A Groundwater Modelling Application for a Groundwater Flow Problem for A Shallow Unconfined Aquifer In Borno State, Nigeria

By

Remi J.P. Allard, P.Eng.

A Report
Submitted to The Department of Civil and Geological Engineering
In Partial Fulfillment of The Requirements for The
Degree of Master in Engineering

University of Manitoba
Winnipeg, Manitoba
May 1994

TABLE OF CONTENTS

EXECUTIVE SUMMARY

This Study is undertaken to demonstrate a basic understanding and working knowledge of the principles of groundwater modelling studied at the master's level in engineering. The task of developing and calibrating a model is not completely fullfilled. However, the author has gained valuable experience in the methodology of modelling through conceptualization, discretization, parameter estimation, calibration and documenting the exercise. The model could not be calibrated sufficiently well enough to permit transient simulations as limited data is available for establishing input parameters and for calibration. An increase in the number of elements, and a finer discretization in critical areas of the model domain are expected to reduce errors caused by large element aspect ratios and vertical flow gradients. A vertical-profile model or unsaturated-saturated flow model is recommended as an altemtaive to the 2-dimensional areal model utilized in this study. The difficulty in calibrating the model illustrates the requirement for more detailed field investigations to determine aquifer parameters and the spatial variability across the basin.

Disclaimer

This work is outside the Terms of Reference for the work undertaken by the author in Nigeria for the Borno State Agricultural Development Project (BOSADP), and is strictly on a personal interest basis. Therefore, the accuracy and usefulness of this information to any interested parties is neither implied nor guaranteed.

1.0 PREFACE

As partial requirements for the fulfillment of the degree of Masters of Engineering, the student is required to demonstrate, through practical application, a working knowledge of the theory and concepts studied at an advanced level. This report details work undertaken by the author in the field of hydrogeology in response to this requirement.

This report outlines the field work undertaken, the formulation of the conceptual and mathematical models, calibration and sensitivity analysis, and finally the conclusions and recommendations drawn from the Study.

2.0 INTRODUCTION AND SCOPE

The purpose of this work is to develop a working groundwater flow model of the Wushi River Basin, Nigeria, and in turn to evaluate the potential impact of hydrologic stresses on the lower reaches of the basin. Such stresses to be evaluated include upstream abstraction, reduced precipitation and recharge, and excessive well development (well interference) in the middle reaches of the basin where large scale banana and mango plantations are proposed for development.

Due to limited field resources and poor climatic records, calibration and verification of the model are only partially successful for this modelling exercise. It was not possible to conduct transient simulations to investigate the potential impacts of stresses on the basin. Nonetheless the development of the conceptual and mathematical models for steady state flow is now presented.

Due to the complexity of the aquifer domain, analytical models are not capable of realistically representing the complex boundary conditions and heterogeneity of the aquifer. Numerical computer modelling is chosen and the United States Geological Survey's, Modular Finite Difference Flow Model (MODFLOW) was initially selected to solve the problem. Due to the irregular aquifer boundary and the inability of MODFLOW to handle such irregular domains, AQUIFEM-1 is the code finally utilized to solve the problem.

The modelling methodology and protocol as outlined in Anderson and Woessner (1992) is utilized for this Study. The methodology is graphically illustrated in Figure 1, with a summary of the critical modelling steps as follows:

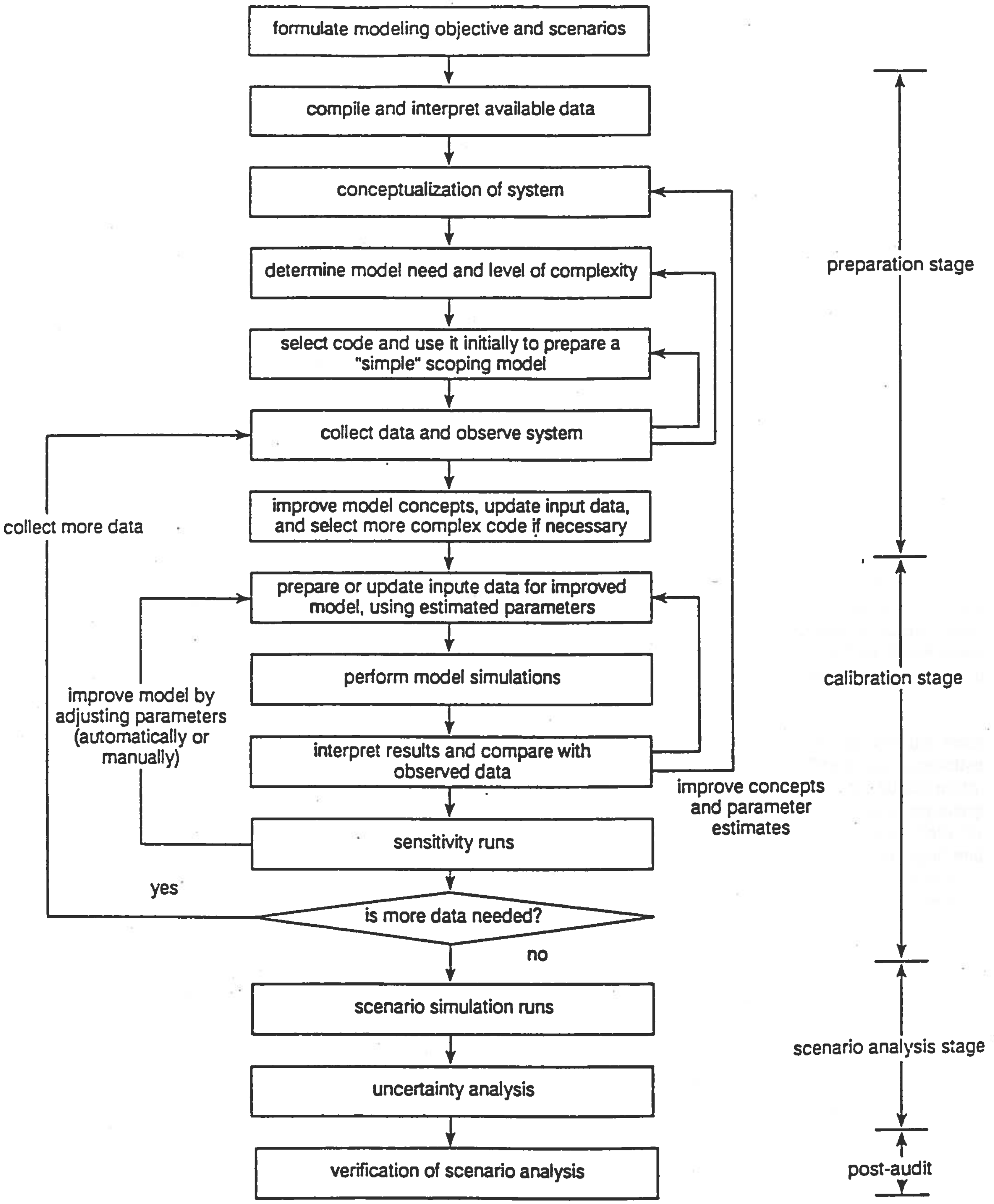
1. The initial step is to define the purpose of the modelling effort and to determine the best method to obtain the desired results. (ie: analytical/numerical modelling of field testing);

2. The next step is to define the conceptual model based on hydrogeological and physical properties such as stratigraphy, physical boundaries, aquifer properties, and other site characteristics such as river flow, precipitation etc. Some of this information can be obtained from previous reports, historical data or field investigations;

3. Based on the conceptual model, the governing equation and suitable computer code are selected to solve the problem;

4. The mathematical model is then constructed by discretizing the aquifer domain into elements and assigning initial parameter values to the elements and boundary and/or initial conditions;

5. The mathematical model is then calibrated by adjusting the selected parameters until the model approximates observed field conditions;



SOURCE: VAN DER HEIJDE ET AL, 1988, GROUNDWATER MODELLING : AN OVERVIEW AND STATUS REPORT INTERNATIONAL GROUNDWATER MODELLING CENTER, HOLCOMB RESEARCH INSTITUTE

FIGURE 1

6. A sensitivity analysis is then undertaken to assess the sensitivity of the model to variation in the input parameters;

7. The model is then verified by assessing the ability of the model to reproduce a new set of data from the aquifer.

8. Following the verification process, the model is used to predict the impacts of various stresses or external conditions imposed on the aquifer.

9. The results of the stress impacts (scenarios) are then compiled and compared and conclusions drawn from the results, and;

10. A postaudit is then conducted to compare the model results with actual field results from pumping tests, etc.

3.0 PHYSICAL SETTING

The Study basin is located in the north east corner of Nigeria, Africa, along the Wushi River at nominal latitude 10°15'north and longitude 12°30'east (See Figures 2 and 3). The basin is comprised of the Wushi and Yangari river floodplains which flow in a westerly direction to join with the much larger Jawi River. Flow is predominantly controlled by bedrock topography as elevation ranges from over 2500 m in the upper reaches of the basin to 750 m where the Wushi River converges with the Jawi River. The drainage basin covers a total area of 416.4 km^2. The topographic map of the Study basin in Figure 4 shows the development in the area is minimal with only sparsely located villages. There are some hand dug wells used for potable water supply and 5 shallow (less than 8 m deep) PVC tubewells used for small scale agricultural farming. Other water use in the basin is by residual moisture farming of rice, cowpea, corn and millet following the rainy season.

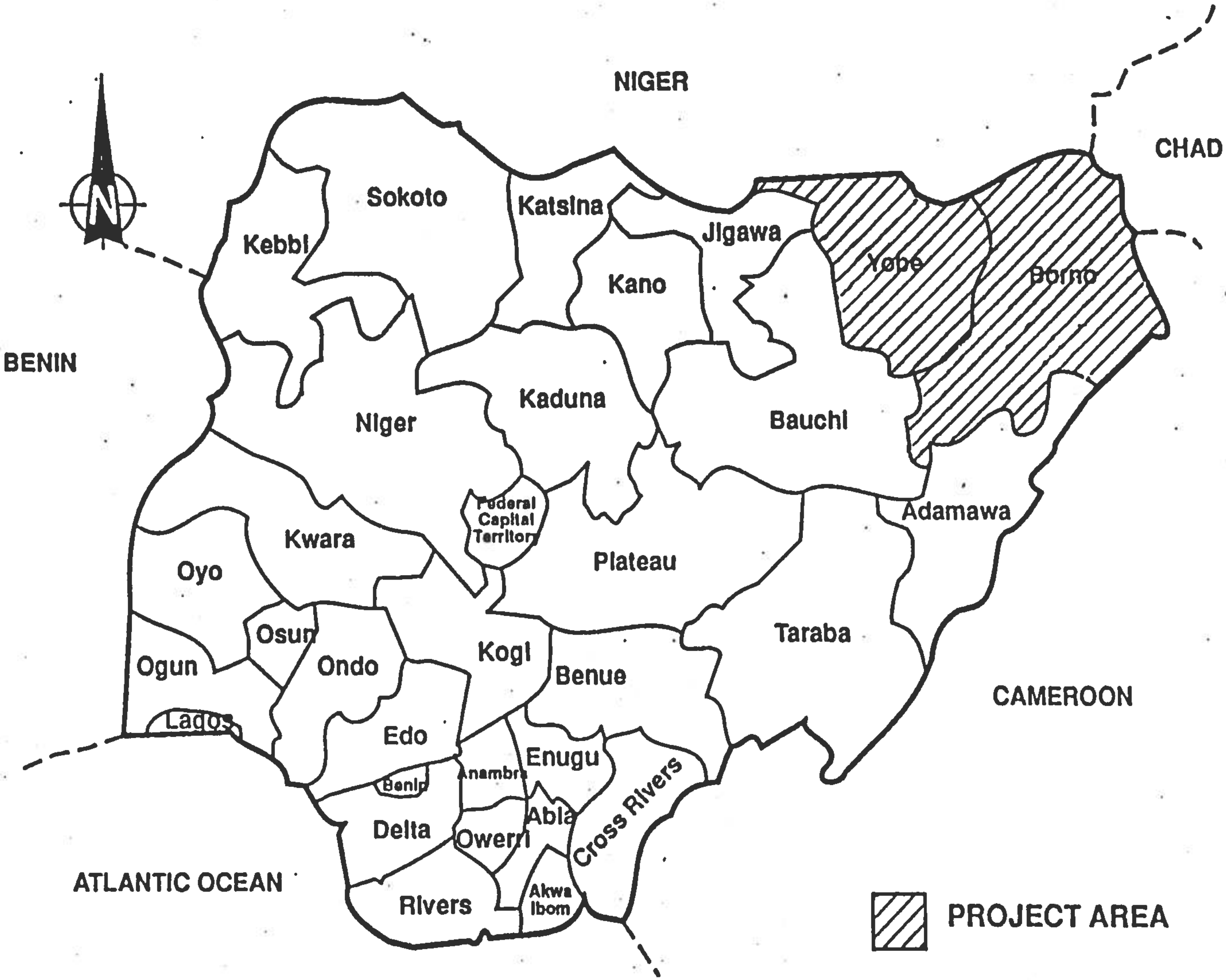
Climatic information from the City of Maiduguri which is located 300 km to the north, as are the most representative data for the Wushi River Basin. This data is presented in Table 1. The total cumulative annual precipitation is 646 mm. Some precipitation records for the town of Biu, located only 50 km north, are available but are not considered statistically valid due to the absence of data for a number of reporting years and extreme inconsistency in the data for years which are available. A comparison of data for Maiduguri and Biu from 1982 through 1984 indicate that rainfall increases to the south from Maiduguri and is 15 percent greater in the area of the Wushi River Basin. Particular note, however, is given to the uneven distribution of rainfall which consists of no precipitation from November through March and over 50 percent of the yearly total occuring in the 2 months of July and August.

Streamflow records for the Wushi, Yangari and Jawi rivers do not exist. Accounts from interviews with the local farmers and field observations indicate that none of the rivers are considered perennial. Maximum peak flows occur during flood stages in the rainy season in late August or early September and last only a few days. For example at the town of Wushi along the middle reach of the Wushi River the peak during 1991 was 2.4 m and lasted from August 23 to September 2.

4.0 GEOLOGY AND HYDROGEOLOGY

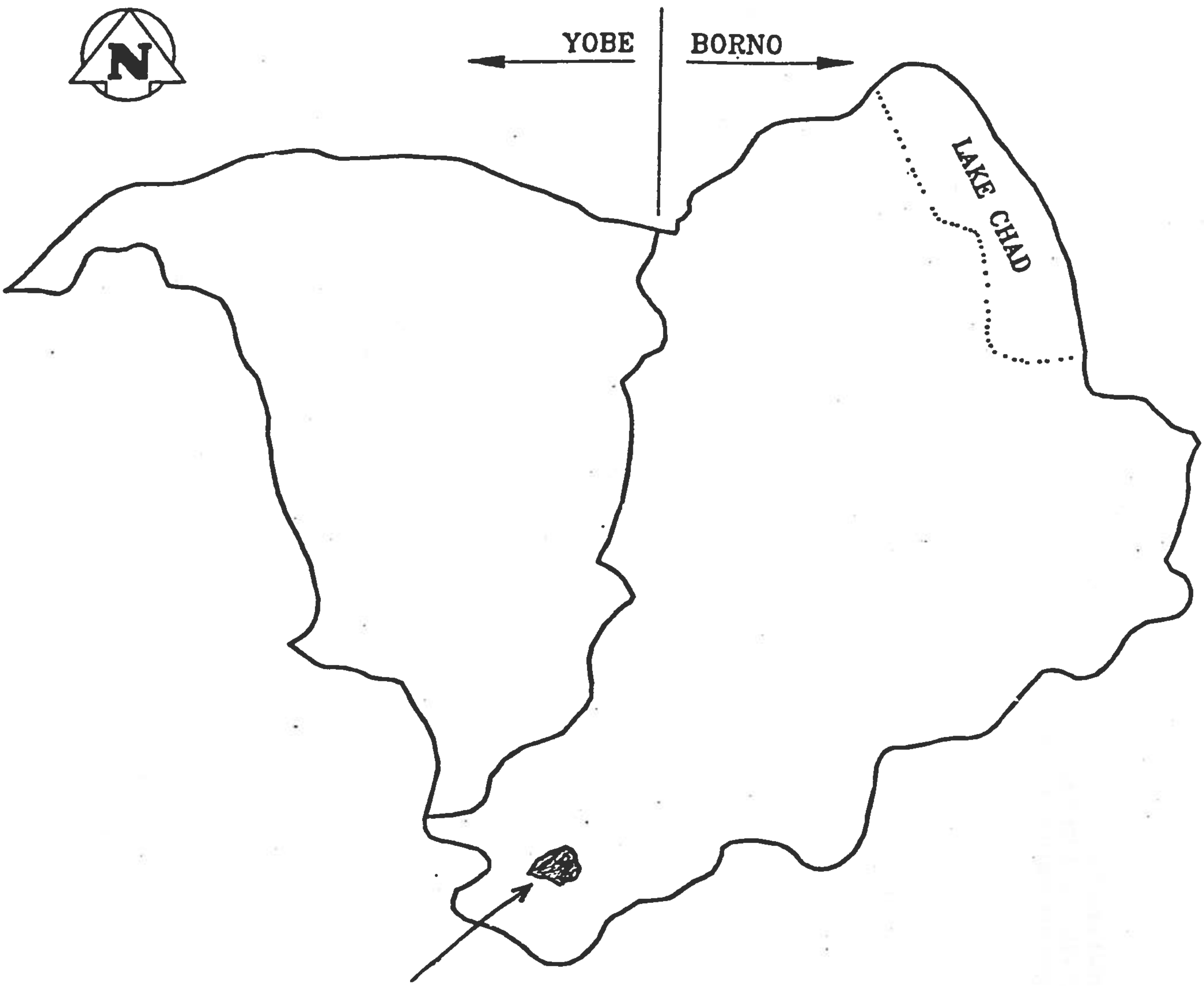
Geology and hydrogeological information for the basin have been summarized in the 1992 report by Wardrop Engineering of Winnipeg, Canada for the Borno State Agricultural Development Project (BOSADP). The report was based on both an office study and a field program directed by the author. A brief summary is given in the following section.

State Map of Nigeria



SOURCE: WARDROP ENGINEERING INC., 1992, STUDY OF IRRIGATION POTENTIAL OF SHALLOW GROUNDWATER IN FADAMA AREAS OF YOBE AND BORNO STATES, A REPORT TO BORNO STATE AGRICULTURAL DEVELOPMENT PROJECT

FIGURE 2



WUSHI RIVER BASIN

FIGURE 3

TABLE 1 CLIMATIC PARAMETERS FOR MAIDUGURI

	Jan	Feb	Mar	Apr	May	June	July	Aug	Sept	Oct	Nov	Dec
Rainfall (mm)	0.0	0.0	0.0	8.4	36.5	75.7	172.6	227.1	107.0	18.6	0.0	0.0
Average Daily Temperature (centigrade)	27.5	32.1	32.1	33.1	33.0	31.9	30.9	27.2	28.6	30.8	30.9	26.7
Relative Humidity (percent)	21.9	15.9	13.9	20.3	30.7	37.8	59.2	68.3	59.1	35.6	22.0	21.2
Sunshine Hours (average monthly)	373	273	270	251	269	244	246	177	229	285	282	210
Sunshine Mean Daily Hours	10.4	4.7	8.7	8.4	8.7	8.1	7.9	5.7	7.6	9.2	9.4	6.8
Potential Evapotranspiration (average in mm/day)	144.5	159.0	201.0	209.0	208.0	172.0	135.0	113.0	130.0	156.0	149.0	132.0
Potential Evaporation (average in mm/day)	4.7	5.7	6.5	6.9	6.7	5.7	4.3	3.6	4.3	5.0	4.0	4.3

SOURCE: WARDROP ENGINEERING INC., 1992, STUDY OF IRRIGATION POTENTIAL OF SHALLOW GROUNDWATER IN FADAMA AREAS OF YOBE AND BORNO STATES, A REPORT TO BORNO STATE AGRICULTURAL DEVELOPMENT PROJECT

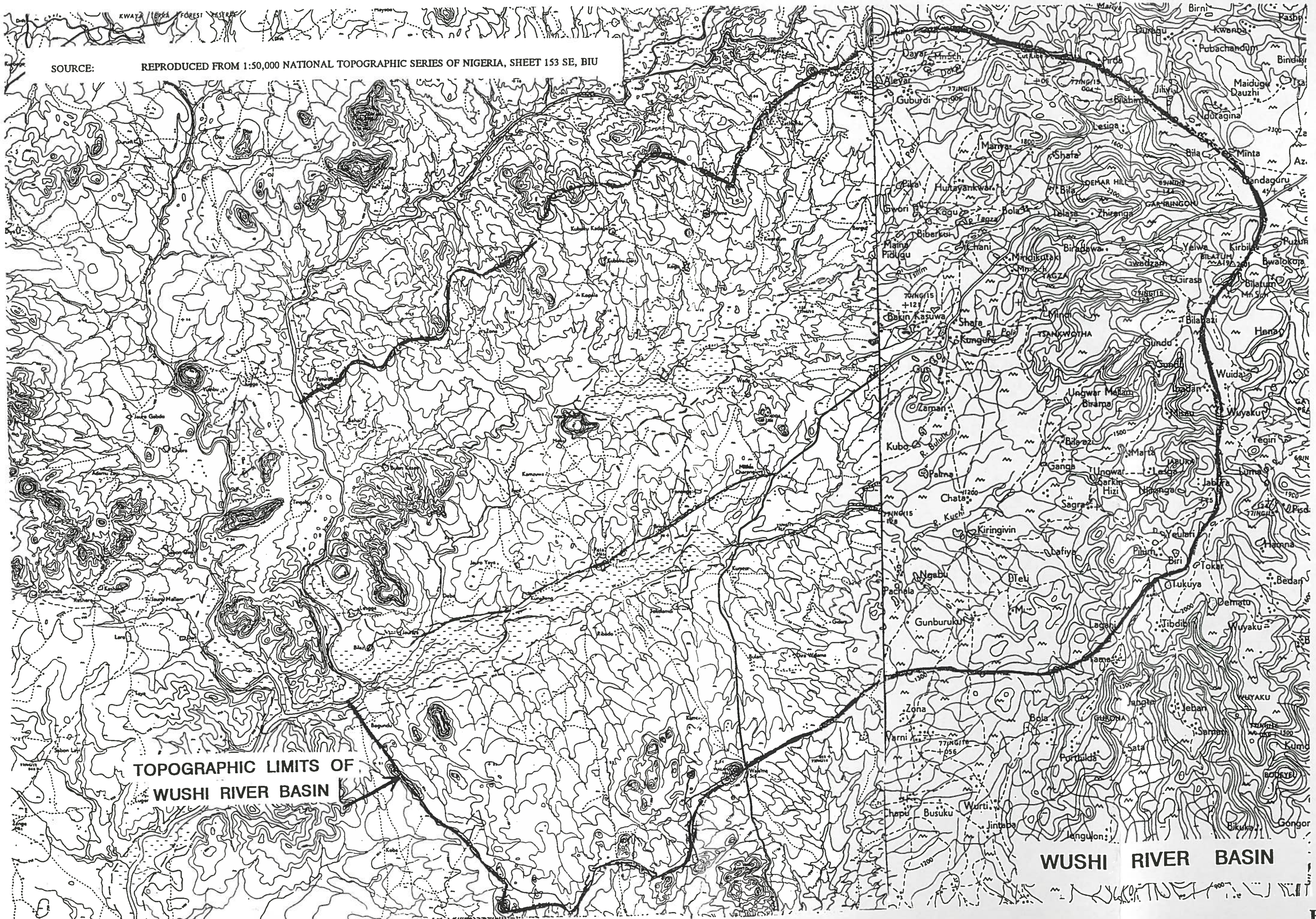

SOURCE: REPRODUCED FROM 1:50,000 NATIONAL TOPOGRAPHIC SERIES OF NIGERIA, SHEET 153 SE, BIU
TOPOGRAPHIC LIMITS OF WUSHI RIVER BASIN
WUSHI RIVER BASIN

FIGURE 4

4.1 HISTORICAL INFORMATION

Reports on the geology of the area had been compiled by The Geological Survey of Nigeria (1963), and the United States Geological Survey (1965). These reports describe the extensive plateaus of the Tertiary age Biu-Longida Basalts, which cover large areas of the Kerri-Kerri formation and the Crystalline-Basement complex. The edges of the plateau and exposed areas of basement complex are deeply dissected and filled with thin sequences (less than 10 m) of recent alluvium. Surface water runoff is reported to be rapid and streams are non-perennial.

More specifically, the Wushi River Basin is dominated by Moku Hill and Bogundu Hill which are both volcanic basalt pillars. The upper reach of the basin is characterized by granitic rock outcrop with little or no overburden.

4.2 FIELD PROGRAM

To augment the topographical and climatic information, a field program was undertaken to determine suitable input parameters for the formulation of an aquifer model. The program included testhole drilling, shallow well construction, pumping tests on existing and new wells and static water level measurements throughout the basin. Detailed testhole logs and pumping test plots are presented in Appendix A. A summary of the field program is given in Table 2. All information is referenced to a Cartesian coordinate system established for the modelling Study.

