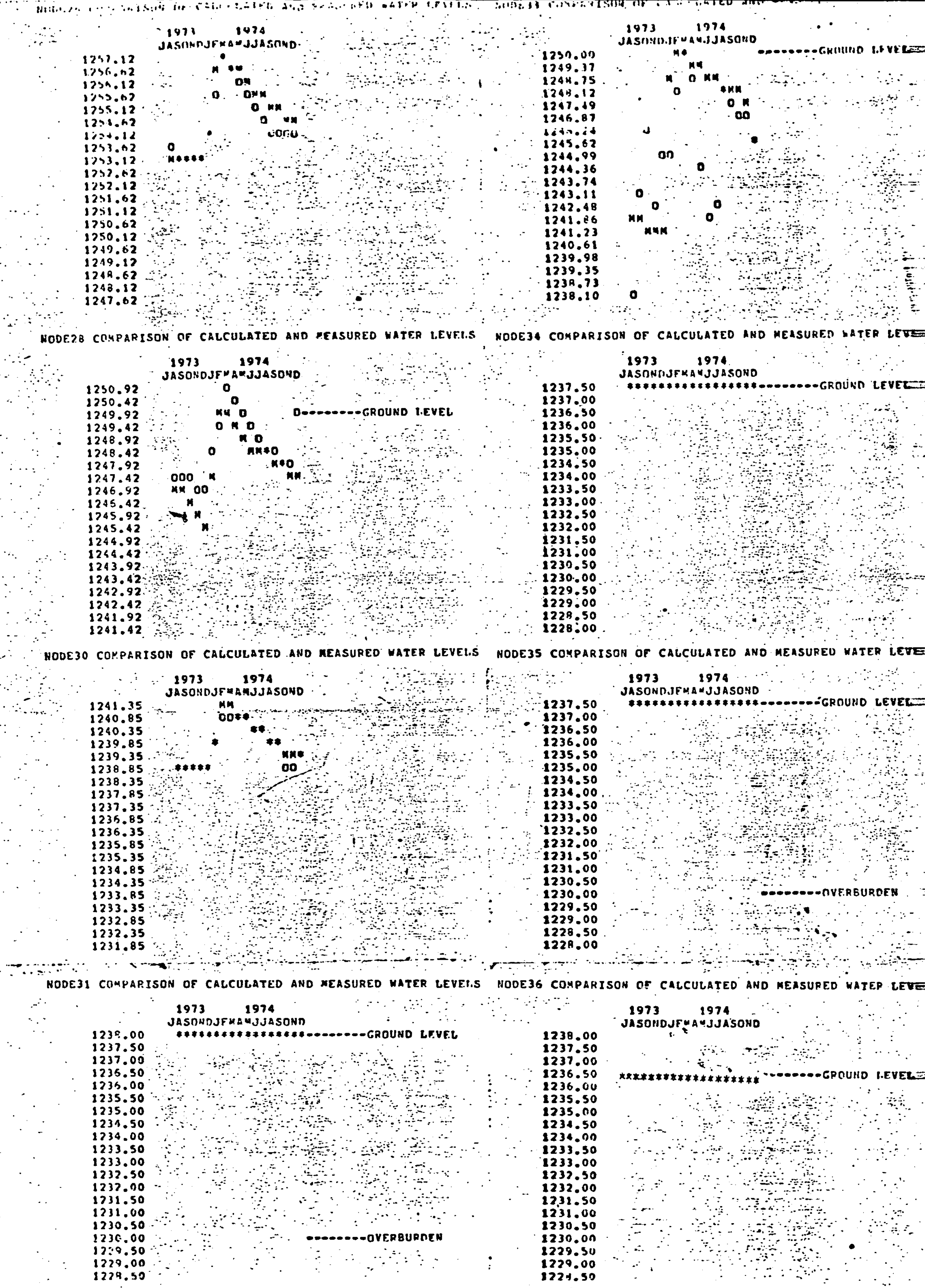


FIGURE 26. Comparison of model and field nodal ground water levels for the final calibration run - standard.

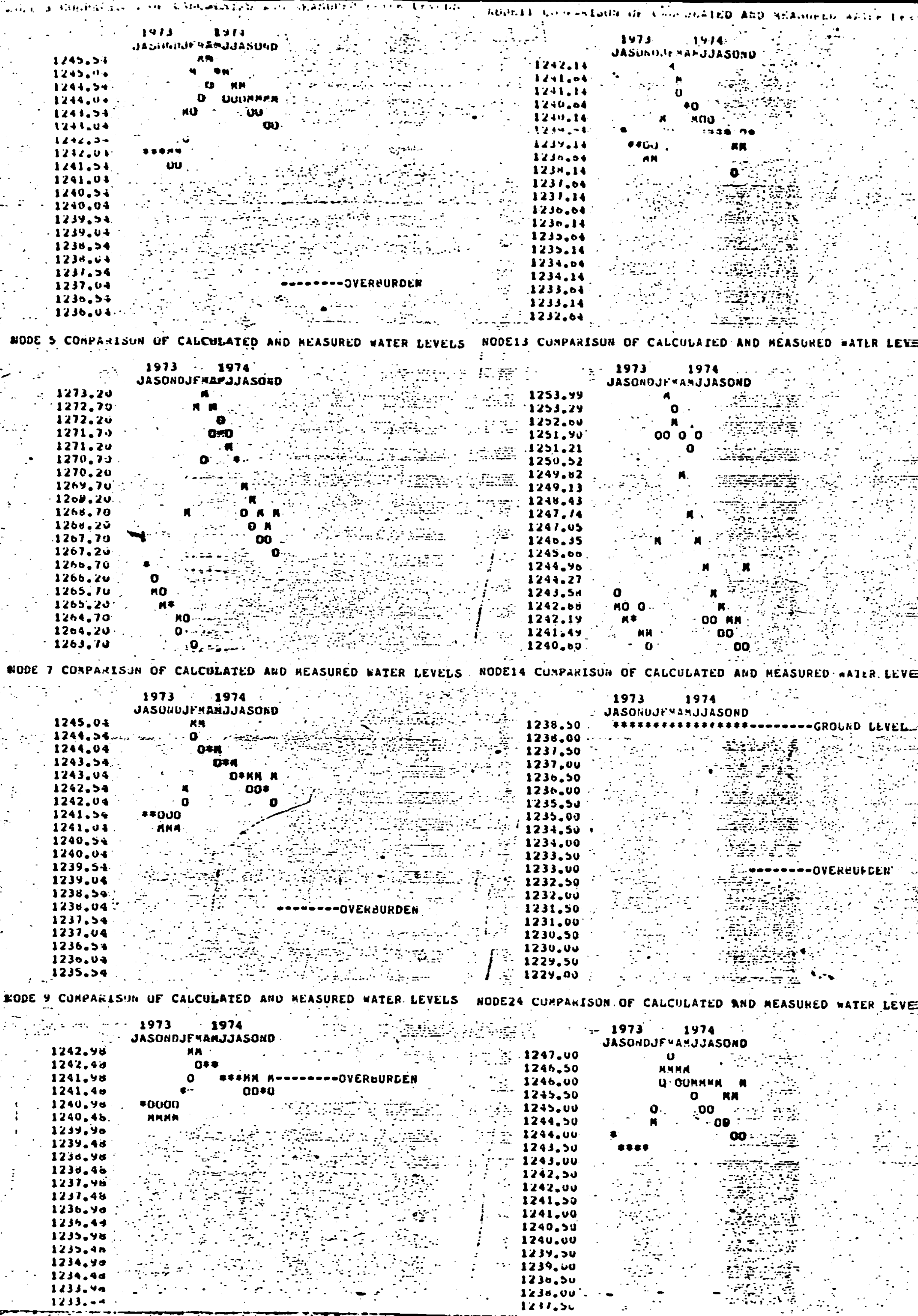


FIGURE 27. Comparison of model and field nodal ground water levels using a Root Constant of 75mm.

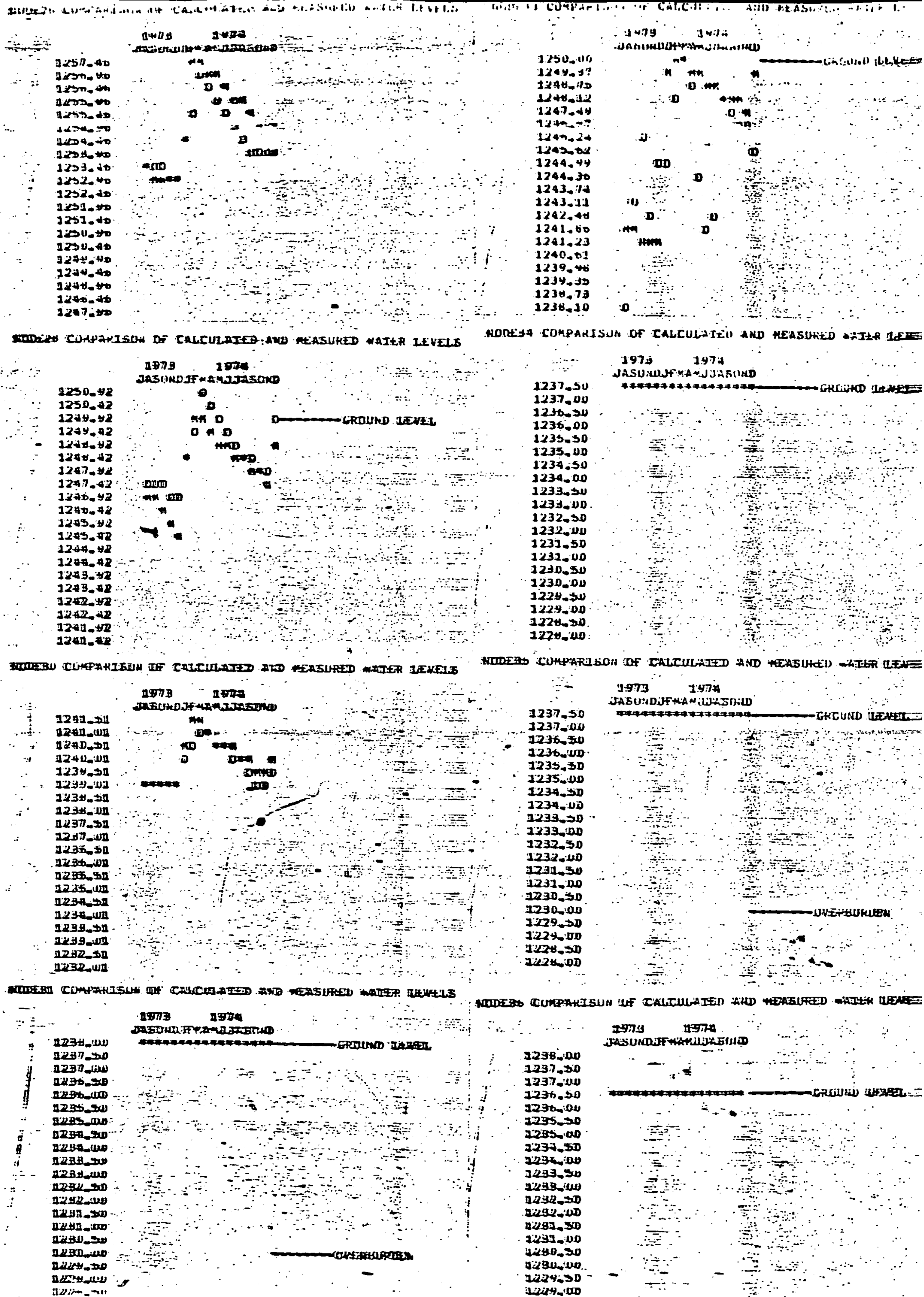


FIGURE 28. Comparison of model and field nodal ground water levels using a Root Constant of 75 mm.

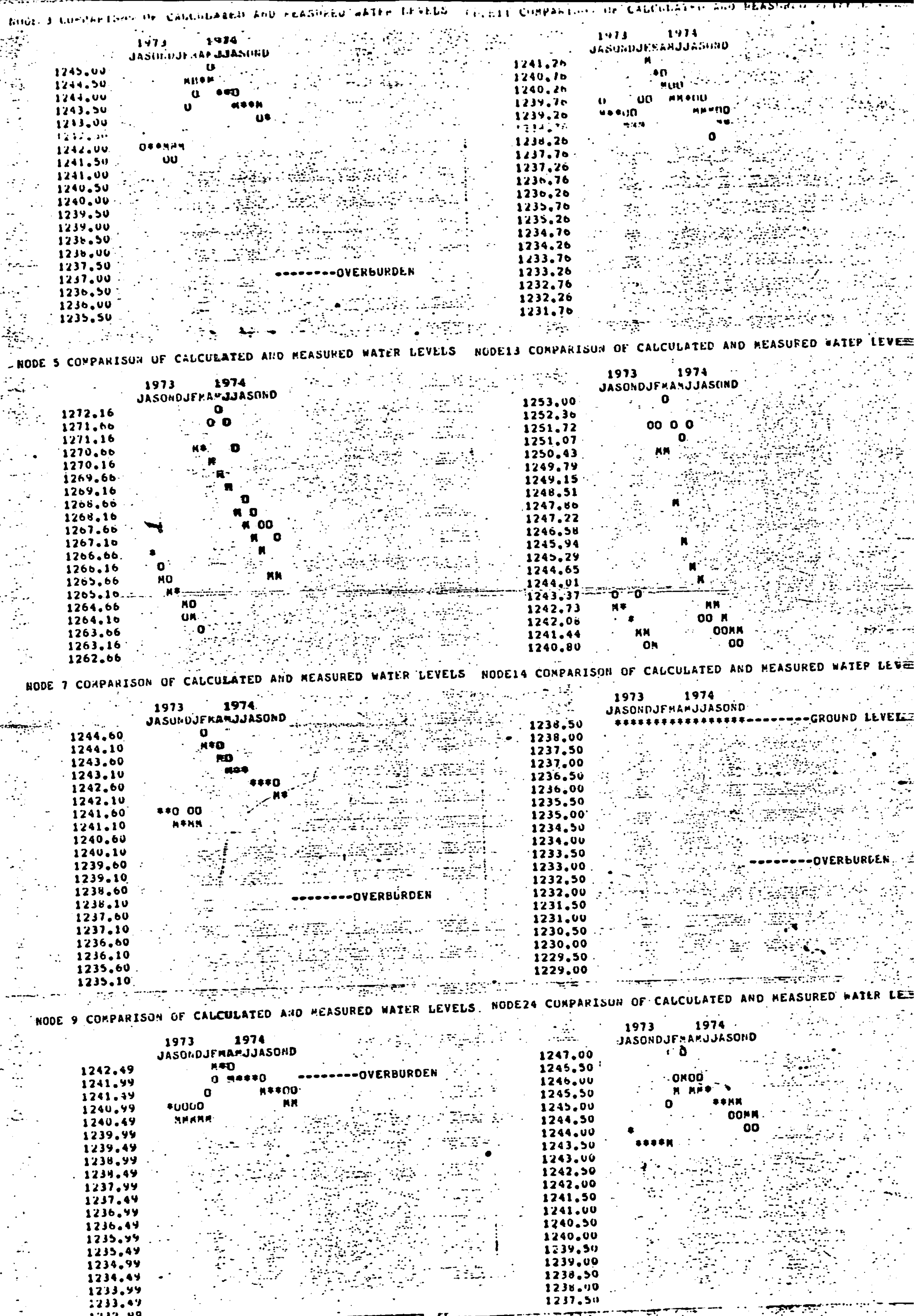
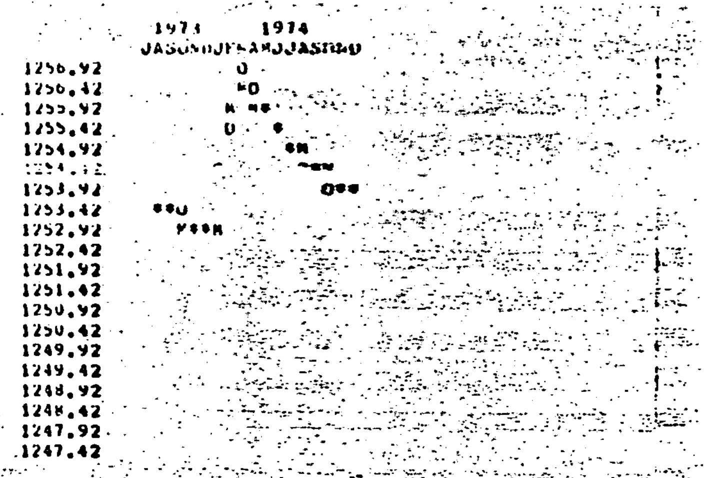
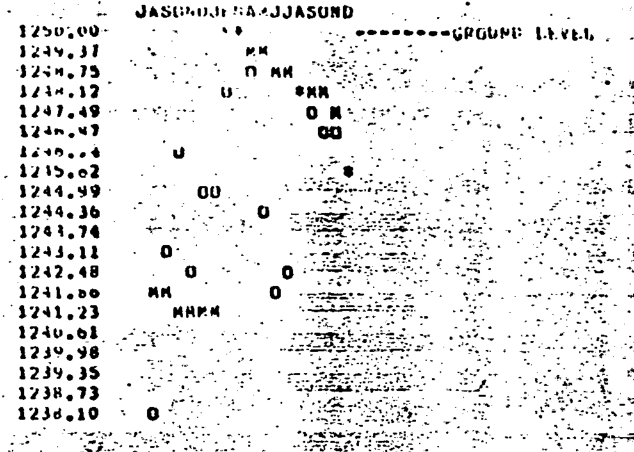


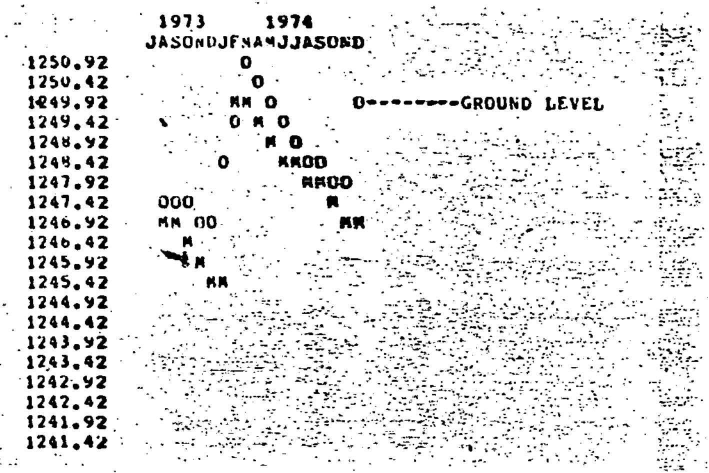
FIGURE 29 . Comparison of model and field nodal ground water levels using a Root Constant of 200mm.

