[JRG074R]

Technical Services Division

GROUND SUBSIDENCE and BORE COLLAPSE associated with GROUNDWATER WITHDRAWALS - NAMOI VALLEY NSW

John Ross
Len Jeffery
Hydrogeology Unit

February 1991
(TS91.007)

CONTENTS

APPENDICES

TABLES

FIGURES

1. INTRODUCTION

The groundwater resources contained in the alluvial sediments of the Namoi Valley in north western NSW are the most intensively developed of any aquifer system in the state. There are a variety of uses ranging from stock, domestic use to irrigation, town water supply and minor mining and industrial use.

During the 1970s and early 1980s there was extensive growth in the demand for groundwater resources. Even though groundwater management plans were introduced in 1983 (WRC, 1983) and 1984 (WRC, 1984), there are still some small areas of the river basin where the groundwater resource is being depleted. Declining water levels have persisted in these areas since the late 1970s, and in recent years have been accompanied by a few bore collapses and minor surface subsidence. The area of main concern is north of the Spring Plain Rd in the lower Namoi Valley (Figures 1 and 2). This report focuses on the extent of these problems and investigations undertaken to date in this area, with a brief outline of surveys in the Mooki Valley (Figures 1 and 3).

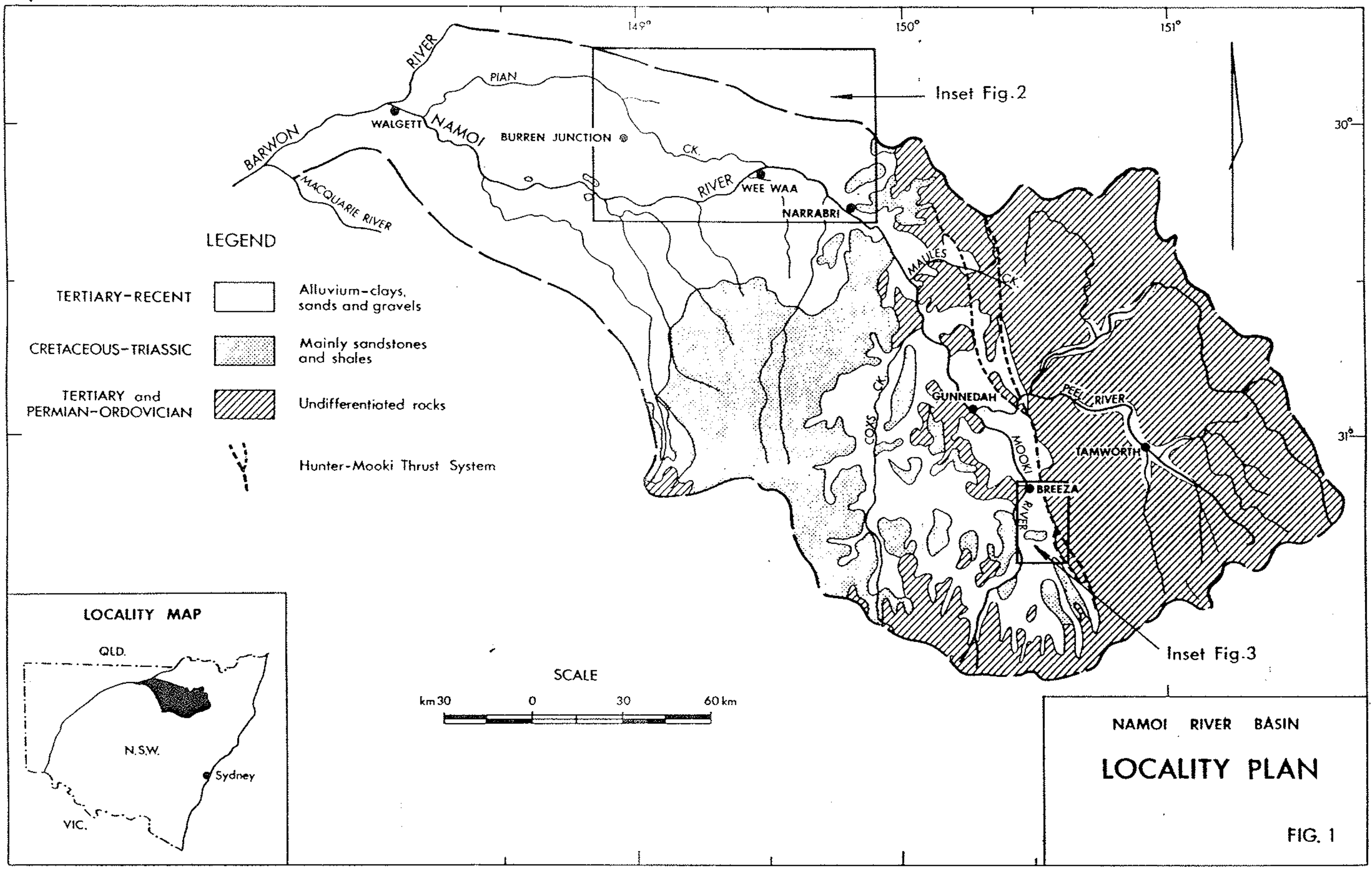
A brief literature review of the nature of subsidence in alluvial areas is given initially. This draws on extensive studies from the USA where subsidence has been recognised for over 50 years.

