GROUNDWATER 4

Studies in Hydrogeology

AUSTRALIA

HYDROGEOLOGICAL MAPPING PILOT STUDY. BALLARAT 1 : 250 000 SHEET AREA

AUSTRALIAN GROUNDWATER CONSULTANTS

BUREAU OF MINERAL RESOURCES, GEOLOGY & GEOPHYSICS

DIVISION OF CONTINENTAL GEOLOGY

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HYDROGEOLOGICAL MAPPING PILOT STUDY: BALLARAT 1:250 000 SHEET AREA

by

Australian Groundwater Consultants Pty Ltd

FOREWORD

There is increasing concern within the community both about the way that we use the nations's groundwater resources and about problems such as salinization, that are related to groundwater. With this in mind, the Bureau of Mineral Resources (BMR) has taken a number of initiatives involving co-operative studies with the States and also with the private sector. This study follows a report on the development of a five year plan for a National Groundwater Data Base Inventory in which a number of recommendations were made on a program of hydrogeological mapping.

In 1986 the BMR Division of Continental Geology commissioned Australian Groundwater Consultants to prepare a hydrogeological map and explanatory notes (together with notes on the methodology adopted and a database listing) for the Ballarat 1: 250 000 sheet area as part of the Federal Water Resources Assistance program (FWRAP). This work was part of a pilot study program being undertaken by the BMR Hydrogeology Group.

Ballarat is one of three 1: 250 000 scale map sheets in Victoria recommended for preparation in the Pilot Program Study. The aims of the study included: the determination of requirements for bore census and data collection, assessment of the suitability of computer graphics methods of compilation for hydrogeological maps, testing of the adequacy of hydrogeological legends proposed by the Hydrogeological Mapping Sub-committee of AWRC, and gaining an awareness of problems encountered during the course of map preparation.

In view of the importance of groundwater to Australia, particularly in the Murray Basin and adjacent areas, this report is being issued in the public domain to provide a wider dissemination of the information and to bring about more informal discussion on hydrogeological mapping and its value.

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PART 2 - EXPLANATORY NOTES ON THE BALLARAT 1: 250 000 SCALE HYDROGEOLOGICAL MAP

SUMMARY

The work presented is the outcome of a pilot program of 2 1/2 month's duration involving the preparation by Australian Groundwater Consultants (AGC) of a hydrogeological map of the Ballarat 1: 250 000 scale sheet, with accompanying explanatory notes. The pilot program was initiated by BMR through funding provided by the Commonwealth Department of Resources and Energy, and was based on recommendations contained in a report to the Department by AGC on the National Groundwater Data Base Inventory 5-Year Forward Program. The pilot program report to BMR by AGC had three parts: volume 1 described the approach and methodology, the second part (volume 2) consisted of a copy of the Victorian Department of Industry, Technology and Resources (DITR) data base used to compile the map, and the third part comprised the map and explanatory notes. In the present record the approach and methodology form part 1, and the explanatory notes and map part 2; only representative examples of the data base files are included in part 1.

DITR data were acquired as a computer printout of three files: Bore Master, Aquifer, and Chemical Files; additional data for an area south of Ballarat were obtained from the Rural Water Commission. AGC officers first scanned the data files quickly on a parish by parish basis to ascertain trends of specific hydrogeological parameters, then followed this by a detailed assessment using data from each bore.

Contours of water level and salinity were hand-drawn based on data from 165 bores for water level and 730 for salinity. A salinity contour map produced by computer showed the same general appearance as the hand-contoured map. During a four-day field program the consultants checked bore locations and status, and measured the salinity of some surface waters.

The map was compiled on an Intergraph computer aided mapping system by digitising various map elements, and storing these data in separate files; the files were then plotted and edited, and the data subsequently selectively plotted (to avoid confusing detail) to produce a final compilation. To reduce costs copies of the map were reproduced photographically. The Intergraph system can operate with different files and at different levels within those files; it has a powerful editing capacity, and any combination of files and levels can be plotted. The system's main limitations are that it requires an experienced operator, and that colour flooding of mapped classes is not possible (because of this the salinity-yield relationship was indicated on the map by a letter-number matrix - and to avoid a multiplicity of lines - without boundaries between the categories).

Hydrogeological symbols used on the map were selected from the legend proposed by the AWRC Hydrogeological Mapping Sub-committee; work on the map demonstrated a need for adding to the legend symbols for hydraulic isopotential lines and rainfall contours (isohyets).

Compilation of similar maps in future will be aided by the use of

a computer menu prepared by BMR containing topographic, geological and hydrogeological symbols; however, this menu was incomplete at the time of the pilot project, and some problems of symbol complexity and density requiring long plotting times were encountered.

Volume 1 of the original report contained constructive comments on how certain detailed aspects of the DITR groundwater data base might be improved, with consequent benefit to all users.

The actual cost of the pilot program was $ 63938 compared with a cost of $41080 estimated in the National Groundwater Data Base Inventory 5-year Forward Program; the increase was due principally to the map's being the first compiled by the computer-assisted method described, and therefore requiring more of the Project Manger's time than had been foreseen, to the fact that the Melbourne-based hydrogeologist familiar with the area had to work on an Intergraph machine in Sydney, and also because some mathematical modelling to define groundwater flow-directions required the services of a computer engineer, and attracted higher computer charges. AGC consider the original cost estimate reasonable once experience is gained in compilation and printing.

A section of the report responds to detailed comments on the map received from the Water Resources Commission of New South Wales (WRC). The more important of these relate to: 1. differing perceptions as to who are the users of hydrogeological maps; AGC aimed at geologists and hydrogeologists whereas WRC regard farmers and other landholders as their clientele. 2. inferior quality of computer-drawn maps; the consultants regard the map as a draft, a final map would be produced cartographically. 3. high cost. 4. errors on the map; the consultants acknowledge these, but ascert that the lack of checking was due to the short time available for the project.

Recommendations include the use of an experienced operator for the Intergraph system, additional symbols for the hydrogeological legend, simpler patterns in the hydrogeological computer menu, and the preparation of guidelines by the AWRC Groundwater Committee on the exchange between State organisations of data base information and graphical data files.

PART 1. APPROACH AND METHODOLOGY

1.0 INTRODUCTION

The hydrogeological mapping pilot program was initiated by the BMR through the Department of Resources and Energy on the basis of recommendations contained within a report prepared for that Department on the National Groundwater Data Base Inventory 5-Year Forward Program by Australian Groundwater Consultants Pty Ltd (AGC, 1985).

The Ballarat 1:250 000 sheet was chosen for the part of the program being carried out by AGC. The aims of the pilot program as set out by AGC were to:

1. determine more precisely overall costing, staffing and logistic requirements for bore census, collection and collation of data.

2. determine computer graphic system, printing requirements and costs more precisely.

3. test the adequacy of hydrogeological legends proposed by the hydrogeological mapping sub-committee.

4. highlight likely problems that could be encountered during collation, compilation, digitizing and the final printing process of the four 1:250 000 sheets selected, the other three being prepared by the BMR Hydrogeological Group.

The work was undertaken during a two and a half month period beginning in the second half of February through to April 1986.

This Volume 1 report describes the approach and methodology and presents the results of the various phases involved in the preparation of the Ballarat map up to the draft stage. It also discusses costing to the draft stage. It also discusses costing aspects. Volume 2 contains the DITR data base used to compile the map. A separate report has been prepared which comprises the explanatory notes for the hydrogeological map.

Australian Groundwater Consultants Pty Ltd would like to extend their appreciation to staff of DITR, BMR, CEANET and RWC who provided data during the project and useful assistance.

2.0 METHODOLOGY

Methodology described here is related to actual map preparation. Background references are described more fully in the Explanatory Notes which accompany the Hydrogeological Map.

2.1 GENERAL

The initial step in the preparation of the map was to obtain from the Victorian Department of Industry, Technology and Research (DITR) a computer printout of the three files of the Victorian data base relevant to the parishes covering the Ballarat sheet. In addition, data were obtained from the Rural Water Commission for the Warrambine Creek catchment situated south of Ballarat. The Warrambine study was carried out between 1976 and 1984.

The three files from which DITR data were used include:

1. Bore Master File

2. Aquifer File

3. Chemical File

Volume 2 of the original report to BMR contains a copy of the data base files used in the preparation of the map. Appendix 1 of the present report contains an example from each of the three files referred to.

The Bore Master File

The Bore Master File contains information within each parish on bore numbers, owner, map number, coordinates, date, bore depth, elevation, bore use, drilling method, available logs and aquifer test. The latter information is expanded in the aquifer file.

The Aquifer File

The Aquifer file contains information by parish on bore number, sequential aquifer number as encountered, aquifer interval, lithology, bore construction, pump depth, static water level, pumping test details (pumping rate, test type, pumping time, drawndown) and other test data.

The Chemical File

The chemical file contains information by parish on bore number, analysis number, sample number, sample date, aquifer interval, static water level, TDS and a full chemical analysis (Cl, CO_3, HCO_3, SO_4, NO, Ca, Mg, Na, K, Fe, Si, Hardness, pH and electrical conductivity).

In total, the files contain information on over eight hundred bores, but not all bores are represented in all the three files. The highest number used was 730 from the chemical file, although many of these bores were not available in the aquifer file.

2.2 USE OF THE DATA FILES

Two methods were used to analyse the data during the project.

Initially a broad-brush approach was used to obtain as a first pass the trends of specific hydrogeological parameters on a parish by parish basis. This was followed by a more detailed analysis on a bore by bore basis.

The initial method was found to be fairly rapid and was completed in a few days. Using this approach, computer files were scanned by eye and averages and ranges of hydrogeological parameters were recorded for each parish in turn.

This was useful, since it provided a conceptual framework for detailed hydrogeological interpretations to follow. It also allowed anomalous values to be identified, and subsequently to be investigated.

The initial approach was followed by a more detailed assessment using data from each bore. In the initial stages of the discussions with BMR it was intended that the bore locations could be plotted by the computer and this information used to machine-generate water level and salinity contours.

However, because of time constraints this transfer of data could not be achieved, and therefore manual methods were used to contour the data. As a result the bore locations were not plotted although we believe that this would be useful in indicating the density and hence reliability of the data.

2.3 WATER LEVEL CONTOUR MAP

The standing water level is possibly the more regularly recorded parameter in the data base. However, if these records are not coupled to an elevation AHD, they cannot be used to produce a water level contour map. Elevation data in the bore master file are very seldom available and, when available, often relate to mineral exploration holes with no groundwater information.

Only 40 bores in the file had a recorded R.L. elevation, which was inadequate to produce a reliable contour map. An additional 125 bores were selected from the 1:100,000 location maps and their co-ordinates read from the maps. In most areas the bores were selected to coincide with topographic contours or in areas where the elevation could be easily extrapolated.

The final 165 bores selected are distributed fairly evenly across the map.

In areas where inconsistency of levels and distorted contours were evident, other bores in the surrounding areas were used for checking purposes. Approximately 35 additional bores were used in this way to supplement the initial number, bringing the total number of bores used to produce the water level contour map to around 200.

2.4 SALINITY CONTOUR MAP

A total of 730 bores were used to produce the salinity contour map. Because this number could not be adequately plotted at the 1: 250 000 scale, the 1:100 000 bore location maps were used instead. Contouring was carried out by hand only.

A salinity contour map was also produced by AGC by computer using the data in the "Knowledgeman"* file. This computerdrawn map, produced at A3 size for initial assessment, on a parish by parish basis had the same general trend and appearance as the manually contoured map.

The 1:100 000 salinity contour maps were reduced to 1:250 000 by conventional drafting using a simple pantograph, and the initial draft map was coloured by hand.

The chemical data file contains many analyses for the same bore over extended periods of time, or a number of analyses on samples obtained during drilling. The result is that often wide-ranging values of T.D.S. were found for the same bore, indicating at best, salinity variations with depth or, at worst, poor or unrepresentative sampling. In such cases, the most recent analysis was chosen.

2.5 FIELD PROGRAM

Following preparation of the draft map, a four day field program was carried out. The aims of the field program were to verify doubtful data on salinity and water levels, to measure salinities in selected rivers, lakes and swamps and to check the accuracy of bore locations, the status of some bores, and so on.

Whilst the field inspection helped to rectify some anomalies in water levels and salinities (particularly in the Creswick area), many bores which had been marked on the map were more than 20 years old and therefore either no longer existed or could not be found.

The greatest discrepancies existed in the Ballarat-Creswick area.

Water electrical conductivity was measured in some lakes and along the Hopkins River.

3.0 INTERGRAPH CAD SYSTEM

Initially, it was intended to use the intergraph terminal at the CANGRAPHICS, Fyshwick, Canberra. However, because of the limited amount of time available at that terminal, it was agreed that the graphic work could be carried out at the CEANET Intergraph Bureau in Sydney.

* Knowledgeman - microcomputer data base package.

The digitising proceeded in stages with the production of the different maps and of elements within those maps in separate files and levels.