Testholes and wells were constructed using the hand bailer/auger method and completed with 100 mm diameter PVC casing. Pumping tests were conducted using a 2.5 hp centrifugal suction lift pump. All coordinates were determined using a satellite positioning instrument.

Based on the field program it is determined that the basin is typically comprised of an unconfined aquifer, ranging up to 8 m thickness. The aquifer thins out laterally away from the main river axes. Sediments are typically poorly graded and sub-rounded. Transmissivities calculated from pumping tests range from 80 m^2/day to 200 m^2/day. Hydraulic conductivities for testhole locations have been estimated based on seive analysis and Hazen's Formula, $k=d_{10}^2$, where d_{10} represents the grain size diameter of 10 percent passing. Transmissivities have also been estimated using T=kb, where transmissivity (T), is calculated based on hydraulic conductivity (k) and saturated thickness (b). Aquifer properties and boundaries are irregular and non-homogeneous.

5.0 CONCEPTUAL MODEL

The conceptual model of the aquifer is based on the geology and hydrogeology of the Study area. The model is defined by identifying physical features to the model such as hydrostratigraphic units, fluxes and boundaries to the aquifer domain. Aquifer properties and other input parameters for the conceptual model have been assigned based on the field program and on relevant climatic data.

The Study basin covers a total area of 416.38 km^2, which comprises the entire drainage basin for the Wushi River as determined by topography. A Cartesian coordinate system is oriented with the x direction roughly parallel to the main axis of the Wushi River. The grid extends for 31 km in the x, and 21 km in the y direction. Approximately 251 km^2 (60 percent) of the total area is located in the higher elevation areas. These areas have limited thickness of alluvium and are designated as a recharge area. The two hills, Moku and Bogundu, are also considered non-active aquifer areas due to elevation and limited thickness of alluvium. At all locations throughout the model domain, the crystalline basement complex is the bottom unit and this unit is assumed to be non-conductive, based on a hydraulic conductivity several orders of magnitiude less than alluvium.

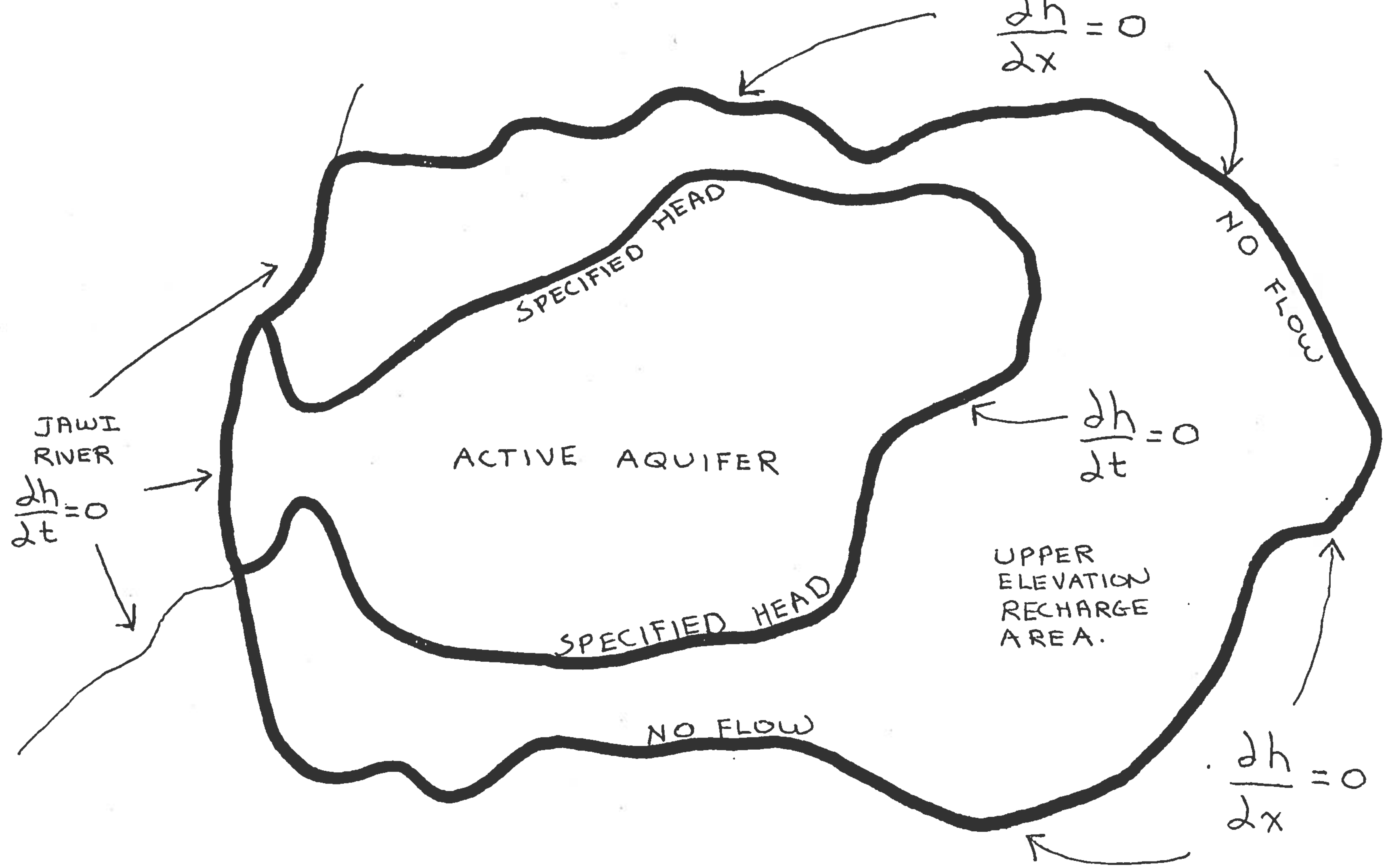


FIGURE 5

CONCEPTUAL MODEL OF WUSHI RIVER BASIN

Groundwater flow throughout the area is topographically driven and occurs generally from the high elevation, eastern uplands towards the Jawi River. The main aquifer is situated along the two rivers (Wushi and Yangari). The flow is primarily horizontal throughout the basin even though the elevation difference from the upper to lower reaches of the basin is 1700 m. The large elevation changes occur in the uppermost portion of the basin, where the flow is primarily horizontal (5 percent gradient). Static water levels are generally within 3 m of the ground surface.

The ground water flow problem is reduced from a three dimensional problem to a two-dimensional problem by invoking the Dupuit assumptions. The Dupuit assumptions include; horizontal flow and vertical equipotentials; a horizontal gradient equal to the slope of the free surface; and the gradient to be invarient with depth (Freeze & Cherry, 1979). In the two-dimensional areal flow model, transmissivity is calculated based on spatial distribution of hydraulic conductivity and saturated thickness.

Surface water flow is present along the river channels of the Wushi and Yangari rivers for part of the rainy season in July and August. The Jawi River, which forms the western boundary to the model, is considered a perennial river for this application, despite the lack of flow data to support this assumption.

A sub-arid tropical climate for the area produces high evapotranspiration rates. Infiltration and recharge into the aquifer are estimated to be less than 40 percent of the total yearly precipitation. This assumption is consistent with evapotranspiration rates established for the area by The Federal Government of Nigeria, Ministry of Agriculture (1976), based on FAO guidelines (United Nations-Food and Agricultural Organization) .

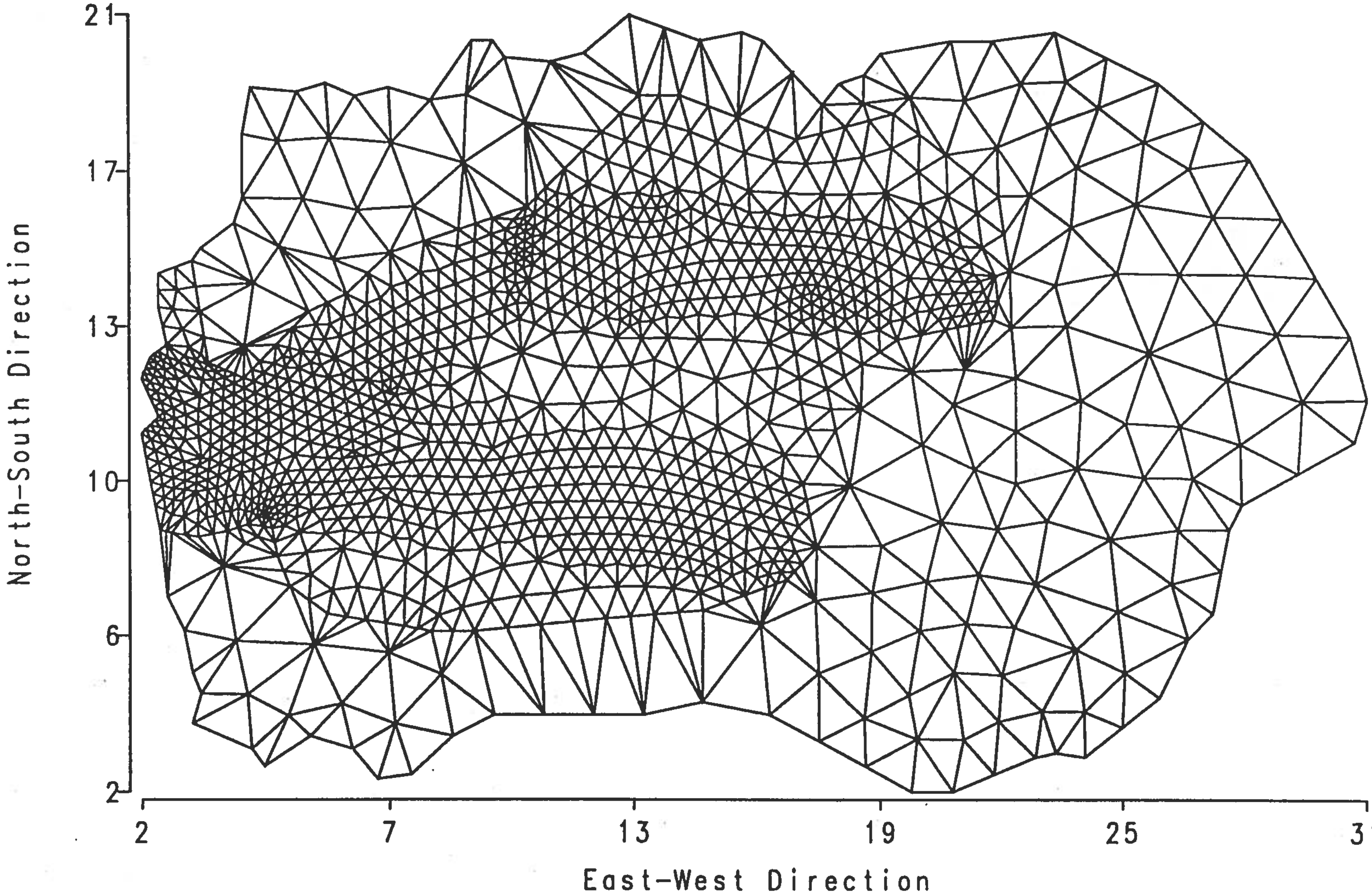
In summary, the chosen conceptual model is a two-dimensional, unconfined, areal flow model incorporating the initial assumptions of a no flow boundary around the majority of the topographical limits of the drainage basin, with a constant head boundary along the Jawi River, where the flow collects and discharges into the river. Several zones are identified to account for regions of varying aquifer properties such as thickness, hydraulic conductivity, recharge rate, and storage coefficient. A sketch illustrating the main features of the conceptual model is shown in Figure 5. During calibration of the model, additional physical restrictions are added to account for rising ground water levels, seepage faces and lateral fluxes. These are described in Section 7.2.

TABLE 2
SUMMARY OF FIELD INVESTIGATIONS

LOCATION	INFORMATION
Node 628 (9.3,10.1) Peta	Testhole, swl, sieve
Node 1018 (20.5,14.4) Wada	Testhole, swl, sieve
Node 1102 (17.1,8.2)	Testhole, swl, sieve
Node 683 (8.4,9.3) Ribado	Testhole, swl, sieve
Node 384 (6.4,10.1) Kunalleng	Testhole, swl, sieve
Node 49 (2.9,10.9) Bilazi	Existing Well Pumping Test, swl, testhole
Node 815 (13.8,9.4) Kumtor	Existing Well Pumping Test, swl, testhole
Node 111 (5.5,16.3) Bahai	Testhole, swl, sieve
Node 831 (11.4,6.9) Kumtor/Bulam	Testhole, swl, sieve
Node 39 (3.1, 13.0) Lessga	Existing Well, swl, testhole
Node 567 (8.0,10.0) Kunalleng	Existing Well Pumping Test, swl, testhole
Node 205 (6.6,16.3) Jauro Yaya	Existing Well, swl, testhole

WUSHI VALLEY AQUIFER

Discretization of Elements



REmi J.P. Allard- Master of Engineering Report 3/ 5/1994

FIGURE 6

6.0 MATHEMATICAL MODEL

A complete overview of the method of finite elements is beyond the scope of this report. It is assumed the reader is familiar with the mathematics behind the formulation of the system of equations utilized for the solution of the groundwater flow problem. For completeness, however, a simplified description of the finite element method is presented. Good summaries of the finite difference method are presented by Anderson and Woessner (1992), Mercer and Faust (1981) and van der Heijde et al., (1988).

The response of an aquifer to pumping depends on the transmissivity and storage coefficient of the aquifer, the hydrologic and geologic boundary conditions, and the points at which water is being withdrawn or recharged within the system (Bachmat et al., 1980). For analytical solutions the variables of transmissivity and storage coefficient are assumed to be homogeneous, isotropic, and the aquifer to be thin, and infinite in areal extent. For more complex aquifer geometries with complex boundary conditions and heterogeneities, a mathematical framework or model comprised of a system of governing partial differential equations (PDE's) are used to describe the flow process. Boundary conditions refer hydraulic conditions at the boundary or limits of an aquifer system.

In the governing partial differential equation for groundwater flow, the aquifer characteristics and heads are depicted as continuously changing. In the finite element method, the continuous heads are replaced with discrete values that are defined at selected points or nodes within the aquifer system.

For a particular groundwater flow problem, the domain of the aquifer must be discretized or divided into elements and nodes. For each element or node, aquifer parameters must be input into the governing equation of flow and the system of equations formed for all the nodes within the aquifer domain forms the system of equations requiring solving.

The governing equation for two-dimensional, horizontal flow in a non-homogeneous, anisotropic aquifer is;

$$Q+S\frac{\delta h}{\delta t}=\frac{\delta}{\delta x}\left(T_{xx}\frac{\delta h}{\delta x}\right)+\frac{\delta}{\delta y}\left(T_{yy}\frac{\delta h}{\delta y}\right)+\frac{\delta}{\delta x}\left(T_{xy}\frac{\delta h}{\delta y}\right)+\frac{\delta}{\delta y}\left(T_{yx}\frac{\delta h}{\delta x}\right)$$

where;

$S= S(x,y,t)$	= aquifer storage coefficient [dimensionless];
$h= h(x,y,t)$	= depth averaged piezometric head [L];
$T_{xx}= T(x)$	= aquifer transmissivity in x direction [L^2/t];
$T_{yy}= T(y)$	= aquifer transmissivity in y direction [L^2/t];
$K'= K'(x,y)$	= vertical averaged permeability of the aquifer [L/t];
$Q= Q(x,y,t)$	= net flux into aquifer from point or distributed sources [L/t];
$B'= B'(x,y)$	= thickness of saturated aqufer [L]
x,y	= Cartesian coordinates oriented along the principle axes of the hydraulic conductivity tensor [L]
t	= time [t]

6.1 Description of Model Source Code

AQUIFEM-1 is a Galerkin based finite-element computer program written in Fortran which utilizes linear interpolation functions and triangular elements. The code was developed to model two dimensional flow both in plan and in profile. Constant head (first type), constant flux (second type) and mixed (Cauchy or third type) boundary conditions are capable of being represented by this model. The source code is public-domain software.

An in depth summary of the code AQUIFEM-1 and further explanation of the mathematics and assumptions incorporated in the computer program development is beyond the scope of this report. For further reading the reader is referred to Townley et al, 1980. For completeness, example input and output files from AQUIFEM-1 are presented in Appendix B.

7.0 MODEL DESIGN AND INPUTS

7.1 Mesh Generation

Using the limits of the Wushi River drainage basin as determined from the topographic map and by overlaying the Cartesian coordinate system, the limits of the modelled area where assigned coordinates for plotting. For ease in assigning element properties at a later stage, the aquifer domain is divided into sub-regions. A triangular finite element mesh is then generated for the entire model domain using the University of Waterloo's, GRIDBUILDER program. Some areas of the mesh have smaller elements to allow for greater solution accuracy. In particular, areas where existing wells are present and where large elevation changes occur over short distances are discretized to a smaller scale. In total, 1187 nodes and 2272 elements are generated for the solution of the problem. The finite element mesh is shown in Figure 6 and the GRIDBUILDER data input file is presented in Appendix B.

7.2 Boundary Conditions

The equation of flow is a general statement of fluid continuity within a region being modelled. However, the simulation has to account for the effects of conditions outside of the region. Boundary conditions are mathematical translations of physical conditions along the boundary of the aquifer domain. The boundary conditions for this model are dictated by the unique geology of the Wushi River Basin. They are summarized as follows:

- The outer limits of the basin (except where adjacent to the Jawi River) is a fixed no-flow boundary;

- The majority of the higher elevation areas, where aquifer thickness is less than 1 m, is designated as a non-active, transition area. This area is eliminated from the main model Study, as large elevation changes exist. These cause large vertical flow gradients and unsaturated conditions to develop. By setting the vertical recharge flux equal to zero for this area, and fixing the head along the interface between this area and the active model, the interface becomes a constant horizontal flux boundary (constant head boundary). This condition is also applied to the volcanic cone areas at Bogunda Hill and Moku Hill.

- The lower west-end of the aquifer domain along the Jawi River is designated as a fixed-head boundary controlled by the elevation of water in the river. It is assumed that the river is perennial, and fully penetrates the aquifer.

- Due to the irregular precipitation and flooding which occurs during the intense rainy season, it is anticipated that ground water levels would rise significantly above surface elevation during steady state simulation runs. To accomodate rising levels, ground water rising nodes (first-type rising water level nodes) are established along all stream axes.

- In addition to rising groundwater level nodes along streams, areas where seepage faces were possible are designated as first type rising water level nodes.

- The initial conditions included the initial estimate of the head distribution (static water level distribution) throughout the model domain. This distribution was taken as the surface elevation as determined from a topographic map of the area.

7.3 Parameter Estimation (Aquifer Properties)

Based on interpretation of the geology and hydrogeology of the area, the model is divided into 11 sub-regions, each with distinct aquifer properties. These properties are based primarily on assigned hydraulic conductivities. Initial estimates of hydraulic conductivity are based on testhole profiles, pumping test results, and seive analysis. Element and nodal elevations are calculated by kriging the original field elevation values taken from the topographic map. The properties are adjusted in value during calibration until predicted heads from simulation runs are in agreement with observed field values. The initial input parameters are shown in Figures 7 through 12. The best simulation results are obtained with the distribution of hydraulic conductivities as shown in Figure 13 and Table 3.

Zones 5,6,7, and 8 are the main aquifer zones along the axes of the Wushi and Yangari rivers. The hydraulic conductivity is based on pumping tests and saturated thicknesses observed in testhole drilling. The initially-assigned and final calibrated values for these sub-regions did not change significantly during calibration.

The general lower recharge area is slightly higher in elevation and dominated by finer grained sands and a reduced thickness of aquifer. This area is therefore assigned a slightly lower hydraulic conductivity. This value is estimated at 30 m/day, initially.

The upper recharge area is assigned a low hydraulic conductivity to allow significant accumulation of head behind the horizontal flux boundary. This value changed from an initial estimate of 2 m/day to 0.007 m/day.

All values are in general agreement with established values for similar geological materials except the upper recharge area. For reference, the reader is referred to Freeze & Cherry (1979).

- Due to the irregular precipitation and flooding which occurs during the intense rainy season, it is anticipated that ground water levels would rise significantly above surface elevation during steady state simulation runs. To accomodate rising levels, ground water rising nodes (first-type rising water level nodes) are established along all stream axes.

- In addition to rising groundwater level nodes along streams, areas where seepage faces were possible are designated as first type rising water level nodes.

- The initial conditions included the initial estimate of the head distribution (static water level distribution) throughout the model domain. This distribution was taken as the surface elevation as determined from a topographic map of the area.

7.3 Parameter Estimation (Aquifer Properties)

Based on interpretation of the geology and hydrogeology of the area, the model is divided into 11 sub-regions, each with distinct aquifer properties. These properties are based primarily on assigned hydraulic conductivities. Initial estimates of hydraulic conductivity are based on testhole profiles, pumping test results, and seive analysis. Element and nodal elevations are calculated by kriging the original field elevation values taken from the topographic map. The properties are adjusted in value during calibration until predicted heads from simulation runs are in agreement with observed field values. The initial input parameters are shown in Figures 7 through 12. The best simulation results are obtained with the distribution of hydraulic conductivities as shown in Figure 13 and Table 3.

Zones 5,6,7, and 8 are the main aquifer zones along the axes of the Wushi and Yangari rivers. The hydraulic conductivity is based on pumping tests and saturated thicknesses observed in testhole drilling. The initially-assigned and final calibrated values for these sub-regions did not change significantly during calibration.

The general lower recharge area is slightly higher in elevation and dominated by finer grained sands and a reduced thickness of aquifer. This area is therefore assigned a slightly lower hydraulic conductivity. This value is estimated at 30 m/day, initially.

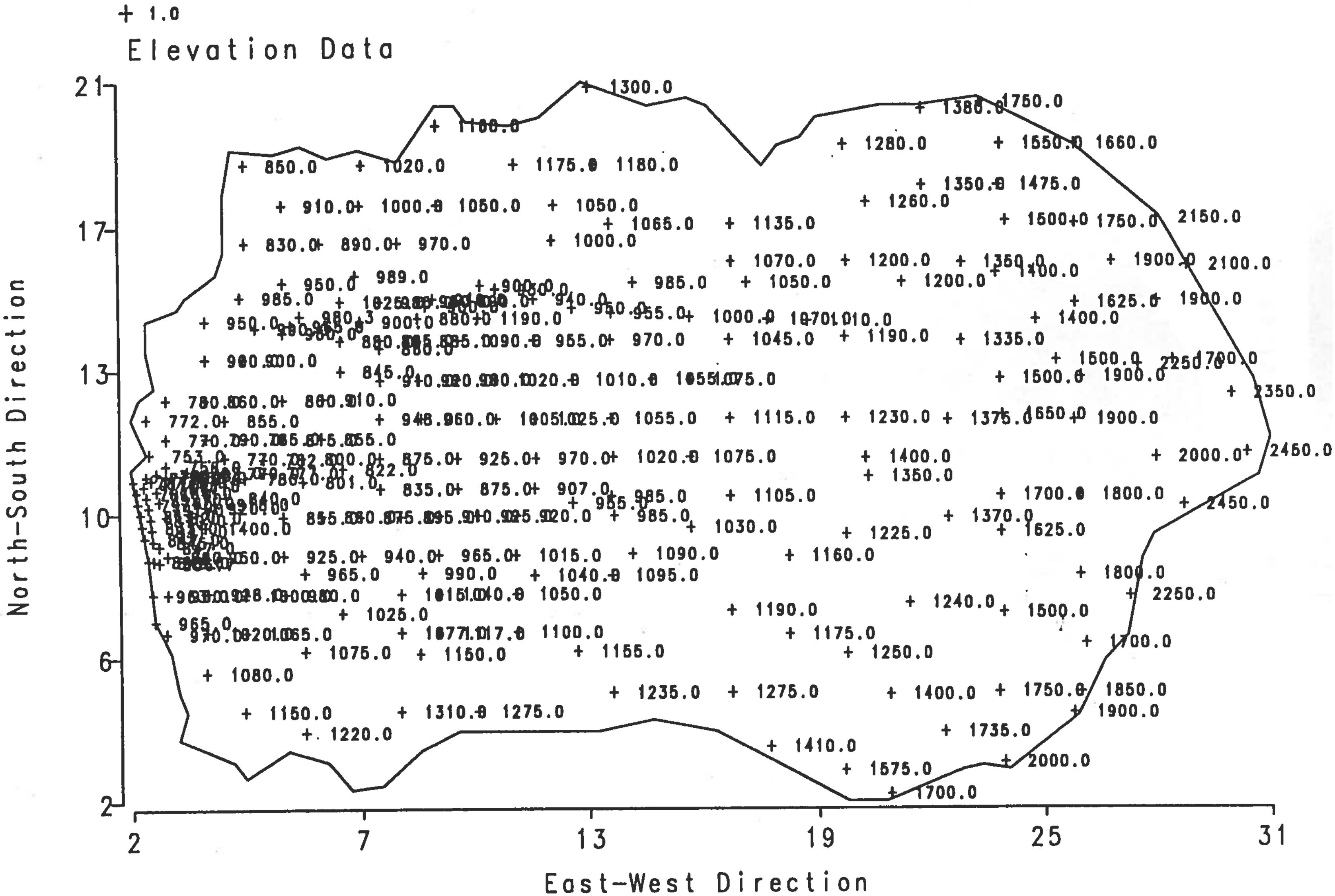
The upper recharge area is assigned a low hydraulic conductivity to allow significant accumulation of head behind the horizontal flux boundary. This value changed from an initial estimate of 2 m/day to 0.007 m/day.