2. THE NATURE OF SUBSIDENCE IN ALLUVIAL AREAS

Land subsidence and its impact on groundwater systems is well documented in other parts of the world. It can be described as either endogenic (caused by processes originating within the planet) or exogenic (caused by processes originating near the Earth's surface, including the consequences of human activity) (Prokopovich, 1984). Exogenic subsidence can be further subdivided into three main types:

- removal of support;
- weakening of support;
- increase in loading.

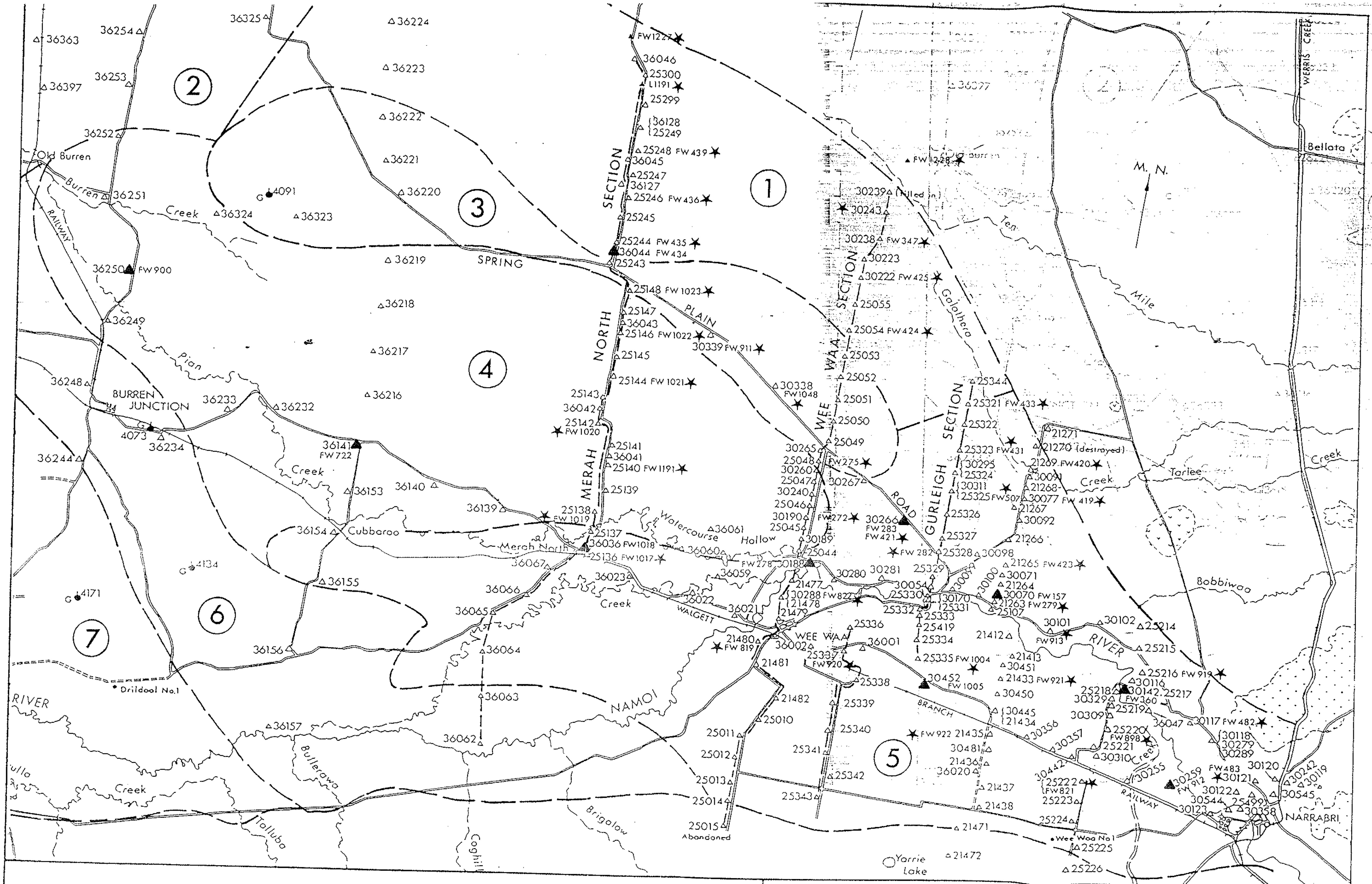
Principal causes of exogenic subsidence are excessive groundwater withdrawals, mining and tunnelling. In Australia there are very few examples of subsidence due to groundwater withdrawals. Gloe (1984) has given a case history of subsidence in the Latrobe Valley, Victoria where large groundwater withdrawals have been necessary to mine brown coal by open cut. Up to 1.7 metres of subsidence has taken place in this part of the Gippsland Basin which contains some 700m of interbedded clays, sands and brown coal seams of Tertiary age.



NAMOI RIVER BASIN

LOCALITY PLAN

FIG. 1



LEGEND

▲ 36044 FW434 Major (Control) Bench Marks (Bedrock)

✶ 25244 FW435 Subsidence Bench Marks (C.T.)