NODE29 COMPARISON OF CALCULATED AND MEASURED WATER LEVELS

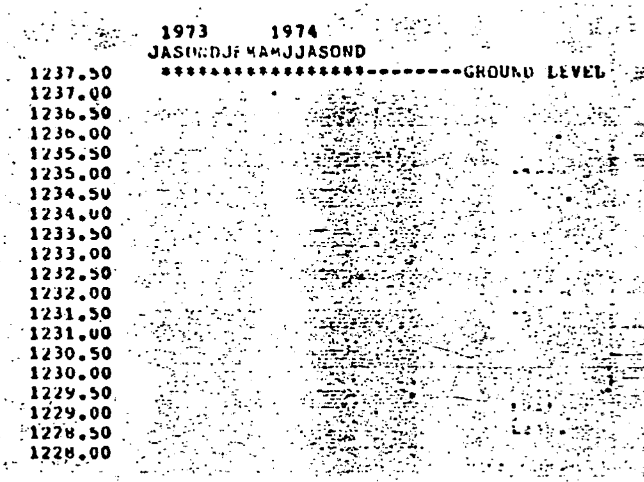




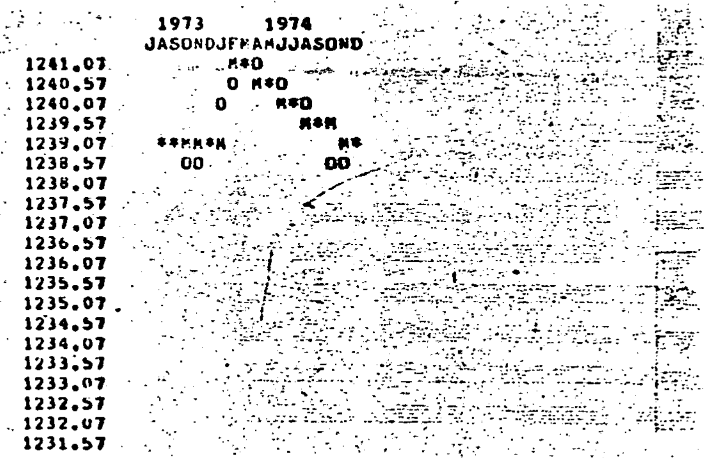
NODE28 COMPARISON OF CALCULATED AND MEASURED WATER LEVELS



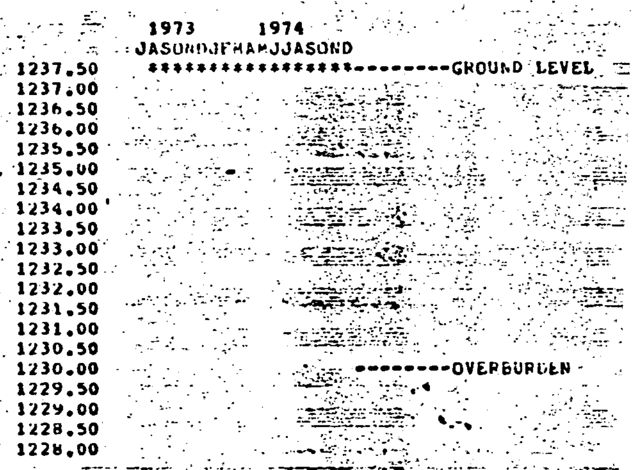
NODE34 COMPARISON OF CALCULATED AND MEASURED WATER LEVE



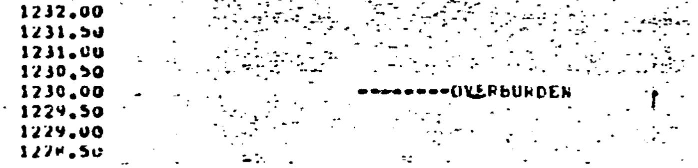
NODE30 COMPARISON OF CALCULATED AND MEASURED WATER LEVELS



NODE35 COMPARISON OF CALCULATED AND MEASURED WATER LEVE



NODE31 COMPARISON OF CALCULATED AND MEASURED WATER LEVELS



NODE36 COMPARISON OF CALCULATED AND MEASURED WATER LEVE

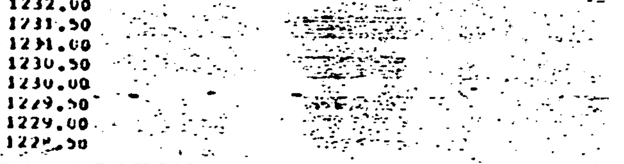


FIGURE 30. Comparison of model and field nodal ground water levels using a Root Constant of 200mm.

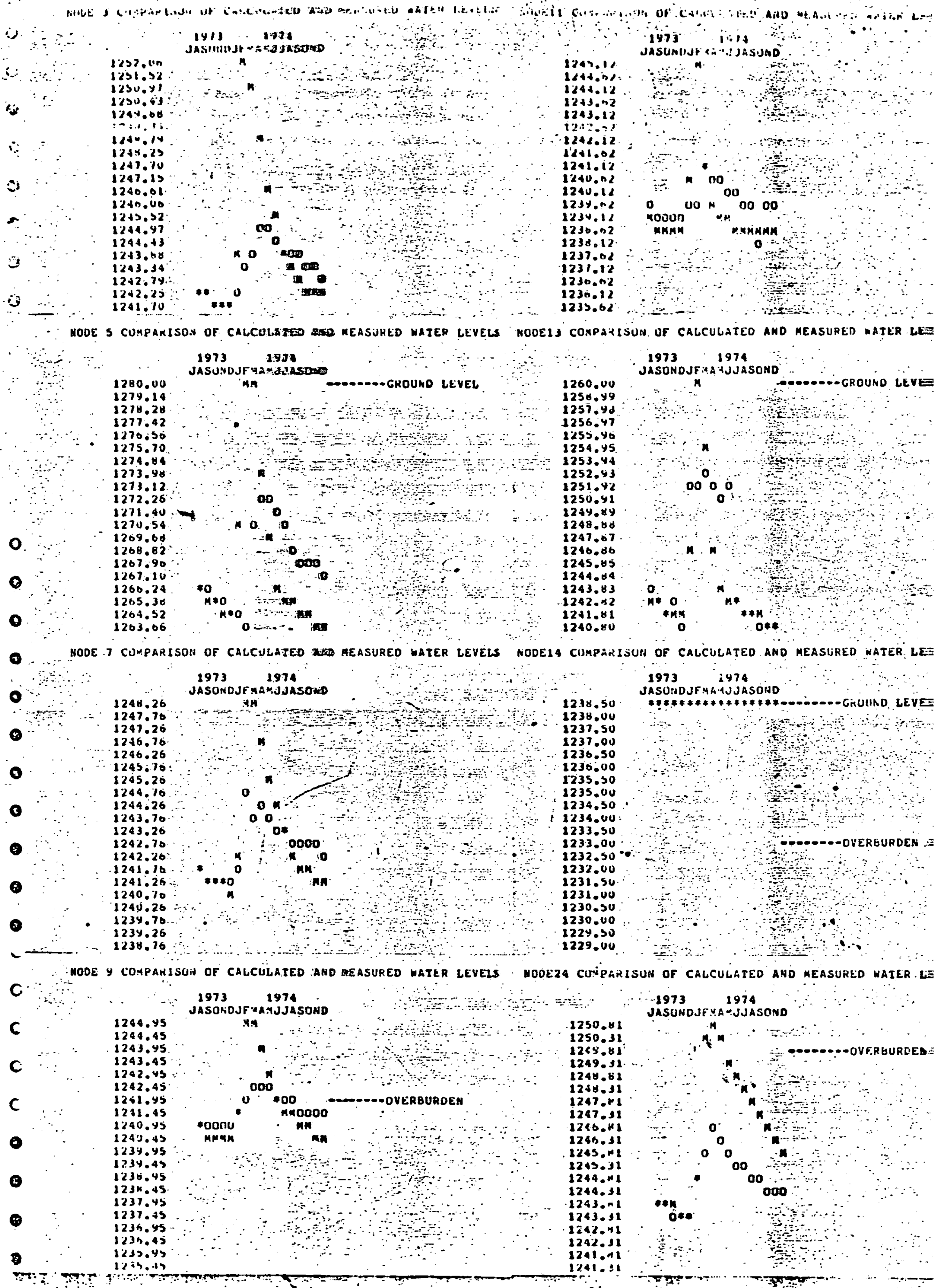


FIGURE 31. Comparison of model and field nodal ground water levels with no increase in storage above 'BASE' level.

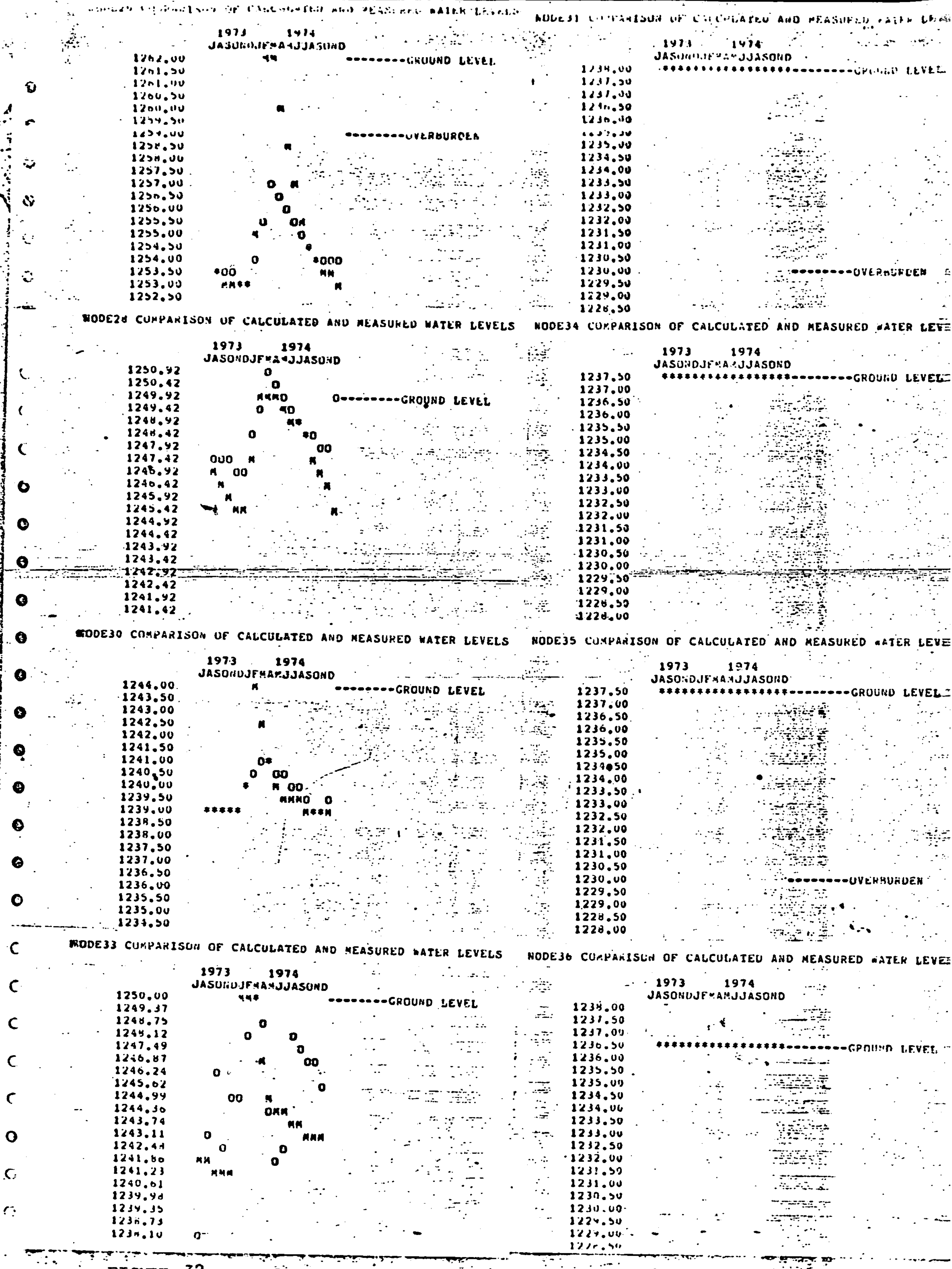


FIGURE 32. Comparison of model and field nodal ground water levels with no increase in storage above 'BASE' level.

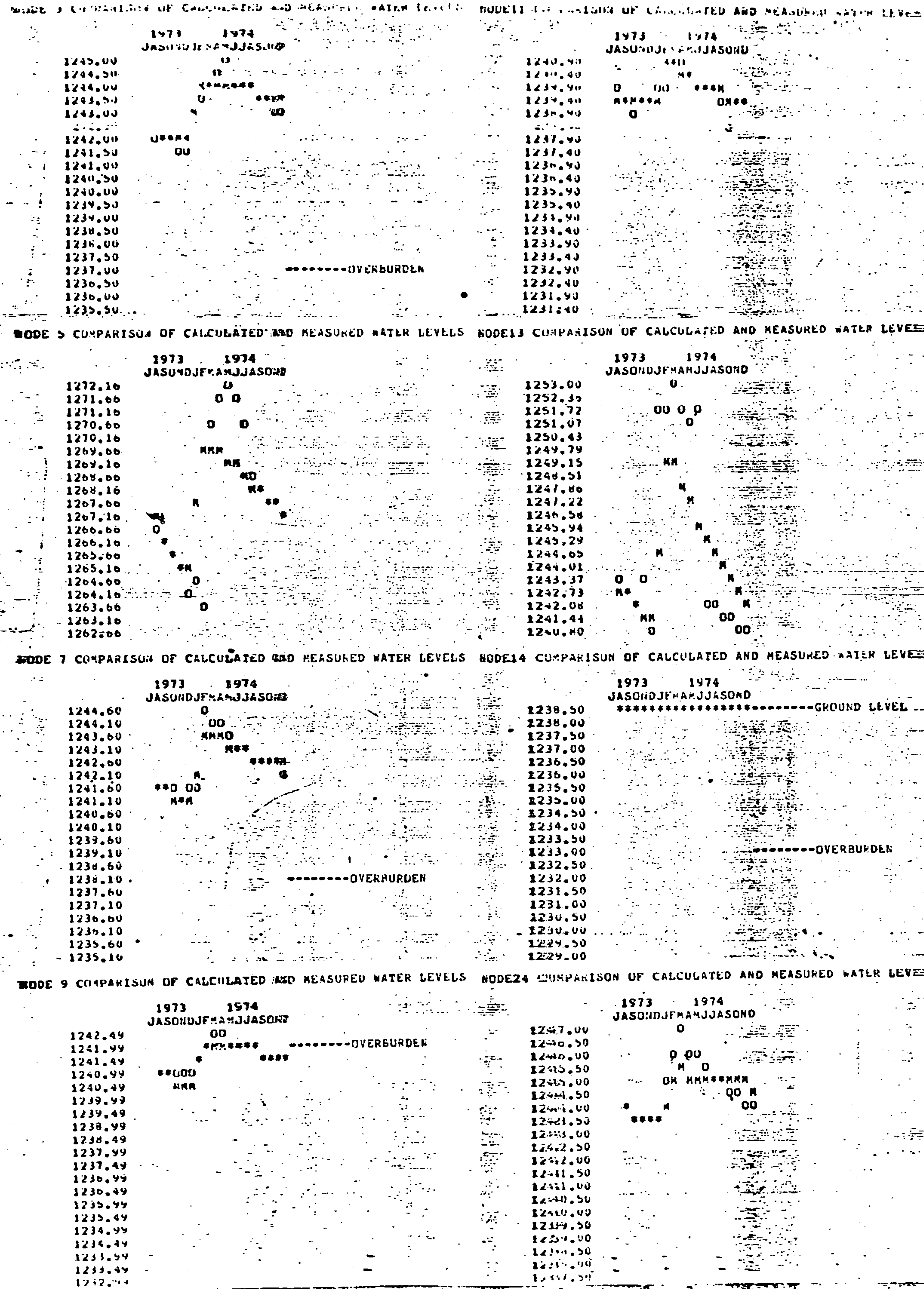


FIGURE 33. Comparison of model and nodal ground water levels with the zonal increase in storage above 'BASE' level doubled over the standard run.