All values are in general agreement with established values for similar geological materials except the upper recharge area. For reference, the reader is referred to Freeze & Cherry (1979).

TABLE 3
HYDRAULIC CONDUCTIVITY DISTRIBUTION
FOR BEST CALIBRATED RESULT

Aquifer Sub-Region		Hydraulic Conductivity (m/day)
1-	Upper Recharge Area	0.007
2-	Wushi South	35
3-	Bogundu Hill High	15
4-	Bogundu Hill Low	35
5-	Wushi Middle	75
6-	Wushi Low	100
7-	Yangari High	75
8-	Yangari Low	80
9-	Jawi South	60
10-	Lessga Rock Knob	35
11-	General Lower Recharge	55

WUSHI VALLEY AQUIFER



Remi J.P. Allard- Master of Engineering Report 3/ 5/1994

FIGURE 7

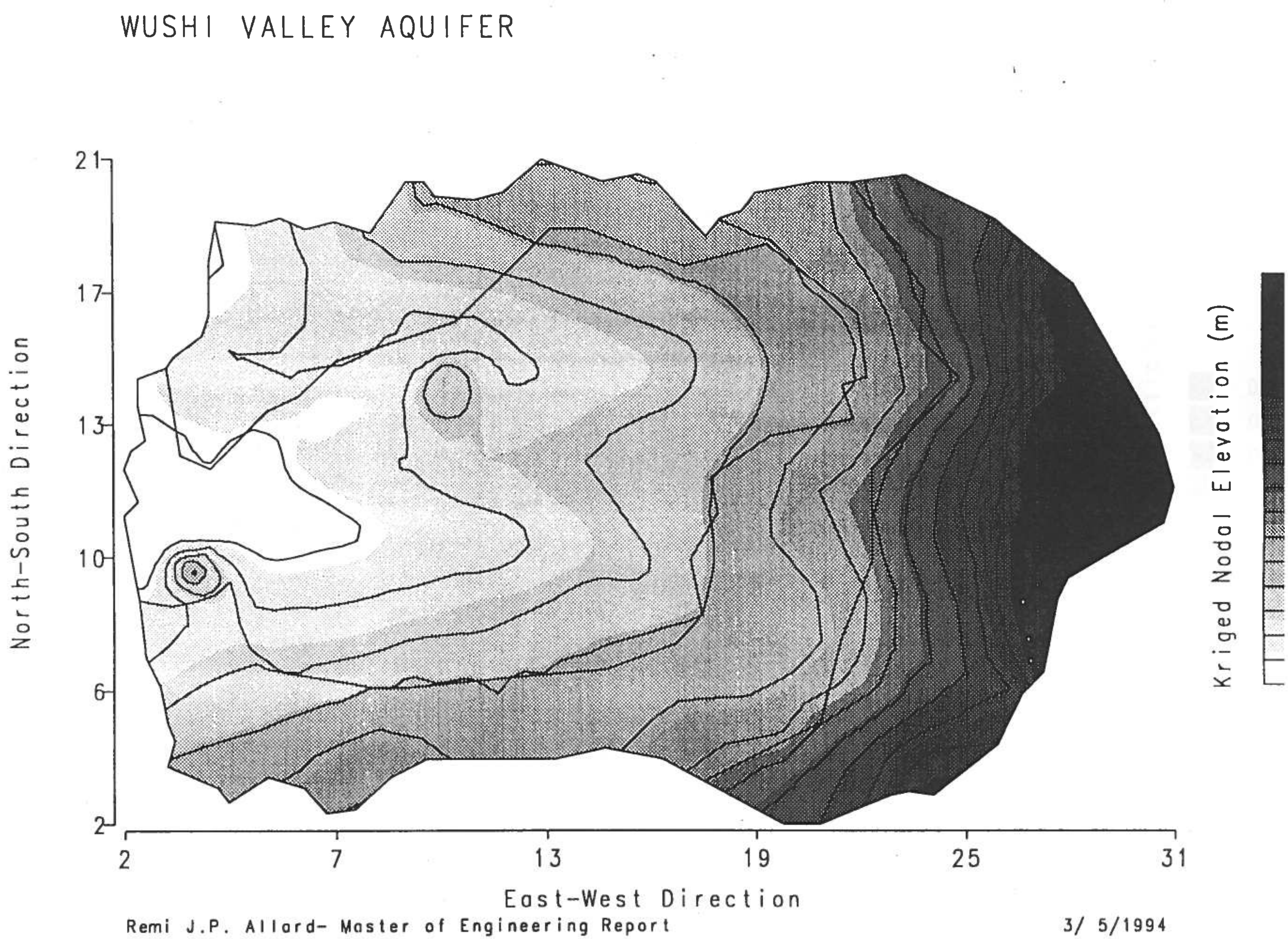
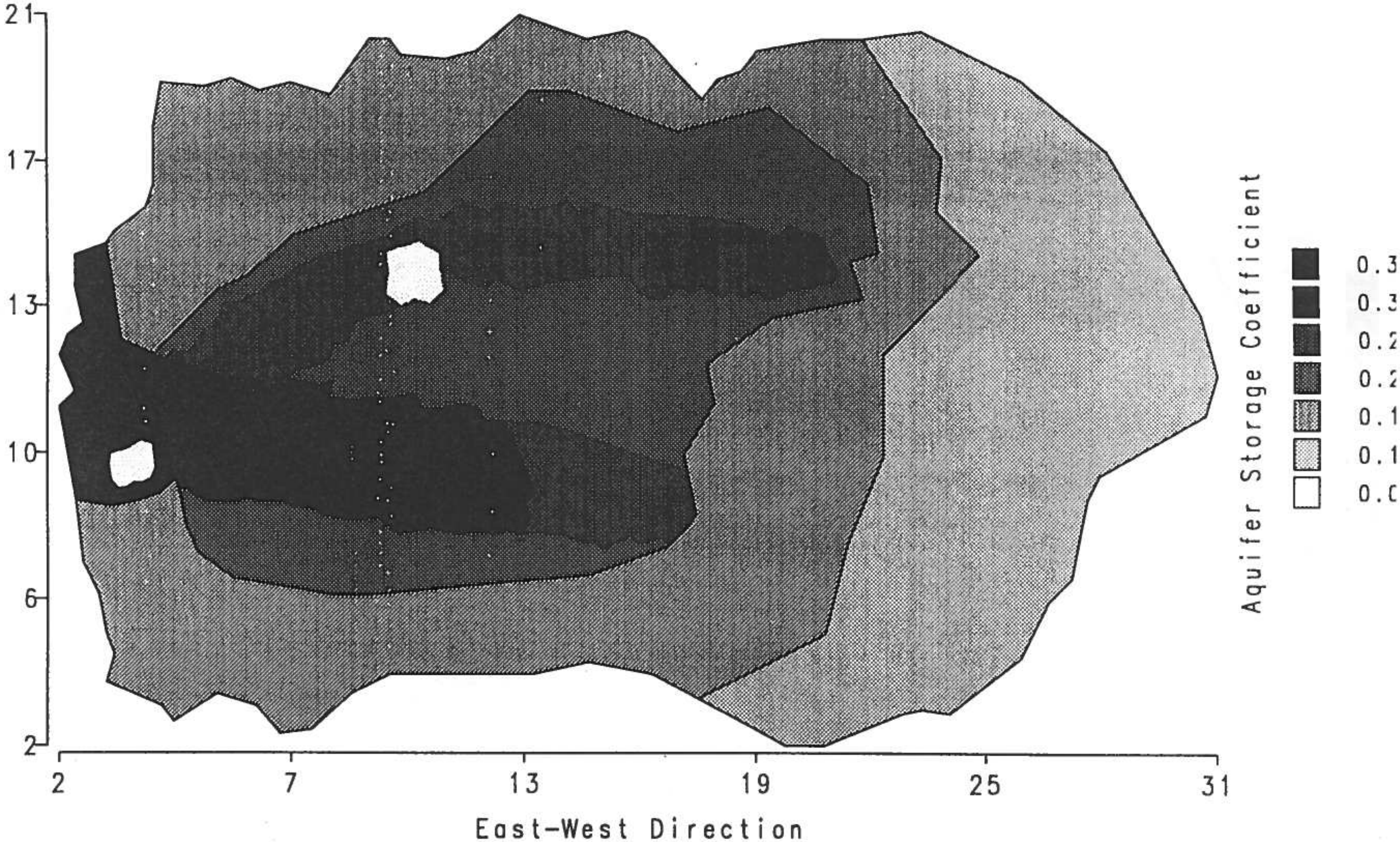

WUSHI VALLEY AQUIFER
North-South Direction
21
17
13
10
6
2
East-West Direction
2
7
13
19
25
31
Kriged Nodal Elevation (m)
Remi J.P. Allard- Master of Engineering Report
3/ 5/1994

FIGURE 8

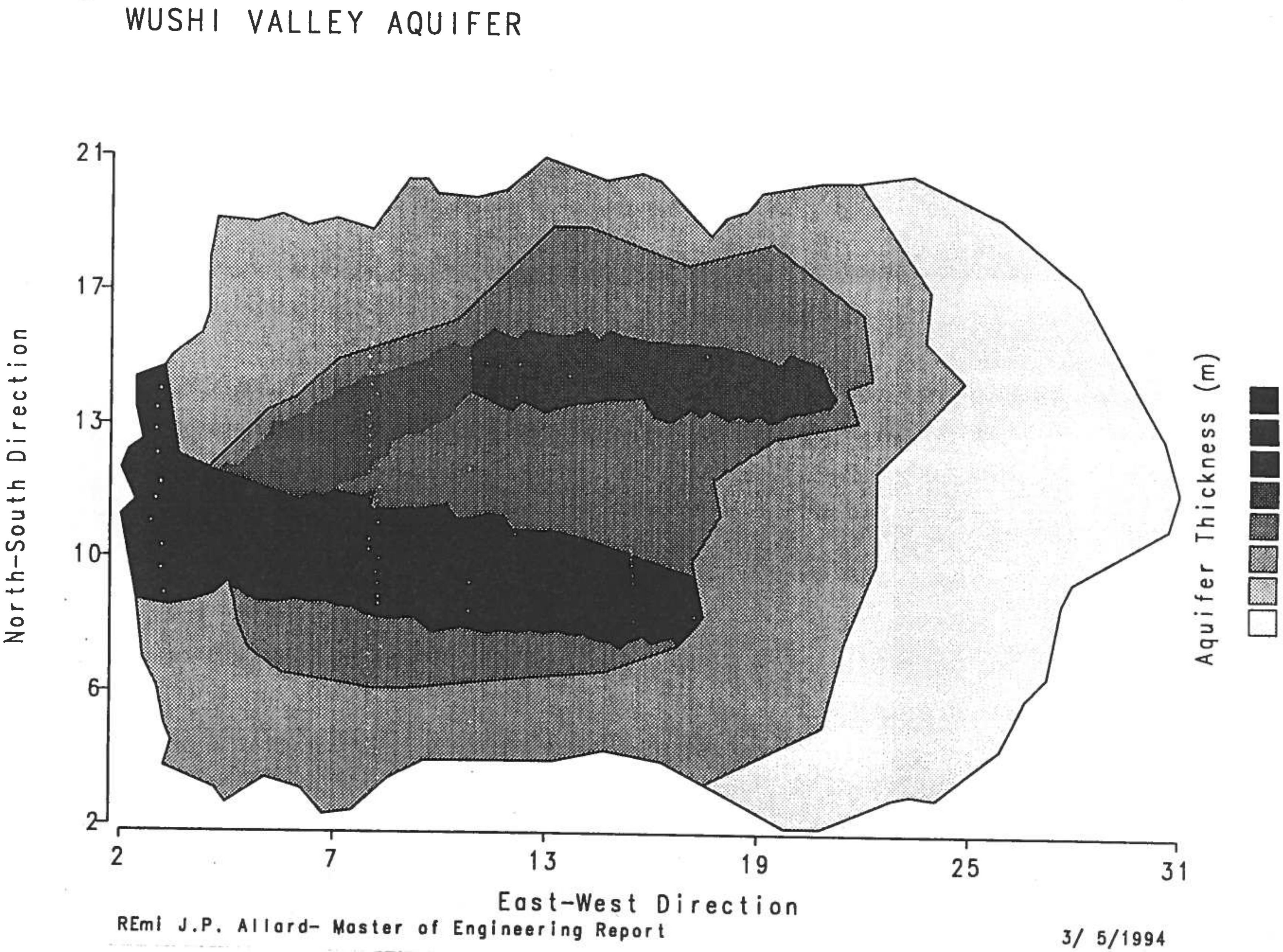
WUSHI VALLEY AQUIFER



Remi J.P. Allard- Master of Engineering Report

3/ 5/1994

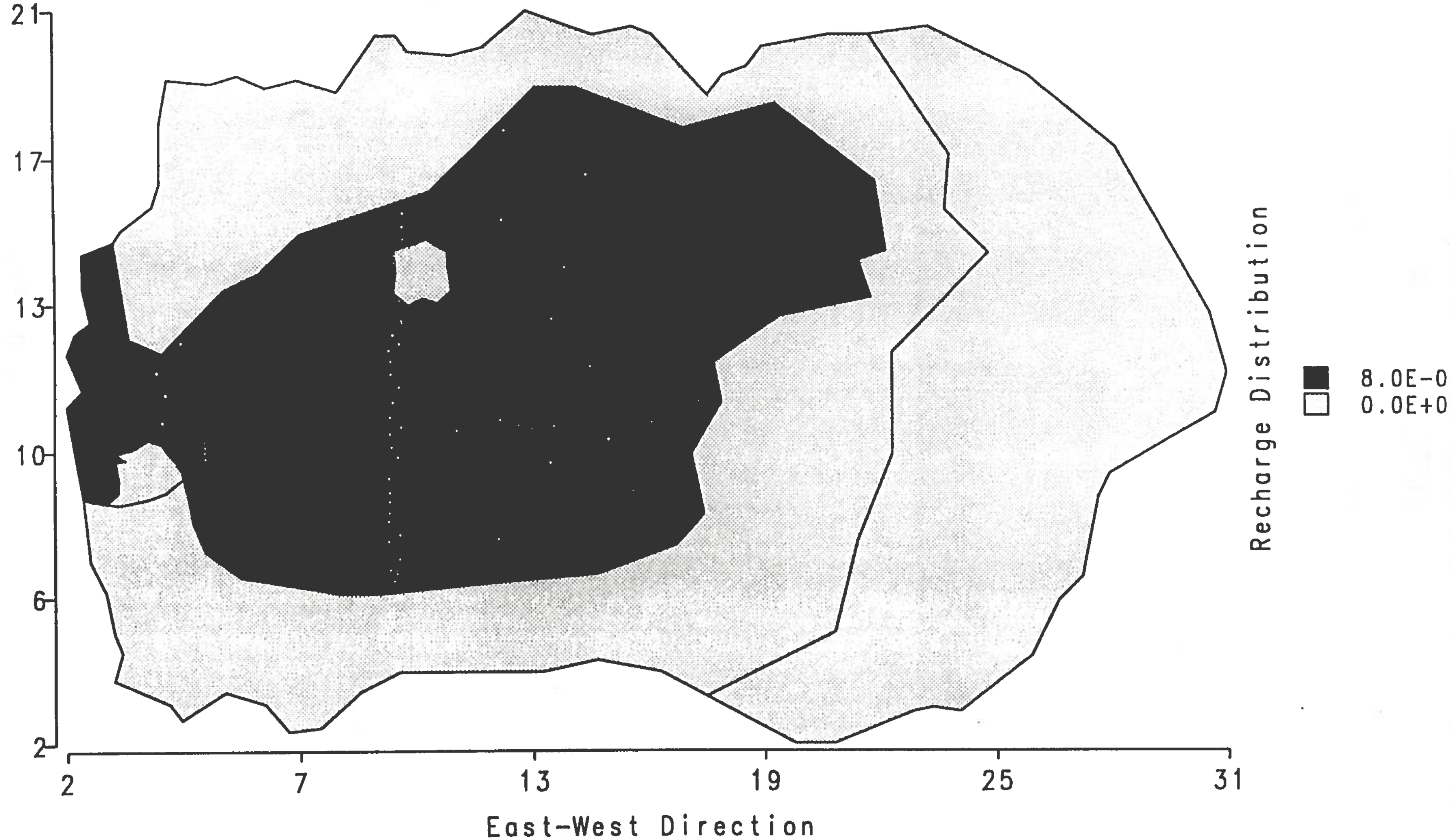
FIGURE 9



WUSHI VALLEY AQUIFER
21
17
13
10
6
2
North-South Direction
2
7
13
19
25
31
East-West Direction
Aquifer Thickness (m)
REmi J.P. Allard- Master of Engineering Report
3/ 5/1994

FIGURE 10

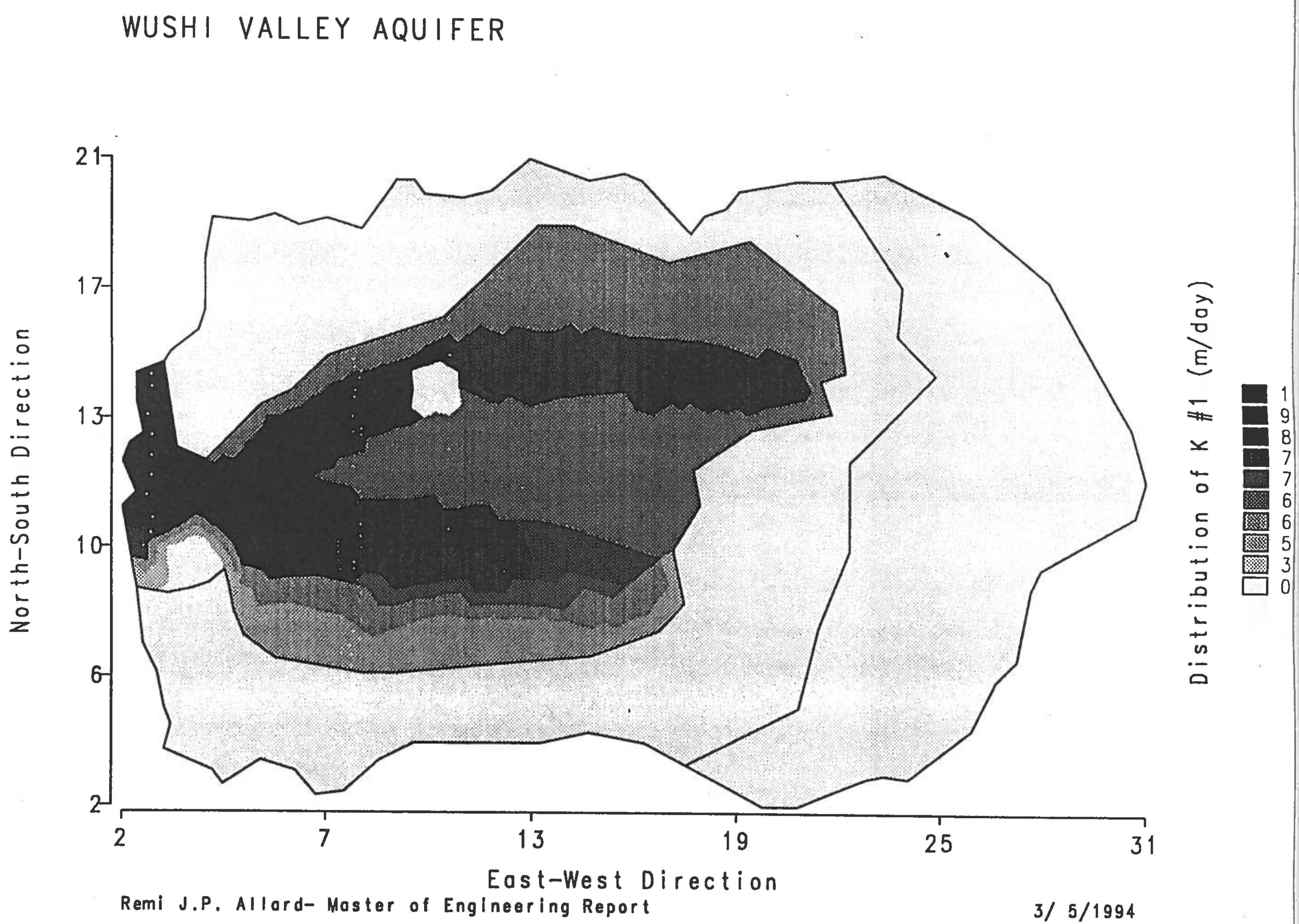
WUSHI VALLEY AQUIFER



Remi J.P. Allard- Master of Engineering Report

3/ 5/1994

FIGURE 11



WUSHI VALLEY AQUIFER
North-South Direction
21
17
13
10
6
2
East-West Direction
2
7
13
19
25
31
Distribution of K #1 (m/day)
1
9
8
7
7
6
6
5
3
0
Remi J.P. Allard- Master of Engineering Report
3/ 5/1994

FIGURE 12

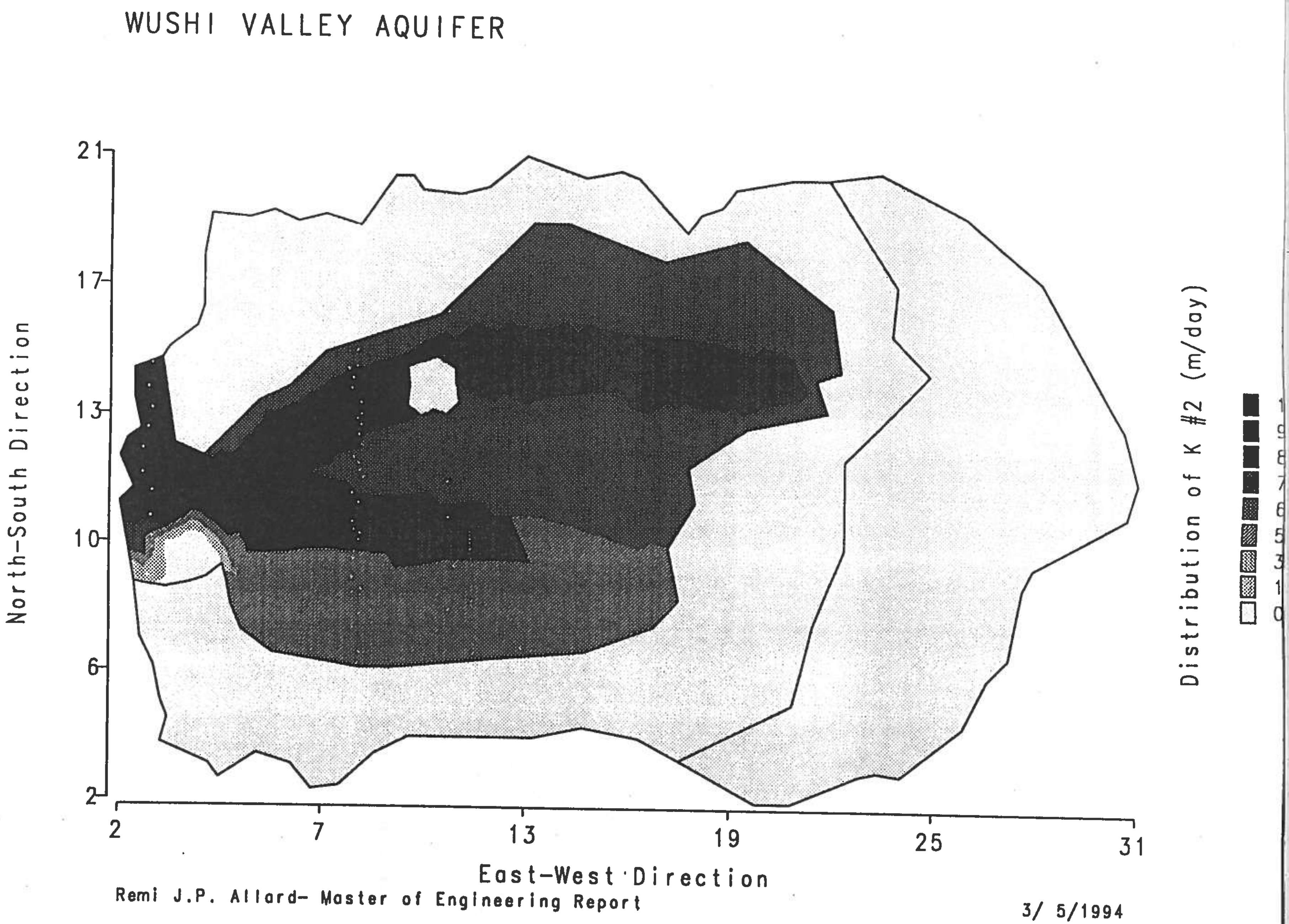

WUSHI VALLEY AQUIFER
21
17
13
10
6
2
North-South Direction
2
7
13
19
25
31
East-West Direction
Distribution of K #2 (m/day)
Remi J.P. Allard- Master of Engineering Report
3/ 5/1994

FIGURE 13

8.0 CALIBRATION OF THE MODEL

Calibration of the model is desired based in this case on a steady state solution with both mass balance and iterative closure of predicted heads. The calibration is not successful.