The order of progress was as follows:

a) preparation of the simplified topographic base.

b) digitization of the water level contours map.

c) digitization of the salinity contours map.

d) digitization of the geological map, repeated in a simplified form.

e) digitization of the geological cross-sections with superimposed computer model results.

f) digitization of the rainfall contours map.

g) digitization of the rainfall and bore water level histogram.

h) preparation of a 1:1 scale base plan to allow the total map layout to be set-up.

i) digitization of the base plan, including the topographic, geological and hydrogeological legends, the title block, etc.

Following digitization, each separate file was plotted on an electrostatic plotter to check, correct and edit the file where necessary.

Finally, when the topographic and geological menus for the map compilation became available from the BMR, the topographic and geological maps were updated according to the conventions adopted in that menu.

It was evident during this stage that selected plotting of features was necessary to retain clarity of the final product.

Consequently, it was decided to eliminate from the map the topographic contours which represented the single, most confusing item, particularly in the high elevation areas of the Grampians.

The inability to use colour flooding and colour tone percentages prevented the use of the salinity-yield relationship colour code. Instead, a letter-number matrix pattern was used. In order to avoid the use of further lines to identify the salinity-yield regions, large size lettering was used to locate broad areas with uniform characteristics. Detail is lost in this manner, but should the map be published in the future in full colour, then this deficiency can be corrected.

Because of prohibitive costs to plot each copy using the plotter, it was decided instead to reproduce the map by photographic methods. The cost of this process is considerably less expensive than using the plotter and, in addition, the cost decreases with the number of copies produced.

The experience gained on the use of the Intergraph CAD system has highlighted advantages which are summarised as follows:

1. The system, with its ability to operate with different files and at different levels within those files, allows a very large degree of flexibility and freedom in the handling of the various elements making up the final map.

2. The system has a powerful editing capacity for correction of line and word errors and for moving inset maps and legends within the map. This provides considerable flexibility for changing the format of the map layout.

3. Individual files and levels can be plotted on fast plotters for checking and editing off the screen.

4. Plots can be produced of any combination of the files and levels.

5. No comment can be made at this stage of the ability of the system to produce direct contour maps from an input data base, since this facility was not used.

The major limitation of the system is that it is not able to use full colour and colour intensity variations to facilitate the separation and highlighting of the various parts of the map. To some extent, this limitation can be offset by use of different colour and thickness lines, but even then clarity requirements limit the amount of information that can be included in the map.

A secondary limitation of the system is that to take the fullest advantage of the equipment a trained operator is required. It is certainly possible for a hydrogeologist or draughtsperson to learn the basic operational steps to enter or edit data, but the bulk and most complex part of the data handling is better performed by an experienced operator. The operator used for the present work had over 2 years experience with INTERGRAPH, and was very competent in manipulating the overall system.

4.0 HYDROGEOLOGICAL LEGEND

Use of the proposed hydrogeological legend symbols did not present any difficulty, although they were used only in a limited way because of the general simplications introduced in the map.

It was found, however, that the legend does not include a symbol for hydraulic isopotential lines, required for the hydrodynamic cross-section nor a symbol for rainfall contours (isohyets).

In the Ballarat map, these two features are presented in the inset maps and sections. These have been added by using purple colour for the isopotential lines and blue for the rainfall contours.

It is recommended that symbols for these two features should be included in the legend.

5.0 HYDROGEOLOGICAL MENU

During the course of the project, the BMR had hoped to prepare a comprehensive hydrogeological menu for use with the Intergraph system. This menu was to be subdivided into three main sections:

a - topographic file

b - geological file

c - hydrogeological file

However, the preparation of a complete menu would have required an amount of time which was not available for the pilot program study. As a result, it was agreed to produce a less ambitious menu which would include only the symbols required for the four maps being produced under this study. However, at the time of plotting the final version of the Ballarat map, only the topographic and geological menus were available. As a result the remaining symbols for the map were digitized directly on the Intergraph system during map preparation.

5.1 COMMENTS ON THE USE OF THE MENU

Topographic File

This file arrived too late to change the established file, however this was not critical since the map only required road, water courses and lake symbols which were standard symbols already available on the system.

Geological File

Not all of the geological patterns supplied could be used because for most symbols (basalt, granite, laterite, schist and undifferentiated metamorphic) the density of the pattern was too great to be used as background on the map. Used in their existing form, these patterns would have been unsuitable for the map.

Consequently, it was decided to decrease the density of the patterns and some problems arose:

1. The origin, increments and directions of those patterns were difficult to find and it appears that the origin was not always the same.

2. Most patterns are made of an array of six symbols within each cell; these cells are then repeated in the x and y directions

to fill in the required areas. It would have been preferable to have only one symbol in each cell so that a reasonable space between symbols could be achieved without overcrowding. AGC created their own cells for this purpose.

3. Some patterns, in particular the basalt pattern, is made of several lines (double lines on the "V" areas) which requires double processing and plotting time. A simple line, such as on the granite and schist symbols, would have been preferable.

4. Similarly, dots used for the sand pattern are made of little squares which also require longer processing time. AGC have been advised that these dots could have been made as "active points", i.e. single dots, thus saving processing and plotting time.

5. AGC digitizing was too advanced at the time when the menus arrived and hence various items had been assigned levels in the files which did not coincide with those of the BMR menus.

6. Patterning was done through the use of a GPPU (graphic polygon processing utility). Patterning at the density provided by the BMR required exceedingly long times. Even at the reduced density, the basalt plains in the southern half of the map required 4 hours and 7 minutes at 90% machine processing availability. It was found advisable to break up large geological areas into smaller areas to speed up this process and, possibly, use night shift or delay queuing to save on machine costs.

6.0 COMMENTS ON THE VICTORIAN DATA BASE

The pilot program study has given the opportunity to peruse one of the States' comprehensive data bases in a manner that has highlighted its positive and negative aspects from a user viewpoint.

The following pages contain comments that are given with a constructive intention and that will hopefully lead to an improvement of the system, which will be beneficial to all users of the data base.

6.1 GENERAL

The Victoria groundwater data base is overall well set up, easy to understand, easy to use and contains, generally, adequate information for most purposes. However, it does contain numerous inconsistencies which appear to result from insufficient control on the data entered, on checking and editing rather than on the structure of the system itself.

6.2 THE GROUNDWATER DATA FILES

Following is a listing of observed inconsistencies which should be rectified.

Bore Master File

a) It would be helpful when scanning through the file to have the Parish number listed in the first column of the bore master and aquifer files, as in the chemical file.

b) Bore coordinates are missing on a large proportion of the bores. Whilst it is understood that the coordinates might be missing for bores drilled more than 100 years ago and for mineral exploration purposes, it is less understandable that coordinates are missing for bores of the 10000 series, drilled therefore since 1969 and subject to the regulations of the Groundwater Act.

   A great proportion of these bores are listed as owned by the DME.

   Often the groundwater information cannot be used because a bore is not, or cannot, be plotted on the location maps.

c) Bore depth is not always recorded and some errors have been observed when this parameter is compared with the aquifer file. On occasions it was found that the bore depth is shallower than the aquifer depth listed.

d) The bore-use column does not list the DITR official and equipped observation wells that are part of the regular monitoring network. However, it is understood that this matter has already been rectified, at least for other parts of Victoria.

e) The Reduced Level of the Natural Surface (RLNS) column contains only very few values, only 41 for Ballarat sheet. It is understood that it is obviously a value which is difficult to obtain accurately without the site being surveyed and levelled. However, in many cases, reasonably accurate topographic maps are available to enable a trained person to extract the R.L. of the bore at the time of plotting that bore on the locality map. The file then should show that this value has been estimated from a map, or surveyed, as is done in the coordinates method column.

Aquifer File

The main comments related to this file are those concerning the pumping test columns, where the pumping time and drawdown columns are not always consistently filled in. This should be done with bores of the 1000 series.

A minor comment relates to the unnecessary use of three decimal digits for the pumping rate which is given in L/sec, where one digit would suffice.

Chemical File

The chemical file appears to contain the largest volume of data per bore, as several chemical analyses often appear for one bore.

The analyses often carry different dates indicating repetition over the years, but occasionally analyses carry the same date with different results. It is not clear whether this difference is due to poorly collected samples, errors in transmission of samples, or are genuine samples collected during a pumping test where salinity changes could have occurred.

The single greatest deficiency of this file is that the column of the sodium analysis often contains no results for several bores in the same parish. It is not clear why this important chemical determination is missing from otherwise complete chemical analyses. The lack of this parameter prevents the use of the analysis when it is required to plot it on a Schoeller or Piper diagram, or prevents the calculation of the ionic balance.

One small item needs correction, i.e., the unknown meaning of the % sign under the pH column.

The above comments relate to the individual files. However, when a study of the nature of the Ballarat 1:250 000 is carried out, the major deficiency of the the system is the high degree of inconsistency of entry of data in the files. As a result:

- bores entered in one file are not found in others.
- parishes that might have one or two bores only in the bore master file do not appear in the aquifer file or in the chemical file or in both.
- chemical analyses of bores drilled recently are not available, although they are entered in the other two files.
- chemical analyses are available for bores not entered in the bore master file or not plotted on the locality maps.

Whilst this lack of correspondence between the files is less important where parishes contain many bores, so that at least some consistent data are available, it can, in other parishes, eliminate the available data.

6.3 OTHER FILES

Attempts have been made to check information on the original reports from which the data originated. This is a lengthy and tiresome process. Some records are kept on one floor of the building, others on another and, original pumping tests data are kept at the drilling branch depot.

Location of those reports requires a system of report numbers, drill numbers, etc., which appear counterproductive and cumbersome. Maybe the adoption of a unique bore number, like those used in the South Australian Department of Mines and Energy could be beneficial. This number could incorporate the parish number at the start, so that the relation to the State system is obvious.

Obtaining original data on pumping tests and on the location of these tests files or reports is a difficult task. It was suprising that such important information, the basic tool of hydrogeological studies, is not properly collected, filed and cross-referenced.

At present, the only way of locating reports on pumping tests, appears to be to search one by one through the library microfiche system, a task capable of discouraging even the most determined person.

From the conversations with geologists in the DITR, it appears that at present locating those records and reports depends on the memory of the individuals and on their own sense of organisation.

It is strongly recommended that the DITR initiates a pumping test data base, with reference to the position of the geologists' reports on those tests in the library and some indication in the aquifer and pumping test file of the existence of such reports.

6.4 CONCLUSIONS AND RECOMMENDATIONS

The Victoria groundwater data base is overall well set up and accessible. However, a more stringent check on the quality of the data prior to entry in the files and a careful check of the data after they are entered, would greatly increase the value of the data base.

The recommendations included in this Appendix should be implemented, and, in particular, those related to the consistent entry of data in the three main files and those related to the implementation of a pumping test data base.

7.0 COSTING

Table 7-1 below summarises the actual and the estimated costs set out in the AGC report (1985).

TABLE 7-1

Item	Estimated $ (Based on full Colour/Field work but no printing*)	Actual $
Supervising Hydrogeologist	7,800	17,600
Hydrogeologist	20,480	18,500
Sub-Professional	2,500	3,700
Computer Engineer	-	2,900
Drafting: (report, report covers, collation)	--**	1,100
INTERGRAPH/COMPUTER COSTS	6,300	13,900
Field Expenses	4,000	6,238

* AGC 1985 National Groundwater Data Base Inventory, Volume 1 and 2 (Ref 1).

** Allowance for this made in printing costs in AGC Report (1985).

Overall costs shown are higher than estimated in the report; however, much of this cost can be attributed to a number of factors.

1. Because the map was the first one produced using the methodology outlined above, considerably more time was spent by the Project Manager on the work.

2. This included developing the overall concepts and methodology, time spent in visiting Canberra to liaise with BMR staff and input into the modelling work that was undertaken. It is likely however, that this would decrease with the number of maps produced, that is, with experience gained with the production of each map.

   Nevertheless it is considered that the time required for the Supervising Hydrogeologist is important and should be increased from that originally estimated in the Data Base Inventory report.

2. Actual time spent by the Hydrogeologist for the project was below that estimated; however this was offset by an experienced Senior staff member of AGC carrying out the work. It is likely, for example, that someone with less experience would have required a longer time period. Also, time spent in the field was only 4 days and had the field time been extended to 20 days, there would have been additional hours to add to the total cost.

   Costs for a computer engineer were not included in the initial cost estimates; however this was required to carry out some cross-sectional finite element modelling to define in a general way the groundwater flow directions in the area.

   The Drafting item shown includes time to modify parts of the plotted map, and in preparing, collating and printing the notes and covers.

   Intergraph and other computer costs have been integrated here. The additional computer charges were as a result of the cross-section modelling undertaken. This required considerable time for setting up and preparing the finite element grid. Automatic mesh generation was not used in this instance. In addition, it also includes time required to enter the selected data from the computer printouts onto the KNOWLEDGEMAN data base system.