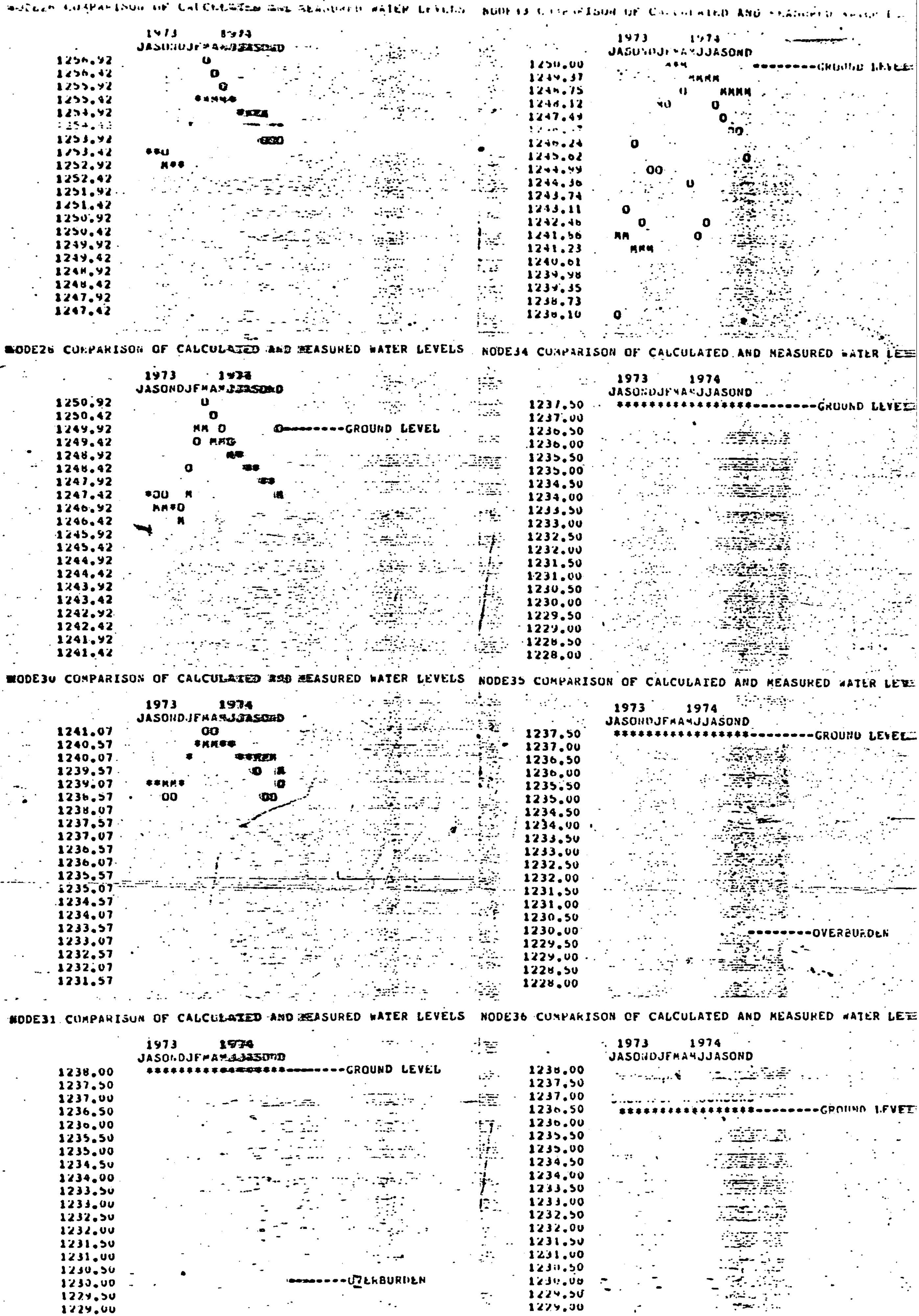


FIGURE 34. Comparison of model and field nodal ground water levels with the zonal increase in storage doubled over the standard.

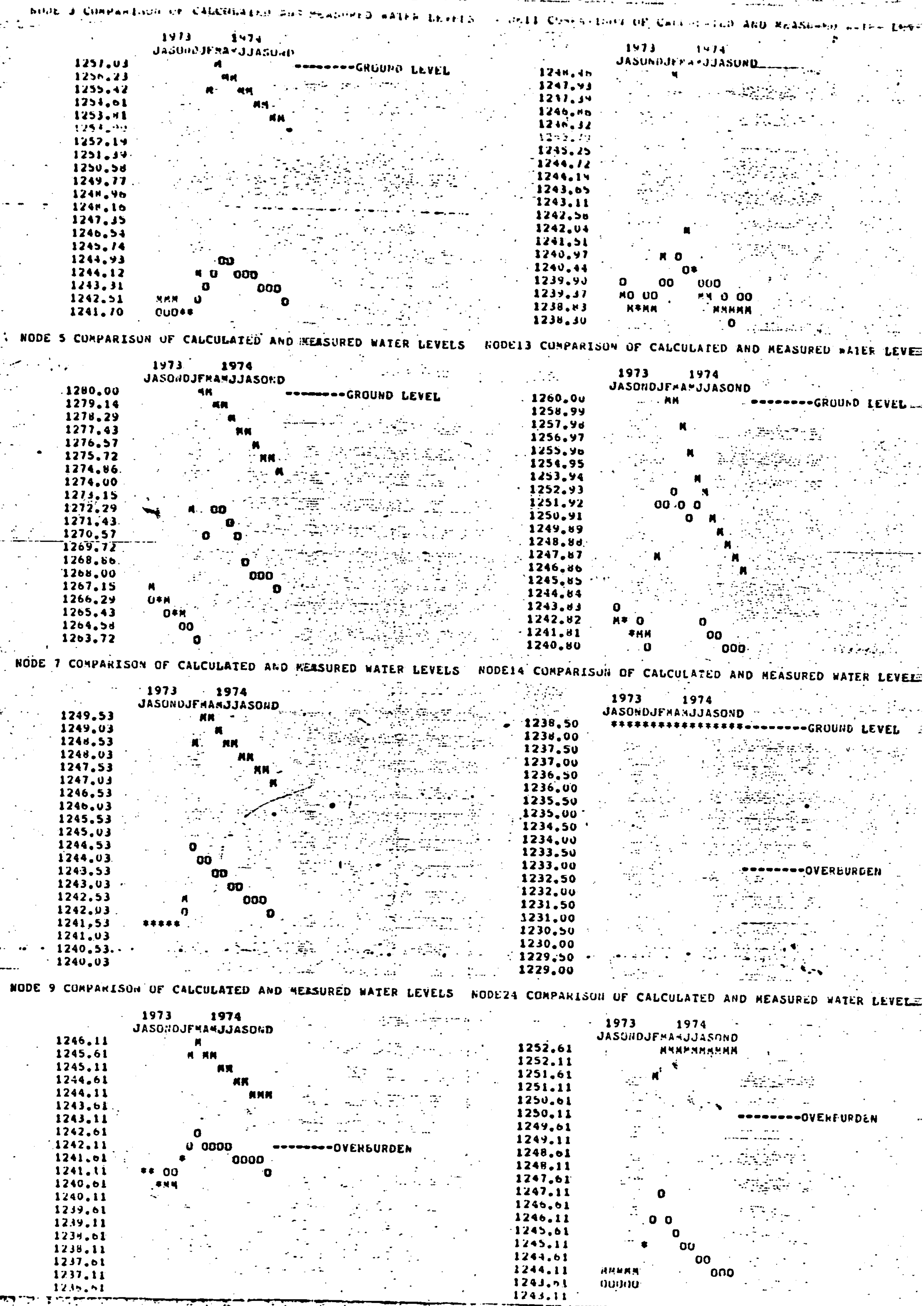


FIGURE 35. Comparison of model and field nodal ground water levels with no increase in Transmissivity or Storage above 'BASE' level.

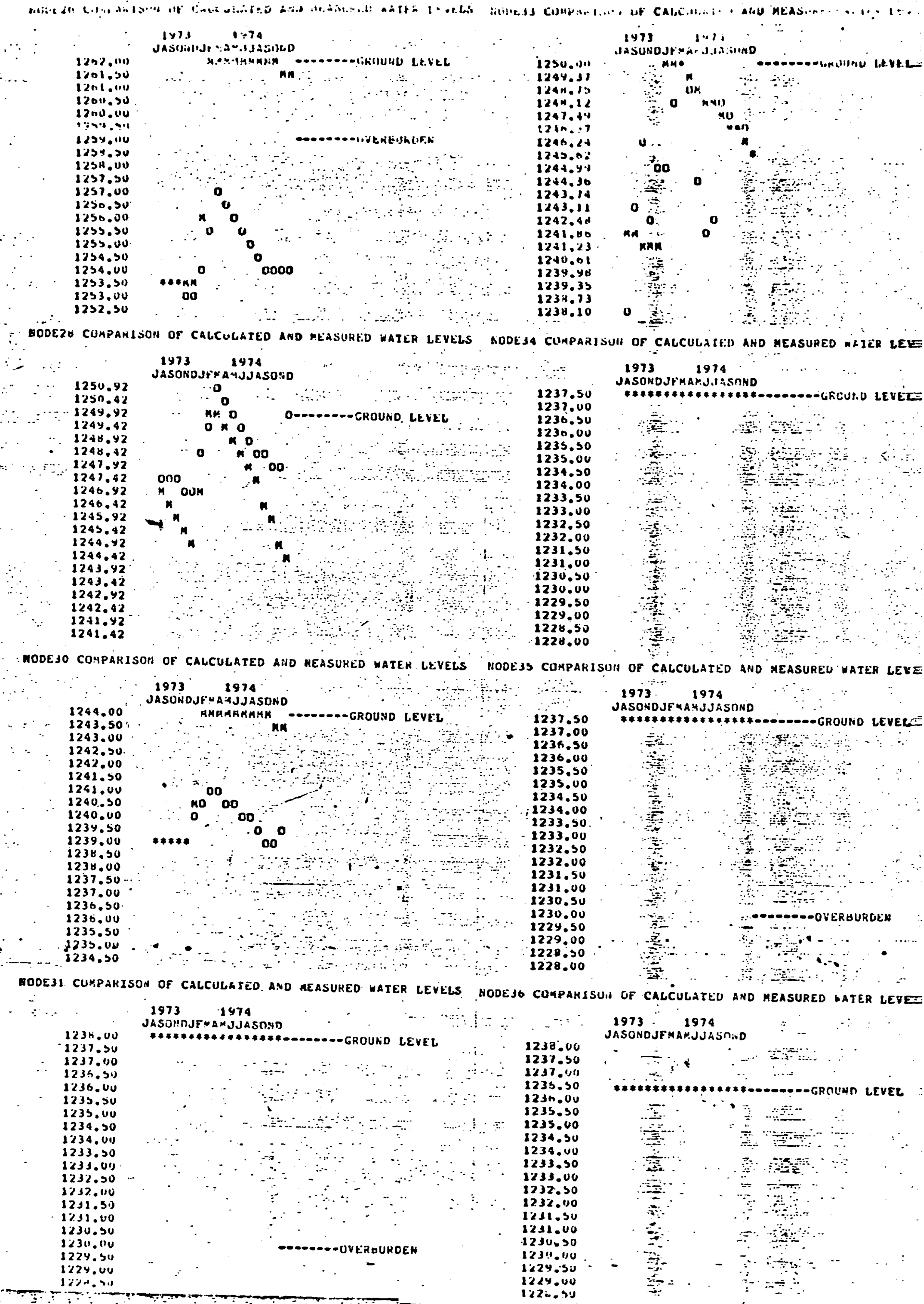


FIGURE 36. Comparison of model and field nodal ground water levels with no increase in Transmissivity or Storage over the 'BASE' level.

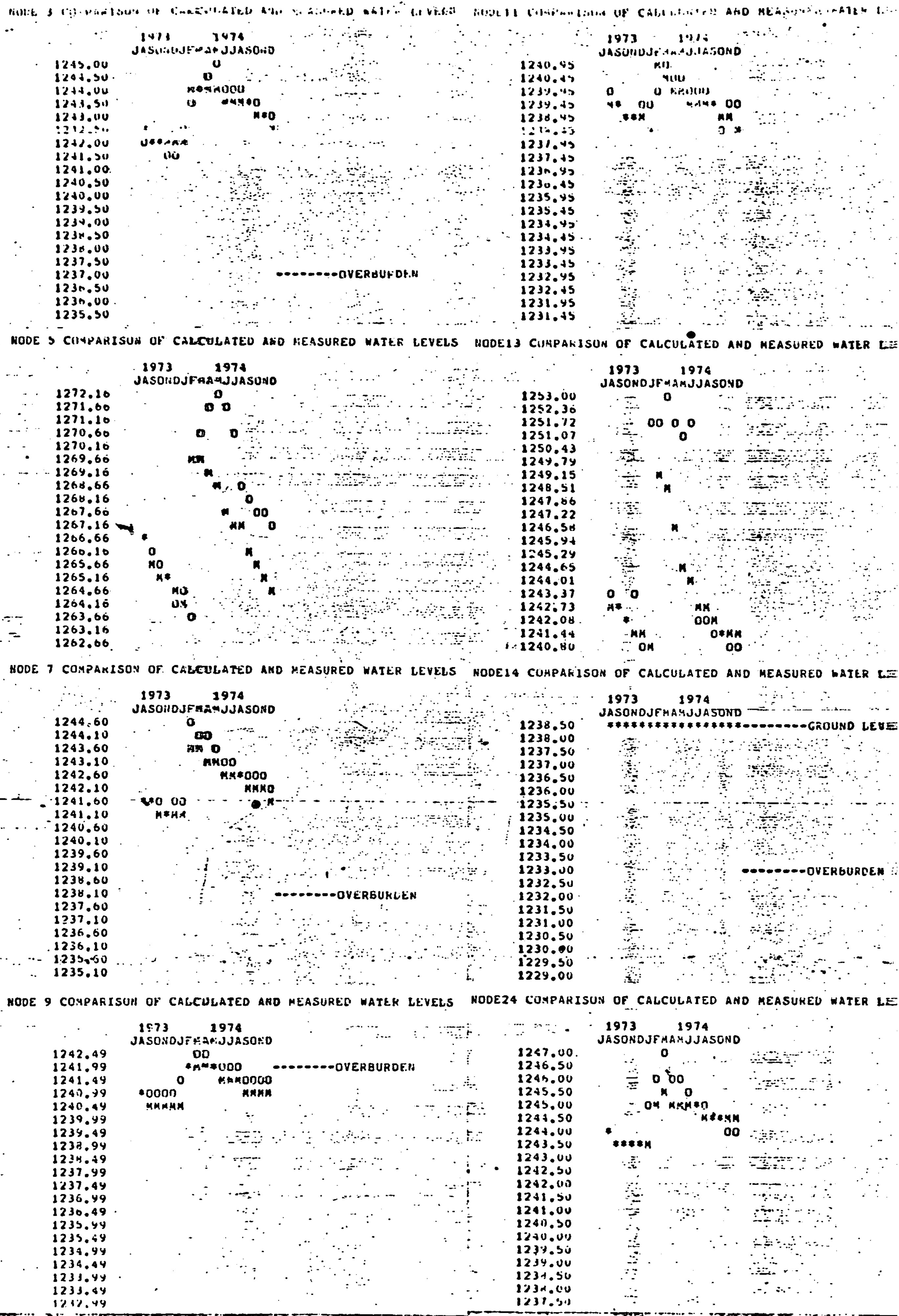


FIGURE 57. Comparison of model and field nodal ground water levels using the Turc estimate of potential evaporation.