The best calibration run for the model is based on mass balance considerations and is in error by 10 %, with inflows exceeding outflows. This is due to the flux boundary along the interface between the upper recharge area and the lower active aquifer. The intent is to set the total amount of flux across the boundary equal to the total recharge which would have accumulated in the upper recharge area at the vertical flux rate assigned to the lower active area. Individual nodal heads are set at the lowest possible elevation without running dry. However, the flux could not be reduced sufficiently enough to provide a lower total flux across the boundary and still keep the upper recharge area saturated. A higher degree of discretization along this boundary may reduce this problem. The resulting distribution of heads is shown in Figure 15, and in general shows good agreement with observed heads. Large errors occur between calculated and predicted head (> 30 m) around the base of Moku Hill and Bogunda Hill. Most head values are slightly above the upper level of the aquifer for this balance to occur. This suggests confined or semi-confined aquifer conditions exist at many locations throughout the aquifer.

Calibration of the model with respect to heads is not successfull. The solution is based on a steady state vertical flux (recharge rate) averaged from the cumulative annual precipitation data for the area. This caused problems as, for the majority of the year, the recharge rate is much lower than the average calculated for the year. As the recharge rate is very diifficult to determine, the assigned value is chosen on an arbitrary basis. The result in model runs is that high confined pressures are generated along the steeper slopes in the model domain. The AQUIFEM-1 code does not have the ability to recognize these areas as potential seepage faces. To release the pressure at these points, rising ground water level nodes are established. The identification of these areas seemed never ending and when most had been found and the appropriate ground levels set, the mass balance is in error and the resultant plot of predicted heads is not in good agreement with the observed heads. The best run based on distribution of heads had a maximum error of 5.8 m. The plot of head distribution based on iterative closure of heads is presented in Figure 16.

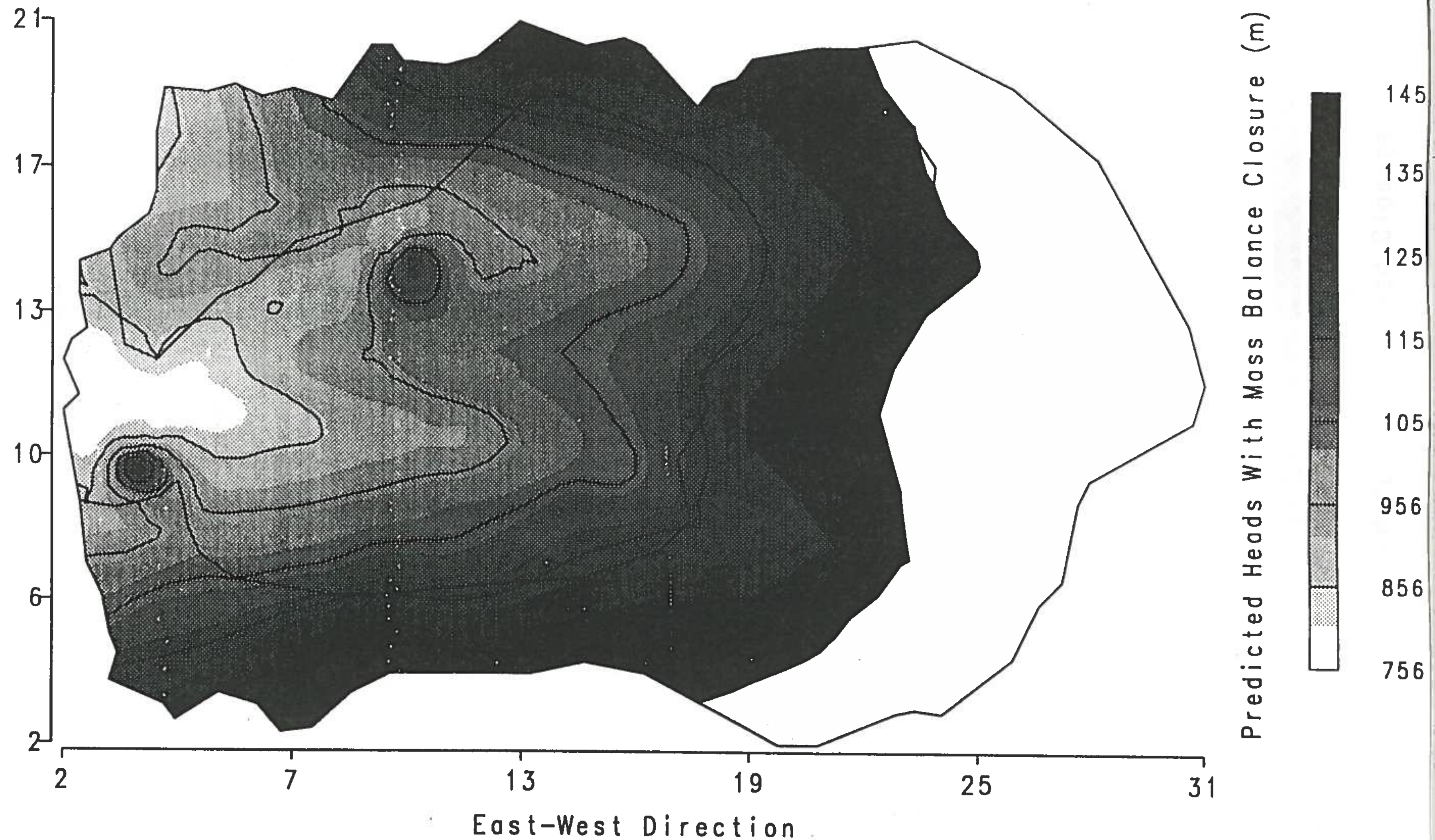
9.0 SENSITIVITY ANALYSIS

The model, although not calibrated sufficiently to permit verification, is tested to determine sensitivity to variations in input parameters. The parameters tested for sensitivity include hydraulic conductivity, boundary conditions, and recharge rate. The model is found to be most sensitive to changes in hydraulic conductivity, particularly changes in the lower reaches of the model domain (lower Wushi). Less sensitive are the fixed heads along the lower fixed head boundary along the Jawi River. The vertical recharge flux in the lower model area is still less sensitive and least sensitive is the horizontal flux across the interface between the upper recharge area and the lower active area. A summary of the sensitivity analysis is presented in Table 4.

TABLE 4
SUMMARY OF SENSITIVITY ANALYSIS

Scenario	Head Node 49 (m)	Head Node 384 (m)	Head Node 628 (m)	Head Node 1018 (m)	Mass Balance (m^3/day)
Control Scenario	791.0	911.92	962.2	1227	12419
Lower Upper Recharge Boundary 0.2 m	790	910	953	1221	12870
Lower Upper Recharge Boundary 1.0 m	790	910	953	1221	12973
Set Upper Recharge to K=0.007	790	910	953	1221	12972
Set Vertical Recharge to 0.00435	790	910	953	1222	6573
Set Region 6 to K= 120	793	912	960.7	1227	15320
Set Region 7 to K=90	791	911.9	962.2	1224	16652

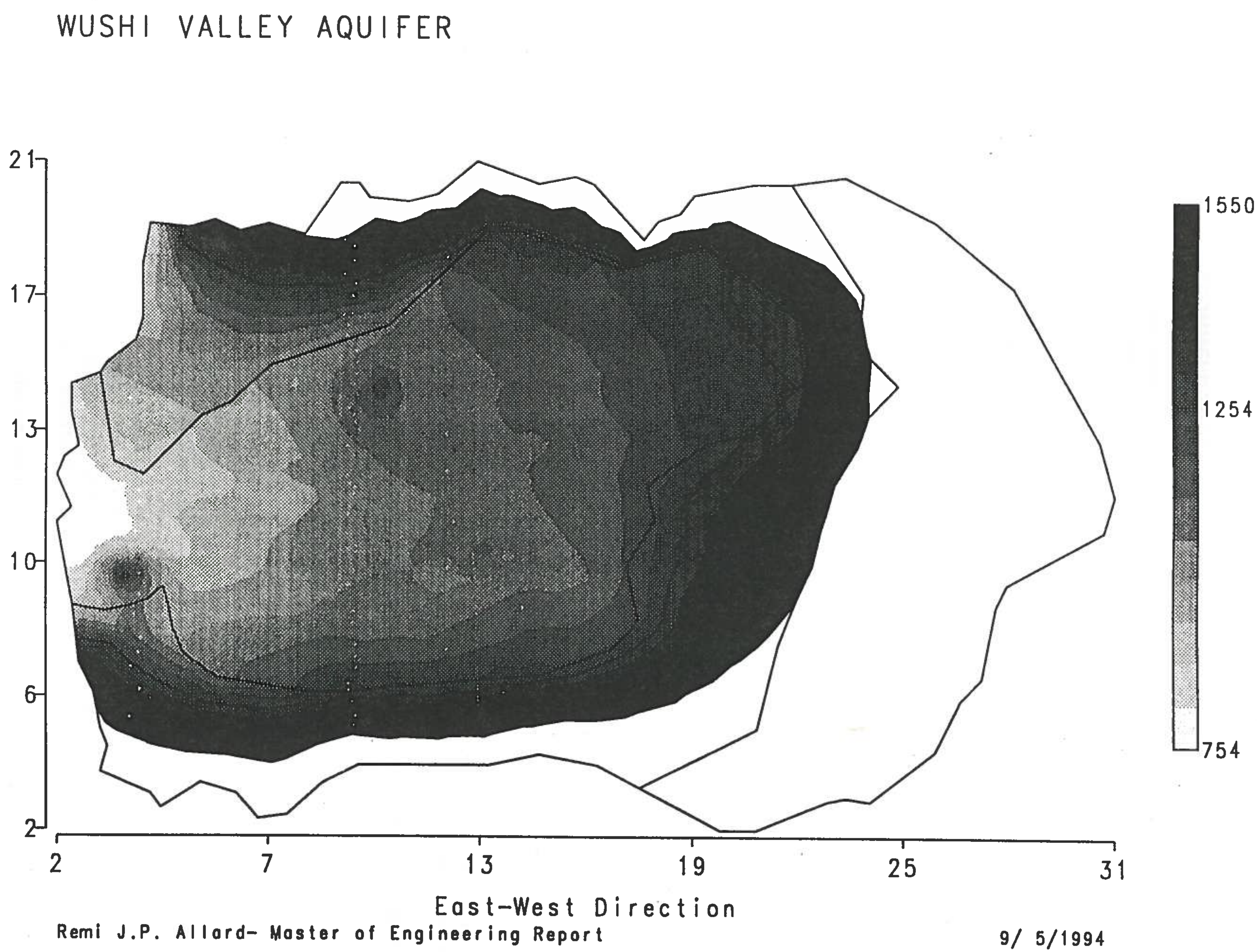
WUSHI VALLEY AQUIFER



Remi J.P. Allard- Master of Engineering Report

9/ 5/1994

FIGURE 14



WUSHI VALLEY AQUIFER
21
17
13
10
6
2
2
7
13
19
25
31
East-West Direction
1550
1254
754
Predicted Heads with Head Closure
Remi J.P. Allard- Master of Engineering Report
9/ 5/1994

FIGURE 15

10.0 CONCLUSIONS AND RECOMMENDATIONS

This Study is undertaken to demonstrate a basic understanding and working knowledge of the principles of groundwater modelling studied at the master's level in engineering. The task of developing and calibrating a model is not completely fullfilled. However, the author has gained valuable experience in the methodology of modelling through conceptualization, discretization, parameter estimation, calibration and documenting the exercise.

A simple summary of the effort is as follows:

- the model could not be calibrated sufficiently well enough to permit transient simulations;
- limited data is available for establishing input parameters and for calibration;
- large elevation differences across individual elements caused problems which could be overcome by a higher degree of discretization;
- the upper recharge area could have been eliminated from the model and represented by an exterior boundary condition. This was not realized until after calibration efforts commenced;
- the establishment of fixed head boundaries atop the volcanic cones does not appear to be conceptually correct. At locations where the topography becomes excessively high to rise above the top elevation of the aquifer, a 'hole' in the finite element mesh should appear, with a no flow condition fixed along the boundary;
- in the original conceptual model, no consideration is given to rising ground water level nodes along the rivers and for seepage faces. By graphically analyzing the model output with the assistance of GRIDBUILDER, it is easy to identify areas where heads accumulated anomalously and to investigate these areas in greater detail. In doing so, the modelling process is an exercise in the study of flow processes and understanding the hydrogeological regime of the basin;
- an increase in the number of elements, and a finer discretization in critical areas of the model, domain would reduce errors caused by large element aspect ratios and vertical flow gradients;
- a vertical-profile model or unsaturated-saturated flow model is recommended as an alternative to the 2-dimensional areal model utilized in this study;
- the difficulty in calibrating the model illustrates the requirement for more detailed field investigations to determine aquifer parameters and the spatial variability across the basin.
- additional information required to more accurately model the Wushi Basin includes:
    - many more (at least 10) static water level monitoring points, particularly in the upper reaches of the Yangari River and in the higher elevation areas .
    - 20 or 30 additional testholes to determine lithology and aquifer thickness.
    - hydraulic conductivity (or transmissivity) values from pumping tests, falling head tests and estimates from seive analysis for 10 more locations; and
    - more detailed river flow and climatic data for the area.

11.0 ACKNOWLEDGEMENTS

Following completion of course work, the author accepted a position as managing hydrogeologist on a feasibility study for establishing the potential of utilizing shallow aquifers for irrigation in Borno State, Nigeria. Independent of the project, the author undertook field work on the Wushi River Basin within the state for personal interest. Apon returning to Canada, the idea of constructing and calibrating a model of the basin was proposed to the author's academic advisor, Dr. Al Woodbury, P.Eng., as a Master of Engineering project.

In undertaking this work the author has been assisted by many people with their valuable time, effort and patience. Most importantly gratitude is offer ed to Dr. Woodbury, who patiently waited for 3 years for completion of this work while the author was working overseas. Gratitude is also extended to fellow students, Dave Farrell and Steve Weicek who worked on other projects of similar scope and whose technical assistance was invaluable. Ingrid Trestrail from the Geological Engineering Department has also been very helpful. My thanks also go to my wife Pina and my employer, Wardrop Engineering, who have tolerated my alternating spells of hard work and laziness throughout this task.

REFERENCES

Anderson,M. and Woessner, W., 1992, **Applied Groundwater Modelling- Simulation of Flow and Advective Transport**, Academic Press, 381 p.

Domenico, P.A. and Schwartz, F.W., 1990, **Physical and Chemical Hydrogeology**, John Wiley and Sons, 824 p.

Freeze, R.A. and Cherry,J.A., 1979, **Groundwater**, Prentice-Hall, 604 p.

McDonald, M.G., and Harbaugh, A.W., 1984, **A Modular Three-Dimensional Finite-Difference Ground-water Flow Model (MODFLOW).** U.S. Geological Survey, U.S. Department of the Interior, Washington, D.C.

Mercer, J.W. and Faust, C.R., 1981, **Ground-water Modelling,** National Water Well Association, Wothington, Ohio, 60 p.

Pinder, G.F., and Gray, W.G., 1977, **Finite Element Simulation in Surface and Subsurface Hydrology,** Academic Press, New York, 295 p.

Schwartz et al, 1990, Groundwater Models: Scientific and Regulatory Applications, **Committee on Ground Water Modelling & Assessment, National Academy of Science, 303 p.**

Townley, L.R. and Wilson,J.L., 1980, **Description of and User's Manual for a Finite Element Aquifer Fow Model - AQUIFEM-1,** Ralph M. Parsons Laboratory for water Resources and Hydrodynamics, 266 p.

van der Heijde et al, 1988, **Groundwater Modelling: An Overview and Status Report,** International Groundwater Modelling Center, Holcomb Research Institute, 242 p.

Wang, H.F., and Anderson, M.P, 1982, **Introduction to Groundwater Modelling- Finite Difference and Finite Element Methods,** W. H. Freeman, San Francisco, 237 p.

Wardrop Engineering Inc., 1992, **A Study of Irrigation Potential of Shallow Aquifers in Fadama Areas of Borno and Yobe States in Nigeria,** A WORLD BANK report to Borno State Agricultural Development Programme (BOSADP)

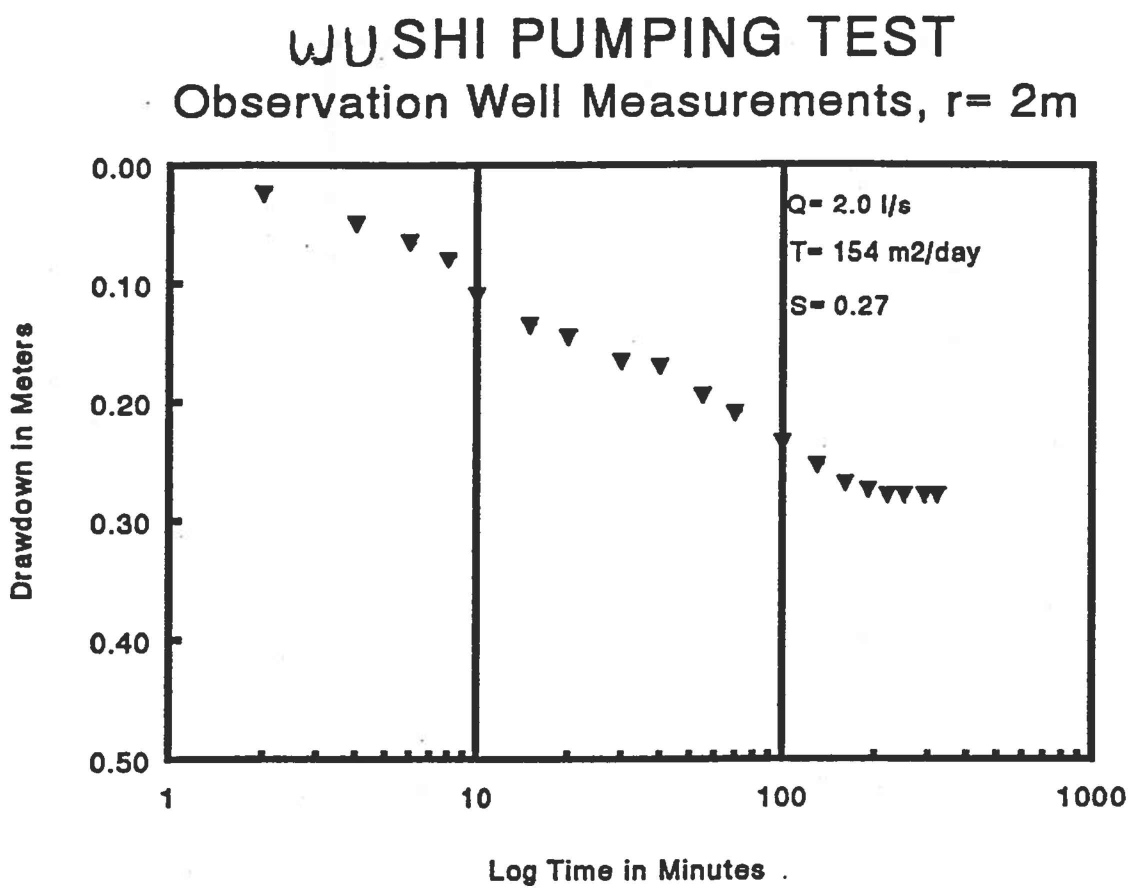
Federal Government of Nigeria, Ministry of Agriculture, 1976, **An Agricultural Atlas of Nigeria,** Federal Government Press , 432 p.