   Costs related to field expenses were higher than those estimated; however, expenses here were those incurred as a result of extensive air travel to and from Canberra and to the field site, by both the Supervising Hydrogeologist and Hydrogeologist and also other transport costs. In addition it includes accommodation costs for the Melbourne based Hydrogeologist familiar with the region, to reside in Sydney during the digitizing and plotting phases of the work. This was necessary since CEANET have an INTERGRAPH facility in their Sydney offices, but not in the Melbourne office.

8.0 DISCUSSION AND COMMENTS

8.1 WATER RESOURCES COMMISSION COMMENTS

Whilst we were preparing this report some detailed comments were received from the Water Resources Commission regarding the maps which were forwarded to us by the BMR. These comments were quite detailed, and it is not proposed to document in this report answers to all aspects referred to; only the major issues will be addressed. Overall the comments reveal perhaps a misunderstanding of the scope, intent and background of the final product and also the perceived market of the maps. However, we appreciate WRC pointing out errors which occurred during compilation and plotting of the map.

Each of the broad aspects identified by the Commission are discussed below in the hope that it will clarify some of the issues to other readers.

1. Definition of Target Users

   The WRC have indicated that they perceive that the hydrogeological maps should be used largely by non-specialists and not for specialists such as geologists and hydrogeologists.

   We have aimed the maps more for the latter audience, and for those in a management role. It was heartening to note that the Rural Water Commission commented that they have already used the map for that purpose. Discussion with the WRC indicates they consider that farmers and landholders are an important target for those ultimately using the maps.

2. Drafting Quality

   The WRC have indicated the generally poor drafting quality of the map when (presumably) compared with cartographically produced maps. We agree with this, however it should be borne in mind that the present map is a draft only - the intention was that the final printed map be produced by cartographic means. The intent of using the INTERGRAPH was to test this CAD system and to demonstrate hopefully its greater flexibility in manipulating the graphics, particularly for editing and its ability to produce perhaps several maps together where data were inadequate to present at the 1:250 000 scale.

   As the WRC have indicated if computer-produced maps are adopted "the quality could be regarded as an acceptable side effect" and we support this statement.

3. Cost

The WRC have indicated that a cost of $50,000 is very high for production of a map. However discussions with them have indicated that not all costs have been taken into account in their assessment. No allowance has been made for overheads, and their estimates are based on the production of the FORBES map which differs in many ways in its details and content from the Ballarat sheet. The additional costs also included preparation of explanatory notes plus a report on Methodology and Approach which the WRC have not included for example in their FORBES map.

4. Errors, Details, Editing

The WRC have noted several errors in the map produced which we acknowledge. Other aspects which have been raised we disagree with. However, errors which have occurred are largely the result of the time frame available to produce the map. Checking is important, and this could have been achieved given more time to complete the map.

Our response to other relevant points raised is summarised below:

Map Preparation

The map data and contours prepared by hand using 1:100 000 map sheets and individual bore data. The information was not averaged over each parish; this was done only initially during a first pass. The data and contours were then digitized onto the INTERGRAPH system.

Salinity/Yield Boundaries and Colours

Whilst it was intended to show these on the completed map, two factors resulted in our adopting a different approach.

Firstly, it is not possible to use the INTERGRAPH system to produce colour flooding and we have already pointed this out as a disadvantage of the system. However, the colour matrix was intended to allow colour flooding in the final production since it was only intended that the matrix be used in the draft. However, it was found as the data were analysed that although it was possible to draw salinity contours, information on yields was lacking and therefore boundaries could not be drawn realistically. Thus matrix values were placed only in those locations where discharge data were available. If forced to, boundaries could have been drawn, but these would have been perhaps misleading.

Salinity in Profile

Most bores in the area are generally less than 50 metres deep, and hence, there is insufficient data to draw either salinity contours or ranges of values on the profiles drawn on the map.

Modelling of Cross-sections

Whilst the explanatory notes show different scales on vertical/horizontal axis, actual scale distances were used in the model.

Cultural Details

Several versions of the map were produced with detailed topographic and cultural details; however they were found to clutter the map and in one version to make it virtually indecipherable. As a result only the major features were included.

Geological Symbols

An attempt was made to simplify the symbols in consultation with the BMR Hydrogeological Group. The intention was to include all rock types of a similar character under one symbol.

Relationship of Rainfall/Groundwater Levels

It is agreed that the use of MW2 and MW6 are not particularly suitable to establish a relationship, however, these are the only bores available with basic series data. Other bores, although thought to have the required data (re. RWC bores drilled for the AWRC project and others) were found to be unsuitable.

Salinity Contours

We believe these are a valid interpretation and can be justified as being representative at the mapping scale. Independent checking in the field of additional bore salinities confirmed the contours shown. Unfortunately, few data were available on changes in salinity with depth, and no definite relationship could be established although some possible trends were evident.

Reliability of Data

This was discussed in the explanatory notes. AGC did not come up with a satisfactory way of depicting this on a map. This aspect should be addressed by the Hydrogeological Mapping Group.

Transmissivity Determined from Single Drawdown

It is agreed this is a crude estimate but it was the only choice. In most cases where the yields are small, well losses components are also small and therefore they will have little effect on the drawdown value. The method provided suitable approximations for the application required. (i.e. modelling flow directions in an approximate way in the cross-section on the map).

Plotting of Bore Data

AGC believe this would be useful, and in fact was intended. However, transfer of the bore data coordinates onto the INTERGRAPH system could not be achieved in the time available.

8.2 OTHER ASPECTS

There is no doubt that the INTERGRAPH system is by far the most flexible and advanced system for undertaking this kind of work. However, the rapid development in CAD facilities on micro-computer should not be dismissed. This is a rapidly expanding field, and whilst it will be some time before the capabilities of the INTERGRAPH or similar systems are emulated on these smaller systems, many of its features are already available at relatively small cost. Continuing improvements and further developments will no doubt occur over the next 5 years and these should be kept in mind as an alternative to the larger more costly systems.

Should such alternative be considered however, compatibility will be essential so that interchange of data between the States is assured. It is suggested that AWRC Groundwater Committee be used as a vehicle to develop guidelines for such interchange of graphical data.

The possibility of a hybrid approach could also be considered. Such a system is already operational, and AGC have obtained details of systems, whereby INTERGRAPH files can be manipulated using standard IBM PC and compatibles as terminals.

Obviously, because of the rapidly expanding nature of the computing developments, an open minded approach is required in this area. In the interim, flexibility and transportability of data bases and graphical data created are particularly important.

It is clear from the efforts to enter data manually from the Victoria Data Base, that a better means should be available for transferring data from data bases. Because of the increasing use of IBM PC and compatibles, it is recommended that some standard method be implemented between the States to transfer information in this format.

9.0 CONCLUSIONS

1. The INTERGRAPH system is a suitable means of producing draft quality hydrogeological maps. although the system has some limitations.

2. Limitations of the system are:

   a) The need to use an experienced operator

b) Colour flooding cannot be used on the plotted map.

3. The Hydrogeological legends were found to be suitable except for the need to include symbols for hydraulic isopotentials or rainfall contours.

4. More work is required on the development of a suitable hydrogeological menu, particularly with regard to the ornaments that can be used.

5. Whilst costing will vary depending on the area and the data available, some general conclusions can be drawn.

a) Overall costs were higher than estimated; however these additional costs can be attributed to a number of factors. Original cost estimates (AGC 1985) for map preparation are considered reasonable, once experience is gained in compilation and printing.

b) If some form of modelling is intended to show flow directions in cross-section for example, allowance needs to be made for computer time plus relevant staff.

10. RECOMMENDATIONS

It is recommended that:

1. Use be made of an experienced operator if the INTERGRAPH system is used to prepare maps;

2. Symbols for both hydraulic isopotential lines and rainfall contours be included in the hydrogeological legend;

3. Improvements be made to the Hydrogeological Menu, particularly with regard to patterning;

4. The AWRC Groundwater Committee prepare and update guidelines on the exchange of data base information and graphical data files.

5. With respect to the DITR data base it is recommended that:

   - before entering data in the files, these should be carefully checked by a geologist for consistency;

   - each bore should have entries in all files. If data for a particular file are not available, then the bore number should still be entered and a comment included as to the lack of information. In this way, the user is informed that data are not available and is not left with the doubt that, instead, data might not have been entered.

11.0 REFERENCE

1. Australia Groundwater Consultants Pty. Ltd, 1985 - National Groundwater Data Base Inventory. Five year forward

program. Vol. 1 & 2.
Bureau of Mineral Resources, Dept. of Resources and Energy.

BORE LOCATION FILE

****

G E O L O G I C A L   S U R V E Y   O F   V I C T O R I A

BOREHOLE DATA SYSTEM

BOREHOLES IN SELECTED PARISHES

GENERATION 43 (JAN 85)

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PARISH OF ADDINGTON (NUMBER 2) IMPERIAL SHEET 826/7

BORE NUMBER	OWNER	AMG MAP	AMG ZN.	AMG EAST	AMG NORTH	CO-ORD METHOD	COMPLETED DATE	BORE DEPTH	RLNS	BORE-USE	DRILL METHOD	LOGS GE	DR	WR	A Q	TESTS WPRMPCF	G
1 CONSEC 24/73/003	DMF	7623	S54	734089	5861567	DIGIT	9/03/1973	56.38	453.85	GROUNDWATER	CABLE						5
8001	PRIVATE						8/10/1954			USE-UNKNOWN							15
8002	PRIVATE	7623	S54	734979	5863493	DIGIT	24/06/1960			GROUNDWATER							6
8003	PRIVATE	7623	S54	736459	5863184	DIGIT	24/16/1964	25.38		GROUNDWATER							6
8004	PRIVATE	7623	S54	734706	5863138	DIGIT	24/06/1960			USE-UNKNOWN							15
8005	PRIVATE	7623	S54	737563	5859170	DIGIT	1968			USE-UNKNOWN							15
8006	PRIVATE	7623	S54	734157	5861169	DIGIT	3/10/1955	40.54		GROUNDWATER		N	Y				21
10002 PERM 1988	PRIVATE	7623	S54	734334	5864277	DIGIT	10/07/1973	13.71		WATER-S&D							15
10003 PERM 966	PRIVATE						1/02/1972			USE-UNKNOWN							15
10004 PERM 9578	PRIVATE	7623	S54	734975	5864142	DIGIT	5/01/1978	56.00		WATER-IRRIG	HAMMER						5

PARISH OF AMHERST (NUMBER 12) IMPERIAL SHEET 816/7

BORE NUMBER	OWNER	AMG MAP	AMG ZN	AMG EAST	AMG NORTH	CO-ORD METHOD	COMPLETED DATE	BORE DEPTH	RLNS	BORE-USE	DRILL METHOD	LOGS GE	DR	WR	A Q	TESTS WPRNPCF	G
1	DME						1884	43.12		MINERALS							
2	DME						1885	43.19		MINERALS							
3	DME						1885	38.92		MINERALS							
4	DME						1885	20.72		MINERALS							
5	DME						1885	23.56		MINERALS							
6	DME						1885	32.88		MINERALS							
7	DME	7623	S54	738599	5883515	DIGIT	1940	17.37		MINERALS							
8	DME	7623	S54	738599	5883515	DIGIT	1940	18.89		MINERALS							
9	DME	7623	S54	738599	5883528	DIGIT	1940	19.20		MINERALS							
10	DME	7623	S54	738599	5883515	DIGIT	1940	18.89		MINERALS							
11	DME	7623	S54	738598	5883502	DIGIT	1940	18.28		MINERALS							
12	DME	7623	S54	738598	5883502	DIGIT	1940	20.11		MINERALS							
13	DME	7623	S54	738585	5883503	DIGIT	1940	18.28		MINERALS							
14	DME	7623	S54	738598	5893502	DIGIT	1940	19.20		MINERALS							
15	DME	7623	S54	738598	5883502	DIGIT	1940	17.67		MINERALS							
10001 PERM 25543	PRIVATE	7623	S54			SCALED	1/09/1984	49.00		WATER-S&D	HAMMER	N	Y				39

PARISH OF AMPHITHEATRE (NUMBER 13) IMPERIAL SHEET 906/6

BORE NUMBER	OWNER	AMG MAP	AMG ZN	AMG EAST	AMG NORTH	CO-ORD METHOD	COMPLETED DATE	BORE DEPTH	RLNS	BORE-USE	DRILL METHOD	LOGS GE	DR	WR	A Q	TESTS WPRNPCF	G
1	DMF	7523	S54	712147	5875430	DIGIT	1/09/1958	9999.99		GROUNDWATER	CABLE	N	N				37
8001	PRIVATE	7523	S54	710054	5871901	DIGIT	15/11/1954	12.19		GROUNDWATER		N	Y				21
8002	PRIVATE	7523	S54	711875	5873996	DIGIT	24/11/1954	18.59		GROUNDWATER		N	Y				21
8003	PRIVATE	7523	S54	710091	5378713	DIGIT	23/07/1957	23.77		GROUNDWATER		N	Y				21