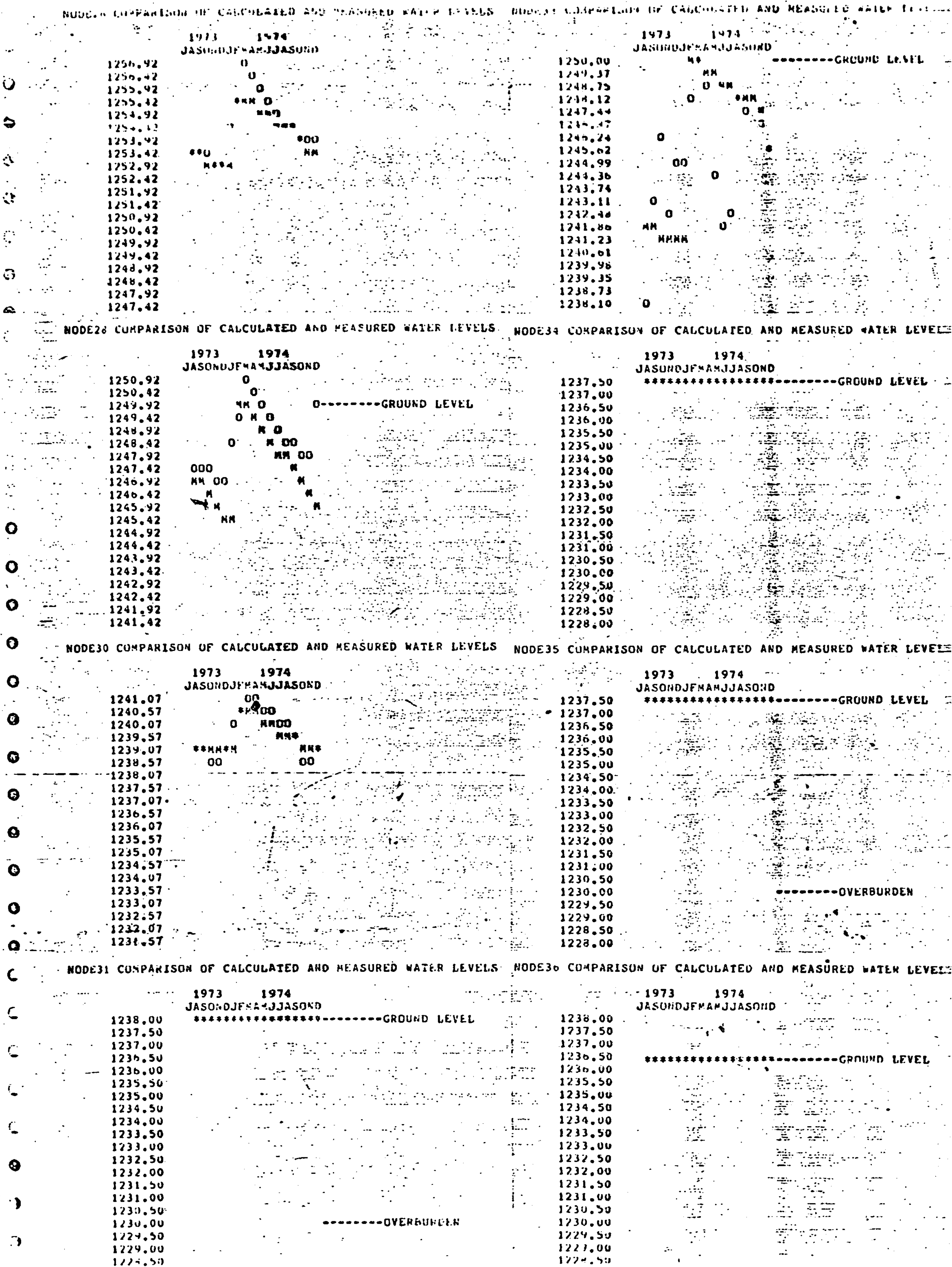


FIGURE 38 . Comparison of model and field nodal ground water levels using the Turc estimate of potential evaporation.

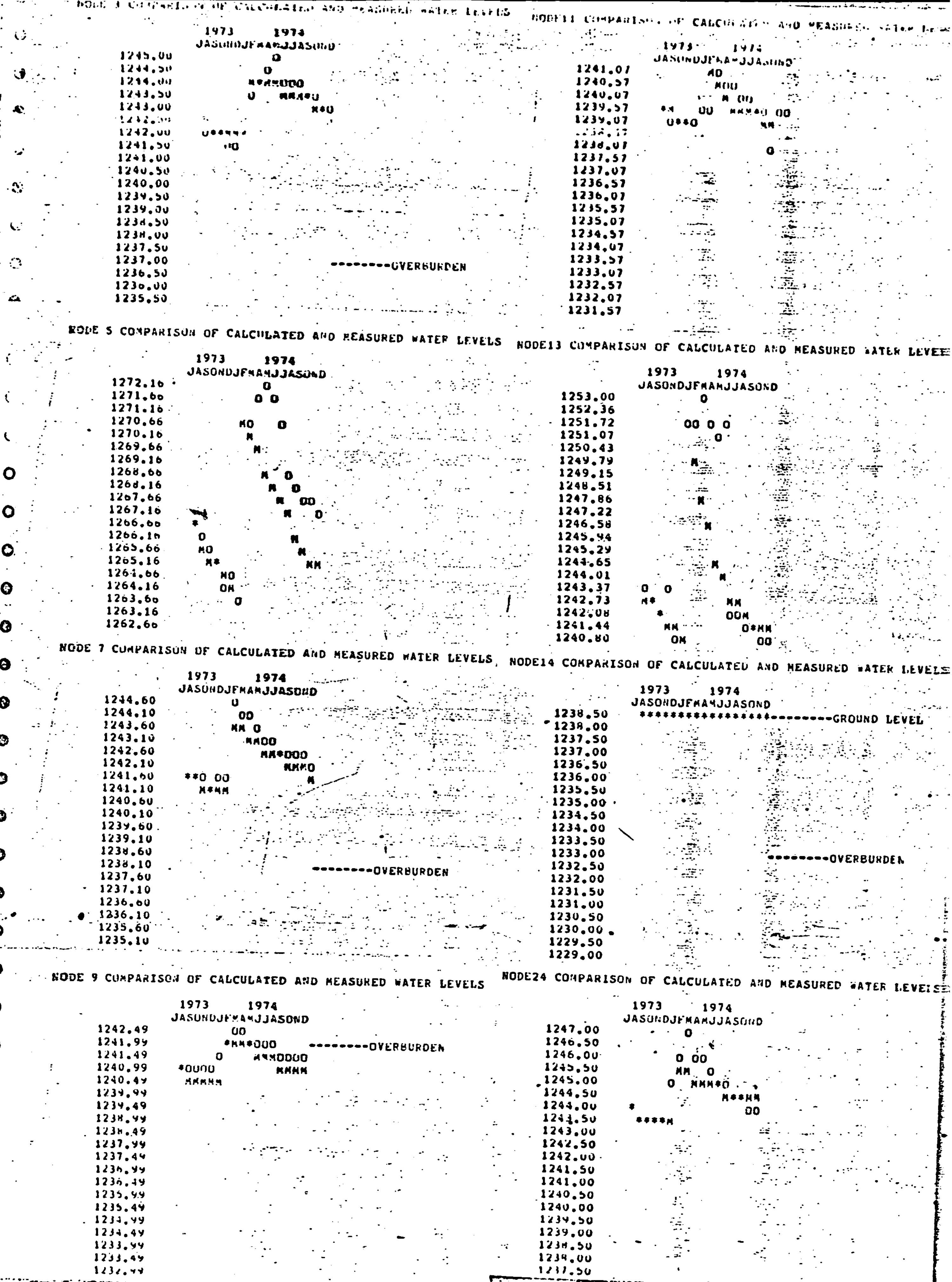


FIGURE 39. Comparison of model and field nodal ground water levels using the Aune (pan) estimate of potential evaporation.

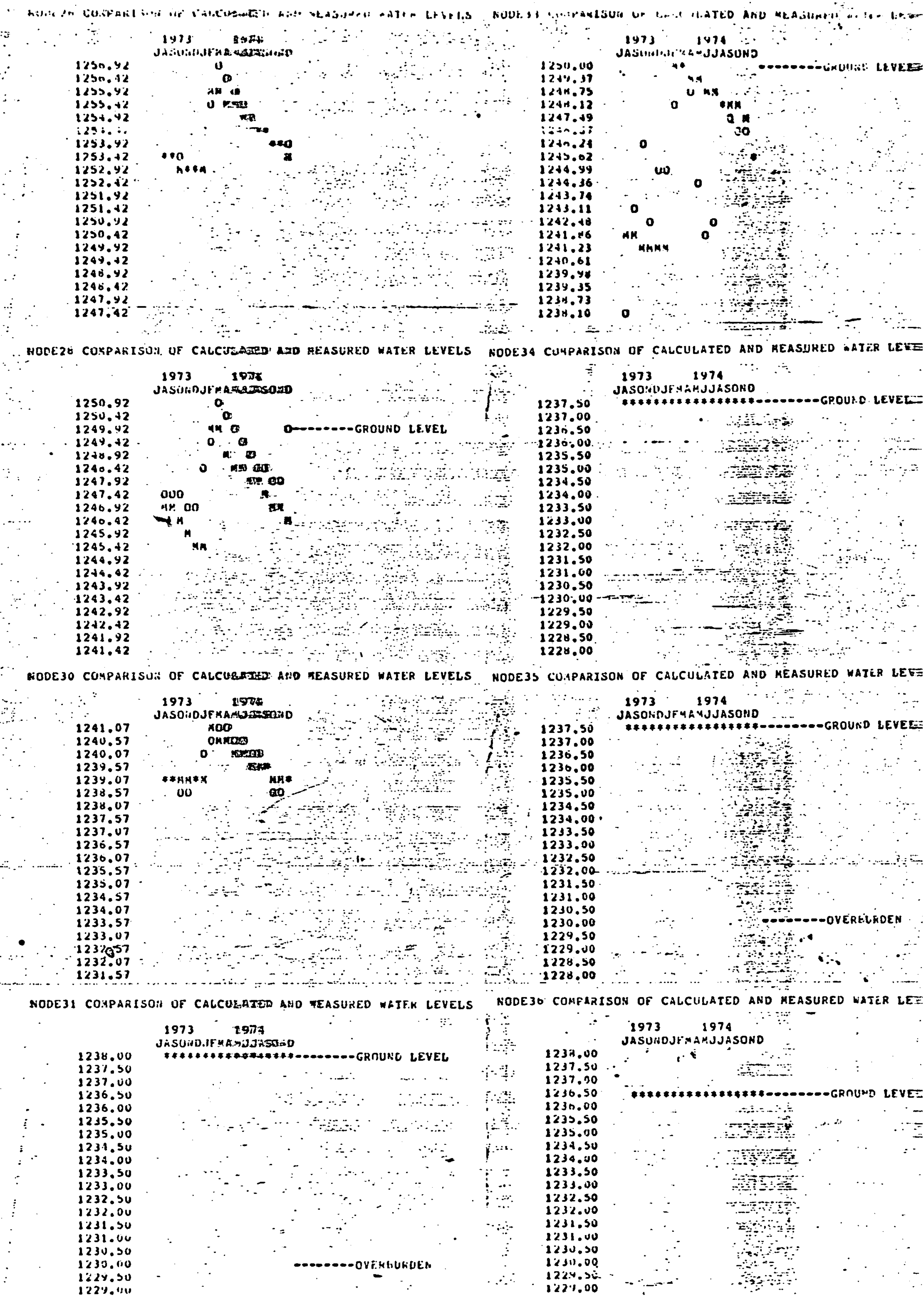


FIGURE 40. Comparison of model and field nodal ground water levels using the Aune (pan) estimate of potential evaporation.

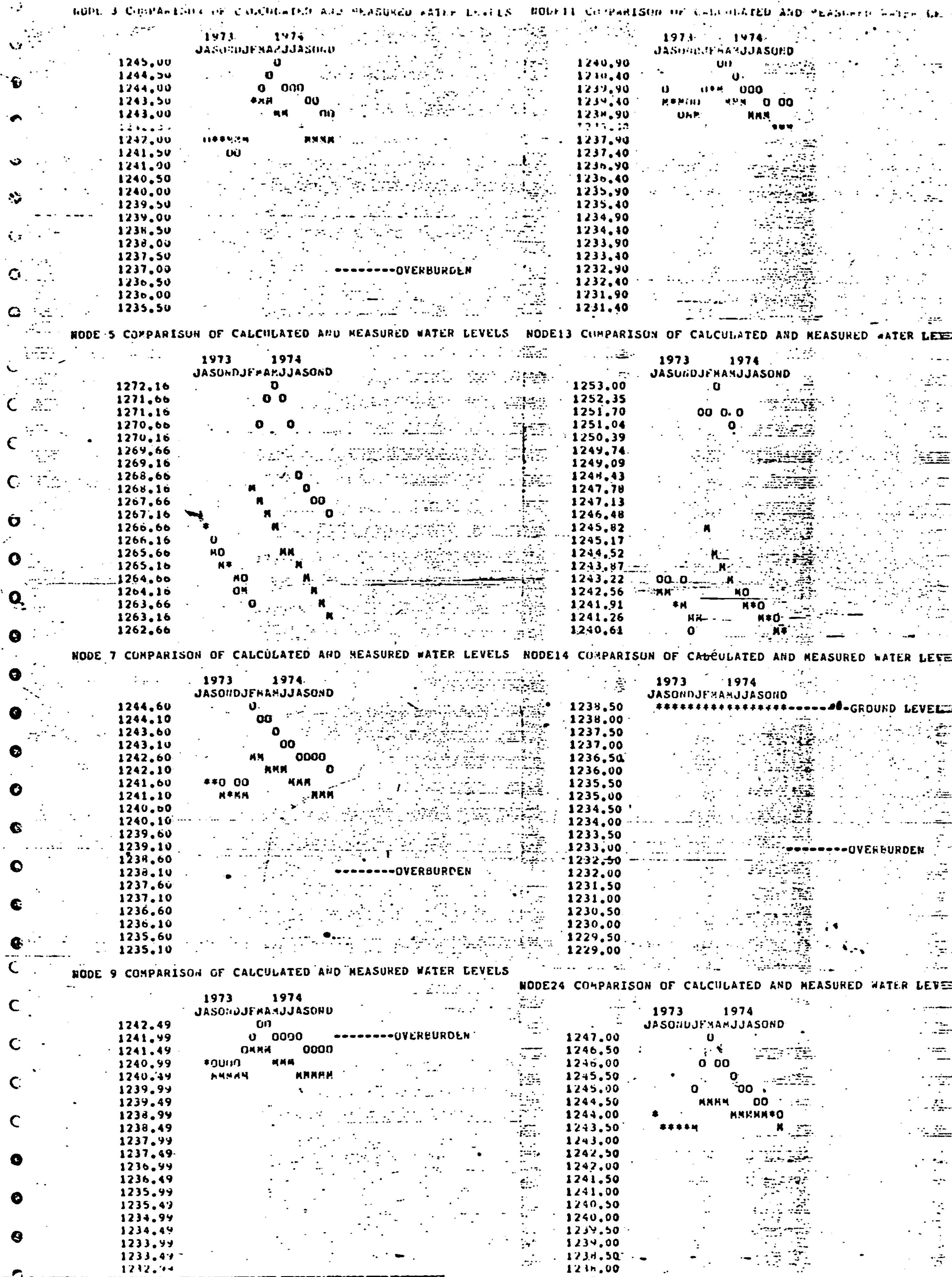


FIGURE 41. Comparison of model and fieldnodal ground water levels using the Blaney Criddle estimate of potential evaporation.