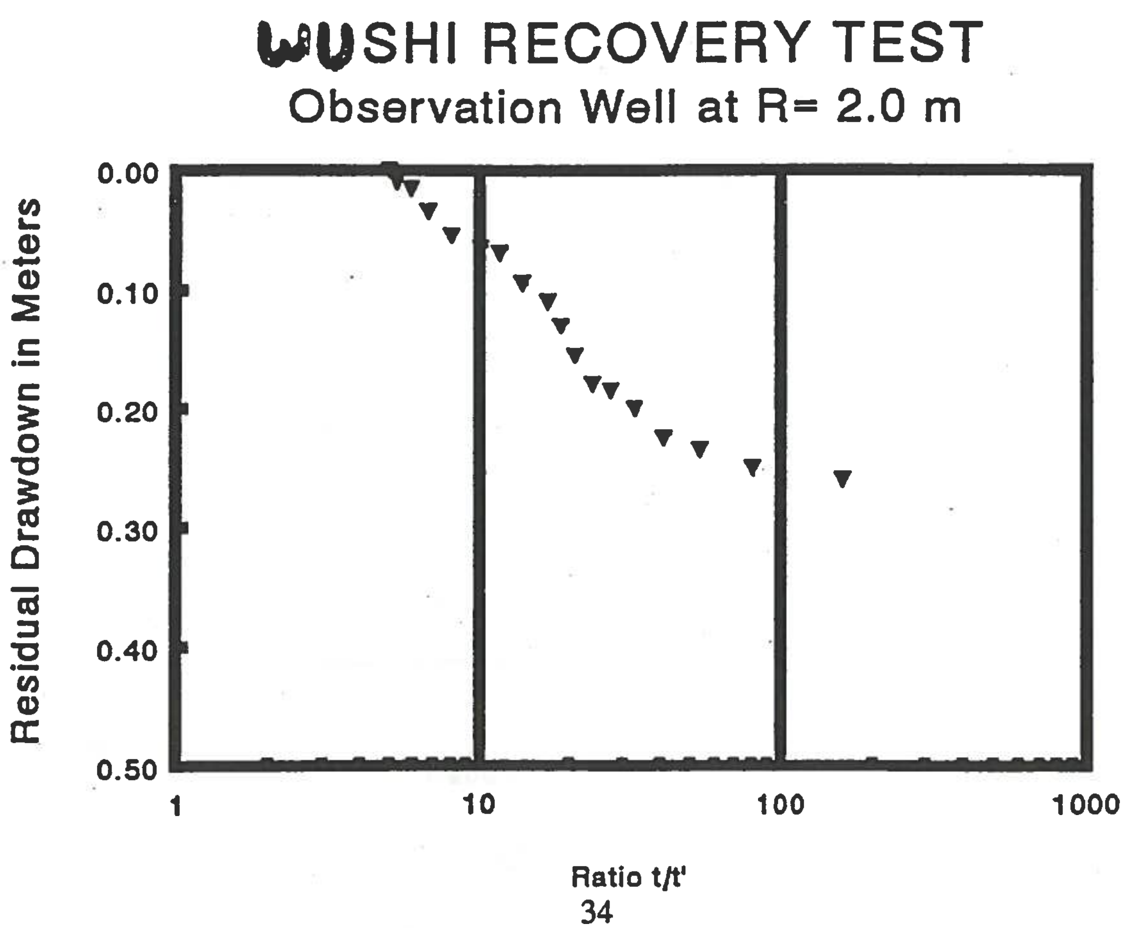
APPENDICES

APPENDIX A

TESTHOLE LOG SUMMARY

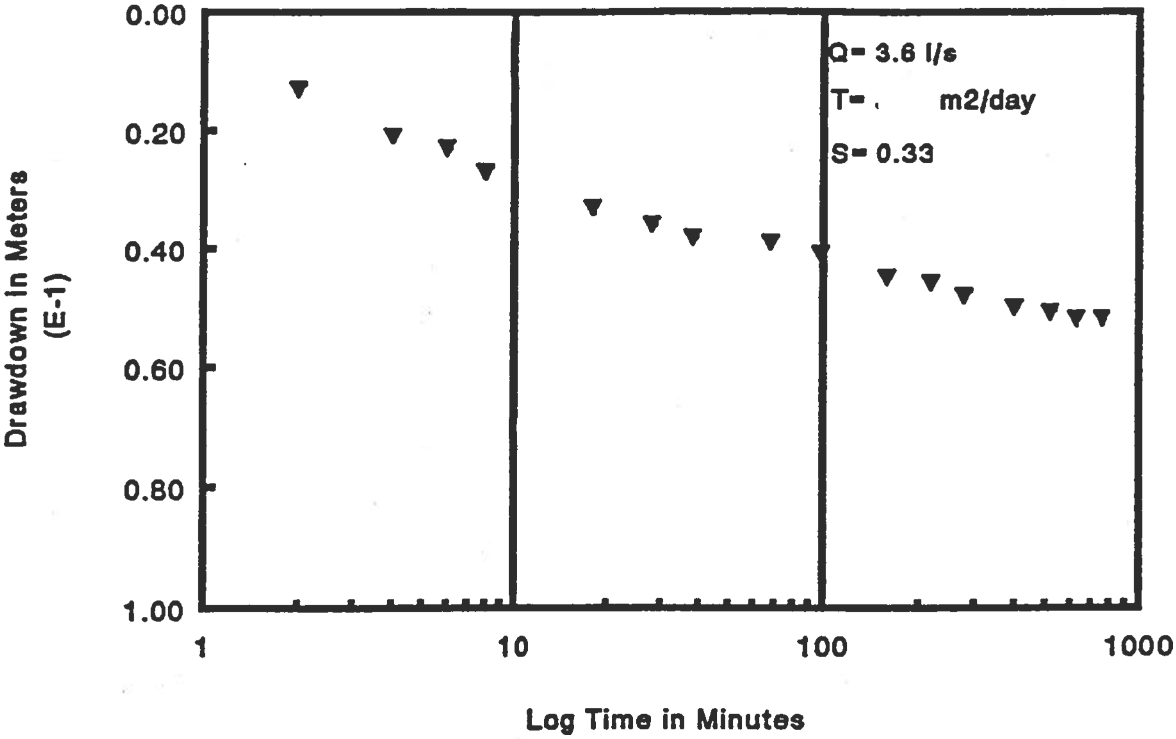
NODE	NAME	DEPTH	UNIT	DESCRIPTION
628 (9.3,10.1)	PETA	0.0 - 0.4	CLAY	brown, firm, iron staining, some organics, damp
		0.4 - 1.0	SAND	medium grained, well graded,brown, compact, damp
		1.0 - 2.3	SAND	medium grained, well graded,brown, loose, moist
		2.3 - 4.5	GRAVEL	well graded, brown to black, loose, wet
		4.5 - 5.0	GRAVEL	well graded, brown to black, occasional rock fragments, loose, wet
1018 (20.5,14.4)	WADA	0.0 - 0.9	CLAY	brown, soft to firm , dry
		0.9 - 2.2	SAND	medium grained, well graded,brown, compact, damp
		2.2 - 3.0	SAND	medium grained, well graded,brown, loose, wet
1102 (17.1,8.2)	UNNAMED	0.0 - 0.75	GRAVEL	well graded, brown to black, occasional rock fragments, loose, wet
683 (8.4,9.3)	RIBADO	0.0 - 0.4	CLAY	brown, firm, iron staining, some organics, damp
		0.4 - 0.8	SAND	medium grained, well graded,brown, compact, damp
		0.8 - 2.0	SAND	medium grained, well graded,brown, loose, moist
		2.3 - 3.8	GRAVEL	well graded, brown to black, loose, wet
384 (6.4,10.1)	KUNALLENG	0.0 - 0.4	CLAY	brown, firm, iron staining, some organics, damp
		0.4 - 1.7	SAND	medium grained, well graded,brown, compact, damp
		1.7 - 2.8	SAND	medium grained, well graded,brown, loose, moist
		2.8 - 4.5	GRAVEL	well graded, brown to black, loose, wet
		4.5 - 5.6	GRAVEL	well graded, brown to black, occasional rock fragments, loose, wet
49 (2.9,10.9)	BILAZI	0.0 - 0.7	SAND	medium grained, well graded,brown, compact, damp
		0.7 - 2.2	SAND	medium grained, well graded,brown, loose, moist
		2.2 - 6.2	GRAVEL	well graded, brown to black, loose, wet
815 (13.8,9.4)	KUMTOR	0.0 - 0.8	CLAY	brown, firm, iron staining, some organics, damp
		0.8 - 1.2	SAND	medium grained, well graded,brown, compact, damp
		1.2 - 2.0	SAND	medium grained, well graded,brown, loose, moist
		2.0 - 4.5	GRAVEL	well graded, brown to black, loose, wet
111 (5.5,16.3)	BAHAI	0.0 - 0.4	CLAY	brown, firm, iron staining, some organics, damp
		0.4 - 0.9	SAND	medium grained, well graded,brown, occasional rock fragments, loose, we
		0.9 - 1.3	SAND	medium grained, well graded,brown, loose, wet
		1.3 - 1.5	ROCK	black, weathered, hard
831 (11.4,6.9)	KUMTOR/BULA	0.0 - 0.3	CLAY	brown, firm, iron staining, some organics, damp
		0.3 - 1.9	SAND	medium grained, well graded,brown, compact, damp
		1.9 - 4.8	SAND	medium grained, well graded,brown, loose, moist
		4.8 - 4.9	ROCK	black, weathered, hard
39 (3.1,13.0)	LESSGA	0.0 - 0.4	SAND	medium grained, well graded,brown, compact, damp
		0.4 - 2.7	SAND	medium grained, well graded,brown, occasional rock fragments, loose, we
		2.2 - 3.0	SAND	medium grained, well graded,brown, loose, wet
		3.0 - 3.1	ROCK	black, weathered, hard
567 (8.0,10.0)	KUNALLENG	0.0 - 0.4	CLAY	brown, firm, iron staining, some organics, damp
		0.4 - 1.7	SAND	medium grained, well graded,brown, compact, damp
		1.7 - 2.8	SAND	medium grained, well graded,brown, loose, moist
		2.8 - 4.5	GRAVEL	well graded, brown to black, loose, wet
		4.5 - 5.6	GRAVEL	well graded, brown to black, occasional rock fragments, loose, wet
205 (6.6,16.3)	JAURO YAYA	0.0 - 0.4	SAND	medium grained, well graded,brown, compact, damp
		0.4 - 2.7	SAND	medium grained, well graded,brown, occasional rock fragments, loose, we
		2.2 - 3.0	ROCK	black, weathered, hard
		3.0 - 3.1		


WUSHI PUMPING TEST
Observation Well Measurements, r= 2m
Q= 2.0 l/s
T= 154 m2/day
S= 0.27
Drawdown in Meters
0.00
0.10
0.20
0.30
0.40
0.50
1
10
100
1000
Log Time in Minutes


WUSHI RECOVERY TEST
Observation Well at R= 2.0 m
Residual Drawdown in Meters
0.00
0.10
0.20
0.30
0.40
0.50
1
10
100
1000
Ratio t/t'