PARISH OF ARARAT (NUMBER 20) IMPERIAL SHEET 905/6

BORE NUMBER	OWNER	AMG MAP	AMG ZN	AMG EAST	AMG NORTH	CO-ORD METHOD	COMPLETED DATE	BORE DEPTH	RLNS	BORE-USE	DRILL METHOD	LOGS GE	DR	WR	A Q	TESTS WPRNPCF	G
1	DME	7423	S54	675593	5859543	DIGIT	1913	49.98	299.61	MINERALS							
2	DME	7423	S54	676062	5869363	DIGIT	1913	46.32	300.53	MINERALS							
3	DME	7423	S54	676316	5869198	DIGIT	1913	36.57	302.66	MINERALS							

AQUIFER AND PUMPING TESTS DATA FILE

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GEOLOGICAL SURVEY OF VICTORIA

GROUND WATER DATA SYSTEM

AQUIFER AND PUMP TEST DESCRIPTIONS

GENERATION 30 (DEC 85)

****

PARISH OF ADDINGTON (2) Creswick (NUMBER 2)

BORE	AQ #	AQ-FR	AQ-TO	LITHOLOGY	CASING DPTH	DIA	TYPE	SCREENED INTERVAL FR	TO	TYPE	DIA	APER	PUMP DEPTH	SWL	PUMP RATE	TEST TYPE	PUMP TIME	DRAW DOWN	TEST-DATE	G
1	1	39.9	42.0	BASALT										3.0	0.631				28-02-1973	Q
1	2	45.1	48.4	BASALT										2.7	0.757				28-02-1973	O
1	3	49.3	51.8	CLAY										2.8	0.631				29-02-1973	0
10002	1	4.2	12.8	BASALT										0.6	0.189				10-07-1973	0
10004	1	18.0	56.0	BASALT										1.0	50.000	AIR			5-01-1978	5

PARISH OF AMHERST (12) Creswick (NUMBER 12)

BORE	AQ #	AQ-FR	AQ-TO	LITHOLOGY	CASING DPTH	DIA	TYPE	SCREENED INTERVAL FR	TO	TYPE	DIA	APER	PUMP DEPTH	SWL	PUMP RATE	TEST TYPE	PUMP TIME	DRAW DOWN	TEST-DATE	G
10001	1	18.9	44.0	SLATE	47.0	125	PVC	18.0	44.0	PVC			49.0	15.0	0.253	AIR			1-09-1984	28

PARISH OF ARARAT (NUMBER 20)

BORE	AQ #	AQ-FR	AQ-TO	LITHOLOGY	CASING DPTH	DIA	TYPE	SCREENED INTERVAL FR	TO	TYPE	DIA	APER	PUMP DEPTH	SWL	PUMP RATE	TEST TYPE	PUMP TIME	DRAW DOWN	TEST-DATE	G
8001	1	21.3	27.4	GRAVEL										13.7	0.505	BAIL			17-03-1963	6
10001				BASALT																
10002	1	13.4	13.7	BASALT										6.0	0.505				19-05-1975	0
10003	1	4.8	5.1	CLAY										9.1	0.311				12-05-1975	0
10003	2	23.9	30.4	BASALT										9.1	1.248				12-05-1975	0
10004				?																
10005	1	22.8	23.1	GRAVEL										22.8	0.063				18-10-1976	0

PARISH OF ARGYLE (NUMBER 26)

BORE	AQ #	AQ-FR	AQ-TO	LITHOLOGY	CASING DPTH	DIA	TYPE	SCREENED INTERVAL FR	TO	TYPE	DIA	APER	PUMP DEPTH	SWL	PUMP RATE	TEST TYPE	PUMP TIME	DRAW DOWN	TEST-DATE	G
10001	1	4.5	6.0	CLAY	10.5	140	PVC	4.5	6.0	SLOT PVC	125	3.00	16.5	1.8	0.100	BAIL	0:15		18-01-1983	20

PARISH OF ABBOT (Creswick) (NUMBER 27)

BORE	AQ #	AQ-FR	AQ-TO	LITHOLOGY	CASING DPTH	DIA	TYPE	SCREENED INTERVAL FR	TO	TYPE	DIA	APER	PUMP DEPTH	SWL	PUMP RATE	TEST TYPE	PUMP TIME	DRAW DOWN	TEST-DATE	G
10003	1	20.4	24.9	BASALT										10.3	0.441				23-01-1973	0
10004	1	26.5	61.5	BASALT										6.4	3.788				24-11-1972	0
10005	1	42.0	48.4	BASALT										7.0	7.577				18-06-1973	0
10006	1	55.4	74.9	BASALT										21.9	6.314				0-07-1973	0
10007	1	19.3	23.7	BASALT										2.4	0.378				0-00-1973	0
10007	2	39.6	41.4	BASALT										2.4	1.515				0-00-1973	0
10008	1	38.0	63.7	BASALT										7.0	14.040	AIR			0-12-1972	6

CHEMICAL DATA FILE

PARISH NO	BORE NO	LAB-NO	S A M	SAMPLE DATE	AQUIF FROM M	AQUIF TO M	SWL	ICS	CL	CO3	HCO3	SO4	NO3	CA	MG	NA	K	FE TOT	FE SOL	SI	HARD NESS	PH %	ELEC COND MS/CM
								(- - -	- - -	- - -	- - -	- - -	- - -	- - -	- - -	- - -	- -MILLIGRAMS/LITRE	- - -	- - -	- - -	- - -)		

PARISH OF ACHERON MILITARY SHEET NO 820/7

1	10001			24-05-74				159	17	0	54	7	27	9	8	19	**	11.0	0.1	18		7.0	
1	10001			24-05-74				139	14	0	58	3	18	8	7	15	**		0.5	16		6.7	
1	10001	74-1728	10	24-05-74	3.0			140S	14	0	58	3	18	8	7	13	2		0.5	16	47	6.7	179
1	10003	77-1577	12	9-05-77	2.4	3.6	2.4	172S	46	0	47	10	0	5	7	34	1	31.0	0.3	22	42	6.9	265

PARISH OF ADDINGTON CRESWICK MILITARY SHEET NO 826/7

2	1	73-1619	10	29-02-73	49.3	51.8	2.9	363S	47	0	190	5	0	20	21	36	2	21.0	0.1	42	135	7.5	440
2	1	73-1930	13	29.02.73	39.9	42.0	3.0	406S	63	0	220	0	0	18	26	54	4	80.0	0.9	20	153	7.3	551
2	1	73-1931	13	29-02-73	45.1	48.4	2.7	412S	62	0	228	0	0	17	27	54	4	84.0	0.1	20	152	7.7	551
2	1	73-1636	12	7-03-73	39.9	51.8	2.9	349S	50	0	178	6	0	19	21	36	2	9.0		37	136	7.5	438
2	1	73-1637	12	8-03-73	39.9	51.8	2.9	383S	56	0	189	4	8	20	24	40	2	1.1	0.9	39	151	7.7	502
2	1	73-1638	12	8-03-73	39.9	51.8	2.9	382S	58	0	191	4	6	21	24	40	2	1.0		36	151	7.7	502
2	1			29-02-73	45.1	48.4		419	62	0	228	0	0	17	27	58	**	84.0	0.1	20		7.7	
2	1			29-02-73	39.9	42.0		406	63	0	220	0	0	18	26	58	**	80.0	0.9	20		7.4	
2	1			29-02-73	49.3	51.8		363	47	0	190	5	0	20	21	38	**	21.0	0.1	42		7.6	
2	8002	60-0675	13	24-06-60				550E	264	0	20	10	0	8	27	0				0	132	5.4	
2	8003	60-0676	12	24-06-60	1.8	25.6		170E	18	0	53	6	32	10	10	0				0	63	5.5	
2	10002	73-2908	10	10-07-73	4.2	12.8	0.6	463C	89	0	56	0	189	30	34	0		2.0		0	215	7.1	754
2	10003	72-2566	10	20-06-72				301C	42	0	194	0	0	19	17	0				0	117	8.1	467
2	10004	78-1420	10	5-01-78	18.0	56.0	1.0	553S	128	0	225	5	0	17	31	91	3	3.0		53	170	8.0	750

PARISH OF ADZAR MILITARY SHEET NO 911/E

4	1	67-1755	13	28-11-67	40.2	42.6	20.7	21EOU	1140	4	57	109	0	86	21	0			0.1	11	303	8.1	3780
4	1	68-0042	12	1-12-67	66.4	68.5	13.4	2090	1013	0	276	88	0	85	96	0			0.2	32	607	7.6	3600
4	1	67-1824	12	7-12-67	35.9	40.2	13.1	2090	1009	10	264	78	0	71	54	0		0.2	0.2	32	400	8.1	3600
4	10001	73-2572	11	12-05-73	18.8	23.0	9.5	6135C	2680	0	595	176	0	129	398	0		1.1	0.1	0	1959	7.8	8500
4	10002	76-2587	11	6-01-76	29.2	30.0	15.1	6397S	3490	37	433	249	0	110	506	1527	7	0.5	0.1	38	2357	8.1	10550

PARISH OF AIRE MILITARY SHEET NO 933/6

5	10	68-1319	12	13-05-68	25.9	28.9	6.0	340U	82	0	175	2	0	21	11	0			0.4	36	98	7.4	550
5	10001	74-1889	10	6-05-74				606S	147	102	55	67	0	20	10	180	6		0.4	19	93	8.1	1020

PARISH OF ALBERTON EAST MILITARY SHEET NO 877/7

* 7	1			16-10-51		182.8		380	140	0	100	0	0	0	0					0			
* 7	2			20-03-58	148.1	153.0		331	165	0	45	1	0	11	10	0		2.1	1.7	10		6.0	
* 7	2			13-06-58	148.1	153.0		330	163	0	44	0	0	0	0	0				0		6.6	
7	2	58-0111	13	4-02-58	152.4	153.9		590U	273	0	132	0	0	0	0	0				0		7.3	
7	2	58-0288	10	15-03-58	148.1	153.0		340U	160	0	37	0	0	0	0	0				0		5.9	
7	2	58-0308	10	20-03-58	149.1	153.0		330U	163	0	44	0	0	0	0	0				0		6.6	
7	2	58-0309	10	20-03-58	148.1	153.0		350U	155	0	45	0	0	0	0	0				0		6.6	
7	2	58-0784	10	13-06-58	148.1	153.0		320U	163	0	53	0	0	0	0	0				0		6.0	

PART 2. EXPLANATORY NOTES ON THE BALLARAT 1: 250 000 SCALE HYDROGEOLOGICAL MAP

INTRODUCTION

The Ballarat 1:250 000 hydrogeological map was prepared by Australian Groundwater Consultants Pty. Ltd. (AGC) as part of a Pilot Program Study being carried out by the Bureau of Mineral Resources (BMR), Canberra. The pilot program was initiated by the BMR on the basis of recommendations contained within a report prepared for the Department of Resources and Energy on the National Groundwater Data Base Inventory 5-Year Program (AGC 1985).

The work presented was undertaken over a two and a half month period from mid February to April, 1986.

Further details of the background, approach and methodology used to prepare the Ballarat sheet including the raw data used, are given by a report prepared for the BMR by Australian Groundwater Consultants Pty. Ltd. (AGC 1986).

The map presented has been prepared on the INTERGRAPH system as a final digitized draft map awaiting final printing. As a result, some simplification of the topographic and geological base maps was required to avoid overcrowding of the various mapping elements.

Symbols have been used to signify the Yield/Salinity colour matrix in accordance with that system presently being considered by the hydrogeological Mapping Sub-Committee (AWRC, 1985).

2.0 THE AREA

The Ballarat 1:250 000 map covers an area of approximately 14 700 km^2, bounded by longitude 142°30′ and 144°0′ and latitude 37° and 38°.

Within the sheet, many major urban centres exist including Ballarat, Ararat, Stawell, Beaufort, Avoca and Maryborough. The area is characterised by a varied landscape dominated by the Great Dividing Range which crosses the region from east to west and separates a generally flat basalt plain to the south and the hilly and mountainous region to the north. To the west, the sheet includes the southeastern portion of the Grampians (Clk on map), which rise sharply from the basalt plains to an elevation of 1167m A.H.D. at Mt. William.

The basalt plains are punctuated by low rounded hills, generally devoid of vegetation, which are the remnants of the eruption centres from which issued the lava covering the plains. The more symmetrically shaped cones were generally produced by later scoria and ash type eruptions.

Most of the original vegetation on the basalt plains has been cleared for the agricultural pursuits of the area. The plains are marked by numerous swamps and lakes which occupy depressions in the topography caused by the numerous lava flows. Several of these lakes are permanent (Lake Bolac, Lake Burrumbeet, Lake Learmonth), whereas others do not persist over dry climatic periods. There are many other depressions, but these consist mainly of clay pans with salt crusting at the surface.

The Great Dividing Range within the Ballarat Sheet forms the upper catchment areas of major rivers such as the Wimmera and Avoca rivers and part of the Loddon River (for example, McCallum Creek), which flows north towards the Murray Basin. Other rivers such as the Hopkins and Woady Yallock rivers flow towards the south away from the Range.