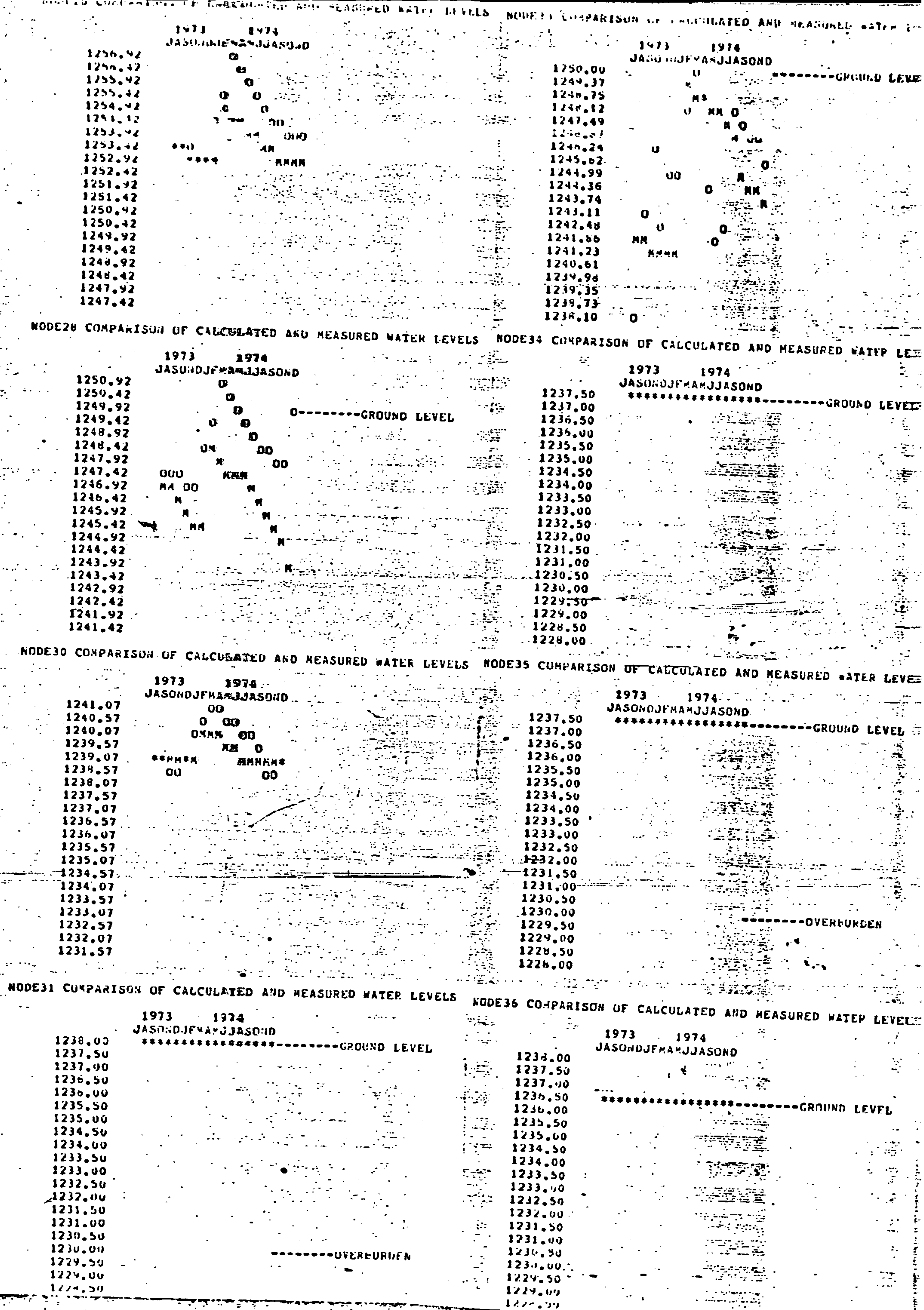


FIGURE 42. Comparison of model and field nodal ground water levels using the Blaney Criddle estimate of potential evaporation.

PART 7 WATER BALANCE

Table 5 shows the monthly water balance achieved in the final calibration run. Although the calibration period was taken from July 1973 - December 1974 complete field data for the flow over the causeway was only available from October 1973 and so the period shown in the table is for October 1973 - December 1974, i.e. months 4 - 18 inclusive, to allow comparison with the Colquhoun report for the same period. Table 6 shows the monthly water balance data taken from the Colquhoun report for this period. As can be seen there are certain differences between the two sets of data.

(i) Rainfall. The Colquhoun rainfall figures were calculated by the Thiessen polygon method using data from each of the 16 stations which lie within the catchment area. For the model a mean monthly figure was used for the catchment as a whole. However, the main discrepancy lies in the actual catchment area used in the calculation of total rainfall. The Colquhoun report favours a larger catchment area in the region of nodes 18 and 20 over that of the model which is based on the catchment area as defined in the draft version of the Colquhoun report. As this area lies to the east of the barrier boundary between nodes 22 and 24 and, as shown in section 6.2., has little effect on the main catchment area, this difference is unimportant.

(ii) Change in Surface Flow. Figure 16 shows that there is reasonable correlation between the model's causeway discharge and that recorded in the field.

(iii) Abstraction. The ground water abstraction figures used in the model are taken directly from the Colquhoun report. The surface water abstraction figures (i.e. abstraction from the Itawa dambo) only differ in the model from the Colquhoun figures when there is not enough stored surface water to permit the required abstraction.

(iv) Change in Storage. The change in ground water storage is not calculated on a monthly basis in the Colquhoun report, estimates being made over a 12 month period.

TABLE 5 : Ground Water Balance Summary from the Model

units of $m^3 \times 10^6$

1973 - 1974	(i) RAIN	(ii) CHANGE IN SURFACE FLOW	(iii) ABSTRACTION	(iv) CHANGE IN G.W. STORAGE	(v) EVAPORATION	(vi) CHANGE IN SOIL MOISTURE DEF	(vii) BALANCE (i)-(ii)-(iii)-(iv)-(v)-(vii)
OCT	5.5	0.	0.	-1.3	14.2	-7.8	0.4
NOV	40.4	1.0	0.4	-0.9	27.7	12.3	-0.1
DEC	60.0	2.7	0.4	-0.7	27.7	29.9	0.
JAN	97.1	8.7	0.5	15.8	29.8	42.4	-0.1
FEB	120.1	26.5	0.3	68.2	25.0	0.	0.1
MAR	15.1	15.1	0.3	4.1	26.8	0.	0.
APR	22.4	9.5	0.4	-9.9	53.9	-31.6	0.
MAY	19.6	7.7	0.4	-8.2	24.8	-5.0	-0.1
JUN	0.	4.6	0.5	-6.8	15.7	-13.9	-0.1
JUL	0.	3.5	0.5	-5.8	11.4	-9.6	-0.1
AUG	0.	2.3	0.6	-4.9	10.4	-8.3	-0.1
SEP	0.	1.2	0.6	-4.2	11.8	-9.4	0.
OCT	0.6	0.9	0.7	-3.9	11.7	-8.8	0.
NOV	20.8	2.5	0.7	-3.5	22.9	-1.7	-0.
DEC	123.7	12.4	0.6	-3.1	27.7	86.2	-0.1
TOTAL	556.6	98.7	6.9	38.4	341.3	74.5	0.4

TABLE 6 : Ground Water Balance Summary from the Colquhoun Report

units of $m^3 \times 10^6$

1973 - 1974	(i) RAIN	(ii) CHANGE IN SURFACE FLOW	(iii) ABSTRACTION	(iv) CHANGE IN G.W. STORAGE	(v) EVAPORATION	(vi) BALANCE (i)-(ii)-(iii)-(iv)-(v)
OCT	6.2	0.	0.7		45.8	
NOV	46.4	0.	0.4		52.8	
DEC	68.5	0.1	0.4		44.0	
JAN	111.4	11.2	0.5		37.6	
FEB	138.0	22.4	0.3		35.6	
MAR	53.3	22.1	0.3		38.6	
APR	25.7	11.2	0.4		30.7	
MAY	22.6	8.9	0.4		21.5	
JUN	0.	4.6	0.4		10.5	
JUL	0.	3.7	0.5		11.6	
AUG	0.	2.4	0.6		8.5	
SEP	0.	0.1	0.6		22.6	
OCT	0.6	0.	0.8		45.8	
NOV	23.9	0.	0.7		52.8	
DEC	142.1	8.1	0.6		44.0	
TOTAL	638.7	94.8	7.6	38.6	503.1	5.4

(v) Evaporation Losses. The different methods of calculating the total evaporative losses has been discussed in section 6.3.3. showing probable errors in the Colquhoun estimates.

(vi) Change in Soil Moisture Deficit. This factor does not enter into the Colquhoun water balance. The monthly values of soil moisture deficit occurring in the model are plotted in figure 42.

Examination of the two tables 5 and 6 shows that both the model and the Colquhoun report give good balances for the water budget over the calibration period, both less than 1% error. However, Table 6 shows that on a monthly basis a balance is not achieved using the Colquhoun figures, the reason for this error lying chiefly is the estimates of evaporative losses. The monthly balance achieved <u>with</u> the Colquhoun figures is not given in Table 6 due to the uncertainty in the distribution of the change in ground water storage.

During the initial stages of calibration of the model it was attempted to not only bring the model ground water levels and surface flows into line with the field data but also to obtain a water balance comparable in each aspect to that produced in the Colquhoun report. However, when this proved difficult the procedure described in this report was followed with the results as discussed above.

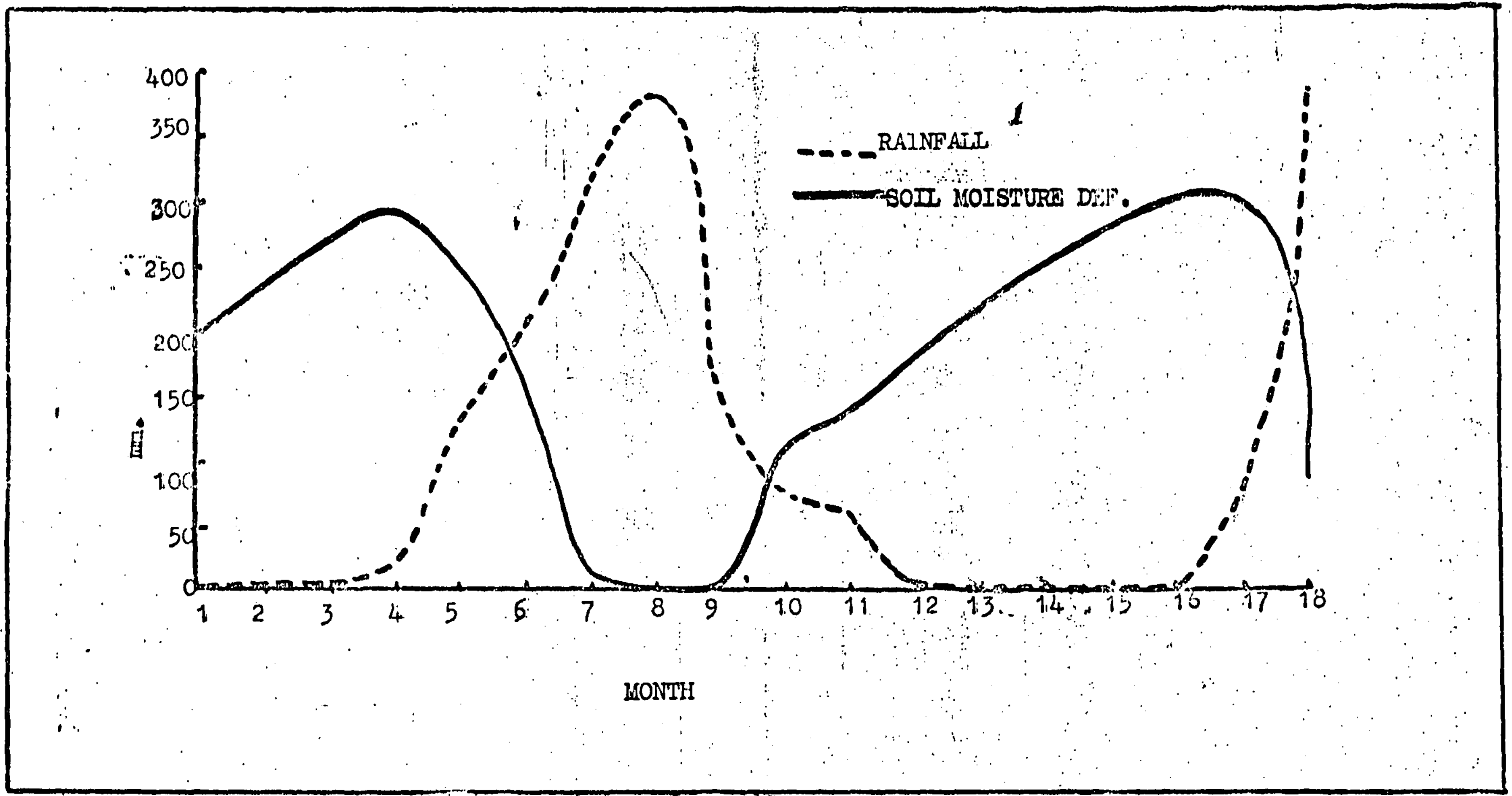


FIGURE 43 . Plot of model monthly soil moisture deficits and input monthly rainfall data.

PART 8 FURTHER FIELD INVESTIGATIONS

As with any groundwater model the need for continual collection of data and model modification based on new field evidence can not be overemphasised; however long the initial calibration period used, continued collection of field data can only help to improve the models calibration and hence its predictive reliability.

Calibration of the Kakontwe ground water model has indicated several points which are worthy of further field investigation, for example the question of direction of flow in the south eastern part of the catchment. Previously it had been assumed that the direction of ground water flow was related to the topography, there being poor borehole coverage in this area to give any more accurate assessment of the situation. However, the model has shown that with the relatively small transmissivities and storage coefficients that are known to exist in this area, it is more likely that flow is in fact in the opposite direction, towards Zaire. Although the quantity of water involved is quite large (20% of the entire catchment area is "upstream" of the apparent barrier boundary between nodes 22 and 24) the model has shown that due to the low regional transmissivity it has little effect on the surface flow at the dambo. In order to resolve this question of flow direction a more detailed piezometric observation network into the Kakontwe dolomite is required in this area. Although not of great importance some further geological field investigations may be able to determine the exact nature of the barrier boundary to the west of Lake Chirengura (i.e. between nodes 22 and 24) causing this flow problem. It is possible that the lineations marked on the geological map as possible fissures are in fact dykes.

Also resulting from the calibration of the model was the concept of zonal Transmissivity and Storage. Although such a concept is logical for a karstic region aquifer, testing will not necessarily determine the separate T and S values. In fact the aquifer tests carried out as part of the field investigation for this model were all completed during a period of low ground water levels, therefore there is no indication of the order of mangitude of the upper transmissivity and storage coefficient values. In order to obtain estimates of the higher values it would be necessary to carry out aquifer tests during periods of high ground water levels i.e. between February and July.

Another point of interest resulting from calibration of the model is that of evaporation. In the final model potential evaporation estimates of 0.75 of the Turc estimates were found to give better results than any of the potential evaporation estimates given in the Colquhoun report. Coupled with evaporation estimates is the use of a root constant. In the final model a root constant of 100 mm was used as an overall value which considering that short grass is generally considered to have a root constant of 75 mm is not unreasonable. However, the choice of potential evaporation estimates and root constants gave rise to several problems in the calibration and emphasised the need for further research (not just in this area) into the whole problem of the relationship between precipitation, evaporation and vegetation.

PART 9 REFERENCES

Anonymous. 1971. Estimated Soil Moisture Deficit and Potential Evapotranspiration over Great Britain, Explanatory Notes. Meteorological Office Note.

Balek, J. 1971. Luano Catchment Research Project. Daily Fluctuation of the Potential Evaporation. Water Resources Research Report WR9 of the National Council for Scientific Research, Zambia.

Brian Colquhoun and Ptnrs. 1975. Ndola Water Supply (Report on Phase 1 Studies) 4 volumes.

Foster, S.S.D. and Milton, V.A. 1974. The Permeability and Storage of an Unconfined Chalk Aquifer. I.A.H.S. Hydrol. Sci. Bull. 19.

Hadwin, P. 1972. The Groundwater Resources of the Greater Ndola Area. Ground Water Resources Paper No 1 of Dept. of Water Affairs, Lusaka, Zambia.

Penman, H.L. 1949. The Dependence of Transpiration on Weather and Soil Science Vol 1 pp 74 - 89.

Pliska, S.R. 1968. A Mathematical Model of a Groundwater Basin. Paper from ORSA/TIMS meeting San Francisco, California.

Tyson, H.N., Weber, E.H. 1964. Ground Water Management for the Nation's Future - Computer Simulation of Ground Water Basin. Proc. Am. Soc. Civ. Eng. Journ. Hydraulics Div. HY4 pp 59 - 77.