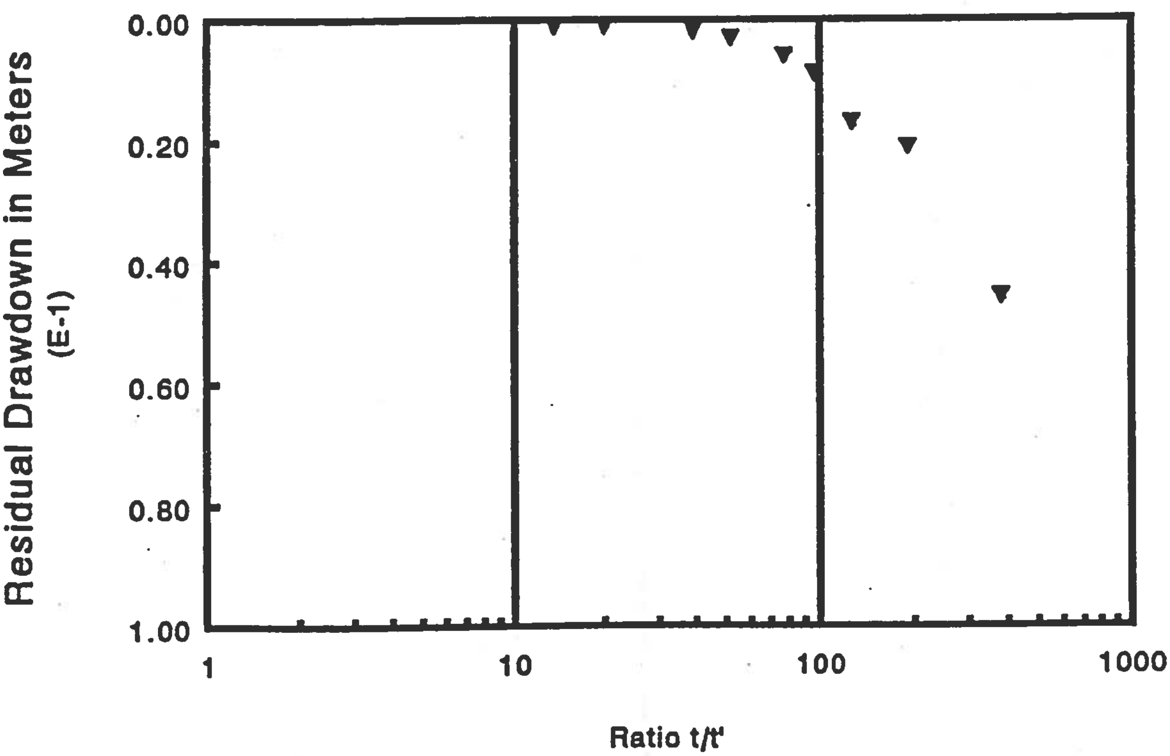
BILAZI PUMPING TEST

Observation Well Measurements, r= 1.5m



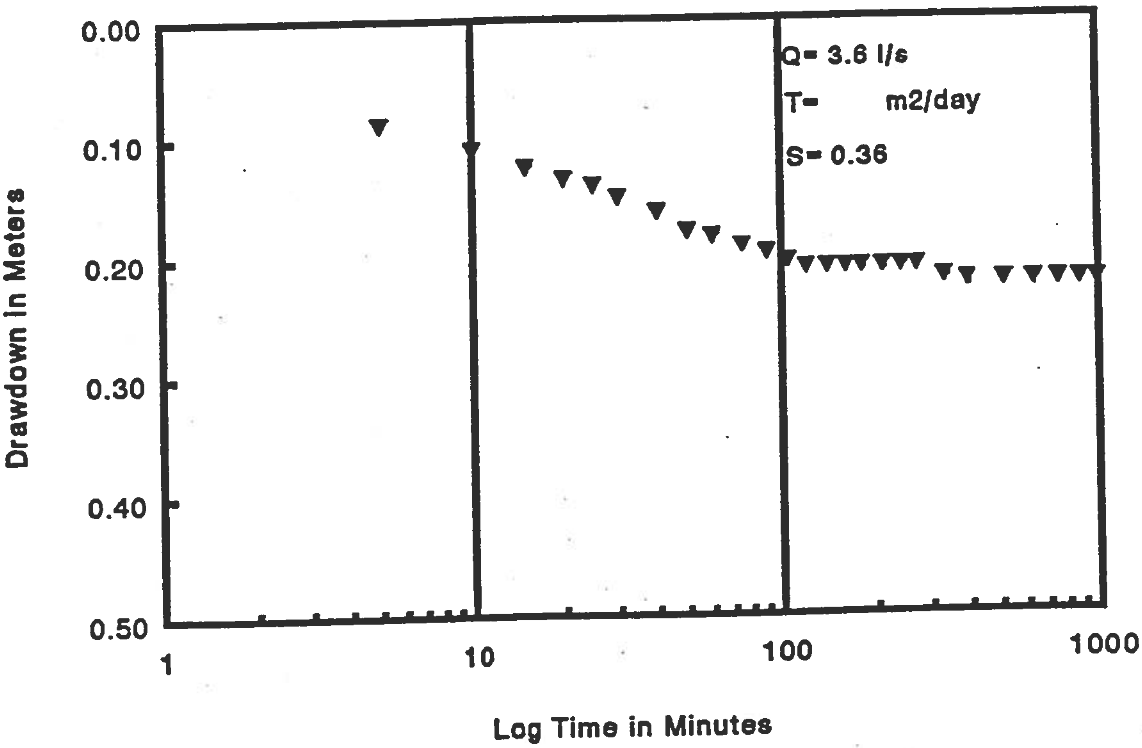
BILAZI RECOVERY TEST

Observation Well at R= 1.5 m



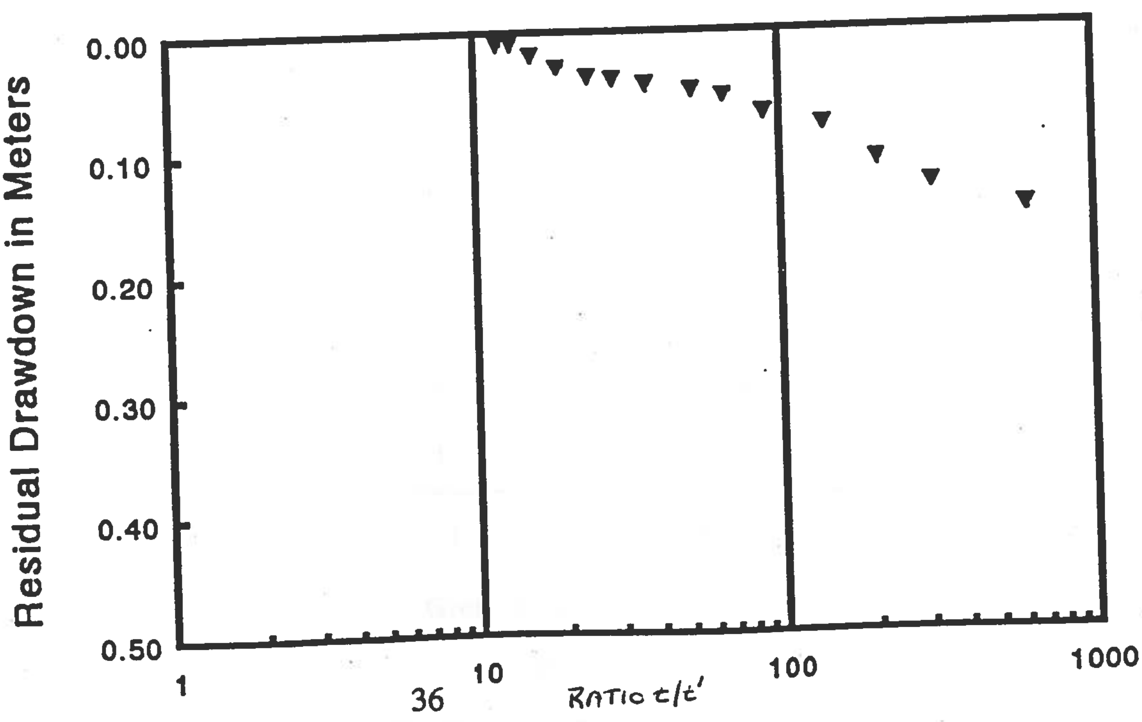
PETA PUMPING TEST

Observation Well Measurements, r= 3m

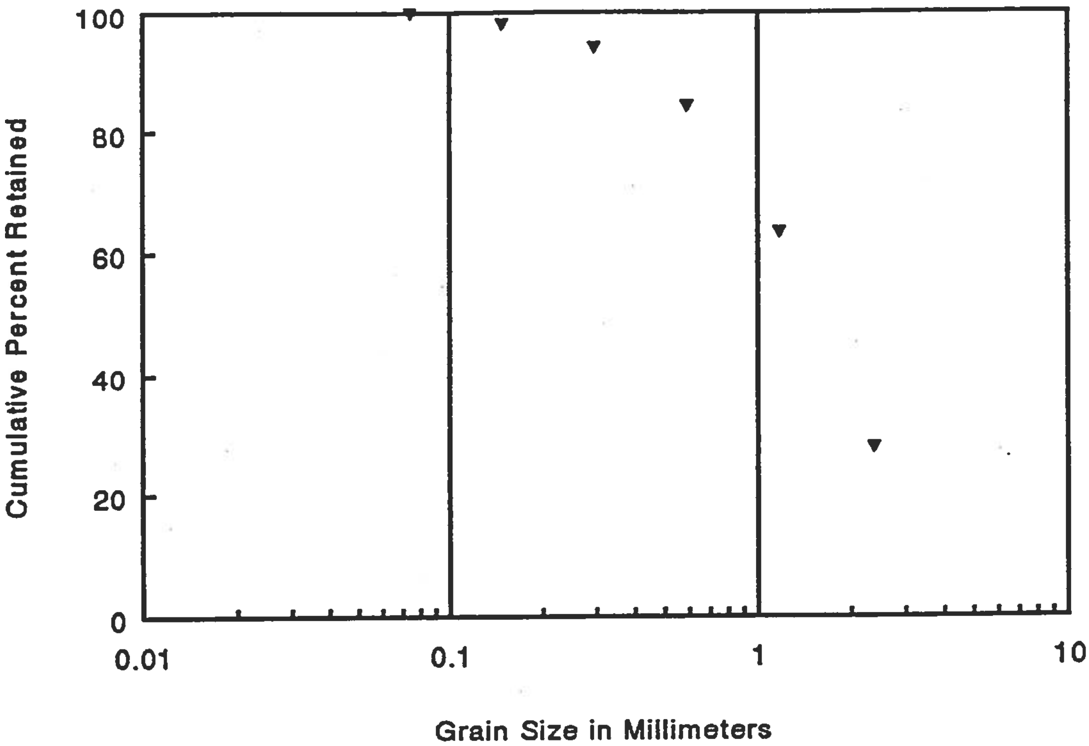


PETA RECOVERY TEST

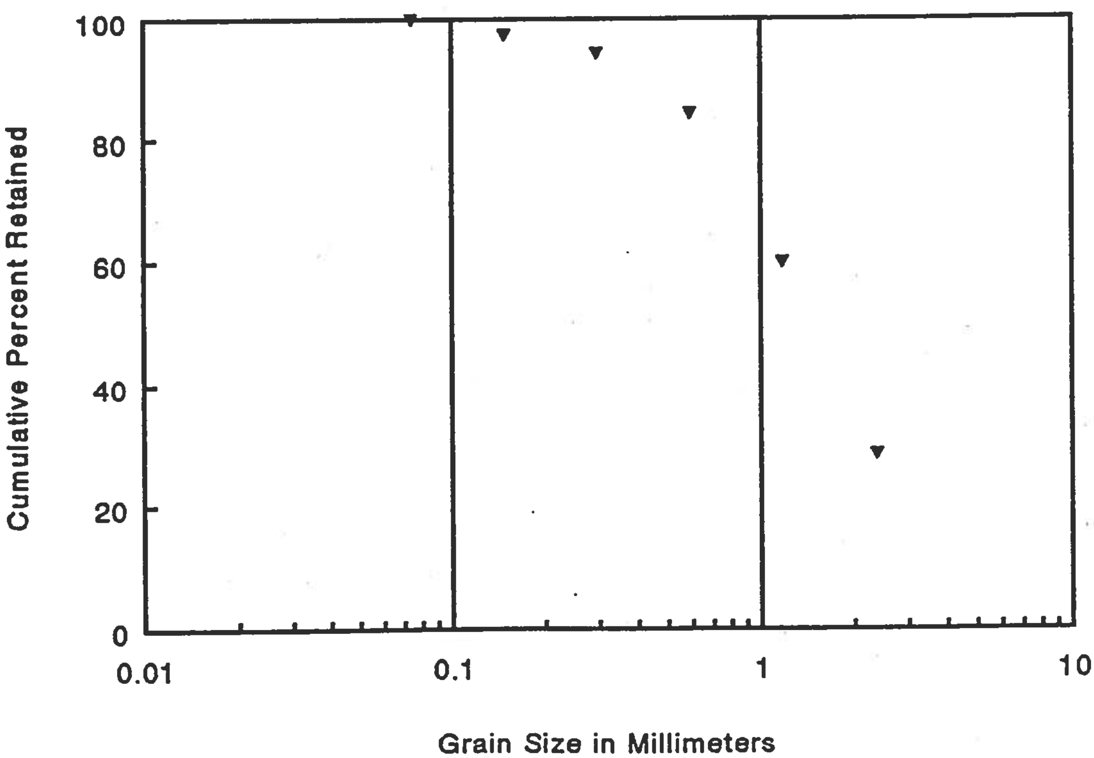
Observation Well at R= 3.0 m



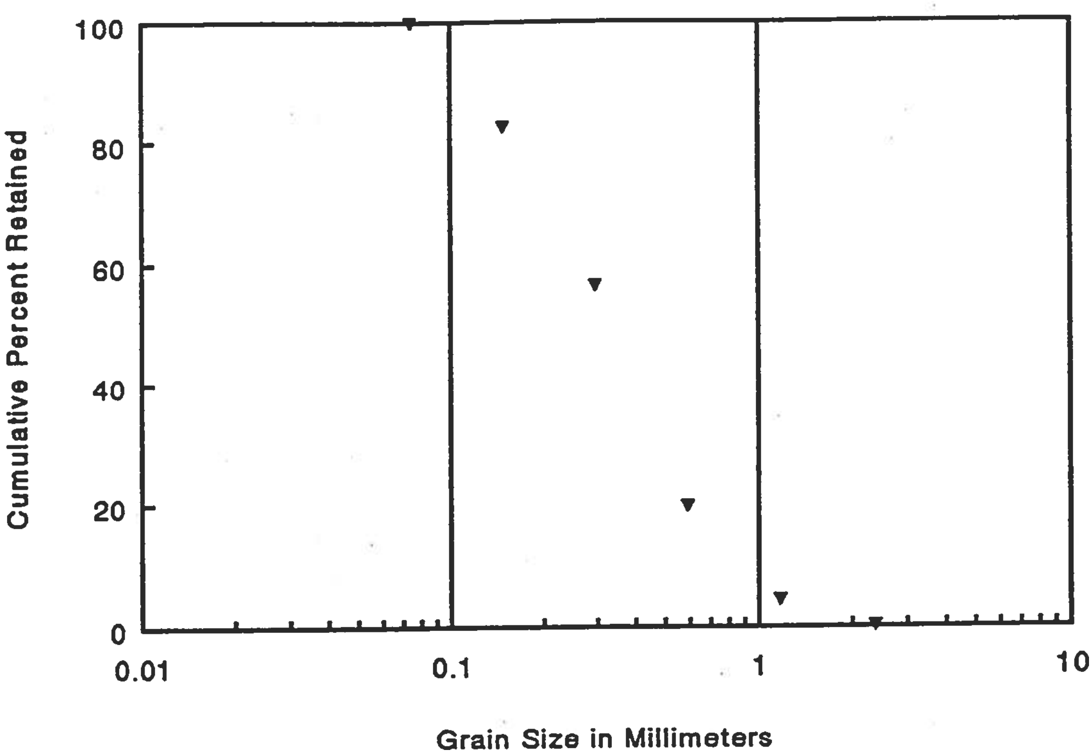
PETA #1 SAMPLE SIEVE ANALYSIS



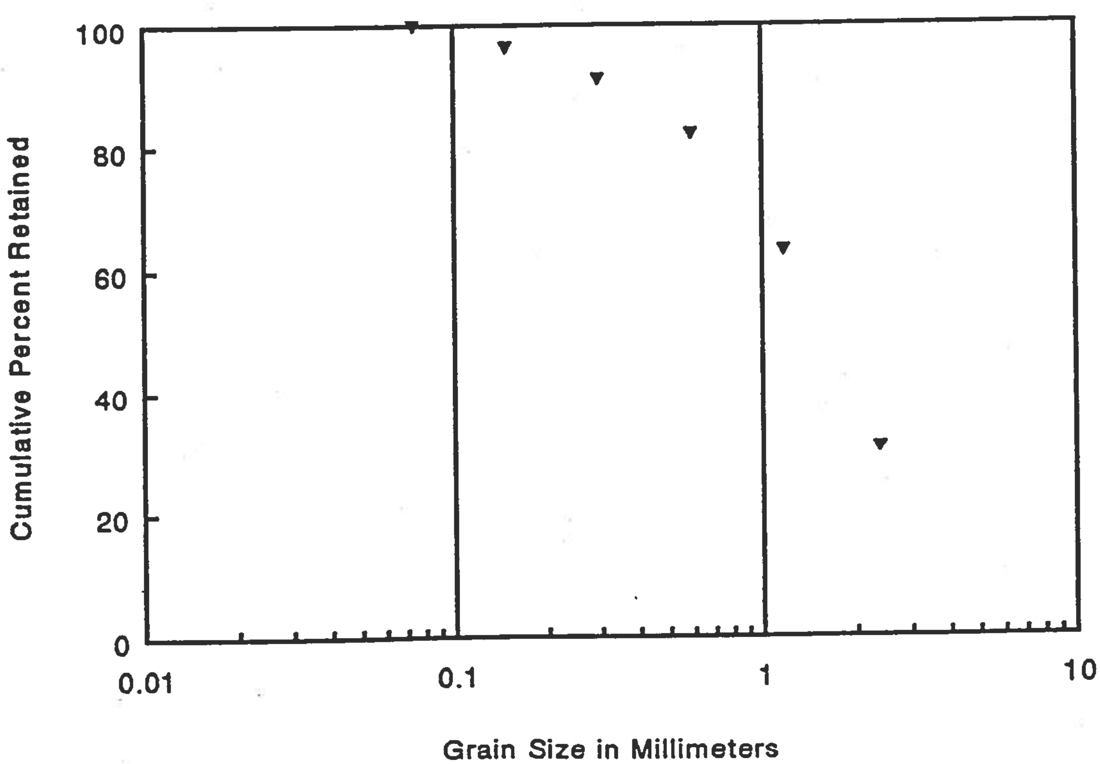
PETA #2 SAMPLE SIEVE ANALYSIS



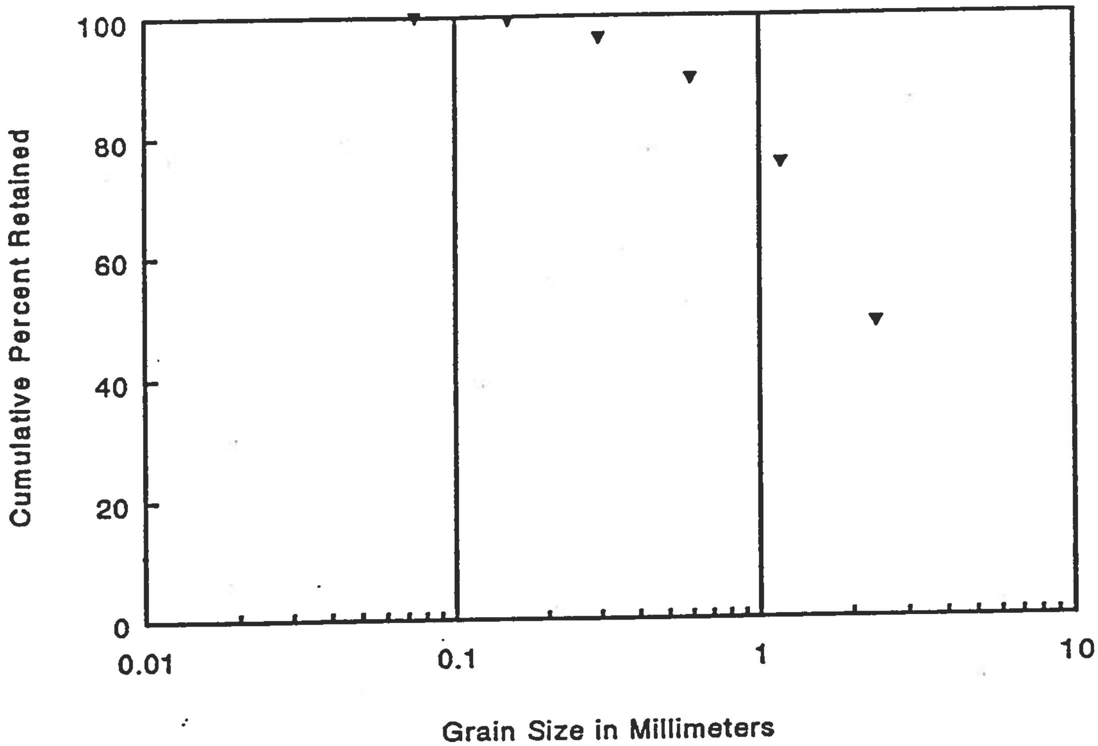
BILAZI #1 SAMPLE SIEVE ANALYSIS



BILAZI #2 SAMPLE SIEVE ANALYSIS



BILAZI #3 SAMPLE SIEVE ANALYSIS



APPENDIX B

```
WUSHI VALLEY AQUIFER
Discretization of Elements
Title block - line 3
   T               ! Plan-view/cross-section
        1187                    ! Number of nodes
        2272                    ! Number of elements
          65                    ! Bandwidth
           3                  ! Number of areas
     1.60000                      ! Grid X minimum
     31.0000                      ! Grid X maximum
     2.20000                      ! Grid Y minimum
     20.6000                      ! Grid X maximum
     1.60000                   ! Screen X minimum
     31.1632                   ! screen X maximum
     2.20000                   ! screen Y minimum
     21.6733                   ! screen X maximum
     12.9891                        ! Screen-user x-scale
     107.217                        ! Screen-user x-translate
     12.2732                        ! Screen-user y-scale
     68.9989                        ! Screen-user y-translate
     1.00000                        ! Character size in x
    0.800000                        ! Character size in y
    1.000000E-02                  ! Mouse precision in x
    1.000000E-02                  ! Mouse precision in y
     1.00000          ! Plotted output scale
    0.000000E+00      ! Plotted output horizontal shift
    0.000000E+00      ! Plotted output vertical shift
(F10.1)
(F10.1)
     1.60000            ! X-axis start
     31.0000            ! X-axis end
     5.88000            ! X-axis increment
     2.01600            ! X-axis y-placement
    0.220800            ! X-axis tic length
     1.28000            ! X-axis tic label y-placement
    0.800000            ! X-axis tic label size
(I10)
East-West Direction
     16.3000            ! X-axis label x-placement
    0.176000            ! X-axis label y-placement
    0.800000            ! X-axis label size
     2.20000            ! Y-axis start
     20.6000            ! Y-axis end
     3.68000            ! Y-axis increment
     1.30600            ! Y-axis x-placement
    0.294000            ! Y-axis tic length
     1.12960            ! Y-axis tic label x-placement
    0.800000            ! Y-axis tic label size
(I10)
North-South Direction
    -1.34000            ! Y-axis label x-placement
     11.4000            ! Y-axis label y-placement
    0.800000            ! Y-axis label size
     1.60000       24.2800       1.60000       21.5200       1.60000       20.7840       ! X,Y  titles
```

```
      1.00000        0.900000        0.900000         ! X,Y  title sizes
REmi J.P. Allard- Master of Engineering Report
      1.60000      -0.560000          ! Company name placement
     0.600000             ! Company name size
      27.4720      -0.560000          ! Date placement
     0.600000             ! Date size
      1.60000       22.4400             ! Field name placement
     0.800000              ! Field name size
     0.500000             ! Field labels size
(F10.1)
      1.60000       21.5200             ! Vector name placement
     0.500000             ! Vector name size
(1PE10.2)
      1.60000       22.4400           ! Head name placement
      1.60000       21.5200           ! Stream name placement
     0.500000              ! Head, stream name size
      35.4100       11.4000           ! Property name placement
     0.800000            ! Property name size
      90.0000            ! Property name angle
(F10.2)
(F10.2)
      3.46020           ! colour legend xmin
      9.04516           ! colour legend ymin
      3.50100           ! colour legend xmax
      9.68000           ! colour legend ymax
      3.52140           ! colour legend label x placement
     0.700000           ! colour legend label size
(I10)
      3.46020           ! fill legend xmin
      9.04516           ! fill legend ymin
      3.50100           ! fill legend xmax
      9.68000           ! fill legend ymax
      3.52140           ! fill legend label x placement
     0.700000           ! fill legend label size
(I10)
(F10.2)
(1PE10.1)
(F10.2)
     0.800000
     0.550000
(F10.2)
   T             ! Plot outer boundary
   T             ! Plot area boundaries
   T             ! Plot elements
   F             ! Plot element numbers
   F             ! Plot elements shrunken
   F             ! Plot nodes
   F             ! Plot node numbers
   T  T  F
   T     ! Plot x-axis
   T     ! Plot x-axis label
   T     ! Plot y-axis
   T     ! Plot y-axis label
   T     ! Plot date
```

```
  T     ! Plot company name

Boundary data
          22  first-type nodes
           1      5.47717
           3      5.51873
           4      5.43241
           8      5.56029
           9      5.38765
          15      5.64341
          16      5.34288
          25      5.79668
          27      5.29812
          36      5.21626
          41      5.94994
          53      5.13439
          60      6.08294
          73      5.05253
          83      6.50000
          87      6.35796
          88      6.21593
         100      4.97067
         127      5.05000
         157      5.09000
         195      5.13000
         233      5.22000
           0 non-zero second-type nodes
           0  third-type nodes

Boundary data
          22  first-type nodes
           1      5.47717
           3      5.51873
           4      5.43241
           8      5.56029
           9      5.38765
          15      5.64341
          16      5.34288
          25      5.79668
          27      5.29812
          36      5.21626
          41      5.94994
          53      5.13439
          60      6.08294
          73      5.05253
          83      6.50000
          87      6.35796
          88      6.21593
         100      4.97067
         127      5.05000
         157      5.09000
         195      5.13000
         233      5.22000
           0 non-zero second-type nodes
```

1

```
*******************************************************************************

                                   AQUIFEM-1
                                   =========
*******************************************************************************

                     TWO DIMENSIONAL FINITE ELEMENT MODEL
                          OF GROUNDWATER FLOW WITH
                         LINEAR TRIANGULAR ELEMENTS

                        DEPARTMENT OF CIVIL ENGINEERING
                     MASSACHUSETTS INSTITUTE OF TECHNOLOGY
                        CAMBRIDGE, MASSACHUSETTS, 02139

                            NOVEMBER 1979 VERSION

*******************************************************************************

                   (w3in) - 60,70,80's and .02's, constant head 3e-4

*******************************************************************************


PROBLEM DESCRIPTION
===================

TYPE OF AQUIFER.....................................................LINEAR=       .F.
   LINEAR=.T.  LINEAR (CONFINED) OR LINEARIZED AQUIFER
   LINEAR=.F.  NONLINEAR (UNCONFINED OR MIXED) AQUIFER

TYPE OF PROBLEM.....................................................STEADY=       .T.
   STEADY=.T.  STEADY STATE PROBLEM
   STEADY=.F.  UNSTEADY OR TRANSIENT PROBLEM

INITIAL CONDITIONS/GUESSES PARAMETER................................INITAL=       .F.
   INITAL=.T.  COMPUTE LINEAR SOLUTION AS A FIRST GUESS FOR A NONLINEAR PROBLEM
               AND/OR INITIAL STEADY STATE SOLUTION FOR AN UNSTEADY PROBLEM
   INITAL=.F.  READ INITIAL CONDITIONS OR GUESSES

FINAL STEADY STATE SOLUTION PARAMETER...............................FINAL=        .F.
   FINAL=.T.  COMPUTE FINAL STEADY STATE SOLUTION WITH BOUNDARY CONDITIONS AT TIME=ENDTIM
   FINAL=.F.  DO NOT COMPUTE FINAL STEADY STATE SOLUTION

DATA CHECK PARAMETER................................................CHECK=        .F.
   CHECK=.T.  CHECK DATA THEN STOP
   CHECK=.F.  EXECUTE PROGRAM NORMALLY

1
FINITE ELEMENT GRID PARAMETERS
==============================

NUMBER OF ELEMENTS..................................................NUMEL=       2272

NUMBER OF NODE POINTS...............................................NUMNP=       1187

FLAG FOR PRINTING GEOMETRIC DATA....................................PRGEOM=       .T.
   PRGEOM=.T.  PRINT GEOMETRIC DATA
   PRGEOM=.F.  DO NOT PRINT GEOMETRIC DATA

FLAG FOR PRINT-PLOTTING GEOMETRIC DATA..............................PLGEOM=       .T.
   PLGEOM=.T.  PLOT GEOMETRIC DATA
   PLGEOM=.F.  DO NOT PLOT GEOMETRIC DATA

SCALING FACTOR FOR X-COORDINATES....................................XSCALE=   1000.000

SCALING FACTOR FOR Y-COORDINATES....................................YSCALE=   1000.000

LARGEST ELEMENT IDENTIFICATION NUMBER...............................MAXELT=       2272

LARGEST NODE IDENTIFICATION NUMBER..................................MAXNOD=       1187

1
AQUIFER PROPERTY PARAMETERS
===========================

NUMBER OF REGIONS WITH REGIONALLY DEFINED AQUIFER PROPERTIES........NAQR=            0

NUMBER OF INDIVIDUAL ELEMENTS OR NODES WITH SPECIALLY DEFINED AQUIFER PROPERTIES.....NSPEC=   2272

METHOD BY WHICH AQUIFER PROPERTIES ARE GIVEN........................BYNODE=       .F.
   BYNODE=.T.  BY NODES
   BYNODE=.F.  BY ELEMENTS

METHOD BY WHICH HYDRAULIC PROPERTIES ARE GIVEN......................PERM=         .T.
   PERM=.T.  PERMEABILITIES KXX,KYY ARE GIVEN
   PERM=.F.  TRANSMISSIVITIES TXX,TYY ARE GIVEN
```

```
1
 BOUNDARY CONDITION PARAMETERS
 ===========================

 NUMBER OF PRESCRIBED BOUNDARY HEAD NODES.................................................NHNODE=        281

 NUMBER OF TIMES WHEN PRESCRIBED HEAD BOUNDARY CONDITIONS ARE SET........................NTBH=            1

 NUMBER OF NODES WHERE GROUND LEVELS ARE SPECIFIED.......................................NGRD=          190

 NUMBER OF TIMES WHEN GROUND LEVELS ARE SET..............................................NTGRD=           1

 NUMBER OF FLUX ELEMENTS.................................................................NFLXE=        2272

 NUMBER OF TIMES WHEN PRESCRIBED BOUNDARY FLUXES ARE SET.................................NTFLXE=          1

 NUMBER OF REGIONS WITH REGIONAL ELEMENT FLUX.............................................NEFR=            0

 NUMBER OF FLUX SIDES.....................................................................NFLXS=           0

 NUMBER OF TIMES WHEN PRESCRIBED SIDE FLUXES ARE SET......................................NTFLXS=          0

 NUMBER OF FLUX NODES.....................................................................NFLXN=           0

 NUMBER OF TIMES WHEN PRESCRIBED NODE FLUXES ARE SET......................................NTFLXN=          0


 NUMBER OF 3RD-TYPE BOUNDARY SIDES........................................................NBC3=            0

 NUMBER OF TIMES WHEN 3RD-TYPE BOUNDARY HEADS ARE SET......................................NTBC3=           0

 NUMBER OF NODES ON THE 3RD-TYPE BOUNDARY SIDES............................................NNOD3=           0

 3RD-TYPE BOUNDARY PARAMETER...............................................................BEDBC3=       .F.
    BEDBC3=.T.  USE RIVER BED LEVELS TO MODIFY 3RD-TYPE INFLOWS
    BEDBC3=.F.  DO NOT USE RIVER BED LEVELS

 NUMBER OF NODES WHERE HEADS IN ADJACENT AQUIFER ARE GIVEN.................................NHADJ=           0

 NUMBER OF TIMES WHEN HEADS IN ADJACENT AQUIFER ARE SET....................................NTHADJ=          0

 ADJACENT AQUIFER PARAMETER................................................................ATTOP=        .F.
    ATTOP=.T.  ADJACENT AQUIFER IS ABOVE AQUIFER UNDER STUDY
    ATTOP=.F.  ADJACENT AQUIFER IS NOT AT TOP

 METHOD OF SUPPLYING ADJACENT HEADS.........................................................HAVARY=       .F.
    HAVARY=.T.  ADJACENT HEADS VARY IN SPACE
    HAVARY=.F.  ADJACENT HEADS ARE CONSTANT

 TYPE OF INITIAL CONDITIONS/GUESSES IF INITAL=.F............................................ICVARY=       .T.
    ICVARY=.T.  INITIAL CONDITIONS VARY IN SPACE
    ICVARY=.F.  INITIAL CONDITIONS ARE CONSTANT

1
 SOLUTION STRATEGY
 =================

 START TIME.................................................................................STRTIM=    0.0000

 END TIME...................................................................................ENDTIM=    0.0000

 TOLERANCE FOR CONVERGENCE..................................................................TOL=       5.0000

 INDICATOR FOR CONVERGENCE CRITERION........................................................ITOL=           1
    ITOL=0  ROOT MEAN SQUARE ERROR CRITERION
    ITOL=1  MAXIMUM ABSOLUTE ERROR CRITERION

 MAXIMUM NUMBER OF ITERATIONS...............................................................MAXIT=         30

 TIME STEP..................................................................................DT=       0.00000

 ALPHA PARAMETER FOR TIME INTEGRATION SCHEME................................................ALPHA=     0.5000

 TIME STEP PARAMETER........................................................................DTPARM=    0.0000

 INDICATOR FOR CHANGING TIME STEP...........................................................IDT=            0
    IDT=0  NO CHANGE OF TIME STEP
    IDT=1  DT=DT*DTPARM AFTER NDT TIME STEPS
    IDT=2  DT=DT+DTPARM AFTER NDT TIME STEPS

 NUMBER OF CONSTANT LENGTH TIME STEPS BEFORE CHANGING ACCORDING TO IDT......................NDT=            1

 NUMBER OF ITERATIONS WITH SAME LEFT HAND SIDE SYSM MATRIX..................................NSYS=           1
    NSYS=999  REFORM SYSM ONCE EACH TIME STEP
```

1
OUTPUT CONTROL
==============

FIRST TIME STEP FOR PRINTED OUTPUT...ISTPRT= 0

NUMBER OF TIME STEPS BETWEEN PRINTED OUTPUTS...NDTPRT= 1

NUMBER OF SPECIAL PRINTED OUTPUT TIMES...NOUT= 0

FIRST TIME STEP FOR PLOTTED OUTPUT...ISTPLT= 1000000

NUMBER OF TIME STEPS BETWEEN PLOTTED OUTPUTS...NDTPLT= 1

NUMBER OF SPECIAL PLOTTED OUTPUT TIMES...NPLT= 0

PLOT SCALING FACTOR..PSCALE= 1000.00

INCREMENT FOR LABELLING PLOT AXES...PDELTA= 0.00

ROTATION PARAMETER...NRFLAG= 1
NRFLAG=0 ROTATION OF PLOT IS ALLOWED
NRFLAG=1 NO ROTATION IS ALLOWED, X-AXIS ACROSS THE PAGE
NRFLAG=2 ROTATION IS FORCED, Y-AXIS ACROSS THE PAGE

NUMBER OF ROWS/COLUMNS AROUND PLOT BOUNDARY..NBOUND= 3

NUMBER OF DECIMAL PLACES IN PLOTTED VALUES OF HEAD...NDP= 1

NODE POINT COORDINATES
======================

NODE	X	Y	NODE	X	Y	NODE	X	Y	NODE	X	Y	NODE	X	Y
1	1800.	12500.	2	1941.	12384.	3	1900.	12575.	4	1750.	12375.	5	2160.	12212.

ELEMENT ARRAY
=============

ELEMENT	I	J	K	ELEMENT	I	J	K	ELEMENT	I	J	K	ELEMENT	I	J	K	ELEMENT	I	J	K
1	556	506	505	2	556	557	506	3	557	558	506	4	557	611	558	5	611	612	558

NUMBER OF ELEMENTS (NK) IN SYMMETRIC COMPACTED MATRIX IS 58566

BANDWIDTH OF MATRIX IN FULL FORM WOULD BE 131

413406 WORDS OF STORAGE HAVE BEEN USED OUT OF A TOTAL ALLOCATION OF 800000

CALCULATIONS ARE IN DOUBLEPRECISION

AQUIFER CHARACTERISTICS
=======================

ELEMENT NO	BOTTOM ELEVATION	AQUIFER THICKNESS	KXX	KYY	STORATIVITY	SPECIFIC YIELD	CONF.LAYER K'/B'
1	1149.00	0.75	2.000E-02	2.000E-02	0.000E+00	1.500E-01	0.000E+00
2	1182.00	0.75	2.000E-02	2.000E-02	0.000E+00	1.500E-01	0.000E+00
3	1191.00	0.75	2.000E-02	2.000E-02	0.000E+00	1.500E-01	0.000E+00

PRESCRIBED HEAD BOUNDARY DATA - SPECIFIED PIEZOMETRIC HEADS AND ASSOCIATED NODE NUMBERS
=============================

TIMES......

0.000

NODE NO	HEADS UP TO AND INCLUDING THE ABOVE TIMES......
1	784.100
3	786.300
4	780.400

GROUND LEVEL DATA - FOR NODES WHICH MAY BE AFFECTED BY A RISING WATER TABLE
=================

TIMES......

0.000

NODE NO GROUND LEVELS UP TO AND INCLUDING THE ABOVE TIMES......

64	870.300
90	876.100
114	882.500

PRESCRIBED FLUXES DISTRIBUTED OVER ELEMENTS (L/T) - VOLUME PER UNIT TIME PER UNIT ELEMENT AREA
E.G. EVAPOTRANSPIRATION,NATURAL RECHARGE,IRRIGATION OR DISTRIBUTED WELLS

TIMES......

0.000

ELEMENT FLUXES ARE READ INDIVIDUALLY FOR2272 ELEMENTS

ELEMENT FLUXES UP TO AND INCLUDING THE ABOVE TIMES ...... FLOW IN(+),FLOW OUT(-)

ELEMENT NO	ELEMENT FLUXES
1	0.000000
2	0.000000
3	0.000000

INITIAL HEAD VECTOR

NODE	HEAD	NODE	HEAD	NODE	HEAD	NODE	HEAD	NODE	HEAD	NODE	HEAD	NODE	HEAD	NODE	HEAD	NODE	HEAD	NODE	HEAD
1	787.08	2	781.53	3	792.87	4	783.25	5	775.41	6	781.56	7	776.66	8	797.55	9	779.92	10	776.76

{w3in} - 60,70,80's and .02's, constant head 3e-4

TIME = 0.00000

X COORDINATES RANGE FROM 1600.00 TO 31000.00

Y COORDINATES RANGE FROM 2200.00 TO 20600.00

NODE NO	PIEZOMETRIC HEAD		INTERNAL FLUXES (INSIDE THE AQUIFER)		EXTERNAL FLUXES (THROUGH THE BOUNDARIES)				LOCATION OF NODE	
	HEAD (L)	DRAWDOWN (L)	QX (L2/T)	QY (L2/T)	SOURCE/SINK INFLOWS (L3/T)	LEAKAGE INFLOWS (L3/T)	INFLOWS AT BOUNDARIES (L3/T)	ID	X (L)	Y (L)
1	784.100 PHR	0.000	-1.642	-0.590	6.080	0.000	-50.280	1	1800.000	12500.00
2	786.689	0.000	-2.364	-1.217	24.932	0.000	0.000	0	1941.000	12384.00
3	786.300 PHR	0.000	-2.634	-0.442	11.096	0.000	-325.130	1	1900.000	12575.00
4	780.400 PHR	0.000	-2.076	-1.311	11.649	0.000	-198.960	1	1750.000	12375.00
1187	2477.741	0.000	-0.001	0.000	0.000	0.000	0.848	1	27300.000	6400.00
				TOTALS	129318.170	0.000	-113874.158			

NET FLOW INTO AQUIFER (L3/T) 15444.011

740	0.1221E+04
743	0.1243E+04
791	0.1246E+04
794	0.1276E+04
844	0.1270E+04
897	0.1292E+04
953	0.1270E+04
954	1.3115E+03
1073	0.1240E+04
1011	0.1250E+04
1074	0.1250E+04
1072	0.1263E+04
1071	0.1275E+04
1070	0.1295E+04
1127	0.1280E+04
1129	0.1270E+04
1130	0.1261E+04
1128	0.1254E+04
1138	1.2134E+03
1137	1.1923E+03
1141	1.1782E+03
1086	0.1181E+04
1028	1.1583E+03
971	0.1150E+04
972	1.1552E+03
973	0.1167E+04
923	0.1141E+04
921	0.1128E+04
977	0.1131E+04
1033	0.1138E+04
1038	0.1160E+04
1048	0.1166E+04
1049	0.1177E+04
990	0.1195E+04
991	0.1189E+04
994	0.1188E+04
992	0.1182E+04
993	0.1184E+04
937	1.2155E+03
938	1.1953E+03
883	0.1212E+04
884	0.1173E+04
829	0.1194E+04
830	0.1161E+04
777	1.1935E+03
727	0.1178E+04
673	0.1224E+04
674	0.1160E+04
616	1.1734E+03
617	0.1119E+04
618	0.1103E+04
619	0.1088E+04
561	0.1086E+04
562	0.1057E+04
563	0.1056E+04
509	0.1041E+04
451	1.0462E+03
452	0.9952E+03
453	0.9802E+03
501	0.9771E+03
502	0.9825E+03
503	0.9924E+03
491	0.9951E+03
437	0.9955E+03
379	0.1003E+04
319	0.1009E+04
273	0.1009E+04
229	0.1021E+04
190	0.9202E+03
191	0.9892E+03
192	0.1014E+04
200	0.9601E+03
241	0.9793E+03
284	0.1001E+04
339	0.9419E+03
337	0.9068E+03
336	0.9380E+03
338	0.8971E+03
392	0.8792E+03
533	1.0431e+03
370	1.0772e+03
534	1.0765e+03
479	0.9399e+03
457	0.9199e+03
55	0.8861e+03
56	0.9653e+03
68	0.8355e+03
85	0.9530e+03
759	1.0539e+03
326	1.0731e+03
282	0.9011e+03
180	0.9314e+03
171	1400.943
174	1448.297
172	1480.925
209	1522.821
210	1560.121
251	1614.633
250	1637.076
294	1671.001

295	1664.733
296	1685.690
351	1742.159
404	1759.040
405	1763.306
462	1753.879
519	1776.177
572	1780.716
573	1739.730
630	1735.850
689	1770.227
741	1785.499
790	1818.386
792	1833.794
841	1929.267
893	2080.001
949	2129.271
1004	2177.244
1062	2352.865
1118	2523.619
1121	2511.157
1153	2499.175
1169	2759.826
1175	2929.080
1174	2933.627
1173	2848.057
1172	2737.372
1171	2600.323
1182	2570.405
1187	2477.741
1179	2274.792
1185	2415.027
1186	2363.224
1184	2464.829
1183	2405.875
1181	2314.643
1168	2249.092
1151	2167.190
1107	2115.208
1045	2025.657
987	1897.865
935	1802.267
882	1747.065
828	1737.439
776	1734.298
724	1743.954
672	1779.004
671	1826.338
670	1842.785
669	1832.062
613	1784.527
612	1741.509
611	1741.823
557	1697.390
556	1673.523
505	1623.008
504	1576.969
449	1520.108
393	1479.937
333	0842.920
279	0826.200
237	0804.451
236	0787.860
235	0778.048
234	0772.820
483	1069.810
429	1120.900
420	1178.090
381	920.500
371	1112.000
1112	1129.700
1104	1116.160
1091	1264.180
368	1099.890
126	0.8419e+03
369	1.0164e+03
426	1.0174e+03
293	0.9152e+03
1093	1119.500
1068	1420.000
916	1128.400
283	909.900
84	944.500
1029	1241.700
268	937.630
240	893.350
160	819.880
154	900.900
228	908.500
549	974.100
1056	1147.295
999	1104.400
1092	1100.500
1055	1163.200
1053	1155.400
825	1008.700
872	1045.240
778	1050.345
834	1046.600
396	921.300