The hills and the mountain ranges of folded Ordovician rocks and intrusives are generally thickly wooded with original flora or with pine plantations.

The major economical activities in the area are grazing, agriculture, forestry, light industries and tourism. Gold mining, which originated in this area last century and was a large source of revenue for the country, is still carried out, although at a far more limited scale.

3.0 CLIMATE

The area is characterized by mostly dry summers and wet, cool winters. The rainfall pattern is strongly influenced by the surface topography, ranging from 559 mm/year at Derrinallum at the southern margin of the sheet to 747 mm/year at Ballarat (Ballarat Gardens) near the Great Dividing Range. Over the Divide, rainfall levels decrease rapidly towards the north. For example Avoca and Maryborough are located in a rain shadow and some of the lowest rainfalls in the area have been recorded on these centres.

TABLE 1
SUMMARY OF YEARLY MEAN RAINFALL

Ararat Prison	625 mm/year
Avoca	543
Ballarat Gardens	747
Beaufort	683
Clunes	587
Dereel	742
Derrinallum	559
Maryborough	528
Skipton	627
Smythesdale	739

Eon	Era	Period	Epoch	Age*
	CAINOZOIC	Quaternary	Recent	0.015
			Pleistocene	1.8
		Tertiary	Pliocene	5.0
			Miocene	24.0
			Oligocene	37.0
			Eocene	53.5
			Paleocene	65.0
	MESOZOIC	Cretaceous		135
		Jurassic		195
		Triassic		235
	PALAEOZOIC	Permian		290
		Carboniferous		345
		Devonian		410
		Silurian		435
		Ordovician		490
		Cambrian		570
	PROTEROZOIC	Late		1400
		Middle		1800
		Early		2300
	ARCHAEAN			>3800 (greatest age so far measured)

*Age of base of period or epoch in millions of years

Table 2. Geological Time Scale

A plot of monthly rainfall data for the Ararat Prison station (at Ararat) is presented on the map. This station was chosen as it was the only one which had groundwater recorder data available in the vicinity. The relationship between rainfall and groundwater levels is covered in Section 5.2.1.

4.0 GEOLOGY AND STRUCTURE

The area is situated astride the Great Dividing Range which forms the southern margin of the Murray Basin to the north and the northern continental margin of the Otway Basin to the south (Geological Society of Australia, 1976). Lower Palaeozoic (Table 2) metasediments, metamorphics and intrusives form the high relief hills of the Great Dividing Range. In the southern half of the sheet these rocks in the past had a more subdued topography and have since been covered by at least four successive late Tertiary to early Quaternary basalt flows. As a result, the present topography of this area is relatively flat to gently undulating.

The basalt flows buried the old drainage patterns where auriferous sands and gravels were accumulating (deep leads), and superimposed on them a different topographic pattern which in turn led to the formation of the present swamps and lake systems. Subsequently, younger sands and gravels were deposited in the valleys of streams. These streams have in certain areas cut through to the older gravels and sands.

During the Pliocene, climatic conditions led to the formation of extensive laterite caps, which subsequently eroded away over most of the area, leaving isolated patches, particularly in the south-western corner of the map.

Sandstones of Silurian age form the rugged hills of The Grampians at the western margin of the sheet. On the map these have the symbol Clk, following the usage on the Ballarat geological map, but a note on that map states that K-Ar isotopic determinations on an intruding granite indicate a Silurian age. These rocks have been subjected to several orogenic events. The latest of these events occurred during the Cainozoic, following the development of a major north-south trending fault system over central Victoria. It is through some of these faults and their associated fractures that the basalt flows and volcanic vents originated.

5.0 HYDROGEOLOGY

5.1 OCCURRENCE AND DISTRIBUTION OF GROUNDWATER

Most of the rocks covering the area are capable of yielding useful supplies of water, although some have better hydrogeological characteristics than others.

The major proportion of groundwater is contained in and flows through fractures developed in the hard rocks which include the basalt flows, older folded metamorphic rocks and sandstones. In the unconsolidated sediments, which include the alluvial sediments, deep leads, scoria and ash the groundwater is contained in and flows through the interstices of the rock matrix.

5.1.1 Basement Rocks

Basement rocks include the Cambrian greenstones(Є), Ordovician shales and schists (Ol, Oll)) and the Devonian granitic intrusives (Dgr,Dgd). They have low intrinsic permeability and rely entirely on the development of an adequate fracture system for the generation of any significant yield capacity.

The Ordovician sequence includes some sandstones which can provide small quantities of water but, in general, little is known about these rocks. However, it would be expected that small yields could be obtained at suitable topographic sites that receive adequate recharge.

No reports on pumping tests are available or could be found in the time available to assign values of hydraulic conductivity and storativity to these rocks. Tests carried out in the Daylesford area (Melbourne 1:250 000 map sheet) northeast of Creswick in Ordovician metasediments similar to those which occur in Ballarat sheet have hydraulic conductivity values of less than 1 m/d. Marked anisotropy in intrinsic permeability can be expected in rocks of this type.

5.1.2 Grampians Group

The Grampians Group (Clk) outcropping in the northwest corner of the Ballarat sheet comprises yellow-grey and red sandstones and siltstones intruded by granodiorite dykes. Apart from the main Grampians range, this Group also outcrops south and northwest of Lake Bolac.

The silicified sandstones and siltstones, with a few conglomerates, are composed of up to 90% quartz, with usually less than 5% feldspars. The metasediments were gently folded during successive orogenies. Because of the absence of major clay producing components, the fracture systems appear to be generally open and are therefore able to transmit groundwater.

No pumping tests are available from bores in this area to derive values of hydraulic conductivity and storativity. The non-saline nature of the sediments, the high relief and the relatively high rainfall yield groundwater in the Grampians Group with a very low salinity (generally less than 500 mg/L). Bores drilled in these rocks yield generally small quantities of groundwater (less than 1 L/sec). However, these yields probably reflect more closely the supply requirements in the area, which is a national park, than the aquifer yield potential. Nevertheless, it is expected that high yields could not be obtained from these rocks since fracturing decreases rapidly with depth and intergranular permeability is generally low.

It should be noted, however, that there are several bores in the area which have yielded up to 10 L/sec. Records indicate that these supplies were obtained in sand. However, it is possible that these yields may have been obtained from friable or weathered sandstones which are part of the Grampian Group. This has not been completely resolved and for the present, the yields have been attributed to sandy alluvial/colluvial deposits described further on in these notes.

5.1.3 Deep Leads

The Deep Leads are Cainozoic deposits of sands and gravels of integrated drainage systems later buried under finer textured alluvium and/or basalt flows.

The sands and gravels of the Deep Leads form major aquifer systems north and northeast of the Ballarat Sheet where they attain considerable thickness and can yield large supplies of groundwater of low salinity. These aquifers are also important in the Ballarat-Creswick-Avoca area, where the sediments were first mined for gold and were subjected to large scale pumping for dewatering purposes.

The Deep Leads vary in width and depth according to their position in relation to the original divide, but typically they are between 100 and 300 m wide and are found at depths ranging from 30 to 150 m. The gravel, or the coarser portion within these deposits, is generally between 1 and 10 m thick, and commonly lies directly over basement rocks which in turn is overlain by a sequence of alternating lenses of sands and clays. Yields up to 40 L/s have been obtained from properly designed, constructed and developed bores. Water quality is generally less than 1500 mg/L, being adequate for human consumption and irrigation.

Whilst several bores have been constructed in the Deep Leads in the area, information about their hydraulic parameters is lacking. A pumping test carried out on a bore near Clunes (Clunes 65 bore - not shown on map) by the then DME (now DITR) in 1983 gives an average hydraulic conductivity of 12.5 m/d. No storativity value is available.

5.1.4 Laterite (Tpb)**

The laterite profile developed over various rocks during the Pliocene is of limited areal extent and patchy. Information about the aquifer potential of this formation is poor. The material is commonly above the water table and has been given little attention, the target generally being deeper formations.

5.1.5 Newer Volcanics (Qvh, Qvs, Qvn)

The Newer Volcanics basalts, with associated scoria, ash and tuff, represent the major aquifer in the area. The lava flows filled in a fairly rugged topography, so that the cover thickness varies from a few metres to over 100 metres, with an average over the plains of around 60 metres. Up to four separate flows have been identified in the Ballarat area, separated by sand and clay layers, palaeosols and other sub-aerial weathering products. The effect of these interflow sediments is to confine the aquifers in places.

* Symbols for Tpb and Quaternary units are reversed on map

The basalts vary in texture from massive to vesicular, but their yield potential depends substantially upon the degree of interconnected fracturing. Other pyroclastic products, such as scoria, ashes and tuffs, have primary intergranular porosity, but they are generally limited in extent and, often, are located at a sufficiently high elevation above the basalt plains as to be only partially saturated. Where conditions are favourable, such at at Mt. Elephant near Derrinallum, good quality water (less than 1000 mg/L) is available from these materials.

The basalt aquifers, due to the nature of their formation, generally exhibit high but irregular anisotropy, with the horizontal hydraulic conductivity component several times greater than the vertical component. Evidence of this difference was found by a series of tests carried out by AGC in an area to the east of the Ballarat sheet.

The basalts yield potential varies greatly within the Ballarat Sheet, as a result of the degree of tectonism of the area. The eastern and northeastern portion of the map, north and south of the divide, is represented by thick and highly fractured volcanics, capable of commonly providing yields of about 10 L/s, with a few recorded yields up to to 60 L/s. Water salinity from these high yielding bores is commonly less than 1000 mg/L. In the remainder of the sheet, the basalts are not as highly fractured and yields are more commonly in the range 1 to 2 L/s. Water quality is generally poor, with salinities in the range 1500 to 10000 mg/L with localised values above 14000 mg/L. As a result bores are sunk and equipped to provide only small flows generally for stock watering. Thus, the yields obtained do not necessarily reflect the potential available in the area.

The youngest basalts are those forming the "stony rises", predominant in the central and southern part of the map area. These rises often have a relief of up to 15 m above the plain. They normally only develop thin soil cover below which the basalt is unweathered. These factors appear to result in areas which produce better quality water, at least at shallow depths.

A predominant feature of the basalts is salinity layering, with the salinity generally increasing with depth. However, the opposite is also possible. The reason for this reverse relationship is not clear and since little information is available on the method used to collect the samples and on the construction of the bores, the interpretation is not entirely reliable.

It is possible, in principle, that the reversal occurs in and around depressions where shallow groundwater is likely to be more saline than the deeper groundwater.

As indicated earlier, the basalt hydraulic conductivity is primarily dependent upon the degree of fracturing, so that a wide range of values, from 0.1 to 158 m/d, has been determined for this parameter from existing specific capacity data. The higher values are commonly found in the eastern portion of the sheet. No storativity data are available, but this parameter can be expected to be in the range from 10^{-2} to 10^{-4}.

5.1.6 Quaternary Sediments (Qra, Qrm, Qrc, Qpa)

Quaternary sediments, clay, sands and gravels are present throughout, but are more common in the northern half of the map area, where they attain their maximum thickness. The most significant of these sediments are those associated with the eastern slopes of The Grampians and with the valleys of the Avoca (Qra) and Wimmera (Qpa) rivers.

Near The Grampians, colluvial and alluvial sand accumulations up to 30 m form aquifers capable of supplying 1-2 L/s of water with less than 500 mg/L T.D.S.

Elsewhere, the sand thickness is highly variable and the yields reflect this variability.

Salinity varies in the range 1000-3000 mg/L, with higher values recorded near zones of groundwater discharge. These areas include the valley betwen The Grampians and the Great Dividing Range and the southern part of the Hopkins River valley (not shown on map) where discharge and subsequent evaporation cause accumulation of salts.

Values of hydraulic conductivity calculated from specific capacity data indicate a range from 0.1 to 358 m/d with most values around 15-20 m/d. Storativity values can be expected to be in the unconfined to semi-unconfined aquifer range.

5.2 POTENTIOMETRIC SURFACE

The water level contours shown on the map are based on a total of 165 bores which were selected from the data base to obtain a reasonably even distribution over the sheet area. Of these bores only 41 have accurate elevations (from the data base), whereas the elevation of the other 124 bores was estimated from the 1: 100 000 topographic maps used by the DITR as bore locality maps. Provided that the bores are correctly plotted on those maps, their elevation and, therefore, the water table elevation can be estimated in most cases with a reasonable degree of accuracy (±2 m). After the first contours based on the 165 bores were produced, some anomalies emerged so that a process of checking and data "infill" using other bores was carried out where necessary to refine the results.

The contours range from R.L. 150 m, at the southern edge of the map, to R.L. 550 m, east of Ballarat on the Great Dividing Range. The pattern generated by the contours closely follows the surface topography with the highest points aligned along the crest of the Range.

Water table gradients can be divided into two groups. Near the Range, they are generally about 0.01, whilst on the northern and southern plains they average about 0.004.