APPENDIX 1

PROGRAM LISTING

The results given in the report are for a calibration period of 18 months, however, since the initial work was completed on the model a total of 27 months (July 1973 - September 1975) field data has been made available. The following listing is taken from the final calibration run completed on the 27 month period.

```
//X3BR1677 JOB (AN03,N6,4-00,15,,,,0),ADAMS,CLASS=A
/*ROUTE  PRINT ELECTRIC BACKUP=R15,HC=2
//  EXEC FGCLG,REGION=200K
//C.SYSIN  DD *
      DIMENSION X(36),WIDTH(36,36),GL(36,20),PATH(36,36),ELE(36),
     CSCK(36),SFLOW(36),OV(36,20),DEFCT(36),VB(36,27)
     C,IER(13),C(36,36),RAIN(36),EVAP(36),ABZ(36),ALVEL(3
     C6),VINC(36),HOLD1(36),HOLD2(36),STOR(36),EXCSS(36),
     CVX(27,20),SUMC(36),SFLW(36),ASFLW(36)
     C,DAM(27),SPILL(27),FLOUT(27),VPERM(36),SCON(36)
     C,REGUR(36),SMRES(36)
     C,TRANS(36,36),BASE(36,6),PERM(36,6),T6477(36,6),UPTR(36,6)
     C,AMNTH(87),ESMDF(27),PASTD(36),BASE2(36)
     C,ZSTOR(27),ZBSTR(27),ZRAIN(27),ZVAP(27),ZINF(27),ZUMFL(27)
     C,ZSABS(27),ZSMDF(27),ZPILL(27),ZSURF(27)
      INTEGER SUMCA,HOLD3(36),ADJ(36,6),RA(27),E(27),
     CQOUT(36,27),AREA(36),SUMA,OVERB(36),SABST(27),CAREA(36)
      REAL*8 VT(36),WL,O(36,6),SUMQ(36),S(36),HEADN,V(36,27)
     C,ADELT,DIFF,VP(36)
      REAL INF(36) ,NDDEF(36)  ,MTHDS
       NIN=5
      NOUT=6
C     NSTEP IS NO OF TIME STEPS
      NSTEP=27
      NIXT=87
C     AMNTH=NO OF MONTHS IN TIME STEP
      BA=1.6
      SPRED=1.0
      D=1
      Z1=0.
      Z2=0.
      Z3=0.
      Z4=0.
      Z6=0.
      Z5=0.
      Z7=0.
      Z8=0.
      BSMDF=0.
      BSTOR=0.
      BBSTR=0.
      BRAIN=0.
      BVAP=0.
      CINF=0.
      BSABS=0.
      SUMFL=0.
      TOTSF=0.
      SUMFL=0.
C     ZINC IS THE MIN VERT SCALE DIVISION IN FINAL G.W HYDROGRAPHS
      ZINC=0.5
      XY=0.10
```

```
C     *********************************************************
C 1   INITIALISE ARRAYS
C     *********************************************************
      DO 1 I=1,13
    1 IER(I)=0
      DO 2 L=1,36
      DO 2 M=1,36
      WIDTH(L,M)=0.0
      TRANS(L,M)=0.0
      PATH(L,M)=0.0
    2 C(L,M)=0.0
      DO 3 L=1,36
      DO 3 M=1,6
    3 ADJ(L,M)=0
      DO 4 M=1,36
      PASTD(M)=0.
      ELE(M)=0.0
      OVERB(M)=0.
      SCK(M)=0.
      ABZ(M)=0.
      EXCSS(M)=0.
      STOR(M)=0.
      DEFCT(M)=0.
      REQUR(M)=0.
      ASFLW(M)=0.
    4 INF(M)=0.
      DO 5 M=1,36
      SFLOW(M)=0.
      RAIN(M)=0.
    5 EVAP(M)=0.
      DO 6 M=1,36
      DO 6 L=1,6
    6 Q(M,L)=0.
      DO 7 L=1,36
      DO 7 M=1,27
    7 QOUT(L,M)=0.
      DO 8 I=1,13
    8 IER(I)=0.
      BSTOR=0.
      BBSTR=0.
      BRAIN=0.
      BVAP=0.
      CINF=0.
      BSABS=0.
      BSMDF=0.
C     *********************************************************
C 2   READ DATA
C     *********************************************************
      SUMFL=0.
      SUMSP=0.
```

```
      PFLW=520000.
      SFLW(36)=520000.
      PAST=520000.
    9 READ(NIN,1000)NODE,(ADJ(NODE,L),L=1,6)
 1000 FORMAT(I2,8X,6(I2,8X))
      READ(NIN,1001)(HOLD1(I),I=1,6),(HOLD2(I),I=1,6),(HOLD3(I),I=1,6
 1001 FORMAT(10X,6(F5.2,5X),/,10X,6(F5.2,5X),/,10X,6(I5,5X))
      DO 11 I=1,6
      J=ADJ(NODE,I)
      IF(J)11,11,10
   10 PATH(NODE,J)=HOLD1(I)
      WIDTH(NODE,J)=HOLD2(I)
      TRANS(NODE,J)=HOLD3(I)
   11 CONTINUE
      READ(NIN,1007)AREA(NODE),SCK(NODE),OVERB(NODE),ELE(NODE),VPERM(
     C  NODE),CAREA(NODE),SCON(NODE)
      IF(NODE-36)9,12,12
   12 READ(NIN,1002)NODE
 1002 FORMAT(I2)
      READ(NIN,1003)(QOUT(NODE,L),L=1,NSTEP)
 1003 FORMAT(8(4X,I6))
      IF(NODE-36)12,13,13
   13 READ(NIN,1008)(RA(L),L=1,NSTEP)
      READ(NIN,1008)(E(L),L=1,NSTEP)
      DO 14 L=1,NSTEP
      TVAP=1.0*FLOAT(E(L))
      E(L)=AINT(TVAP)
   14 CONTINUE
   15 READ(NIN,1002)NODE
      READ(NIN,1009)(VB(NODE,L),L=1,NSTEP)
      IF(NODE-36)15,16,16
   16 CONTINUE
      READ(NIN,1004)(DAM(L),L=1,NSTEP)
 1004 FORMAT(8(2X,F8.0))
      READ(NIN,1005)(SPILL(L),L=1,NSTEP)
 1005 FORMAT(8(1X,F9.0))
      READ(NIN,1006)(SABST(L),L=1,NSTEP)
 1006 FORMAT(8(4X,I6))
 1007 FORMAT(10X,I8,2X,F6.4,4X,I4,6X,F6.1,12X,F6.4,I8,1X,F6.4)
 1008 FORMAT(16(2X,I3))
 1009 FORMAT(8(3X,F7.2))
      DO 17 I=1,NSTEP
   17 E(I)=E(I)
      DO 18 M=1,36
      DO 18 K=1,36
      TRANS(M,K)=TRANS(M,K)*10
   18 CONTINUE
   19 READ(NIN,1010)NODE,(PERM(NODE,L),L=1,6)
 1010 FORMAT(I2,1X,F7.0,5(3X,F7.0))
      IF(NODE-36)19,20,20
```

```
   20 READ(NIN,1011)NODE,(BASE(NODE,L),L=1,6)
      IF(NODE-36)20,21,21
   21 CONTINUE
 1011 FORMAT(I2,1X,F7.2,5(3X,F7.2))
   22 READ(NIN,1010)NODE,(T6477(NODE,L),L=1,6)
      IF(NODE-36)22,23,23
   23 CONTINUE
   24 READ(NIN,1010)NODE,(UPTR(NODE,L),L=1,6)
      IF(NODE-36)24,25,25
   25 CONTINUE
      BASE(14,4)=BASE(35,2)
      DO 29 NODE=1,36
      DO 29 L=1,6
      IF(PERM(NODE,L)-0.)29,29,26
   26 IF(UPTR(NODE,L)-T6477(NODE,L))28,27,28
   27 PERM(NODE,L)=1.0
      GO TO 29
   28 PERM(NODE,L)=(UPTR(NODE,L)-T6477(NODE,L))/(BASE(NODE,L)+SPRED
     C-BASE(NODE,L)+SPRED )
   29 CONTINUE
 1012 FORMAT(7(12F6.5,/),3F6.5)
      READ(NIN,1012)(AMNTH(IXT),IXT=1,NIXT)
      READ(NIN,1013)(VPERM(I),I=1,36)
 1013 FORMAT(3(10(F6.4,2X),/),6(F6.4,2X))
      DO 30 I=1,36
   30 SCK(I)=0.05
      SCK(5)=0.02
      SCK(9)=0.07
      SCK(13)=0.05
      SCK(17)=0.002
      SCK(18)=0.5
      SCK(28)=0.01
      SCK(33)=0.05
      READ(NIN,1014)(BASE2(I),I=1,36)
 1014 FORMAT(4(8(3X,F7.2),/),4(3X,F7.2))
      DO 31 N=1,36
      SCON(N)=0.08
   31 CONTINUE
      SCON(3)=0.3
      SCON(5)=0.15
      SCON(7)=0.1
      SCON(9)=0.2
      SCON(11)=0.2
      SCON(13)=0.2
      SCON(17)=0.08
      SCON(18)=0.5
      SCON(20)=0.2
      SCON(22)=0.2
      SCON(24)=0.2
      SCON(26)=0.2
```

```
      SCON(28)=0.3
      SCON(30)=0.2
      SCON(33)=0.1
      DO 32 L=1,27
   32 E(L)=E(L)*0.75
      AREA(7)=CAREA(7)
      AREA(13)=CAREA(13)
      AREA(9)=CAREA(9)
      AREA(30)=CAREA(30)
      AREA(24)=CAREA(24)
      AREA(17)=CAREA(17)
C     ************************************************
C 3    WRITE OUT INPUT DATA
C     *****************.*********************************
      WRITE(NOUT,1015)
 1015 FORMAT(1H1,'LIST OF ADJACENT NODES')
      WRITE(NOUT,1016)
 1016 FORMAT(1H0,1X,'NODE   ADJ1  ADJ2   ADJ3   ADJ4   ADJ5   ADJ6 ')
      DO 33 NODE=1,36
   33 WRITE(NOUT,1017)NODE,(ADJ(NODE,L),L=1,6)
 1017 FORMAT(1H ,2X,I2,6X,6(I2,5X))
      WRITE(NOUT,1018)
 1018 FORMAT(1H1,'LIST OF NODAL PARAMETERS')
      WRITE(NOUT,1019)
 1019 FORMAT(1H0,' NODE AREA(M**2)  SCK  OVERB  ELEVATION  VPERM'
     C,'   SCON')
      DO 34 I=1,36
   34 WRITE(NOUT,1020)I,AREA(I),SCK(I),OVERB(I),ELE(I),VPERM(I),SCON(I)
 1020 FORMAT(1H ,2X,I2,4X,I8,2X,F6.4,2X,I4,5X,F6.1,4X,F6.4,4X,4X,F6.4)
      WRITE(NOUT,1021)
 1021 FORMAT(1H1,'MONTHLY RAINFALL DATA IN MM.')
      WRITE(NOUT,1022)
 1022 FORMAT(1H0,' M1  M2  M3  M4  M5  M6  M7  M8  M9  M10 M11 M12 M13 '
     C,'M14 M15 M16 M17 M18 ')
      WRITE(NOUT,1023)(RA(L),L=1,27)
 1023 FORMAT(1H ,1X,I3,26(1X,I3))
      WRITE(NOUT,1024)
 1024 FORMAT(1H0,'MONTHLY EVAPORATION DATA')
      WRITE(NOUT,1022)
      WRITE(NOUT,1023)(E(L),L=1,27)
      WRITE(NOUT,1025)
 1025 FORMAT(1H1,'MEASURED MONTHLY WATER LEVEL DATA')
      WRITE(NOUT,1026)
 1026 FORMAT(1H0,'NODE MONTH1  MONTH2  MONTH3  MONTH4  MONTH5  MONTH6  M
     CONTH7  MONTH8  MONTH9  MNTH10  MNTH11  MNTH12  MNTH13  MNTH14  MNTH15
     CH15  MNTH16')
      DO 35 I=1,36
   35 WRITE(NOUT,1027)I,(VB(I,L),L=1,16)
 1027 FORMAT(1H ,1X,I2,1X,16(F7.2,1X))
      WRITE(NOUT,1025)
```

```
      WRITE(NOUT,1028)
 1028 FORMAT(1H0,'NODE MNTH17  MNTH18 ')
      DO 36 I=1,36
   36 WRITE(NOUT,1029)I,(VB(I,L),L=17,27)
 1029 FORMAT(1H ,1X,I2,1X,11(F7.2,1X))
      WRITE(NOUT,1030)
 1030 FORMAT(1H1,'MONTHLY ABSTRACTION DATA IN M**3 * 10**-3')
      WRITE(NOUT,1026)
      DO 37 I=1,36
   37 WRITE(NOUT,1031)I,(QOUT(I,L),L=1,16)
 1031 FORMAT(1H ,1X,I2,1X,16(I7,1X))
      WRITE(NOUT,1032)(SABST(L),L=1,16)
 1032 FORMAT(1H ,1X,'36S',16(I7,1X))
      WRITE(NOUT,1030)
      WRITE(NOUT,1028)
      DO 38 I=1,36
   38 WRITE(NOUT,1033)I,(QOUT(I,L),L=17,27)
 1033 FORMAT(1H ,1X,I2,1X,11(I7,1X))
      WRITE(NOUT,1034)(SABST(L),L=17,27)
 1034 FORMAT(1H ,1X,'36S',11(I7,1X))
      WRITE(NOUT,1035)
 1035 FORMAT(1H1,' INTER NODAL BASE VALUES')
      WRITE(NOUT,1036)
 1036 FORMAT(1H0,' NODE    ADJ1       ADJ2       ADJ3       ADJ4       A
     CDJ5      ADJ6       ')
      DO 39 NODE=1,36
   39 WRITE(NOUT,1037)NODE,(BASE(NODE,L),L=1,6)
 1037 FORMAT(1H ,2X,I2,1X,6(1X,E10.5))
      WRITE(NOUT,1038)
 1038 FORMAT(1H1,' INTER NODAL PERMEABILITY VALUES M/DAY')
      WRITE(NOUT,1036)
      DO 40 NODE=1,36
   40 WRITE(NOUT,1037)NODE,(PERM(NODE,L),L=1,6)
      WRITE(NOUT,1039)
 1039 FORMAT(1H1,' T6477 CUT OFF TRANS VALUES')
      WRITE(NOUT,1036)
      DO 41 NODE=1,36
   41 WRITE(NOUT,1037)NODE,(T6477(NODE,L),L=1,6)
      WRITE(NOUT,1040)
 1040 FORMAT(1H1,' UPTR UPPER VALUES OF TRANS')
      WRITE(NOUT,1036)
      DO 42 NODE=1,36
   42 WRITE(NOUT,1037)NODE,(UPTR(NODE,L),L=1,6)
      WRITE(NOUT,1041)
 1041 FORMAT(1H1,' BASE2 AND SCON VALUES '///)
      DO 43 NODE=1,36
   43 WRITE(NOUT,1042)NODE,BASE2(NODE),SCON(NODE)
 1042 FORMAT(1H ,3X,I2,3X,F7.2,3X,F6.4)
      WRITE(NOUT,1043)
 1043 FORMAT(1H1,' NODAL CATCHMAENT AND OUTCROP AREAS '/
```

```
     C' NODE         CAREA          AREA'///)
      SUMCA=0.
      SUMA=0.
      DO 44 N=1,36
       WRITE(NOUT,1044)N,CAREA(N),AREA(N)
 1044 FORMAT(1H ,1X,I2,8X,I9,5X,I9)
      SUMCA=SUMCA+CAREA(N)
      SUMA=SUMA+AREA(N)
   44 CONTINUE
      WRITE(NOUT,1045)SUMCA,SUMA
 1045 FORMAT(1H0,' TOTALS    ',I10,4X,I10)
      WRITE(NOUT,1046)
 1046 FORMAT(1H1,43X,'TABLE 2(A)'///)
      WRITE(NOUT,1047)
 1047 FORMAT(1H ,'T6477.LOWER INTERNODAL ZONAL TRANSMISSIVITY VALUES, ',
     C';I.E. VALUES BELOW BASE.'//)
      WRITE(NOUT,1048)
 1048 FORMAT(1H ,' NODE       ADJ1               ADJ2              ADJ3
     C  ADJ4              ADJ5              ADJ6')
      DO 45 N=1,36
   45 WRITE(NOUT,1049)N,ADJ(N,1),T6477(N,1),ADJ(N,2),T6477(N,2),ADJ(N,3)
     C,T6477(N,3),ADJ(N,4),T6477(N,4),ADJ(N,5),T6477(N,5),ADJ(N,6),T6477
     C(N,6)
 1049 FORMAT(1H ,2X,I2,1X,6('(',I2,')',E10.5,1X))
      WRITE(NOUT,1050)
 1050 FORMAT(1H1,43X,'TABLE 2(B)'///)
      WRITE(NOUT,1051)
 1051 FORMAT(1H ,'UPTR. UPPER INTERNODAL ZONAL TRANSMISSIVITY VALUES, I.
     CE. VALUES ABOVE BASE. '//)
      WRITE(NOUT,1048)
      DO 46 N=1,36
   46 WRITE(NOUT,1049)N,ADJ(N,1),UPTR(N,1),ADJ(N,2),UPTR(N,2),ADJ(N,3),
     CUPTR(N,3),ADJ(N,4),UPTR(N,4),ADJ(N,5),UPTR(N,5),ADJ(N,6),UPTR(N,6)
      WRITE(NOUT,1052)
 1052 FORMAT(1H1,23X,'TABLE 3'///)
      WRITE(NOUT,1053)
 1053 FORMAT(1H ,'ZONAL STORAGE COEFFICIENTS'//)
      WRITE(NOUT,1054)
 1054 FORMAT(1H ,' NODE   STOR.COEFF.ABOVE BASE     STOR.COEFF.BELOW BAS
     CE')
      WRITE(NOUT,1055)
 1055 FORMAT(1H ,'                    (SCON)                       (SCK)'//)
      DO 47 N=1,36
   47 WRITE(NOUT,1056)N,SCON(N),SCK(N)
 1056 FORMAT(1H ,1X,I2,13X,F5.4,21X,F5.4)
C     ***************************************************************