0.0000

64	0.8703E+03
90	0.8761E+03
114	0.8825E+03
147	0.8931E+03
162	0.9071E+03
163	0.9171E+03
136	0.9157E+03
107	0.9285E+03
108	0.9468E+03
133	0.9554E+03
164	0.9657E+03
169	0.9625E+03
181	0.9571E+03
182	0.9610E+03
214	0.9684E+03
213	0.9728E+03
218	0.9786E+03
219	0.9845E+03
216	0.1010E+04
217	0.1026E+04
215	0.1036E+04
256	0.1015E+04
302	0.1005E+04
306	0.1005E+04
360	0.1008E+04
359	0.1017E+04
362	0.1021E+04
361	0.1034E+04
416	0.1038E+04
464	0.1040E+04
520	0.1043E+04
527	0.1047E+04
581	0.1049E+04
580	0.1053E+04
639	0.1057E+04
695	0.1061E+04
749	0.1072E+04
755	0.1082E+04
756	0.1093E+04
802	0.1100E+04
805	0.1114E+04
852	0.1122E+04
100	0.8531E+03
99	0.8555E+03
71	0.8569E+03
69	0.8600E+03
49	0.8613E+03
67	0.8632E+03
65	0.8657E+03
92	0.8672E+03
91	0.8693E+03
117	0.8714E+03
148	0.8748E+03
185	0.8777E+03
224	0.8850E+03
267	0.8938E+03
318	0.9011E+03
377	0.9111E+03
433	0.9126E+03
488	0.9223E+03
515	0.9317E+03
514	0.9376E+03
567	0.9476E+03
568	0.9626E+03
624	0.9724E+03
628	0.9807E+03
647	0.9825E+03
648	0.9882E+03
605	0.9997E+03
604	0.1008E+04
602	0.1014E+04
662	0.1012E+04
663	0.1025E+04
714	0.1044E+04
715	0.1060E+04
764	0.1075E+04
765	987.580
817	1002.000
870	1019.330
918	1027.600
919	1037.350
976	1056.350
97	771.130
124	781.740
158	783.910
159	785.260
197	791.180
238	809.840
280	830.790
334	845.040
335	847.600
485	1018.260
244	884.360
245	896.070
290	908.100
340	918.920
348	936.060
374	945.930
375	945.580

400	927.740
431	942.320
432	950.240
427	1052.610
534	1076.400
438	970.720
421	1095.820
380	964.030
312	1074.100
161	903.920
225	877.450
204	898.390
202	896.960
269	890.400
424	961.160
481	944.440
719	949.640
772	969.010
320	957.820
321	907.970
381	924.810
983	1105.250
1042	1123.570
1051	1161.000
1054	1166.000
1040	1091.000
984	1187.000
880	1030.000
436	1024.000
378	1039.000
492	973.780
818	993.340
819	1007.500
249	898.680
264	903.070
998	1120.310
982	1093.620
944	1062.110
931	1043.260
914	1083.510
888	1037.470
878	1025.010
810	1089.670
807	1071.040
761	1071.390
709	1056.640
656	1043.500
203	877.830
243	864.870
316	931.590
543	1021.880
056	936.893
276	1268.300
420	1145.850
403	1144.860
315	929.040
1094	1127.640
824	1003.220
782	950.300
598	1031.070
549	975.380
439	938.780
093	791.920
482	1038.130
493	950.170
926	1064.800
930	1075.330
927	1090.760
928	1065.720
942	1081.920
985	1085.400
112	981.660
312	1073.900
48	0.8148e+03
94	0.8266e+03
399	0.8936e+03
382	0.8934e+03
270	0.8554e+03
226	0.8351e+03
246	0.8397e+03
364	1.0574e+03
387	1.0590e+03
1043	1.1080e+03
1113	1142.000
1057	1128.000
874	1021.000
933	1059.000
934	1069.500
929	1055.000
917	1124.600
984	1087.500
0.0000	
	10.0000E+00
	20.0000E+00
	30.0000E+00
1	787.080
2	781.529
3	792.871