The contours indicate that:

a. Recharge takes place over the map by direct infiltration. This recharge is greater over the Great Dividing Range which also has a higher precipitation.

b. The steeper gradients over the Range are due to the combination of the lower permeability of the Devonian and Ordovician rocks, higher rainfall and the greater elevation differences.
c. Underflow is generally away from the Range to the north and south. However, in the area at the foothills of the Grampians, flow lines from the east and west converge and a groundwater discharge regime is delineated by several saline swamps and lakes.
d. The groundwater flow directions are towards the major rivers including the Wimmera and Avoca rivers to the north and the Hopkins and Yarrowee rivers towards the south. The increasing salinity of the surface streams, particularly for the southern flowing rivers indicates that river discharge is maintained mostly by base flow.

The water level contours relate to formations and rocks of different types and characteristics, which can be considered as individual aquifers. Therefore it could be argued, that two separate sets of water level contours should be produced for at least the two major units - the basalts and the basement rocks. However, it is believed that the region is substantially in hydrodynamic equilibrium since no large hydrogeological stresses are, or have been, at least in the last 80 years, imposed on the system. Hence the various aquifers and aquitards can be considered as a continuous system on a regional basis. Thus, the water level contours are representative of the total hydraulic head in the region.

5.2.1 Relationship of Rainfall and Groundwater Levels

Long term bore hydrographic records are not available, although the DITR has a total of 8 regional observation bores in the area. Seven of these are in the Ararat sheet (NW corner) and one in the parish of Wareek, at the northeastern margin of the map, so that these bores do not cover the sheet evenly. The records for two wells, Moyston West No. 2 and No. 6, start in 1973, with a gap until 1979 where most of the others also begin.

Other records from shallow bores exist for the Warrambine Creek area south of Ballarat, where the State Rivers and Water Supply Commission (now Rural Water Commission) carried out a catchment study for the Water Resources Council between 1976 and 1984.

The relationship between rainfall recharge and aquifer response is shown by the rainfall histogram for Ararat Prison Station together with the water level records for bores Moyston West 2 and 6. Unfortunately, geological records for these two bores are incomplete. Moyston West no. 2 bore is not included in the aquifer data file so that no information is available on its depth and aquifer type. However, from its location at the foothills of the Grampians, it is likely that the geological sequence would comprise mainly colluvial sand and/or weathered sandstone, with only a thin soil cover.

Static water level in bore Moyston West No. 2 is available only as an elevation R.L. From the position of the bore in relation to the topographic contours, it is estimated that the depth to water table would be about 3 metres.

Moyston West No. 6 bore is also located at the foothills of the Grampians alongside Mt. William Creek. The aquifer data file indicates the aquifer to be sand between 1 and 31.5 metres. It is estimated that the surficial horizon would be composed of alluvial sandy material. As for Moyston West No. 2, static water level is available only as an elevation R.L. and the depth to water table is estimated to be approximately 2 m below ground level.

The geological conditions of the two bores indicate that rainfall infiltration would be reasonably rapid and that they show a significant response to rainfall events.

From the graphs in the map it can be seen that rainfall and water level plots follow the same pattern, although it appears that a delay of up to 3 months exists in the water level response to rainfall events.

It is expected that a similar pattern would apply to the rest of the sheet, but no adequate data are available to support this conclusion.

5.3 SALINITY CONTOURS

All the chemical data related to bores that were plotted, or could be plotted, on the 1: 100 000 locality base maps have been used in the production of the salinity contours. The salinity contours were produced at that scale and then reduced to the map scale. The bores used totalled 730, subdivided as follows:

Creswick	1:100 000 sheet	273
Ballarat	1:100 000 sheet	155
Beaufort	1:100 000 sheet	53
Skipton	1:100 000 sheet	91
Ararat	1:100 000 sheet	58
Willaura	1:100 000 sheet	100

The table above shows that the distribution of the data is uneven over the six base maps; furthermore, substantial unevenness of data is evident within single maps, particularly those including the Great Dividing Range, where only scattered data are available owing to the mountainous nature of the terrain. Some inaccuracy has probably resulted in extending the contours across such areas.

The salinity contours for the most part, like those of the potentiometric surface, reflect the surface topography, since better quality water is associated with the elevated areas and with the higher rainfall of those areas.

High salinity, in excess of 14000 mg/L, is associated with some groundwater discharge areas; for example, in the foothills of the Grampians, where the salinity increases rapidly from west to east towards these discharge areas.

142°30'E 144°E

Ararat	Beaufort	Creswick	37°S
Willaura	Skipton	Ballarat	38°S

Index to 1: 100 000 sheets composing Ballarat 1:250 000 Sheet

5.4 HYDRODYNAMICS

The previous sections have provided a conceptual model of the overall groundwater regime of the area. In summary it shows a recharge zone with high potentiometric heads, generally coinciding with the surface water divide (Great Dividing Range), and with flow away from these areas to the north and the southern part of the sheet. Groundwater discharge zones occur along rivers, swamps and lakes located in lower lying areas.

In order to evaluate this conceptual model further a steady state numerical computer model was set up along two geological sections, one running nearly N-S in the eastern half of the map and one running almost W-E from the Grampians at the western half of the map. These sections and the computer model results are presented on the Ballarat sheet. The cross sections show the possible distribution of potentials and groundwater flow directions.

The third geological cross-section, which was not modelled, is presented in Figure 1.

5.4.1 Model Description

The computer model solves the equations of steady state flow for a discretized cross-section using triangular finite elements. The finite element grids used in the model are presented in Figure 2. The output of the program generates a series of hydraulic heads from which potential lines can be drawn. From these potential lines the flow directions can be determined. Data for the model included a water table profile obtained from the regional potentiometric map and hydraulic conductivity values obtained from specific capacity data collected in the region. In order to represent more closely the variation of permeability with depth, the surface, or near-surface hydraulic conductivity values obtained from bores (generally less than 50 m deep) were allowed to decrease exponentially with depth. The equation used was $K = Ko \exp(-cz)$ where K is the computed hydraulic conductivity at depth z (L/T); Ko is near-surface hydraulic conductivity (L/T); z is the depth from the surface (L); c is a constant taken as 0.05 (AGC 1984).

5.4.2 Section AB

Section AB runs across the Creswick and Ballarat 1: 100 000 sheets and is nearly at right angles to the surface and groundwater divides. Water table elevations range from 155 m at the southern end to approximately 460 m near Mt. Bolton on the Great Dividing Range. The section includes most rock types that appear on the sheet. The water table profile indicates two main groundwater mounds north and south of Lake Burrumbeet and it appears that the lake is a groundwater discharge area. The lake is situated in an area having a groundwater salinity in the range 1500 and 3000 mg/L. The surface water salinity in March 1986 was measured at 1350 mg/L near the northern shore of the lake.

Towards the south and within the basalt plains, the water table has a regular gradient toward groundwater discharge areas in the Colac region which include numerous salt lakes.

5.4.3 Section CD

Section CD runs from the Grampians to south of Ararat, across two groundwater divides. Water table elevation ranges from around 410 m under the Grampians to around 258 m under the unnamed drained swamp at the lowest elevation of the cross-section.

The regional potentiometric surface indicates the presence of two groundwater divides, one beneath The Grampians and the other under Mt. Moornambool. The salinity map indicates a steep salinity gradient from the west and from the east, with the intervening valley lying in an area with values above 7000 mg/L and localised values greater than 14000 mg/L. Salt crusting is evident around and within the swamps and lakes.

The model indicates that opposite flow lines from the two mounds meet under the swamp region and that upward groundwater flow occurs, resulting in discharge into the lakes and in evaporation which in turn results in salt accumulation.

The higher potentiometric head in The Grampians area produces a distortion of the equipotential lines towards the east under Mt. Moornambool. Another potential discharge area exists at the eastern end of the section, indicated by the upward inflection of the flowlines.

It appears that, in both sections, the hydraulic conductivities of the different rocks, all in the low value range, play a secondary role in the overall flow pattern of the area. The dominant factors, as would be expected, are rainfall recharge and topography which establish the groundwater divides and mounds which in turn dictate the general sub-surface flow pattern.

5.5 RECHARGE/FLOW NET ANALYSIS

The regional groundwater flow regime over the map area, although conceptually simple, reveals itself to be complex when attempts to evaluate a groundwater balance are made.

This study has allowed a reasonable estimate to be made of the various parameters necessary to set up a computer model to evaluate the groundwater regime of the area. However, in the time allocated for the preparation of the map, it was not possible to carry out this type of analysis.

5.6 HYDROCHEMISTRY

Water quality varies markedly over the sheet from less than 500 mg/L in The Grampians and around Ballarat to over 14000 mg/L at many localities. The overall trend is for total dissolved solids to increase away from the groundwater divide and to increase to the north and to the south. A study of the variation of the water chemical character with distance from the recharge zone indicates a typical Chebotarev evolutionary sequence, (Chebotarev, 1955; Freeze and Cherry, 1979) with the relative percentage bicarbonate decreasing and the sulphate and chloride ions percentages increasing along the flow path.

However, the groundwater, even in areas close to recharge zones, has a relative composition which approximates sea water, this similarity increasing with increasing TDS. The water in general can be classified as a sodium-chloride-sulphate type.

Although rocks of different geochemical composition and their weathering products make up the main aquifers in the area, it would appear that the major influence on the evolution of the groundwater is the residence time in the aquifer rather than the aquifer type.

6.0 RELIABILITY OF RESULTS

The water level and salinity contours, the hydrodynamic regime of the area and therefore, the level of hydrogeological understanding achieved as a result of this pilot program are dependent upon the reliability that can be placed on the original data base and on the distribution of that information within the map area.

6.1 WATER LEVEL CONTOURS

In general, the information in the data base related to water levels is adequate in number and sufficiently reliable, as it is a parameter that can be easily obtained.

It should be pointed out, however, that, as generally there is only one value of SWL per bore in the data base, the contours presented in the map include levels collected at all times of the year and do not allow for possible water level fluctuations in recharge areas. However, it is felt that such fluctuations, even if in the order of 5-8 m, would not alter the basic pattern and understanding of the water level contours map, as the contours are at an interval of 50 m.

Relating the depth to water level in a bore to an elevation A.H.D. becomes problematic when survey data are not available. This was found for most bores, and as a result elevations had to be determined from the topographic map. Estimating the surface elevation of the bore can be difficult, since it depends on the accuracy with which the bore is located on the map.

Nevertheless, considering the 'averaging out' effect of the contouring process and that obvious discrepancies were checked in the field, it is considered that a substantial degree of reliability can be placed upon the water level contours at the scale presented.

6.2 SALINITY CONTOURS

Approximately 730 bores were used in the production of the salinity contour map, but a lesser degree of reliability can be placed on this data base, which produced these contours, than on the water level contour map data.

There are several factors responsible for this lower reliability. They include the uncertainty about exact sampling depths and how the samples were collected and handled before analysis. Also, reference to the aquifer depth and type is often missing, including bore construction data.

As a result, adjacent bores commonly show sharp variations in salinity many of which cause apparently steep salinity gradients over short distances. However, these data have been included in the map as there is no apparent reason for rejecting these values after investigations were undertaken in the field to resolve the apparent discrepancies.

The overall picture of the salinity distribution over the map area is considered to be reasonably accurate as it matches the general hydrodynamic flow pattern of the area. However, locally some inaccuracies could be found.

6.3 HYDRAULIC CONDUCTIVITY AND STORATIVITY

There are no long term pumping test data with drawdown versus time data that could be found to enable the calculation of the transmissivity and, hence, hydraulic conductivity of the various aquifers. Pumping test records are not kept in the computer data base files by the DITR.

However, the data base does often provide information on pumping rate, test duration and type and drawdown. In the majority of the cases, the tests are undertaken by bailing or airlift rather than by controlled pumping. The test duration is commonly less than half an hour and no indication is generally given on how and when the drawdown was measured. It has to be assumed for all data that it was measured at the end of the test.

Overall, data from 67 bores were used to calculate transmissivities using one drawdown measurement but the quality of these data is fair to poor, thus their reliability is also fair to poor. Transmissivity was calculated using a simple computer program (Kalf, F.R., 1982).

Where possible values of hydraulic conductivity were calculated from the transmissivity values. However, data on aquifer thickness were often not available to allow hydraulic conductivity to be determined.

In summary, the water level contour map is considered fairly reliable, the salinity contour map is considered reasonably reliable, but the reliability of the aquifer test data used to assess the hydrodynamics of the region is considered to be only fair to poor.

7.0 CONCLUSIONS

The hydrogeological mapping pilot program has upgraded the status of the Ballarat 1: 250 000 sheet from unknown/unevaluated to conceptually evaluated.

The hydrogeological, hydrodynamic and hydrochemical regimes of the area have been identified and evaluated. It is believed that with some selective field work and the collection of accurate data, some areas of the map (Creswick and Ballarat, for instance) could be elevated to a design evaluated status.