C 4   SET ROOT CONSTANT
C     **************************************************************8
      ROOT=100.
      STDEF=200.
```

```
      ESMDF(1)=STDEF
      DO 50 N=1,36
      PASTD(N)=STDEF
      IF(ROOT-STDEF)48,48,49
   48 SMRES(N)=0.
      GO TO 50
   49 SMRES(N)=(ROOT-STDEF)
   50 CONTINUE
      PASTD(36)=0.
      PASTD(35)=0.
      PASTD(34)=0.
      PASTD(14)=0.
      SMRES(36)=ROOT
      SMRES(35)=ROOT
      SMRES(34)=ROOT
      SMRES(14)=ROOT
C     *************************************************************
C 5   SET UP TIME STEP
C     *************************************************************
      TIME=0.
      DO 120 ISTEP=2,NSTEP
      BSTOR=0.
      BBSTR=0.
      BRAIN=0.
      BVAP=0.
      CINF=0.
       BSABS=0.
      SUMFL=0.
      BSMDF=0.
      MTHDS=0.
      ASTOR=0.
      ARAIN=0.
      AVAP=0.
      AINF=0.
      ABSTR=0.
      TSABS=0.
      CONTINUE
C     *************************************************************
C 6   CONVERT SFLOW(NODE)FROM A MTHLY TOTAL TO A RATE PER DAY
C     *************************************************************
      IF(ISTEP-2)51,51,54
   51 DO 52 NODE=1,36
      VP(NODE)=VB(NODE,ISTEP-1)
      V(NODE,ISTEP)=VB(NODE,ISTEP-1)
   52 V(NODE,ISTEP-1)=VB(NODE,ISTEP-1)
      IF(V(NODE,ISTEP)-FLOAT(OVERB(NODE)))53,54,54
   53 STOR(NODE)=1.0
      GO TO 54
   54 DO 55 NODE=1,36
   55 V(NODE,ISTEP)=V(NODE,ISTEP-1)
```

```
      DO 119 IXT=1,NIXT
      ASTOR=0.
      ARAIN=0.
      AVAP=0.
      AINF=0.
      ABSTR=0.
      TSABS=0.
      ITER =0
      IF(IXT.GT.16)GO TO 56
      ERROR=0.0001
      GO TO 57
   56 ERROR=0.001
   57 PTIME=TIME
      TIME=TIME+AMNTH(IXT)
      ADELT=AMNTH(IXT)*30.5
      DELT=1/ADELT
      DO 58 L=1,36
      NODEF(L)=PASTD(L)
   58 VT(L)=VP(L)
   59 ITER=ITER+1
C     ***********************************************************
C 7   SET UP DO LOOP FOR NODES 1,36
C     8***********************************************************
      DIFF=0.
      DO 94 NODE=1,36
      QL=0.
      SUMQ(NODE)=0.
      SUMC(NODE)=0.
C     ***********************************************************
C 8   SET UP DO LOOP FOR ADJ NODES 1-6
C     ***********************************************************
       IF(NODE.EQ.1)GO TO 93
      IF(NODE.EQ.2)GO TO 93
      IF(NODE.EQ.4)GO TO 93
      IF(NODE.EQ.6)GO TO 93
      IF(NODE.EQ.8)GO TO 93
      IF(NODE.EQ.8)GO TO 93
      IF(NODE.EQ.10)GO TO 93
      IF(NODE.EQ.12)GO TO 93
      IF(NODE.EQ.15)GO TO 93
      IF(NODE.EQ.16)GO TO 93
      IF(NODE.EQ.19)GO TO 93
      IF(NODE.EQ.21)GO TO 93
      IF(NODE.EQ.23)GO TO 93
      IF(NODE.EQ.25)GO TO 93
      IF(NODE.EQ.27)GO TO 93
      IF(NODE.EQ.29)GO TO 93
      IF(NODE.EQ.32)GO TO 93
      DO 67 L=1,6
      J=ADJ(NODE,L)
```

```
      IF(J.EQ.0)GO TO 67
      IF(J.EQ. 1)GO TO 66
      IF(J.EQ. 2)GO TO 66
      IF(J.EQ. 4)GO TO 66
      IF(J.EQ. 6)GO TO 66
      IF(J.EQ. 8)GO TO 66
      IF(J.EQ.10)GO TO 66
      IF(J.EQ.12)GO TO 66
      IF(J.EQ.15)GO TO 66
      IF(J.EQ.16)GO TO 66
      IF(J.EQ.19)GO TO 66
      IF(J.EQ.21)GO TO 66
      IF(J.EQ.23)GO TO 66
      IF(J.EQ.25)GO TO 66
      IF(J.EQ.27)GO TO 66
      IF(J.EQ.29)GO TO 66
      IF(J.EQ.32)GO TO 66
C     *************************************************************
C 9   COMPUTE TRANSMISSIVITY AND CONDUCTANCE
C     *************************************************************
      IF(VT(NODE)-VT(J))60,60,61
   60 WL=VT(J)
      GO TO 62
   61 WL=VT(NODE)
   62 IF(PERM(NODE,L)-0.)63,63,64
   63 TRANS(NODE,J)=0.
      GO TO 65
   64 CALL TRNS(WL,BASE,NODE,L,J,TRANS,T6477,PERM,UPTR,SPRED)
   65 C(NODE,J)=WIDTH(NODE,J)*TRANS(NODE,J)/PATH(NODE,J)
      Q(NODE,L)=C(NODE,J)*(VT(J)-VT(NODE))
      SUMQ(NODE)=SUMQ(NODE)+Q(NODE,L)
      SUMC(NODE)=SUMC(NODE)+C(NODE,J)
      GO TO 67
   66 C(NODE,J)=0.
      TRANS(NODE,J)=0.
   67 CONTINUE
      SUMQ(NODE)=SUMQ(NODE)*ADELT
      SUMC(NODE)=SUMC(NODE)*ADELT
C     **************************************************************
C 10  COMPUTE RELAX COEFFS.
C     ************************************************************
      IF(STOR(NODE).LT.1.0)GO TO 68
      X(NODE)=BA/(FLOAT(AREA(NODE))*SCK(NODE)+SUMC(NODE))
      GO TO 69
   68 X(NODE)=BA/(FLOAT(AREA(NODE))*SCON(NODE)+SUMC(NODE))
C     *********************************************************
C 11  COMPUTE STORAGE FLOW FOR NODES
C     ***********************************************************
   69 IF(STOR(NODE).LT.1.0)GO TO 70
      CHSCK=SCK(NODE)
```

```
      GO TO 71
   70 CHSCK=SCON(NODE)
   71 S(NODE)=FLOAT(AREA(NODE))*CHSCK*(VT(NODE)-
     CVP(NODE))
C     ***********************************************************
C 12  COMPUTE BALANCE OF ABSTRACTIONS RECHARGE RAIN ETC
C     ************************************************************
      PTIME=PTIME+1
      K=ISTEP
      ABZ(NODE)=FLOAT(QOUT(NODE,K))*10**3*AMNTH(IXT)
C     ***********************************************************
C 13  EVAP AND INF CALCULATIONS
C     *********************************************************
      EVAP(NODE)=0.
      RAIN(NODE)=0.
      ASFLW(NODE)=SFLOW(NODE)
      L=ISTEP
      RAIN(NODE)=FLOAT(RA(L))*FLOAT(CAREA(NODE))*AMNTH(IXT)
     C/1000.
      ASFLW(NODE)=ASFLW(NODE)+RAIN(NODE)
      IF(NODE-36)73,72,73
   72 EVAP(36)=FLOAT(E(L))*800000.*AMNTH(IXT)/1000.
      GO TO 74
   73 EVAP(NODE)=FLOAT(E(L))*FLOAT(CAREA(NODE))*AMNTH(IXT)
     C/1000.
   74 CONTINUE
      BINF=ASFLW(NODE)-EVAP(NODE)
      IF(BINF-0.)75,76,76
   75 REQUR(NODE)=(EVAP(NODE)-ASFLW(NODE))*1000./FLOAT(CAREA(NODE))
      DEFCT(NODE)=NDDEF(NODE)+REQUR(NODE)
      INF(NODE)=0.
      CALL SMD(NODE,DEFCT,AVBLE,REQUR,SMRES,ROOT,SCK)
      EVAP(NODE)=ASFLW(NODE)+(AVBLE*FLOAT(CAREA(NODE))/1000.)
      ASFLW(NODE)=0.
      PASTD(NODE)=NDDEF(NODE)+AVBLE
      GO TO 87
   76 REQUR(NODE)=0.
      AVBLE=0.
      ASFLW(NODE)=BINF
      IF(NDDEF(NODE)-0.)77,77,78
   77 DEFCT(NODE)=0.
      SMRES(NODE)=ROOT
      GO TO 84
   78 DEFCT(NODE)=NDDEF(NODE)-(ASFLW(NODE)*1000./FLOAT(CAREA(NODE)))
      IF(DEFCT(NODE)-0.)79,79,80
   79 ASFLW(NODE)=ASFLW(NODE)-NDDEF(NODE)*FLOAT(CAREA(NODE))/1000.
      PASTD(NODE)=0.
      SMRES(NODE)=ROOT
      DEFCT(NODE)=0.
      GO TO 84
```

```
   80 PASTD(NODE)=DEFCT(NODE)
      SMRES(NODE)=ROOT
      IF(PASTD(NODE)-SMRES(NODE))82,82,81
   81 SMRES(NODE)=0.
      GO TO 83
   82 SMRES(NODE)=SMRES(NODE)-PASTD(NODE)
   83 ASFLW(NODE)=0.
   84 INF(NODE)=VPERM(NODE)*FLOAT(CAREA(NODE)) *ADELT
      IF(INF(NODE)-ASFLW(NODE))85,86,86
   85 ASFLW(NODE)=ASFLW(NODE)-INF(NODE)
      GO TO 87
   86 INF(NODE)=ASFLW(NODE)
      ASFLW(NODE)=0.
   87 CONTINUE
C     **********************************************************
C  14 COMPUTE RESIDUAL FLOW FOR NODE
C     **********************************************************
      RES=SUMQ(NODE)-S(NODE)+INF(NODE)-ABZ(NODE)
C     ***********************************************************
C  15 COMPUTE NEW HEAD AT NODE
C     **********************************************************
      EXCSS(NODE)=0.
      HEADN=VT(NODE)+X(NODE)*RES
      IF(HEADN-ELE(NODE))89,88,88
   88 EXCSS(NODE)=RES
      HEADN=ELE(NODE)
   89 DIFF=DIFF+DABS(VT(NODE)-HEADN)
      VT(NODE)=HEADN
C
C     FOLLOWING STATEMENTS PREVENT SMD AT RISING WATER NODES
C
      TEST=EXCSS(NODE)
      EXCSS(NODE)=TEST-PASTD(NODE)*FLOAT(CAREA(NODE))
     C/1000.
      IF(EXCSS(NODE)-0.)90,92,92
   90 PASTD(NODE)=PASTD(NODE)-TEST*
     C1000./FLOAT(CAREA(NODE))
      SMRES(NODE)=ROOT-PASTD(NODE)
      IF(SMRES(NODE).GT.0.)GO TO 91
      SMRES(NODE)=0.
   91 EXCSS(NODE)=0.
      GO TO 94
   92 PASTD(NODE)=0.
      SMRES(NODE)=ROOT
      GO TO 94
   93 CONTINUE
      X(NODE)=0.
      S(NODE)=0.
   94 CONTINUE
C     ************************************************************
```

```
C 16  CHECK TOTAL ABS.CHANGE IN WATER LEVELS AGAINST ERROR
C     **************************************************************8
      IF(ITER-65)97,96,95
   95 WRITE(NOUT,1057)ITER,TIME
 1057 FORMAT(1H1,'WATER LEVELS FOR ITERATION ',I2,'AFTER ',E12.5,'MTHS'
     C)
      DO 96 N=1,36
   96 WRITE(NOUT,1058)N,VP(N)
 1058 FORMAT(1H ,1X,I2,5X,F11.5)
   97 IF(DIFF-ERROR)99,99,98
   98 IF(ITER-70)59,59,99
   99 CONTINUE
      DO 102 NODE=1,36
      VP(NODE)=VT(NODE)
      ASTOR=ASTOR+S(NODE)
      ABSTR=ABSTR+ABZ(NODE)
      ARAIN=ARAIN+RAIN(NODE)
      AVAP=AVAP+EVAP(NODE)
      AINF=AINF+INF(NODE)
      ASFLW(NODE)=ASFLW(NODE)+EXCSS(NODE)
      SFLOW(NODE)=ASFLW(NODE)
C     (*************************************************************
C 17  IS NEW HEAD>BASE2(NODE)
C     **************************************************************
      IF(VP(NODE)-BASE2(NODE))100,101,101
  100 STOR(NODE)=1.
      GO TO 102
  101 STOR(NODE)=0.
      V(NODE,ISTEP)=VT(NODE)
  102 ESDF=0.
      DO 103 N=1,36
      ESDF=ESDF+(PASTD(N)-NDDEF(N))*FLOAT(CAREA(N))/1000.
  103 CONTINUE
      ESTOR=ASTOR
      EBSTR=ABSTR
      ERAIN=ARAIN
      EVAP=AVAP
      EINF=AINF
C     ***********************************************************
C 18  ADD ALL SFLOW INTO NODE 36
C     *************************************************************
      DO 104 NODE=1,35
      SURF=SFLOW(NODE)
  104 CONTINUE
      BADA=SFLOW(36)
      PRFL=BADA-PFLW
      DO 105 NODE=1,35
      SFLOW(36)=SFLOW(36)+SFLOW(NODE)
  105 SFLOW(NODE)=0.
      SURF=SFLOW(36)
```

```
      HOLD=SURF
      TSABS=FLOAT(SABST(ISTEP))*AMNTH(IXT)*10.**3
      SURF=SURF-TSABS
      IF(SURF-0.)106,107,107
  106 TSABS=IFIX(HOLD)/1000
      SURF=0.
  107 DISCH =SURF-DAM(ISTEP)
      IF(DISCH-0.)108,109,109
  108 DISCH=0.
      GO TO 110
  109 SURF=SURF-DISCH
  110 PFLW=SURF
      WATER=DAM(ISTEP)+SPILL(ISTEP)
      MTHDS=MTHDS+DISCH
C     ************************************************************
C 19  CALCULATION TO GIVE CHANGE IN SURFACE FLOW OVER MONTH
C     ************************************************************
      FLUJO=SURF-PAST+DISCH
      TOTSF=TOTSF+SURF
      PAST=SURF
      SUMFL=SUMFL+FLUJO
      SFLOW(36)=SURF
      CONTINUE
C     *************************************************************
C 20  WRITE OUT CALCULATED PARAMETERS FOR NODES
C     ***************************************************************
      DO 111 NODE=1,36
  111 V(NODE,ISTEP)=VP(NODE)
 1059 FORMAT(1H0,'NODE   SUMQ(NODE)      SUMC      RELAX COEFF  STRGE.F
     COW  ABSTR.  RATE  RAIN(NODE)   EVAP(NODE)    INF(NODE)  SMDEF')
 1060 FORMAT(1H ,2X,I2,3X,D12.5,1X,2(E12.5,1X),D12.5,1X,5(E12.5,1X))
C     *****************************************************************
C 21  THE FOLLOWING SECTION MAY BE USED TO PRINT OUT MORE DETAILED
C     MONTHLY INFORMATION BY DELETING THE '*' FROM THE FIRST COLUMN.
C     WARNING!!!
C     ----------
C     IF THIS FACILITY IS REQUIRED IT SHOULD BE SPECIFIED FOR WHICH
C     MONTH (I.E. ISTEP)DETAILED DATA IS REQUIRED TO AVOID EXCESSIVELY
C     LARGE PRINTOUTS.  E.G.  ...
C     IF(ISTEP-13)118,135,118
C     WOULD GIVE DETAILED PRINTOUT FOR FINAL TIME STEP OF MONTH 13
C     ONLY.
C     *****************************************************************