APPENDIX C

```
      program balance
      dimension a(5000),b(5000),c(5000),d(5000),e(5000),f(5000)
      real inflow, outflow, recharge, rivflow
      character infile*20, outfile*20, title*40
c
cccccccccccccccccccccccccccccccccccccccccccccccccccccccc
c
c     This code modified by R. Allard 11/29/93 from source
c     code written by David Farrel from U Of Manitoba,
c     Geological/Civil Engineering Department
c
cccccccccccccccccccccccccccccccccccccccccccccccccccccccc
c
      write(*,*) 'enter the name of the input file'
      read(*,5) infile
      write(*,*) 'enter the name of the output file'
      read(*,5) outfile
      write(*,*) 'enter title'
      read(*,5) title
 5    format(a20)
 6    format(a40)
c
      open(unit=1,file=infile,status='old')
      rewind 1
      read(1,*) npts,inbound,outbound,rivnodes
      open(unit=2, file=outfile, status='unknown')
      rewind 2
      write(2,*)"total model nodes          = ", npts
      write(2,*)"inbound flux nodes         = ", inbound
      write(2,*)"outbound flux nodes        = ", outbound
      write(2,*)"outbound river flux nodes = ", rivnodes
      read(1,*) (a(i),b(i),c(i),i=1,npts)
      write(*,*) a(10),b(10),c(10)
      read(1,*) (d(i),i=1,inbound)
      read(1,*) (e(i),i=1,outbound)
      read(1,*) (f(i),i=1,rivnodes)
      WRITE(*,*) d(2),e(2),f(2)
      inflow=0.0
      outflow=0.0
      rivflow=0.0
      do 20 J=1,npts
      if(c(j).eq.1.0)then
      do 10 k=1,inbound
      if(a(j).eq.d(k))then
      r=d(k)
      inflow=inflow + b(j)
      write(2,*)"node=  ",r," flux in= ",b(j)," cum flux in= ",inflow
      end if
 10   continue
      end if
 20   continue
      write(2,*)""
      do 40 J=1,npts
      if(c(j).eq.1.0)then
```

```
      do 30 I=1,outbound
      if(a(j).eq.e(i))then
      p=e(i)
      outflow=outflow + b(j)
      write(2,*)"node=  ",p," flux out= ",b(j)," cum flux out= ",outflow
      end if
30    continue
      end if
40    continue
      write(2,*)""
      do 60 J=1,npts
      if(c(j).eq.1.0)then
      do 50 k=1,rivnodes
      if(a(j).eq.f(k))then
      s=f(k)
      rivflow=rivflow + b(j)
      write(2,*)"node= ",s," river out= ",b(j),"cum river out=",rivflow
      end if
50    continue
      end if
60    continue
      recharge=inflow-outflow
      write(2,*)"  total flux out=    ",outflow
      write(2,*)"  total flux in =    ",inflow
      write(2,*)"  total recharge=    ",recharge
      write(2,*)"  total river flow=  ",rivflow
      close (unit=1)
      close (unit=2)
      stop
      end
```

```
      program addhead
      dimension a(1000),b(1000),c(1000)
      character infilea*20,outfile*20,title*40
      real delta
      integer a
c
cccccccccccccccccccccccccccccccccccccccccccccccccccccccccc
c
c     This code written by R. Allard 11/29/93 at U Of
c     Manitoba, Geological/Civil Engineering Department
c
cccccccccccccccccccccccccccccccccccccccccccccccccccccccccc
c
      write(*,*) 'name of upper recharge boundary elev file?'
      read(*,5) infilea
      write(*,*) infilea
      write(*,*) 'name for modified file?'
      read(*,5) outfile
      write(*,*) outfile
      write(*,*) 'enter title'
      read(*,6) title
  5   format(a20)
  6   format(a40)
c
      write(*,*) "how much do you wish to modify heads by in m?"
      read (*,*) delta
      open(unit=1,file=infilea,status='old')
      rewind 1
      open(unit=2, file=outfile, status='unknown')
      rewind 2
      read(1,*) nnodea,nnodeb
      do 10 i=1,nnodea
      read(1,*) a(i),b(i)
      c(i)= b(i) + delta
      write(2,8) a(i),c(i)
  8   format(4X,I5,1x,E10.4)
 10   continue
      write(2,*)""
      do 20 i=1,nnodeb
      read(1,*) a(i),b(i)
      c(i)= b(i) + delta
      write(2,18) a(i),c(i)
 18    format(4X,I5,1x,E10.4)
 20   continue
      close (unit=1)
      close (unit=2)
      stop
      end
```

```
      program aquiprop
      dimension a(10000),b(10000),c(10000),d(10000),e(10000)
      dimension f(10000), g(10000)
      integer nelem
      character infilea*20,infileb*20,infilec*20,infiled*20
      character outfile*20,title*40
c
cccccccccccccccccccccccccccccccccccccccccccccccccccccccccc
c
c     This code written by R. Allard 11/29/93 at U Of
c     Manitoba, Geological/Civil Engineering Department
c
cccccccccccccccccccccccccccccccccccccccccccccccccccccccccc
c
      write(*,*) 'enter the name of the elevation input file'
      read(*,5) infilea
      write(*,*) infilea
      write(*,*) 'enter the name of the aquifer thickness file'
      read(*,5) infileb
      write(*,*) infileb
      write(*,*) 'enter the name of the transmissivity input file'
      read(*,5) infilec
      write(*,*) infilec
      write(*,*) 'enter the name of the storativity input file'
      read(*,5) infiled
      write(*,*) infiled
      write(*,*) 'enter the name of the output file'
      read(*,5) outfile
      write(*,*) outfile
      write(*,*) 'enter title'
      read(*,5) title
 5    format(a20)
 6    format(a40)
c
      write(*,*) 'enter the number of elements to assign'
      write(*,*) 'properties to '
      read(*,*) nelem
      write(*,*) nelem
      open(unit=1,file=infilea,status='old')
      rewind 1
      open(unit=2,file=infileb,status='old')
      rewind 2
      open(unit=3,file=infilec,status='old')
      rewind 3
      open(unit=4,file=infiled,status='old')
      rewind 4
      open(unit=5, file=outfile, status='unknown')
      rewind 5
      read(1,*) (a(i),i=1,nelem)
      read(2,*) (b(i),i=1,nelem)
      read(3,*) (c(i),i=1,nelem)
      read(4,*) (d(i),i=1,nelem)
      do 7 i=1,nelem
        f(i)=a(i)-b(i)
```

```
7    continue
      write(5,8) (i,f(i),b(i),c(i),c(i),e(i),d(i),g(i),i=1,nelem)
8    format(i10,e10.4,e10.4,e10.4,e10.4,e10.4,e10.4,e10.4)
     close (unit=1)
     close (unit=2)
     close (unit=3)
     close (unit=4)
     close (unit=5)
     stop
     end
```

```
      program compare
      dimension a(5000),b(5000),c(5000),d(5000),e(5000)
      dimension f(5000),u(5000)
      integer nnode,numel,an,bn,cn,dn
      real sum
      character infilea*20,infileb*20
      character outfile*20,title*40
c
cccccccccccccccccccccccccccccccccccccccccccccccccccccccc
c
c     This code written by R. Allard 11/29/93 at U Of
c     Manitoba, Geological/Civil Engineering Department
c
cccccccccccccccccccccccccccccccccccccccccccccccccccccccc
c
      write(*,*) 'enter the name of the original node elevation file'
      read(*,5) infilea
      write(*,*) infilea
      write(*,*) 'enter the name of modified aquifem head file'
      read(*,5) infileb
      write(*,*) infileb
      write(*,*) 'enter the name of your output file'
      read(*,5) outfile
      write(*,*) outfile
      write(*,*) 'enter title'
      read(*,5) title
 5    format(a20)
 6    format(a40)
c
      nnode=1187
      numel=2272
      open(unit=1,file=infilea,status='old')
      rewind 1
      open(unit=2,file=infileb,status='old')
      rewind 2
      open(unit=3, file=outfile, status='unknown')
      rewind 3
      read(1,*) (a(i),i=1,nnode)
      read(1,*) (f(i),i=1,numel)
      do 10 i=1,numel
      read(1,*)an,bn,cn,dn
      if(f(i).eq.0.0)then
      u(cn)=0.0
      u(bn)=0.0
      u(dn)=0.0
      else
      u(cn)=1.0
      u(bn)=1.0
      u(dn)=1.0
      end if
 10   continue
      read(2,*) (d(i),e(i),b(i),i=1,nnode)
      do 20 i=1,nnode
      c(i)=b(i)-a(i)
```

```
20    continue
      sum=0.0
      write(3,*)"lower recharge area"
      write(3,*)""
      do 40 i=1,nnode
      if(u(i).ne.0.0) then
      c(i)=b(i)-a(i)
      sum=sum+c(i)
      write(3,30) i,a(i),b(i),d(i),e(i),c(i)
30    format(i10,1x,f8.3,1x,f8.3,1x,f8.1,1x,f8.1,1x,f8.3)
      end if
40    continue
      write(3,*)"sum= ",sum
      write(3,*)""
      sum=0.0
      write(3,*)"upper recharge area"
      write(3,*)""
      do 60 i=1,nnode
      if(u(i).eq.0.0) then
      c(i)=b(i)-a(i)
      sum=sum+c(i)
      write(3,50) i,a(i),b(i),d(i),e(i),c(i)
50    format(i10,1x,f8.3,1x,f8.3,1x,f8.1,1x,f8.1,1x,f8.3)
      end if
60    continue
      write(3,*)"sum= ",sum
      write(3,*)""
      close (unit=1)
      close (unit=2)
      close (unit=3)
      stop
      end
```

```
      program elemconv
      dimension x(10000),y(10000),z(10000)
      integer x,y,z
      character infile*20,outfile*20,title*40
c
cccccccccccccccccccccccccccccccccccccccccccccccccccccccc
c
c     This code modified by R. Allard 11/29/93 from source
c     code written by David Farrel from U Of Manitoba,
c     Geological/Civil Engineering Department
c
cccccccccccccccccccccccccccccccccccccccccccccccccccccccc
c
      write(*,*) 'enter the name of the input file'
      read(*,5) infile
      write(*,*) 'enter the name of the output file'
      read(*,5) outfile
      write(*,*) 'enter title'
      read(*,6) title
 5    format(a20)
 6    format(a40)
c
      open(unit=1,file=infile,status='old')
      rewind 1
      read(1,*) nelem
      open(unit=2, file=outfile, status='unknown')
      rewind 2
      write(2,*) nelem
      write(*,*) nelem
      read(1,*) (x(i),y(i),z(i),i=1,nelem)
      write(*,*) x(1),y(1),z(1)
      write(2,15) (i,x(i),y(i),z(i),i=1,nelem)
 15   format(i10,i10,i10,i10)
      close (unit=1)
      close (unit=2)
      stop
      end
```

```
      program nodconv
      dimension x(5000),y(5000)
      character infile*20,outfile*20,title*40
c
ccccccccccccccccccccccccccccccccccccccccccccccccccccccc
c
c     This code modified by R. Allard 11/29/93 from source
c     code written by David Farrel from U Of Manitoba,
c     Geological/Civil Engineering Department
c
ccccccccccccccccccccccccccccccccccccccccccccccccccccccc
c
      write(*,*) 'enter the name of the input file'
      read(*,5) infile
      write(*,*) 'enter the name of the output file'
      read(*,5) outfile
      write(*,*) 'enter title'
      read(*,5) title
 5    format(a20)
 6    format(a40)
c
      open(unit=1,file=infile,status='old')
      rewind 1
      read(1,*) npts
      open(unit=2, file=outfile, status='unknown')
      rewind 2
      write(2,*) npts
      read(1,*) (x(i),y(i),i=1,npts)
      write(2,15) (i,x(i),y(i),i=1,npts)
 15   format(i10,f10.3,f10.3)
      close (unit=1)
      close (unit=2)
      stop
      end
```

```
      program convt
c
c     ******************************************************************
c     *  This programs acts as an interface between the grid gener-    *
c     *  ator (GRDBLDR) and the finite element aquifer modelling code  *
c     *  (AQUIFEM).                                                    *
c     *  The program reads in the node coordinates and the element     *
c     *  connectivity matrix which are generated by the GRDBLDR and    *
c     *  writes the output to a file which AQUIFEM can read.           *
c     *  Modified 29/03/92 to allow the user to read GRDBLDR V2.0      *
c     *  files.                                                        *
c     *  Modified 09/04/92 to read several new input files.            *
c     ******************************************************************
      character ed*4,esc*1,csi*2,sgr1*4,sgr0*4
      character*50 innode,inelem,outfile,title,rfile,afile,hfile
      character*50 rwgfile,rdffile,enffile,sfbfile,nfbfile,bc3file
      character*50 haafile,efiefile,card5,card6,card7,card3,card31
      character*50 dname
      logical linear,steady,inital,final,check,prgeom,plgeom,bedbc3
      logical icvary,attop,havary,bynode,perm
      dimension x(5000),y(5000),in(5000,3),aqprop(7),naqreg(25)
      dimension aqpropr(5,7),nmb(5000),aqpropi(5000,7),tbh(25)
      dimension tgrd(15),nodgrd(50),grd(5,50),tflxe(25),nqreg(25)
      dimension qreg(5,5),nbhn(200),nn3(50),nmpp(5000)
      dimension nqe(50,50),nqee(200),qe(200,5),tflxs(25),nqs(25,50)
      dimension tflxn(25),nqn(25),qn(25,40),tbc3(25),ns3(2,50)
      dimension bedlvl(50),hbc3(25,50),thadj(25),nadj(200)
      dimension prtime(30),pltime(30),hadj(5,200),hnode(50,30)
      dimension perm3(50),num(25,30),hz(200),qs(25,25),width(50)
c
        idum=0
        esc=char(27)
        csi= esc // '['
        ed=csi // '2J'
        sgr0=csi // '0m'
        sgr1=csi // '1m'
c
 1312 write(*,520) ed
      write(*,520) sgr1
      write(*,2501)
      write(*,*)'**********************************************************'
      write(*,*) '*                                                        *'
      write(*,*) '*                       AQUIFEM                          *'
      write(*,*) '*                    PREPROCESSOR                        *'
      write(*,*) '*                                                        *'
      write(*,*) '*                       written                          *'
      write(*,*) '*                          by                            *'
      write(*,*) '*                                                        *'
      write(*,*) '*                    David Farrell                       *'
      write(*,*) '*                                                        *'
      write(*,*) '*              Dept. of Geol. Engineering                *'
      write(*,*) '*                University of Manitoba                  *'
      write(*,*) '*                 Winnipeg, Manitoba                     *'
      write(*,*) '*                        Canada                          *'
```

```
      write(*,*) '*                                                       *'
      write(*,*) '*********************************************************'
      write(*,2501)
 2501 format (////)
      write(*,*) 'enter 1 to continue'
      write(*,*) sgr0
      read(*,*) icont
      if (icont.ne.1) go to 1312

      write(*,520) ed
 520  format(1x,a)
      write(*,*) 'enter the title for this work -> '
      read(*,1) title
 1    format(a50)
c
c
c     main problem parameters
c
      write(*,*) '*********************************************************'
      write(*,520) sgr1
      write(*,*) 'the following MAIN PROBLEM PARAMETERS are required'
      write(*,*) 'refer to the AQUIFEM user manual'
      write(*,520) sgr0
      write(*,*) 'enter F (false) or T  (true) when prompted'
      write(*,*) 'linear analysis (T); non-linear analysis (F) -> '
      read(*,2) linear
      write(*,*) 'steady analysis (T); un-steady analysis (F) -> '
      read(*,2) steady
      write(*,*) 'program computes initial guess (T); user supplies init
     #ial guess (F) -> '
      read(*,2) inital
      write(*,*) 'final steady state solution required using b.c. at tim
     #e=endtime (T); otherwise (F) -> '
      read(*,2) final
      write(*,*) 'execution stops after printing and plotting finite ele
     #ment grid (T); program runs to completion (F) -> '
      read(*,2) check
 2    format(l1)
      write(*,*) '*********************************************************'
c
c
c     geometric parameters
c
      write(*,520) ed
      WRITE(*,1) TITLE
      write(*,*) '*********************************************************'
      write(*,*) 'GEOMETRIC PARAMETERS'
      write(*,*) 'geometric data to be printed out (T); otherwise (F) ->
     # '
      write(*,*) 'Enter the name of the Geometric Parameter file'
      read(*,1399) card3
      open(unit=30,file=card3,status='old')
      rewind 30
```

```
      read(30,*) numel,numnp
      read(30,2) prgeom
      read(30,2) plgeom
      read(30,*) xscale,yscale,maxelt,maxnod
      close(unit=30)
      write(*,*) '*******************************************************'
c
c
c     aquifer property parameters
c
      write(*,520) ed
      write(*,*) '*******************************************************'
      write(*,520) sgr1
      write(*,*) 'AQUIFER PROPERTY PARAMETERS'
      write(*,*) 'refer to card 4, p179 AQUIFEM user manual'
      write(*,520) sgr0
      write(*,*) 'enter naqr -> '
      read(*,*)  naqr
      write(*,*) 'enter nspec -> '
      read(*,*) nspec
      write(*,*) 'enter bynode -> '
      read(*,*) bynode
      write(*,*) 'enter perm -> '
      read(*,*) perm
      write(*,*) '*******************************************************'
c
c
c     boundary and initial conditions
c
      write(*,520) ed
      write(*,*) '*******************************************************'
      write(*,520) sgr1
      write(*,*) 'BOUNDARY AND INITIAL CONDITIONS'
      write(*,*) 'refer to card 5, p180 AQUIFEM user manual'
      write(*,520) sgr0
      write(*,*) 'Enter the name of the Boundary and Initial Conditions
     # file --> '
      read(*,1399) card5
      open(unit=26,file=card5,status='old')
      rewind 26
      read(26,*) nhnode,ntbh,ngrd,ntgrd,nflxe,ntflxe,nefr
      read(26,*) nflxs,ntflxs,nflxn,ntflxn,nbc3,ntbc3,nnod3
      read(26,2) bedbc3
      read(26,*) nhadj,nthadj
      read(26,2) attop
      read(26,2) havary
      read(26,2) icvary
      close(unit=26)
      write(*,*) '*******************************************************'
c
c
c     time integration and iteration parameters
c
      write(*,520) ed
```

```fortran
      write(*,*) '*******************************************************'
      write(*,520) sgr1
      write(*,*) 'TIME INTEGRATION AND ITERATION PARAMETERS'
      write(*,*) 'refer to card 6, p182 AQUIFEM user manual'
      write(*,520) sgr0
      write(*,*) 'Enter the name of the Integration Parameters file -->
     # '
      read(*,1399) card6
      open(unit=27,file=card6,status='old')
      rewind 27
      read(27,*) strtim,endtim,tol,itol,maxit
      read(27,*) dt,alpha,dtparm,idt,ndt,nsys
      close(unit=27)
      write(*,*) '*******************************************************'
c
c
c     output control parameters
c
      write(*,520) ed
      write(*,*) '*******************************************************'
      write(*,520) sgr1
      write(*,*) 'OUTPUT CONTROL PARAMETERS'
      write(*,*) 'refer to card 7, p183, AQUIFEM user manual'
      write(*,520) sgr0
      write(*,*) 'Enter the name of the Output Control Parameters file
     # --> '
      read(*,1399) card7
      open(unit=28,file=card7,status='old')
      rewind 28
      read(28,*) istprt,ndtprt,nout,istplt,ndtplt
      read(28,*) nplt,pscale,pdelta,nrflag,nbound,ndp
      close(unit=28)
      write(*,*) '*******************************************************'
c
c
c     node point coordinates
c
      write(*,520) ed
      write(*,*) '*******************************************************'
      write(*,520) sgr1
      write(*,*) 'NODE POINT COORDINATES'
      write(*,*) 'refer to card 8, p184, AQUIFEM user manual'
      write(*,520) sgr0
      write(*,*) 'enter the name of the input node file  **.NOD -> '
      read(*,5) innode
 940  write(*,*) 'ENTER THE VERSION OF GRDBLDR USED TO CREATE GRID'
      write(*,*) 'enter 1  for files created by GRDBLDR V1.0 --> '
      write(*,*) 'enter 2  for files created by GRDBLDR V2.0 --> '
      read(*,*) iver
c
c     reading the node file
c
      if (iver.eq.1) then
      open(unit=1,file=innode,form='formatted',status='old')
```

```
      rewind 1
      read(1,*) numnp
c 10   format(i10)
c      do 601 i=1,numnp
c      read(1,11) ndmb,x(i),y(i)
c 601  write(*,*) ndmb,x(i),y(i)
      read(1,11) (ndmb,x(i),y(i),i=1,numnp)
 11   format(i10,2f10.0)
c 11   format(8e15.8)
      close(unit=1)
      write(*,*) '*******************************************************'
c
c
c     element connectivities
c
      write(*,520) ed
      write(*,*) '*******************************************************'
      write(*,520) sgr1
      write(*,*) 'ELEMENT CONNECTIVITIES'
      write(*,*) 'refer to card 9, p185, AQUIFEM user manual'
      write(*,520) sgr0
      write(*,*) 'enter the name of the input element file  **.INC -> '
      read(*,5) inelem
c
c     reading the element file
c
      open(unit=3,file=inelem,form='formatted',status='old')
      rewind 3
      read(3,*) numel
c      do 602 j=1,numel
      read(3,30) (ndmb,in(j,1),in(j,2),in(j,3),j=1,numel)
c 602  write(*,*) ndmb,in(j,1),in(j,2),in(j,3)
 30   format(4i10)
c 30   format(26i5)
      close(unit=3)
      else
c     reading version 2 files.
      if (iver.eq.2) then
      open(unit=1,file=innode,form='formatted',status='old')
      rewind 1
      read(1,*) numnp
c 10   format(i10)
c      do 6001 i=1,numnp
c      read(1,11) ndmb,x(i),y(i)
c 6001 write(*,*) ndmb,x(i),y(i)
      read(1,411) (ndmb,x(i),y(i),i=1,numnp)
 411  format(i10,2f10.2)
c 411  format(7(e15.8,1x))
      close(unit=1)
      write(*,*) '*******************************************************'
c
c
c     element connectivities
c
```

```
      write(*,520) ed
      write(*,*) '**********************************************************'
      write(*,520) sgr1
      write(*,*) 'ELEMENT CONNECTIVITIES'
      write(*,*) 'refer to card 9, p185, AQUIFEM user manual'
      write(*,520) sgr0
      write(*,*) 'enter the name of the input element file  **.INC -> '
      read(*,5) inelem
c
c     reading the element file
c
      open(unit=3,file=inelem,form='formatted',status='old')
      rewind 3
      read(3,*) numel
c      do 6002 j=1,numel
      read(3,340) (ndmb,in(j,1),in(j,2),in(j,3),j=1,numel)
c 6002 write(*,*) ndmb,in(j,1),in(j,2),in(j,3)
 340  format(4i10)
c 340   format(20(i5,1x))
      close(unit=3)
      else
      write(*,*) 'INCORRECT VERSION NUMBER'
      go to 940
      endif
      endif
      write(*,*) '**********************************************************'
c
c
c     default aquifer properties
c
      write(*,520) ed
      write(*,*) '**********************************************************'
      write(*,520) sgr1
      write(*,*) 'DEFAULT AQUIFER PROPERTIES'
      write(*,*) 'refer to card 10, p186, AQUIFEM user manual'
      write(*,520) sgr0
      write(*,*) 'Enter the name of the default properties file -> '
      read(*,1399) dname
      open(unit=25,file=dname,status='old')
      rewind 25
      read(25,*) (aqprop(il), il=1,7)
      close(unit=25)
      write(*,*) '**********************************************************'
c
c
c     number of nodes/elements in each aquifer property region
c
      if (naqr.gt.0) then
      write(*,520) ed
      write(*,*) '**********************************************************'
      write(*,520) sgr1
      write(*,*) 'NUMBER OF NODES/ELEMENTS IN EACH AQUIFER PROPERTY REGI
     #ON'
      write(*,*) 'refer to cards 11 & 12, p186, AQUIFEM user manual'
```

```
      write(*,520) sgr0
      write(*,*) 'number of nodes/elements in the mth region of the aqui
     #fer has uniform aquifer properties different from the default valu
     #es'
      write(*,*) naqr,' regions specified'
      write(*,*) 'Enter the name of the node/element file: k region -->
     # '
      read(*,1399) rfile
 1399 format(a20)
      open(unit=10,file=rfile,status='old')
      rewind 10
      read(10,*) (naqreg(m),m=1,naqr)
c 100  format(14i5)
c     write(*,*) '*******************************************************'
c
c
c     node/element numbers for aquifer property regions
c
c      write(*,520) ed
c      write(*,*) '*******************************************************'
c      write(*,*) 'NODE/ELEMENT NUMBERS FOR AQUIFER PROPERTY REGIONS'
c      write(*,*) 'refer to card 12, p187, AQUIFEM user manual'
      do 102 k=1,naqr
      read(10,*) (num(k,n),n=1,naqreg(k))
C 1400 format(14i5)
c     reading aquifer properties
      read(10,*) (aqpropr(k,j),j=1,7)
c 1401 format(7f8.3)
 102  continue
      close(unit=10)
      write(*,520) ed
      write(*,*) '*******************************************************'
      endif
c
c
c     aquifer properties of individual nodes/elements
c
      if (nspec.gt.0) then
      write(*,520) ed
      write(*,*) '*******************************************************'
      write(*,520) sgr1
      write(*,*) 'AQUIFER PROPERTIES OF INDIVIDUAL NODES/ELEMENTS'
      write(*,*) 'refer to card 13, p187, AQUIFEM user manual'
      write(*,520) sgr0
      write(*,*) 'Enter the name of the Aquifer Properties File --> '
      read(*,1399) afile
      open(unit=12,file=afile,status='old')
      rewind 12
      do 104 i=1,nspec
 104  read(12,*) nmb(i),(aqpropi(i,ni),ni=1,7)
c 1402 format(i5,7f8.3)
      close(unit=12)
      write(*,520) ed
      write(*,*) '*******************************************************'
```

```
      endif
c
c
c     times for fixed head boundary conditions
c
      if (nhnode.gt.0) then
      write(*,520) ed
      write(*,*) '*****************************************************'
      write(*,520) sgr1
      write(*,*) 'FIXED HEAD BOUNDARY CONDITIONS'
      write(*,*) 'refer to cards 14 & 15, p188, AQUIFEM user manual'
      write(*,520) sgr0
      write(*,*) 'Enter the name of the Fixed Head Boundary File --> '
      read(*,1399) hfile
      open(unit=11,file=hfile,status='old')
      rewind 11
      read(11,*) (tbh(i),i=1,ntbh)
c 1510 format(9f8.3)
c      write(*,*) '*****************************************************'
c
c
c     fixed head (1st type) boundary condition
c
c      write(*,520) ed
c      write(*,*) 'FIXED HEAD (1st TYPE) BOUNDARY CONDITION'
c      write(*,*) 'refer to card 15, p188, AQUIFEM user manual'
      do 1006 i=1,nhnode
     read(11,*) nbhn(i),(hnode(m,i),m=1,ntbh)
c 1403 format(i5,8f8.3)
 1006 continue
      close(unit=11)
      write(*,520) ed
      write(*,*) '*****************************************************'
      endif
c
c
c     times for 1st type rising water ground levels
c
      if (ntgrd.gt.0) then
      write(*,520) ed
      write(*,*) '*****************************************************'
      write(*,520) sgr1
      write(*,*) '1st TYPE RISING WATER GROUND LEVELS'
      write(*,*) 'refer to cards 16 & 17, p189, AQUIFEM user manual'
      write(*,520) sgr0
      write(*,*) 'Enter the name of the Rising Water Ground Level Data
     # file --> '
      read(*,1399) rwgfile
      open(unit=13,file=rwgfile,status='old')
      rewind 13
      read(13,*) (tgrd(i),i=1,ntgrd)
c      write(*,*) '*****************************************************'
      endif
c
```

```
c
c     1st TYPE RISING WATER GROUND LEVEL DATA
c
      if (ngrd.gt.0) then
c      write(*,520) ed
c      write(*,*) '**********************************************************'
c      write(*,*) '1st TYPE RISING WATER GROUND LEVEL DATA'
c      write(*,*) 'refer to card 17, p189, AQUIFEM user manual'
      do 108 i=1,ngrd
 108  read(13,*) nodgrd(i),(grd(m,i),m=1,ntgrd)
c 1406 format(i5,5f8.3)
      close(unit=13)
      write(*,520) ed
      write(*,*) '**********************************************************'
      endif
c
c
c     times for prescribed element fluxes
c
      if (nflxe.gt.0) then
      write(*,520) ed
      write(*,*) '**********************************************************'
      write(*,520) sgr1
      write(*,*) 'TIMES FOR PRESCRIBED ELEMENT FLUXES'
      write(*,*) 'refer to card 18, p190, AQUIFEM user manual'
      write(*,520) sgr0
      write(*,*) 'Enter the name of the Regionally Defined Flux File -->
     #'
      read(*,1399) rdffile
      open(unit=14,file=rdffile,status='old')
      rewind 14
      read(14,*) (tflxe(i),i=1,ntflxe)
      write(*,*) '**********************************************************'
      endif
c
c
c     regionally defined element fluxes
c
      if (nflxe.gt.0.and.nefr.gt.0) then
c      write(*,520) ed
c      write(*,*) '**********************************************************'
c      write(*,*) 'REGIONALLY DEFINED ELEMENT FLUXES'
c      write(*,*) 'refer to card 19, p190, AQUIFEM user manual'
      do 111 i=1,nefr
 111  read(14,*) nqreg(i),(qreg(i,m),m=1,ntflxe)
c 1408 format(i5,5f8.3)
      close(unit=14)
      write(*,520)
      write(*,*) '**********************************************************'
c
c
c     element numbers in the ith flux region
c
      write(*,520) ed
```

```
      write(*,*) '********************************************************'
      write(*,520) sgr1
      write(*,*) 'ELEMENT NUMBERS IN ith ELEMENT FLUX REGION'
      write(*,*) 'refer to card 20, p191, AQUIFEM user manual'
      write(*,520) sgr0
      write(*,*) 'Enter the name of the Element Number File for the var
     #ious flux regions --> '
      read(*,1399) enffile
      open(unit=16,file=enffile,status='old')
      rewind 16
      do 112 i=1,nefr
      if ((nqreg(i).eq.nflxe).and.(nqreg(i).eq.numel).and.(numel.eq.
     #nflxe))then
      go to 113
      else
      read(16,*) fl1
      read(16,*) (nqe(i,m),m=1,nqreg(i))
c 1410 format(14i5)
      endif
 112  continue
      close(unit=16)
      write(*,520) ed
      write(*,*) '********************************************************'
      endif
 113  continue
c
c
c     element fluxes for individual elements
c
      iadd=0
      do 115 i=1,nefr
 115  iadd=iadd+nqreg(i)
      nn=nflxe-iadd
      if (nn.gt.0) then
      write(*,520) ed
      write(*,*) '********************************************************'
      write(*,520) sgr1
      write(*,*) 'ELEMENT FLUXES FOR INDIVIDUAL ELEMENTS'
      write(*,*) 'refer to card 21, p191, AQUIFEM user manual'
      write(*,520) sgr0
      write(*,*) 'Enter the name of the Element Flux for Individual Elem
     #ent File --> '
      read(*,1399) efiefile
      open(unit=17,file=efiefile,status='old')
      rewind 17
      do 116 i=1,nn
 116  read(17,*) nqee(i),(qe(i,m),m=1,ntflxe)
c 1106 format(i5,8f8.3)
      close(unit=17)
      write(*,520) ed
      write(*,*) '********************************************************'
      endif
c
c
```

```
c     times for prescribed side fluxes
c
      if (nflxs.gt.0) then
      write(*,520) ed
      write(*,*) '*******************************************************'
      write(*,520) sgr1
      write(*,*) 'TIMES FOR PRESCRIBED SIDE FLUXES'
      write(*,*) 'refer to cards 22 & 23, p192, AQUIFEM user manual'
      write(*,520) sgr0
      write(*,*) 'Enter Side Flux Boundary file name --> '
      read(*,1399) sfbfile
      open(unit=18,file=sfbfile,status='old')
      rewind 18
      read(18,*) (tflxs(i),i=1,ntflxs)
c 117  format(9f8.2)
      write(*,*) '*******************************************************'
      endif
c
c
c     side flux (2nd type) boundary conditions
c
      if (nflxs.gt.0) then
c      write(*,520) ed
c      write(*,*) '*******************************************************'
c      write(*,*) 'SIDE FLUX (2nd TYPE) BOUNDARY CONDITIONS'
      do 118 i=1,nflxs
 118  read(18,*) nqs(1,i),(nqs(2,i),qs(j,i),j=1,ntflxs)
c 1414 format(2i5,5f8.3)
      close(unit=18)
      write(*,520) ed
      write(*,*) '*******************************************************'
      endif
c
c
c     times for prescribed nodal fluxes
c
      if (nflxn.gt.0) then
      write(*,520) ed
      write(*,*) '*******************************************************'
      write(*,520) sgr1
      write(*,*) 'TIMES FOR PRESCRIBED NODAL FLUXES'
      write(*,*) 'refer to cards 24 & 25, p193, AQUIFEM user manual'
      write(*,520) sgr0
      write(*,*) 'Enter the name of the Nodal Flux Boundary File --> '
      read(*,1399) nfbfile
      open(unit=19,file=nfbfile,status='old')
      rewind 19
      read(19,*) (tflxn(i),i=1,ntflxn)
c 119  format(9f8.2)
c      write(*,*) '*******************************************************'
c
c
c     nodal flux boundary conditions
c
```

```
c      write(*,520) ed
c      write(*,*) '**********************************************************'
c      write(*,*) 'NODAL FLUX BOUNDARY CONDITIONS'
c      write(*,*) 'refer to card 25, p193, AQUIFEM user manual'
      do 120 i=1,nflxn
 120  read(19,*) nqn(i),(qn(m,i),m=1,ntflxn)
c 1416 format(i5,5f8.3)
      close(unit=19)
      write(*,520) ed
      write(*,*) '**********************************************************'
      endif
c
c
c     times for mixed (3rd type) boundary conditions
c
      if (nbc3.gt.0) then
      write(*,520) ed
      write(*,*) '**********************************************************'
      write(*,520) sgr1
      write(*,*) 'TIMES FOR MIXED (3rd TYPE) BOUNDARY CONDITIONS'
      write(*,*) 'refer to cards 26,27 & 28, p194, AQUIFEM user manual'
      write(*,520) sgr0
      write(*,*) 'Enter the name of the 3rd Type Boundary Link file'
      read(*,1399) bc3file
      open(unit=20,file=bc3file,status='old')
      rewind 20
      read(20,*) (tbc3(i),i=1,ntbc3)
c 121  format(9f8.2)
      write(*,*) '**********************************************************'
c
c
c     location and properties of links on 3rd type boundary condition
c
c      write(*,520) ed
c      write(*,*) '**********************************************************'
c      write(*,*) 'LOCATION AND PROPERTIES OF LINKS ON 3rd TYPE BOUNDARY
c     #CONDITION'
c      write(*,*) 'refer to card 27, p194, AQUIFEM user manual'
      do 122 i=1,nbc3
 122  read(20,*) ns3(1,i),ns3(2,i),perm3(i),width(i)
c 1220 format(2i5,2f8.4)
c      write(*,*) '**********************************************************'
c
c
c     nodal heads on 3rd type boundary
c
c      write(*,520) ed
c      write(*,*) '**********************************************************'
c      write(*,*) 'NODAL HEADS ON 3rd TYPE BOUNDARY'
c      write(*,*) 'refer to card 28, p194, AQUIFEM user manual'
      do 123 i=1,nnod3
 123  read(20,*) nn3(i),bedlvl(i),(hbc3(m,i),m=1,ntbc3)
c 1420 format(i5,f8.3,5f8.3)
      close(unit=20)
```

```
      write(*,520) ed
      write(*,*) '**********************************************************'
      endif
c
c
c     times for heads in adjacent aquifers
c
      if (nhadj.GT.0) then
      write(*,520) ed
      write(*,*) '**********************************************************'
      write(*,520) sgr1
      write(*,*) 'TIMES FOR HEADS IN ADJACENT AQUIFERS'
      write(*,*) 'refer to card 29, p195, AQUIFEM user manual'
      write(*,520) sgr0
      write(*,*) 'Enter the name of Heads in Adjacent Aquifer file --> '
      read(*,1399) haafile
      open(unit=22,file=haafile,status='old')
      rewind 22
      read(22,*) (thadj(i),i=1,nthadj)
c 124  format(9f8.2)
c     write(*,*) '**********************************************************'
c
c
c    heads in adjacent aquifer
c
c     write(*,520) ed
c     write(*,*) '**********************************************************'
c     write(*,*) 'HEADS IN ADJACENT AQUIFER'
c     write(*,*) 'refer to card 30, p195, AQUIFEM user manual'
      if (havary) then
      do 125 i=1,nhadj
 125  read(22,*) nadj(i),(hadj(m,i),m=1,nthadj)
c 1422 format(i5,5f8.3)
      go to 1612
      else
      do 126 m=1,nthadj
      write(*,*) 'enter head in adjacent aquifer at time ',m,' -> '
 126  read(*,*) hadj(m,1)
      endif
      write(*,520)
 1612 close(unit=22)
      write(*,*) '**********************************************************'
      endif
c
c
c     initial conditions/guesses
c
      if ((linear.and.steady).or.inital) go to 999
      write(*,520) ed
      write(*,*) '**********************************************************'
      write(*,520) sgr1
      write(*,*) 'INITIAL CONDITIONS/GUESSES'
      write(*,*) 'refer to card 31, p196, AQUIFEM user manual'
      write(*,520) sgr0
```

```
      write(*,*) 'Enter input file name'
      read(*,973) card31
973   format(a20)
c
      open(unit=31,file=card31,status='old')
      rewind 31
c
      if (icvary) then
c     all nodal points must be read in
c
      do 127 i=1,numnp
127   read(31,*) nmpp(i),HZ(I)
      else
c     only one initial guess needed (applied to all nodes)
c
      read(31,*) hzz
      endif
      CLOSE(UNIT=31)
      write(*,*) '*********************************************************'
999   continue
c
c
c     special times for printed output
c
      if (nout.gt.0) then
      write(*,520) ed
      write(*,*) '*********************************************************'
      write(*,520) sgr1
      write(*,*) 'SPECIAL TIMES FOR PRINTED OUTPUT'
      write(*,*) 'refer to card 32, p197, AQUIFEM user manual'
      write(*,520) sgr0
      do 128 i=1,nout
      write(*,*) 'enter time',i,' -> '
128   read(*,*) prtime(i)
      write(*,*) '*********************************************************'
      endif
c
c
c     special times for plotted output
c
      if (nplt.gt.0) then
      write(*,520) ed
      write(*,*) '*********************************************************'
      write(*,520) sgr1
      write(*,*) 'SPECIAL TIMES FOR PLOTTED OUTPUT'
      write(*,*) 'refer to card 33, p197, AQUIFEM user manual'
      write(*,520) sgr0
      do 130 i=1,nplt
      write(*,*) 'enter plot time ',i,' -> '
130   read(*,*) pltime(i)
      write(*,*) '*********************************************************'
      endif
c
c
```

```
c     writing to the output file
c
      write(*,520) ed
      write(*,*) '***********************************************************'
      write(*,*) 'WRITING TO THE OUTPUT FILE'
      write(*,*) 'enter the name of the output file -> '
      read(*,5) outfile
 5    format(a20)
      open(unit=4,file=outfile,form='formatted',status='unknown')
      rewind 4
      write(4,1) title
      WRITE(*,1) 'CARD 1'
      write(4,50) linear,steady,inital,final,check
      WRITE(*,*) 'CARD 2'
 50   format(5l5)
      write(4,51) numel,numnp,prgeom,plgeom,xscale,yscale,maxelt,maxnod
      WRITE(*,*) 'CARD 3'
 51   format(2i5,2l5,2f10.3,2i5)
      write(4,52) naqr,nspec,bynode,perm
 52   format(2i5,2l5)
      write(4,53) nhnode,ntbh,ngrd,ntgrd,nflxe,ntflxe,nefr,nflxs,ntflxs,
     #nflxn,ntflxn,nbc3,ntbc3,nnod3,bedbc3,nhadj,nthadj,attop,havary,icv
     #ary
 53   format(11i5/3i5,l5,2i5,3l5)
      write(4,54) strtim,endtim,tol,itol,maxit,dt,alpha,dtparm,idt,ndt,n
     #sys
 54   format(2f10.2,f5.1,2i5,f10.2,2f5.1,3i5)
      write(4,55) istprt,ndtprt,nout,istplt,ndtplt,nplt,pscale,pdelta,nr
     #flag,nbound,ndp
 55   format(6i5,2f10.2,3i5)
        do 40 i=1,numnp
 40   write(4,41) i,x(i),y(i)
 41   format(i10,2f10.2)
        do 42 j=1,numel
 42   write(4,43) j,in(j,1),in(j,2),in(j,3)
 43   format(4i10)
      write(4,56) (aqprop(j),j=1,7)
 56   format(10x,7e12.4)
      if (naqr.gt.0) then
      write(4,57) (naqreg(m),m=1,naqr)
 57   format(5i5)
      do 58 k=1,naqr
      write(4,59) (num(k,npp),npp=1,naqreg(k))
 59   format(16i5)
      write(4,60) (aqpropr(k,nnp),nnp=1,7)
 60   format(10x,7e12.4)
 58   continue
      endif
      if (nspec.gt.0) then
      do 61 i=1,nspec
      write(4,62) nmb(i),(aqpropi(i,kk),kk=1,7)
 62   format(i10,7e12.4)
 61   continue
      endif
```

```
      if (nbc3.gt.0) then
      write(4,81) (tbc3(i),i=1,ntbc3)
 81   format(8f12.4)
      do 82 i=1,nbc3
 82   write(4,83) ns3(1,i),ns3(2,i),perm3(i),width(i)
 83   format(2i10,2e12.5)
      do 84 i=1,nnod3
 84   write(4,85) nn3(i),bedlvl(i),(hbc3(m,i),m=1,ntbc3)
 85   format(i10,7e12.5/(8e12.5))
      endif
      if (nhadj.gt.0) then
      write(4,86) (thadj(i),i=1,nthadj)
 86   format(8f12.4)
      if (havary) then
      do 87 i=1,nhadj
 87   write(4,88) nadj(i),(hadj(m,i),m=1,nthadj)
      else
      write(4,88) idum,(hadj(m,1),m=1,nthadj)
      endif
 88   format(i10,7e12.5/(8e12.5))
      endif
      if ((linear.and.steady).or.inital) go to 998
      if (icvary) then
      do 89 i=1,numnp
 89   write(4,90) nmpp(i),hz(i)
      else
      write(4,90) idum,hzz
      endif
 90   format(i10,e12.5)
 998  continue
      if (nout.gt.0) then
      write(4,92) (prtime(i),i=1,nout)
 92   format(8f12.4)
      endif
      if (nplt.gt.0) then
      write(4,93) (pltime(i),i=1,nplt)
 93   format(8f12.4)
      endif
      close(unit=4)
c
      stop
      end
```

```
         0  third-type nodes



C:\GRID>dir w.*/w/p

 Volume in drive C is MS-DOS_5
 Volume Serial Number is 1964-5C8D
 Directory of C:\GRID

W.T12          W.E01          W.E13          W.N05          W.E02
W.IN3          W.GIF          W.BNI          W.NOD          W.INC
W.BNL          W.F01          W.T01          W.T02          W.T03
W.T04          W.T05          W.T06          W.T07          W.T08
W.E03          W.B01          W.T09          W.E04          W.DIG
W.GEN          W.GRD          W.XYC          W.E05          W.E06
W.E07          W.E08          W.E09          W.T10          W.T11
W.T13          W.ELA          W.N01          W.T14          W.E10
W.E11          W.T15          W.T16          W.E12          W.E14
W.E15          W.T17          W.T18          W.T19          W.T20
W.T21          W.T22          W.T23          W.E16          W.E17
W.E18          W.T24          W.E19          W.T25          W.E20
       60 file(s)     1121140 bytes
                     12736512 bytes free

C:\GRID>
```


```
C:\GRID>dir w.*/w/p

 Volume in drive C is MS-DOS_5
 Volume Serial Number is 1964-5C8D
 Directory of C:\GRID

W.T12          W.E01          W.E13          W.N05          W.E02
W.IN3          W.GIF          W.BNI          W.NOD          W.INC
W.BNL          W.F01          W.T01          W.T02          W.T03
W.T04          W.T05          W.T06          W.T07          W.T08
W.E03          W.B01          W.T09          W.E04          W.DIG
W.GEN          W.GRD          W.XYC          W.E05          W.E06
W.E07          W.E08          W.E09          W.T10          W.T11
W.T13          W.ELA          W.N01          W.T14          W.E10
W.E11          W.T15          W.T16          W.E12          W.E14
W.E15          W.T17          W.T18          W.T19          W.T20
W.T21          W.T22          W.T23          W.E16          W.E17
W.E18          W.T24          W.E19          W.T25          W.E20
       60 file(s)     1121140 bytes
                     12736512 bytes free

C:\GRID>
```