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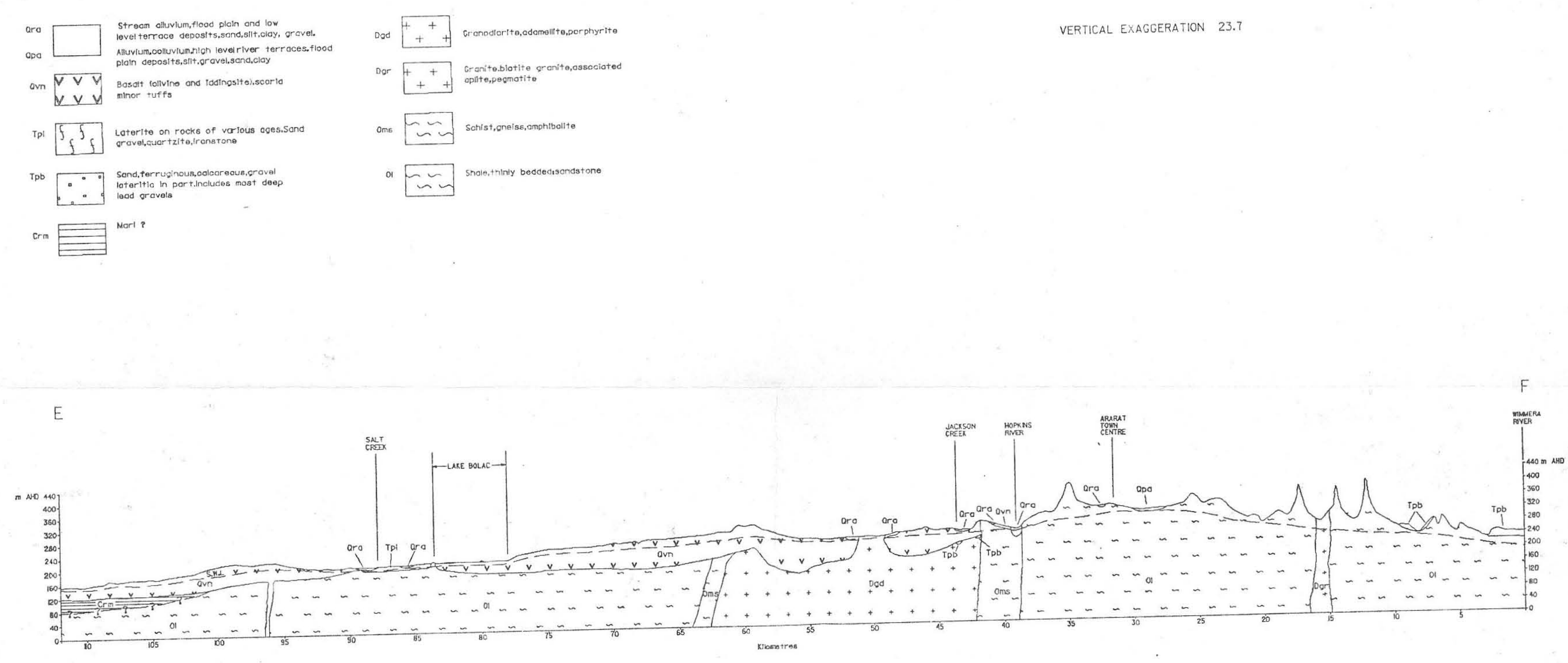


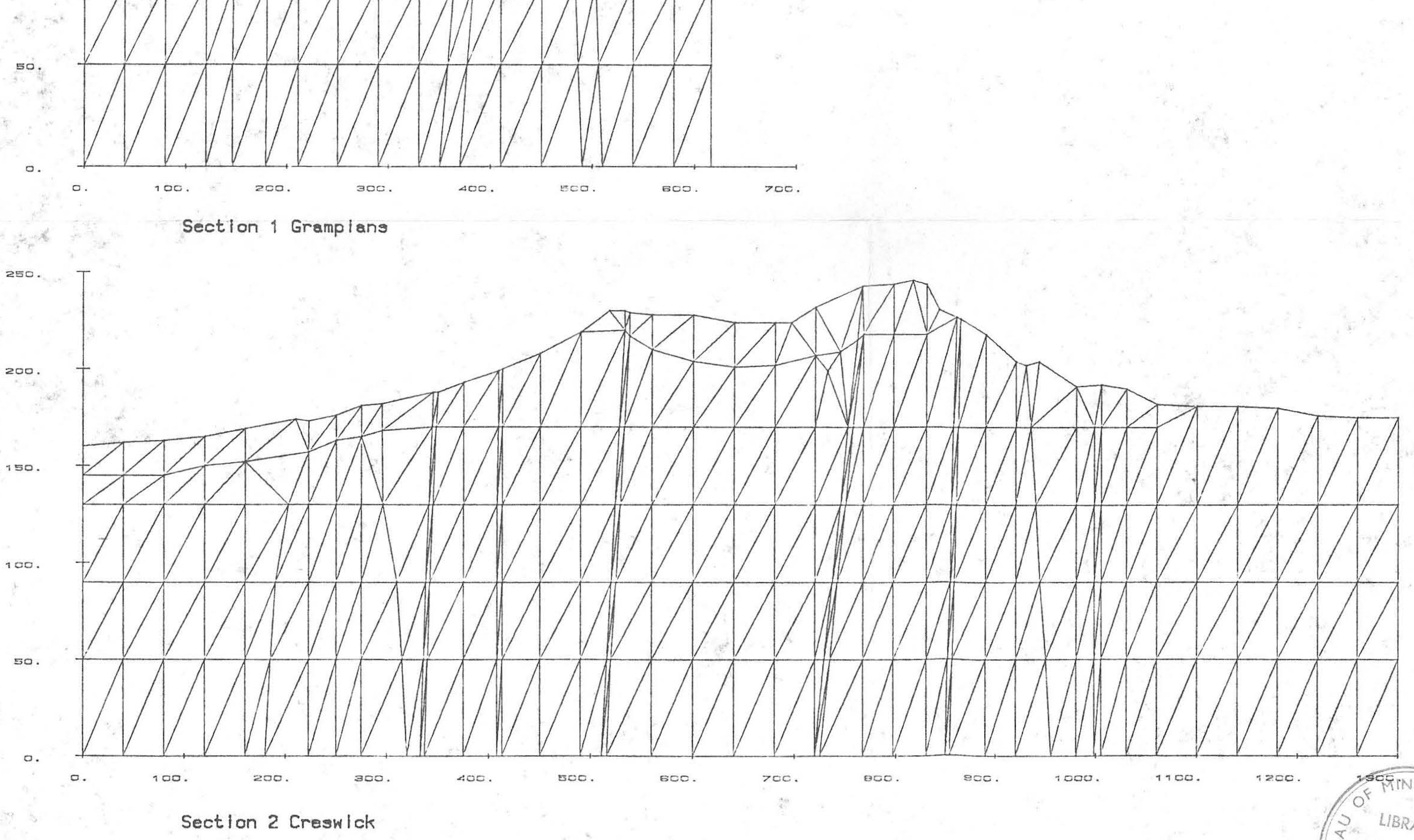
BUREAU OF MINERAL RESOURCES

PILOT STUDY

AUSTRALIAN GROUNDWATER CONSULTANTS PTY LIMITED

EF GEOLOGICAL CROSS-SECTION

Fig. 1



BUREAU OF MINERAL RESOURCES

HYDROGEOLOGICAL MAPPING

PILOT PROGRAMME

FIG. 2

COMPUTER MODEL

FINITE ELEMENT GRIDS

Sect. 1 Grampians

Sect. 2 Creswick

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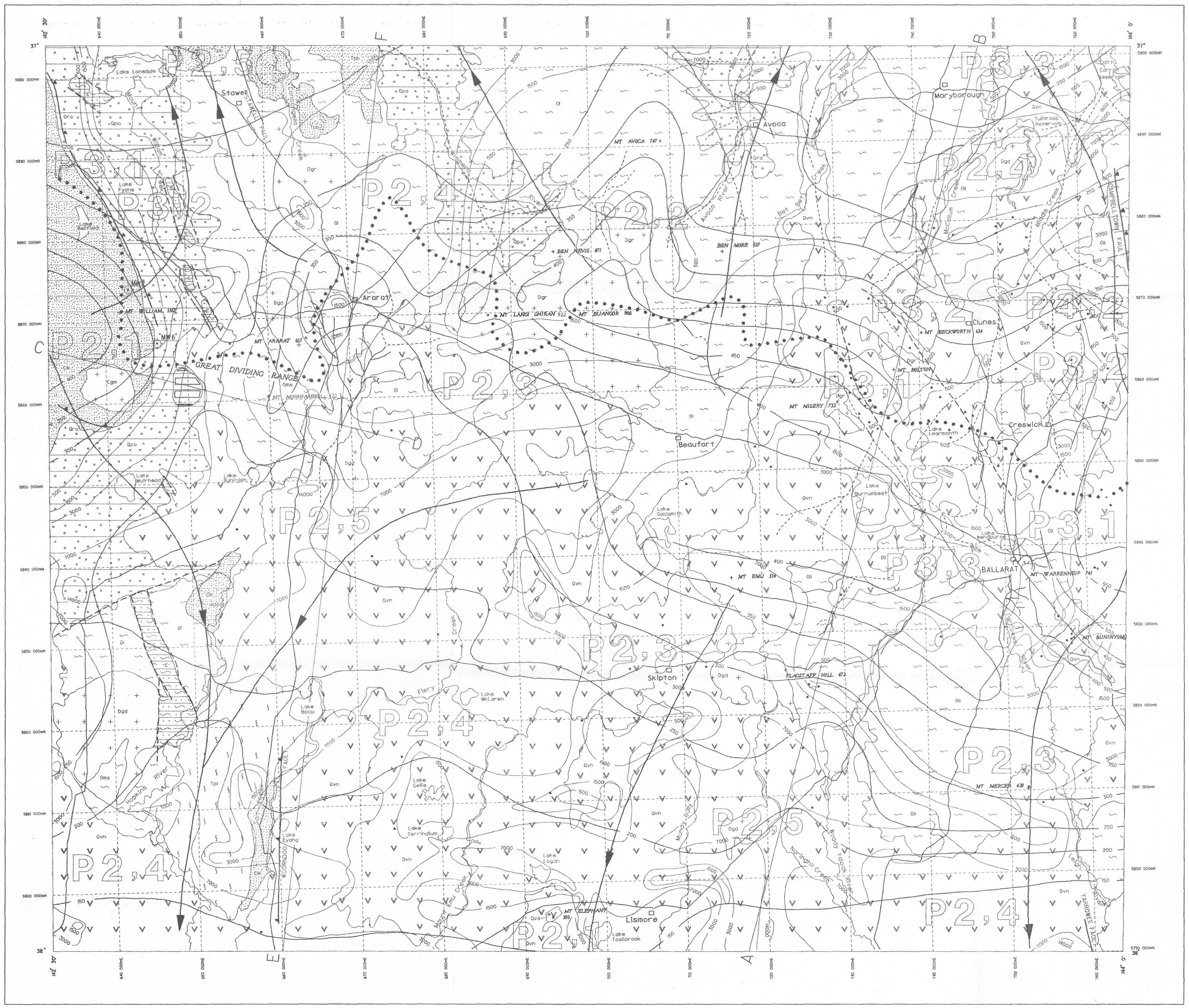