* 135 IF(IXT-87)118,136,118
* 136 WRITE(NOUT,1061)ISTEP
*1061 FORMAT(1H1,'MEASURED W.L.COMPARED TO CALC.W.L.',
*    C'FOR MONTH ',I2)
*     WRITE(NOUT,1062)
*     WRITE(NOUT,1063)
*1062 FORMAT(1H0,' NODE  MEASURED      CALC.
```

```
      CGROUND  WATER FLOW  TO  AND  FROM  ADJACENT  NODES')
 1063 FORMAT(1H ,'          G.W.L.(M)    G.W.L(M)         ADJ1           AD
      CJ2                 ADJ3                  ADJ4             ADJ5
      CADJ6')
       WRITE(NOUT,1064)
 1064 FORMAT(1H ,52X,'( NEGATIVE  VALUES  INDICATE',
      C'   FLOW AWAY FROM NODES )'///)
       DO 112 NODE=1,36
  112 WRITE(NOUT,1065)NODE,VB(NODE,ISTEP),V(NODE,ISTEP),ADJ(NODE,1),Q(NO
      CDE,1),ADJ(NODE,2),Q(NODE,2),ADJ(NODE,3),Q(NODE,3),ADJ(NODE,4),Q(NO
      CDE,4),ADJ(NODE,5),Q(NODE,5),ADJ(NODE,6),Q(NODE,6)
 1065 FORMAT(1H ,1X,I2,4X,F6.1,4X,F11.5,2X,6('(',I2,')',E12.5,1X))
       WRITE(NOUT,1066)
 1066 FORMAT(1H1,'COMPUTED TRANS. VALUES IN M**3/DAY/M.')
       WRITE(NOUT,1067)
 1067 FORMAT(1H0,' NODE     ADJ1        ADJ2        ADJ3        ADJ4        A
      CDJ5        ADJ6')
       DO 116 NODE=1,36
       DO 115 L=1,6
       K=ADJ(NODE,L)
       IF(K-0)113,113,114
  113 HOLD1(L)=0.
       GO TO 115
  114 HOLD1(L)=TRANS(NODE,K)
  115 CONTINUE
  116 WRITE(NOUT,1068)NODE,(HOLD1(L),L=1,6)
 1068 FORMAT(1H ,2X,I2,1X,6(1X,E10.5))
       WRITE(NOUT,1069)
 1069 FORMAT(1H1,' PARAMETERS  IN  WATER  BALANCE  FOR  SYSTEM
      CEXPRESSED  IN   M**3')
       WRITE(NOUT,1059)
       WRITE(NOUT,1070)
 1070 FORMAT(1H ,'        (+VE=INTO NODE)',33X,'(-VE = RECHARGE)'//)
       DO 117 NODE=1,36
  117 WRITE(NOUT,1060)NODE,SUMQ(NODE),SUMC(NODE),X(NODE),S(NODE),ABZ(
      C  NODE),RAIN(NODE),EVAP(NODE),INF(NODE),PASTD(NODE)
       WRITE(NOUT,1075)ASTOR,ABSTR,ARAIN,AVAP
      C,AINF
       CONTINUE
       ESABS=TSABS
 1071 FORMAT(1H ,'TOTAL CHANGE IN STORAGE OVER ADELT   =',E12.5/
      C            ' TOTAL G.W.ABSTRACTION OVER ADELT     =',E12.5/
      C           '  TOTAL SURFACE ABSTRACTION OVER ADELT =',E12.5/
      C            'TOTAL RAINFALL OVER ADELT            =',E12.5/
      C            ' TOTAL EVAPORATION OVER ADELT         =',E12.5/
      C            ' TOTAL INFILTRATION OVER ADELT        =',E12.5/
      C            ' TOTAL CHANGE IN SOIL M.DEF IN ADELT  =',E12.5)
       WRITE(NOUT,1072)
 1072 FORMAT(1H0,'TOTAL CHANGES OVER ADELT EXPRESSED IN M**3')
       WRITE(NOUT,1071)ESTOR,EBSTR,ESABS,ERAIN
```

```
     C,FVAP,EINF,ESDF
      WRITE(NOUT,1074)FLUJO
      ADDN=ERAIN-(EBSTR+ESABS+FVAP+FLUJO-ESDF)
      DIFER=ESTOR-ADDN
      PCENT=ABS(DIFER/ESTOR)*100.
      WRITE(NOUT,1073)ADDN,DIFER,PCENT
1073  FORMAT(1H0,'BAL OF RAIN-(ABS+EVP+CH IN SFLW+CH IN SMD)=',E12.5/
     C' GROUND WATER BALANCE=',E12.5,'M**3',
     C 25X,'PERCENTAGE ERROR =',F6.2,'%')
1074  FORMAT(1H ,'TOTAL CHANGE IN SFLOW OVER MONTH  =',E12.5)
1075  FORMAT(1H0,'TOTALS',39X,5(E12.5,1X))
 118  BSABS=BSABS+TSABS
      BSTOR=BSTOR+ASTOR
      BBSTR=BBSTR+ABSTR
      BRAIN=BRAIN+ARAIN
      CINF=CINF+AINF
      BVAP=BVAP+AVAP
      BSMDF=BSMDF+ESDF
 119  CONTINUE
1076  FORMAT(1H ,I2,2X,'BSTOR=',E12.5,6(2X,E12.5))
      WRITE(NOUT,1076)IXT,BSTOR,BSABS,BBSTR,BRAIN,BVAP,BSMDF,SUMFL
      ZSTOR(ISTEP)=BSTOR
      ZBSTR(ISTEP)=BBSTR
      ZRAIN(ISTEP)=BRAIN
      ZVAP(ISTEP)=BVAP
      ZINF(ISTEP)=CINF
      ZUMFL(ISTEP)=SUMFL
      ZSABS(ISTEP)=BSABS
      ZSMDF(ISTEP)=BSMDF
      ZSURF(ISTEP)=SURF
      ZPILL(ISTEP)=MTHDS
      ADDN=BRAIN-(BBSTR+BSABS+BVAP+SUMFL-BSMDF)
      DIFER=BSTOR-ADDN
      PCENT=ABS(DIFER/BSTOR)*100.
      WRITE(NOUT,1073)ADDN,DIFER,PCENT
 120  CONTINUE
      WRITE(NOUT,1077)
1077  FORMAT(1H ,'S///9999')
      DO 121 J=4,NSTEP
      Z1=Z1+ZRAIN(J)
      Z2=Z2+ZVAP(J)
      Z3=Z3+ZUMFL(J)
      Z4=Z4+ZSTOR(J)
      Z5=Z5+ZBSTR(J)
      Z6=Z6+ZSABS(J)
      Z7=Z7+ZSMDF(J)
 121  CONTINUE
      WRITE(NOUT,1078)
1078  FORMAT(1H1,' WATER BALANCE SUMMARY')
      WRITE(NOUT,1079)
```

```
 1079 FORMAT(1H ,'******************************'////)
      WRITE(NOUT,1080)
 1080 FORMAT(1H ,' MONTH      RAIN                 EVAP       DEL SFLOW    DEL STOR
     C    GW ABST       SURF ABST      DEL SMD        SPILL          STOR '//)
      DO 122 J=4,NSTEP
      WRITE(NOUT,1081)J,ZRAIN(J),ZVAP(J),ZUNFL(J),ZSTOR(J),ZBSTR(J)
     C,ZSABS(J),ZSMDF(J),ZPILL(J),ZSURF(J)
 1081 FORMAT(1H ,2X,I2,3X,10E12.5)
  122 CONTINUE
      WRITE(NOUT,1082)Z1,Z2,Z3,Z4,Z5,Z6,Z7
 1082 FORMAT(1H0,' TOTALS',7E12.5)
      Z9=Z1-Z2-Z3-Z4-Z5-Z6+Z7-Z8
      WRITE(NOUT,1083)Z8
 1083 FORMAT(1H0,'**** FINAL WATER BALANCE =',E12.5,'****')
      WRITE(NOUT,1084)
 1084 FORMAT(1H ,'++++++SPILL FIGURES++++++'   )
      DO 123 J=1,NSTEP
  123 WRITE(NOUT,1085)J,ZPILL(J)
 1085 FORMAT(1H ,1X,I2,3X,E12.5)
      DO 134 NODE=1,36
      IF(NODE.EQ.1)GO TO 134
      IF(NODE.EQ.2)GO TO 134
      IF(NODE.EQ.4)GO TO 134
      IF(NODE.EQ.6)GO TO 134
      IF(NODE.EQ.8)GO TO 134
      IF(NODE.EQ.10)GO TO 134
      IF(NODE.EQ.12)GO TO 134
      IF(NODE.EQ.15)GO TO 134
      IF(NODE.EQ.16)GO TO 134
      IF(NODE.EQ.19)GO TO 134
      IF(NODE.EQ.21)GO TO 134
      IF(NODE.EQ.23)GO TO 134
      IF(NODE.EQ.25)GO TO 134
      IF(NODE.EQ.27)GO TO 134
      IF(NODE.EQ.29)GO TO 134
      IF(NODE.EQ.32)GO TO 134
      VMAX=0.
      VMIN=1300.
      DO 131 ISTEP=2,NSTEP
      IF(V(NODE,ISTEP)-VMAX)125,125,124
  124 VMAX=V(NODE,ISTEP)
  125 IF(V(NODE,ISTEP)-VMIN)126,126,127
  126 VMIN=V(NODE,ISTEP)
      GO TO 127
  127 IF(VB(NODE,ISTEP)-VMAX)129,129,128
  128 VMAX=VB(NODE,ISTEP)
  129 IF(VB(NODE,ISTEP)-VMIN)130,130,131
  130 VMIN=VB(NODE,ISTEP)
  131 CONTINUE
      ALVEL(NODE)=VMAX
```

```
      VINC(NODE)=(VMAX-VMIN)/19.
      IF(VINC(NODE)-ZINC)132,132,133
  132 VINC(NODE)=ZINC
  133 CONTINUE
      CALL PLT1(NODE,V,VB,VINC,ALVEL,VX,GL,ELE,OV,OVERB,IER)
      CALL PLT2(NODE,ALVEL,VINC,VX,IER,GL,OV)
  134 CONTINUE
      WRITE(NOUT,1086)
 1086 FORMAT(1H ,'E///9999')
      STOP
      END
```

```
      SUBROUTINE ERRS(IW,IER)
      DIMENSION IER(13)
      IF(IW-1)12,12,1
    1 IF(IW-2)13,13,2
    2 IF(IW-3)14,14,3
    3 IF(IW-4)15,15,4
    4 IF(IW-5)16,16,5
    5 IF(IW-6)17,17,6
    6 IF(IW-7)18,18,7
    7 IF(IW-8)19,19,8
    8 IF(IW-9)20,20,9
    9 IF(IW-10)21,21,10
   10 IF(IW-11)22,22,11
   11 IF(IW-12)23,23,24
   12 IER(1)=IER(1)+1
      GO TO 25
   13 IER(2)=IER(2)+1
      GO TO 25
   14 IER(3)=IER(3)+1
      GO TO 25
   15 IER(4)=IER(4)+1
      GO TO 25
   16 IER(5)=IER(5)+1
      GO TO 25
   17 IER(6)=IER(6)+1
      GO TO 25
   18 IER(7)=IER(7)+1
      GO TO 25
   19 IER(8)=IER(8)+1
      GO TO 25
   20 IER(9)=IER(9)+1
      GO TO 25
   21 IER(10)=IER(10)+1
      GO TO 25
   22 IER(11)=IER(11)+1
      GO TO 25
   23 IER(12)=IER(12)+1
      GO TO 25
   24 IER(13)=IER(13)+1
   25 CONTINUE
      RETURN
      END
```

```
      SUBROUTINE PLT1(NODE,V,VB,VINC,ALVEL,VX,GL,ELE,OV,OVERB,IER)
      DIMENSION VB(36,27),VINC(36),ALVEL(36),GL(36,20
     C),ELE(36),OV(36,20),IER(13)
      INTEGER VX(27,20),OVERB(36),SYMB(4)
      REAL*8 V(36,27)
      DATA SYMB/'M','O','*',' '/
      DO 19 K=2,27
      DO 18 M=1,20
      AM=FLOAT(M)
      AM1=FLOAT(M-1)
      IF(M-1)2,1,2
    1 THING=SNGL(V(NODE,K))
      IW=IFIX((THING-VB(NODE,K))*2.0+7.5)
      CALL ERRS(IW,IER)
    2 TEST1=AM1*VINC(NODE)-0.5*VINC(NODE)-ALVEL(NODE)
      TEST2=AM *VINC(NODE)-0.5*VINC(NODE)-ALVEL(NODE)
      IF(V(NODE,K)+TEST1)3,5,5
    3 IF(V(NODE,K)+TEST2)5,8,8
    4 VX(K,M)=SYMB(1)
      GO TO 12
    5 IF(VB(NODE,K)+TEST1)6,11,11
    6 IF(VB(NODE,K)+TEST2)11,7,7
    7 VX(K,M)=SYMB(2)
      GO TO 12
    8 IF(VB(NODE,K)+TEST1)9,4,4
    9 IF(VB(NODE,K)+TEST2)4,10,10
   10 VX(K,M)=SYMB(3)
      IASCR=IASCR+1
      GO TO 12
   11 VX(K,M)=SYMB(4)
   12 CONTINUE
      IF(K.GT.2)GO TO 18
      OV(NODE,M)=0.
      GL(NODE,M)=0.
      IF(ELE(NODE)+TEST1)13,15,15
   13 IF(ELE(NODE)+TEST2)15,14,14
   14 GL(NODE,M)=1.
   15 BURDN=FLOAT(OVERB(NODE))
      IF(BURDN+TEST1)16,18,18
   16 IF(BURDN+TEST2)18,17,17
   17 OV(NODE,M)=1.
   18 CONTINUE
   19 CONTINUE
      RETURN
      END
```

```
      SUBROUTINE PLT2(NODE,ALVEL,VINC,VX,IER,GL,OV)
      DIMENSION ALVEL(36),VINC(36),OV(36,20),IER(13),GL(36,20)
      INTEGER VX(27,20)
      NIN=5
      NOUT=6
      IWX=IWX+1
      IWY=IWX-(IWX/2)*2
      IF(IWY-1)2,1,1
    1 WRITE(NOUT,1001)NODE
      GO TO 3
    2 WRITE(NOUT,1000)NODE
 1000 FORMAT(1H0,'NODE',I2,' COMPARISON OF CALCULATED AND MEASURED WATER
     C LEVELS')
 1001 FORMAT(1H1,'NODE',I2,' COMPARISON OF CALCULATED AND MEASURED WATER
     C LEVELS')
    3 WRITE(NOUT,1002)
 1002 FORMAT(1H0,16X,' 1973       1974       1975')
      WRITE(NOUT,1003)
 1003 FORMAT(1H ,16X,'JASONDJFMAMJJASONDJFMAMJJASON')
      DO 6 M=1,20
      VZ=ALVEL(NODE)-FLOAT(M-1)*VINC(NODE)
      IF(GL(NODE,M).GT.0.)GO TO 4
      IF(OV(NODE,M).GT.0.)GO TO 5
      WRITE(NOUT,1004)VZ,(VX(K,M),K=2,27)
 1004 FORMAT(1H ,3X,F10.2,4X,26A1)
      GO TO 6
    4 WRITE(NOUT,1005)VZ,(VX(K,M),K=2,27)
 1005 FORMAT(1H ,3X,F10.2,4X,26A1,'---------GROUND LEVEL')
      GO TO 6
    5 WRITE(NOUT,1006)VZ,(VX(K,M),K=2,27)
 1006 FORMAT(1H ,3X,F10.2,4X,26A1,'---------OVERBURDEN')
    6 CONTINUE
      IF(NODE-36)8,7,7
    7 WRITE(NOUT,1007)(IER(N),N=1,13)
 1007 FORMAT(1H0,'ERRORS RANGE             -2.75 -2.25 -1.75 -1.25 -0.75 -0.2
     C5 0.25  0.75  1.25  1.75  2.25  2.75',/,'                    -2.75
     C-2.25 -1.75 -1.25 -0.75 -0.25  0.25  0.75  1.25  1.75  2.25  2.75'
     C,/,'NUMBER ERRORS ',13I6)
    8 CONTINUE
      RETURN
      END
```

```
      SUBROUTINE SMD(NODE,DEFCT,AVBLE,REQUR,SMRES,ROOT,SCK)
      DIMENSION DEFCT(36),REQUR(36),SMRES(36),SCK(36)
      IF(SMRES(NODE)-0.)4,4,1
    1 IF(DEFCT(NODE)-SMRES(NODE))3,3,2
    2 DEFCT(NODE)=DEFCT(NODE)-SMRES(NODE)
      PLUS=SMRES(NODE)
      SMRES(NODE)=0.
      GO TO 5
    3 AVBLE=DEFCT(NODE)
      DEFCT(NODE)=0.
      SMRES(NODE)=SMRES(NODE)-AVBLE
      GO TO 13
    4 PLUS=0.
    5 A=ROOT
      IF(DEFCT(NODE).LT.A)GO TO 6
      B=(ROOT*4./3.)
      IF(DEFCT(NODE).LT.B)GO TO 7
      C=(ROOT*5./3.)
      IF(DEFCT(NODE).LT.C)GO TO 8
      D=(2.*ROOT)
      IF(DEFCT(NODE).LT.D)GO TO 9
      E=(ROOT*7./3.)
      IF(DEFCT(NODE).LT.E)GO TO 10
      F=(ROOT*10./3.)
      IF(DEFCT(NODE).LT.F)GO TO 11
      AVBLE=0.
      GO TO 12
    6 AVBLE=1.*REQUR(NODE)
      GO TO 12
    7 AVBLE=.96*REQUR(NODE)
      GO TO 12
    8 AVBLE=.68*REQUR(NODE)
      GO TO 12
    9 AVBLE=.52*REQUR(NODE)
      GO TO 12
   10 AVBLE=.40*REQUR(NODE)
      GO TO 12
   11 AVBLE=.28*REQUR(NODE)
   12 AVBLE=AVBLE+PLUS
   13 CONTINUE
      RETURN
      END
```

```
      SUBROUTINE TRNS(WL,BASE,N,L,J,TRANS,T6477,PERM,UPTR,
     CSPRED)
      DIMENSION BASE(36,6),TRANS(36,36),T6477(36,6),PERM(36,6),
     CUPTR(36,6)
      REAL*8 WL
      IF(WL-(BASE(N,L)-SPRED))1,2,2
    1 TRANS(N,J)=T6477(N,L)
      GO TO 6
    2 IF(WL-(BASE(N,L)+SPRED))3,4,4
    3 TRANS(N,J)=T6477(N,L)+PERM(N,L)*(WL-BASE(N,L)
     C+SPRED)
      IF(TRANS(N,J)-(UPTR(N,L)))5,4,4
    4 TRANS(N,J)=UPTR(N,L)
    5 GO TO 6
    6 CONTINUE
      RETURN
      END
```