(2) — — Zone Boundaries

DEPARTMENT OF WATER RESOURCES

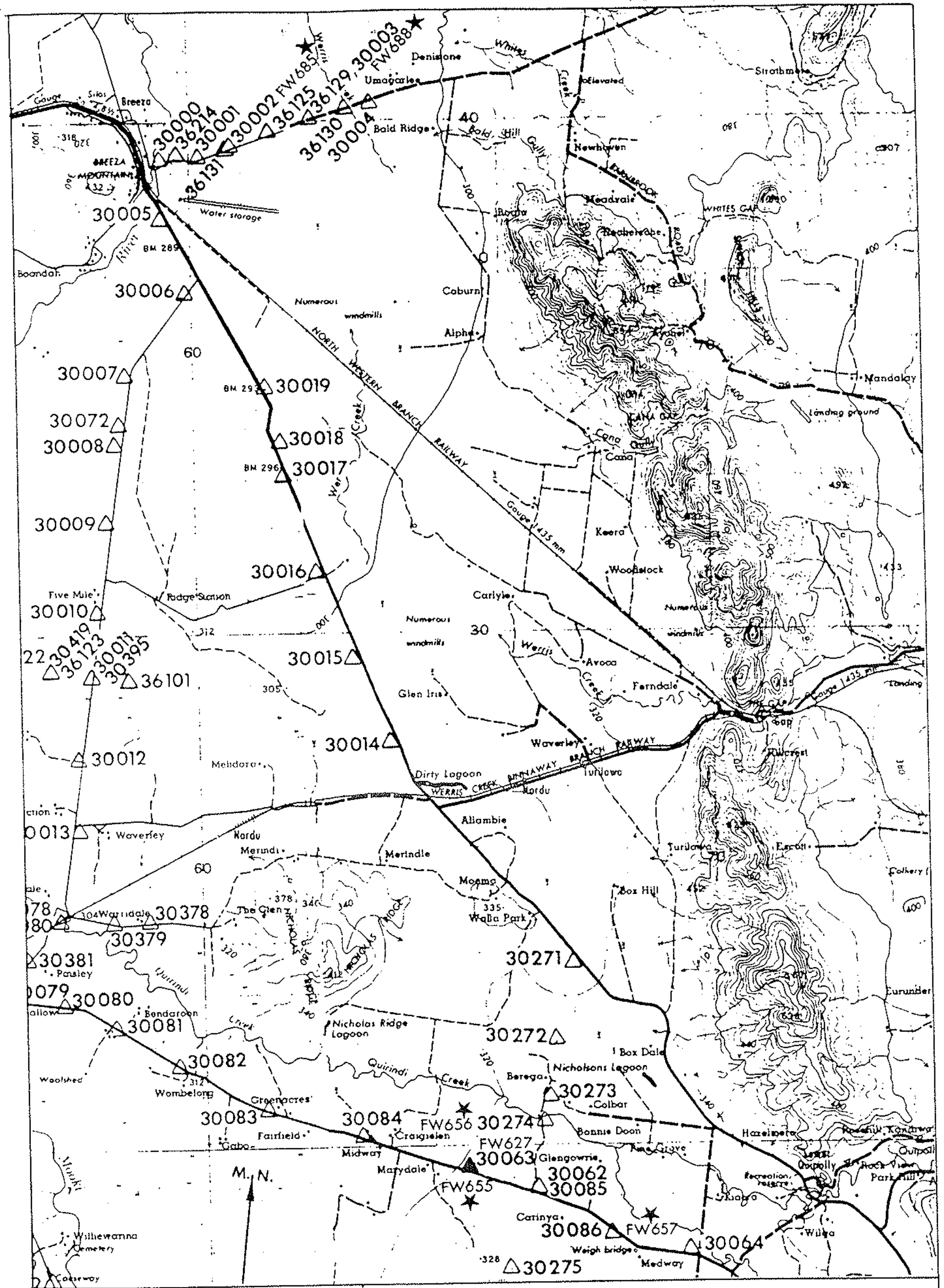
HYDROGEOLOGY UNIT - TECHNICAL SERVICES DIVISION

LOCALITY PLAN - LOWER NAMOI VALLEY

Scale 1:250 000

5 0 5 10 15 Kilometres

FIG. 2



LEGEND:

▲ 30063 FW 627 Major (Control) Bench Marks (Bedrock)

✶ 30086 FW 657 Subsidence Bench Marks

DEPARTMENT OF WATER RESOURCES

HYDROGEOLOGY UNIT - TECHNICAL SERVICES DIVISION

LOCALITY PLAN - MOOKI VALLEY

Scale 1 : 100 000

0 1 2 3 4 5 6 Kilometres

FIG.3

Cobb (1982) suggests that the Barossa Valley may be subject to land subsidence because of large groundwater withdrawals (estimated 1600ML/year in 1979) from the Cainozoic sequence of complex alluvial sediments in this small continental basin of about 175 square kilometres. The South Australian Dept of Mines and Energy commenced relevelling surveys in the area in 1979 but no subsidence has been detected to date (S. Barnett pers com).