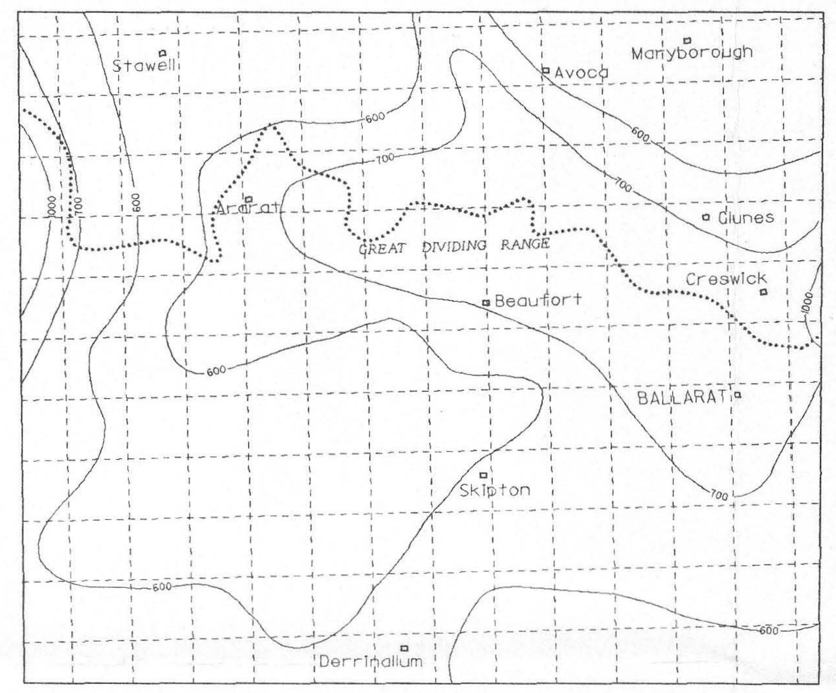
STRATIGRAPHY		LITHOLOGY	AQUIFER TYPE	SALINITY (mg/L)	BORE YIELD (L/sec)	HYDRAULIC CONDUCTIVITY (m/d)	AQUIFER THICKNESS (m)	TRANSMISSIVITY (m^2/d) *	STORATIVITY
QUATERNARY	Qra	Stream alluvium, flood plain and low level terrace deposits, sand, silt, clay, gravel.	Unconfined, sandy, generally thin and of limited extent. Where thicker accumulation occurs, higher yields can be obtained.	Highly variable, with values up to 14000 T.D.S. Generally <3000 Higher salinities in discharge areas.	Generally < 1 but, occasionally, yields up >10 have been recorded.	0.1-30	1-30	0.7-1100	N.D.A.
	Qrm	Swamp and lagoonal deposits, silt, clay, peat, mud.							
	Qrc	Colluvium, fan deposits, fault aprons, high level alluvium, gravel, sand							
	Qpa	Alluvium, colluvium, high level river terraces, flood plain deposits, silt, gravel, sand, clay							
	Qvh	Basalt; valley flows, stony rises	Generally unconfined, sheet-like form in up to 4 separate flows. Hydraulic conductivity depends upon the degree of fracturing.	Highly variable, with values in excess of 14000 Generally better quality in the eastern portion of the sheet.	Variable but mostly around 1	0.1-160	2-50	1-225	N.D.A.
	Qvs	Scoria cones, scoria, basalt, tuff and ash							
	Qvn	Basalt (olivine and iddingsite), scoria minor tuffs							
TERTIARY	Tpl	Laterite on rocks of various ages. Sand gravel, quartzite, ironstone	Unconfined, with limited areal extent, occasional high hydraulic conductivity.	1700-9000 **	0.4-4.5 **	0.3-39	3-9	0.3-39 **	N.D.A.
	Tpb	Sand, ferruginous, calcareous, gravel lateritic in part. Includes most deep lead gravels	Unconfined to confined, with irregular distribution. High hydraulic conductivity exist in the deep lead gravels.	<2000 often <1000	10-40	11-56	8-24	143-809	N.D.A.
Unconformity									
PALAEOZOIC	Cgm	Granodiorite							
	Clk	Quartzose sandstone, red sandstone, siltstone, minor mudstone	Unconfined. Hydraulic conductivity due to fractures.	Mostly <1000	1-3	1-28	>20	2-91	N.D.A.
	Dgd	Granodiorite, adamellite, porphyrite	Unconfined. Limited fracture hydraulic conductivity.	Unknown	Unknown				
	Dgr	Granite, biotite granite, associated aplite, pegmatite	Unconfined. Limited fracture hydraulic conductivity.	Unknown	Unknown				
Unconformity									
	Oms	Schist, gneiss, amphibolite							
	Ol, Oll	Shale, thinly bedded; sandstone	Generally low hydraulic conductivity.	Unknown	Unknown				
	€	Chert, shale, greenstone							

* Calculated from specific capacity data.

** Best estimate only. Inadequate data.

N.D.A. No data available for calculation.

MEAN ANNUAL RAINFALL CONTOURS (mm)



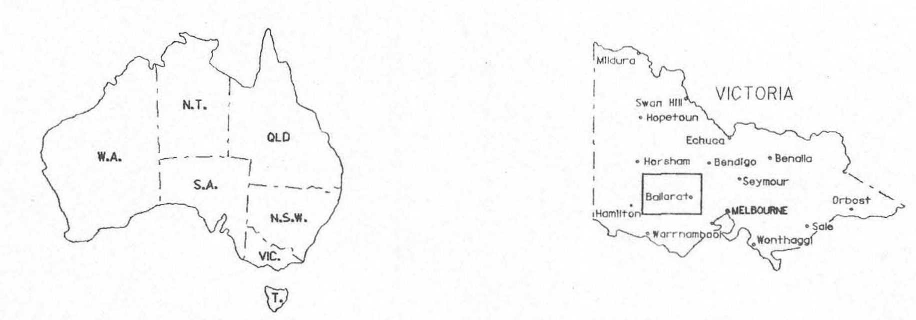
- Town
- Road
- Mountain Name and Height
- Watercourse
- Lake
- Surface water divide
- Rainfall Contours
- A —— B Cross-section
- Geological Boundary
- Fault
- Fault Inferred
- P4.1 Salinity-Yield relationship
- Eruption Centre
- Flowline
- 250 Potentiometric Contours (m A.H.D.)
- Potentiometric Surface (In cross-sections)
- Hydraulic Potentials
- Discharge Zone
- Deep Leads
- 1500 Salinity Contours (mg/L)

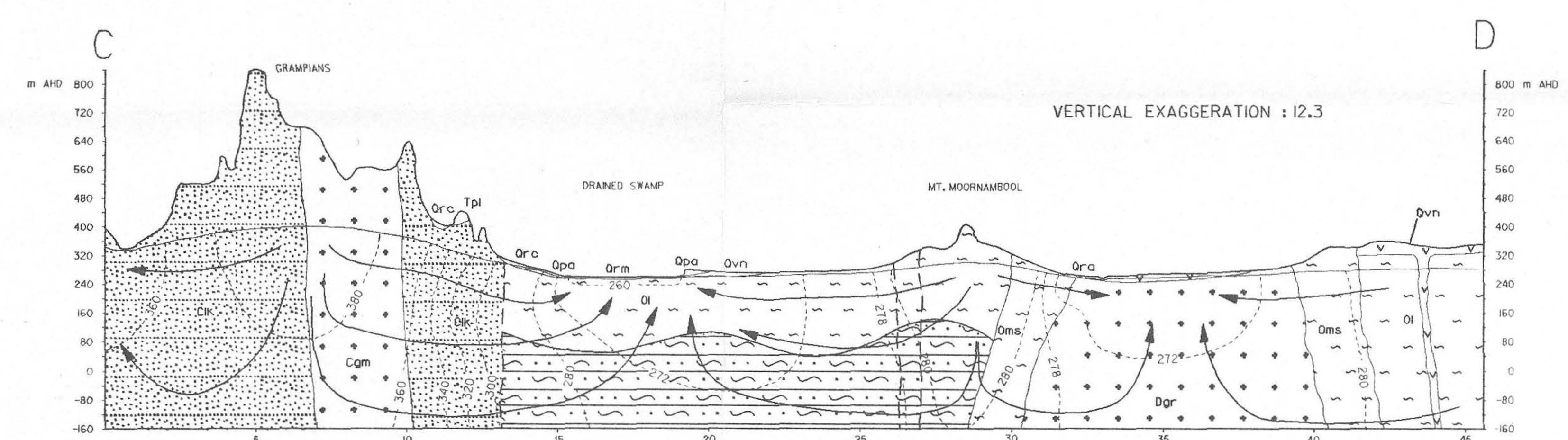
SALINITY mg/L	YIELD L/sec <0.5	0.5-5	5-50	>50
<500	P1.1	P2.1	P3.1	P4.1
500-1500	P1.2	P2.2	P3.2	P4.2
1500-3000	P1.3	P2.3	P3.3	P4.3
3000-7000	P1.4	P2.4	P3.4	P4.4
7000-14000	P1.5	P2.5	P3.5	P4.5
14000-35000	P1.6	P2.6	P3.6	P4.6

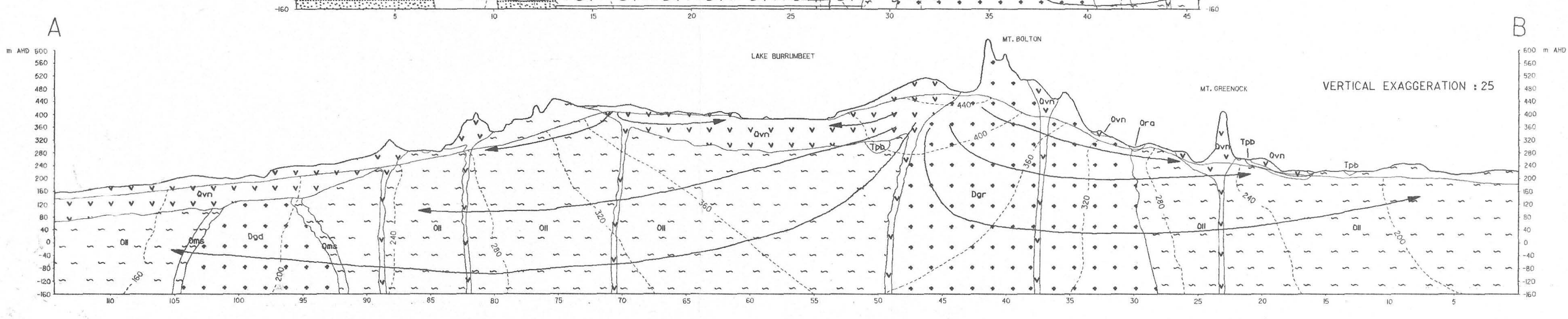
Geology based on the Ballarat 1:250,000 Geological Survey of Victoria Map, 1973. Geology simplified to suit the requirements of this map.

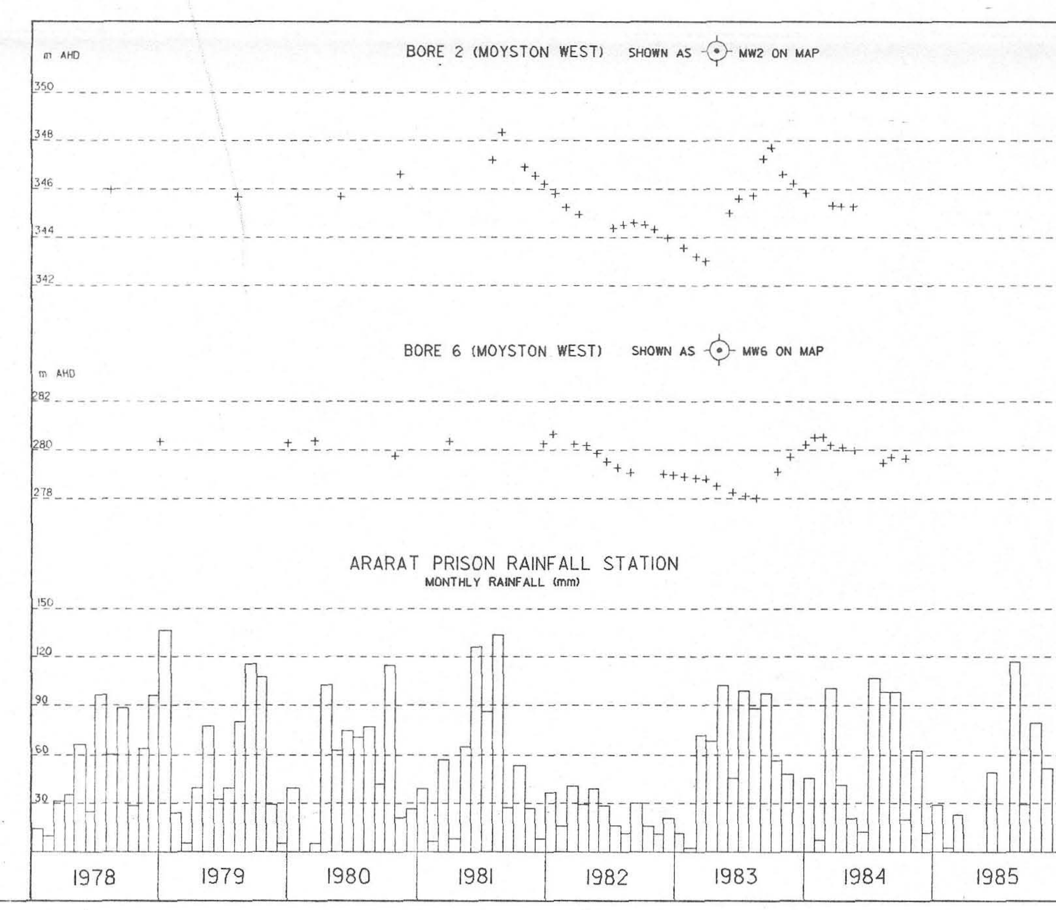
Topography based on the Ballarat 1:250,000 NATMAP and simplified to suit the requirements of this map.

Rainfall contours by Bureau of Meteorology in Atlas of Victoria.









SCALE 1:250,000

5 0 5 10 15 20 25 KILOMETRES

1987/26
Copy 2

Horizontal Datum: Australian Geodetic Datum 1966
Vertical Datum: Australian Height Datum 1971
Map Grid: Transverse Mercator Projection

DEPARTMENT OF RESOURCES AND ENERGY
BUREAU OF MINERAL RESOURCES
NATIONAL GROUNDWATER DATA BASE INVENTORY
5 YEAR FORWARD PROGRAM – PILOT STUDY
HYDROGEOLOGICAL MAP OF BALLARAT

PREPARED BY:
AUSTRALIAN GROUNDWATER CONSULTANTS PTY LIMITED

MAY 1986