Another study of note is Evans (1986) which provides estimates of possible subsidence in the vicinity of the Barwon Downs, Kawarren and Gellibrand borefields which are located in the Otway Basin west of Geelong. At 2 sites, the aquifer systems are confined while at Gellibrand, the response is typical of an unconfined aquifer. In the worst case modelling scenario, 30800 ML are extracted from the Barwon Downs borefield over an 18 to 21 month period (extreme drought situation) with a predicted water level drawdown of 100 metres and a worst case surface subsidence of 1.15 metres.

The best known cases of subsidence in alluvial areas where groundwater is used for agricultural purposes are in the San Joaquin and Santa Clara Valleys in California. Here substantial water level declines and land subsidence of up to 8.5 metres were experienced over an area of 13,500 km^2 between 1926 and 1970 (Lofgren, 1978).

Based on more than 20 years of research and data from these California Valleys, Lofgren established the following basic concepts:

(i) Unconsolidated water-bearing deposits, even at great depth, are highly sensitive to changes in effective stress. Even small, subtle stress changes may cause permanent, widespread compaction. Pumping drawdowns induce effective-stress changes in an aquifer system which cause compressible deposits to compact. These effects may extend to depths below the deepest wells.

(ii) Depending on the type of deposit being stressed and the range of the induced stresses, compaction may be either: (a) elastic (recoverable) or (b) inelastic (largely nonrecoverable). The released water of compaction represents a one-time source of water to wells. Subsidence of the land surface represents the summed compaction of all underlying beds of the aquifer system. Although some beds may be expanding while others are compacting, the net effect is reflected as an elevation change of the land surface.

(iii) During a first cycle of prolonged water-level decline, permanent changes do occur in the storage characteristics of an aquifer system. The virgin specific storage typically is one to two orders of magnitude larger during the first cycle of water level decline than the elastic specific storage during subsequent declines through the same stress range. Thus, 50 to 100 times as much water is available to pumping wells for a given drawdown during the first cycle of pumping overdraft than during a second. Attempts to forecast the response of a groundwater reservoir without an adequate understanding of the storage characteristics, based on actual field data, may be misleading.

(iv) Nonrecoverable compaction occurs principally in the fine-grained, slow-draining interbeds of the aquifer system. No measurable change in transmissivity, storage characteristics or recharge-ability of the coarse grained aquifers has been detected at the sites studied. The significant change during the first cycle of water-level decline, therefore, is a one-time release of interstitial water from the slow-draining aquitards. Less than 5 percent of this water of compaction returns to the interstitial voids of the aquitard when water levels recover.

(v) If and when water levels in the confined aquifer system fall below the base of the confining layer, actual dewatering of the upper part of the newly unconfined aquifer below the confining layer will occur. This will introduce a second set of stresses tending to compact all compressible beds in the system below the dewatered zone. Water levels, however, will decline at a greatly reduced rate, because of the large specific yield of the newly unconfined aquifer system.

(vi) In considering a confined aquifer system as a cyclic-storage reservoir, little usable storage capacity is available after the first cycle of compaction caused by water-level declines, until actual dewatering occurs.

(vii) Bore-hole extensiometers are invaluable in measuring the response of aquifer systems to pumping stresses. We know of no better method of (1) collecting in the field the data needed to calculate the elastic, virgin, and transient storage parameters of an aquifer system, and (2) determining the preconsolidation stresses that must be exceeded before subsidence begins.

Another characteristic of subsidence in alluvial areas is fissuring. Larsen (1984) describes the nature and origin of earth fissures in southern Arizona. Here water levels have declined from 45m to more than 90m and subsidence is generally 0.3m or more. Fissuring is known to occur in a variety of geologic environments, with openings typically several hundred metres long, one metre or more wide and one to twenty metres deep.

Common fissuring environments are shown in Figure 4 with most fissures associated with types A, B and C. No fissuring has been reported in the Namoi Valley, although it would be hard to recognise in any early stage of development as the black soils of the lower Namoi floodplain typically display seasonal cracking and swelling characteristics.

3. HISTORY OF GROUNDWATER DEVELOPMENT IN THE NAMOI VALLEY

The irrigation development based on groundwater resources contained in the alluvial deposits of the Namoi Valley and important tributaries, commenced in the late 1950's, with the greatest impetus occurring with the 1966-1968 drought and the successful establishment of a viable cotton industry.

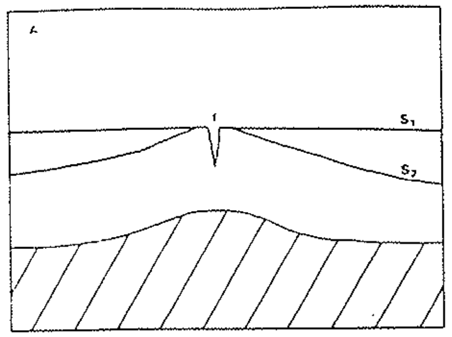
Statistics for both the lower Namoi and upper Namoi Groundwater Management Areas (GWMA's 001 and 004) are given in Tables 1 and 2 for the period since 1980/81. Management area, zone boundaries and bore sections are shown in Figure 2. Further details are given in the Department's Groundwater Status Report series which describe the groundwater use and water level behaviour of these systems. DWR (1988) and DWR (1991) are the latest reports covering the last five years.

TABLE 1: GROUNDWATER USAGE SUMMARY - 1980/81 TO 1988/89 - GWMA001

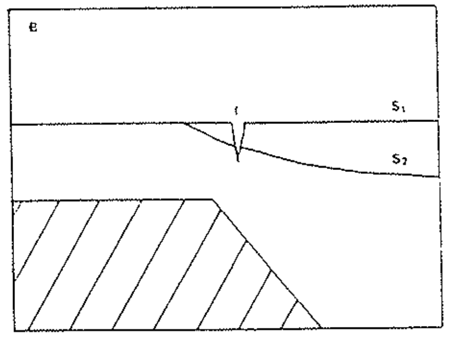
Year	No. of Licensed Bores	No. of Bores in use	Volume of Water Pumped (ML/Year)	Volume of Water Authorised (ML/Year)	Total Area Irrigated (Ha)
1980/81	312	206	112610 x	n/a	15123
1981/82	340	210	89993 x	n/a	16797
1982/83	371	226	120231 x	n/a	16775
1983/84	407	143	19733	169033	6321
1984/85	427	233	64996	169907	21770
1985/86	441	238	65843	166408	17860
1986/87	436	217	61713	161600	12280
1987/88	445	253	74938	155897	18723
1988/89	452	241	76726	156717	14834

Key

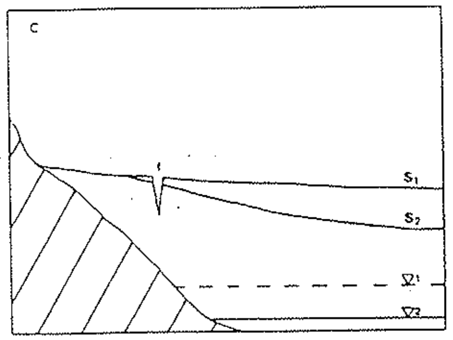
x No allowance for irrigators who failed to provide groundwater return data. Since 1984/85, usage figures have been collected by metering inspectors and volumes recorded are more accurate.



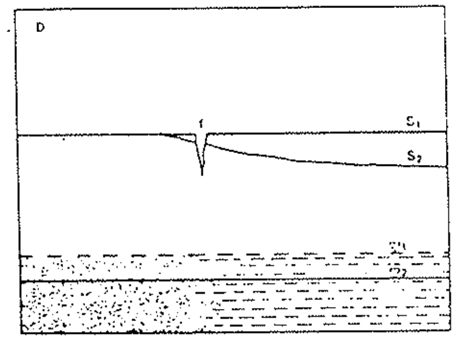
1A. Buried bedrock hill



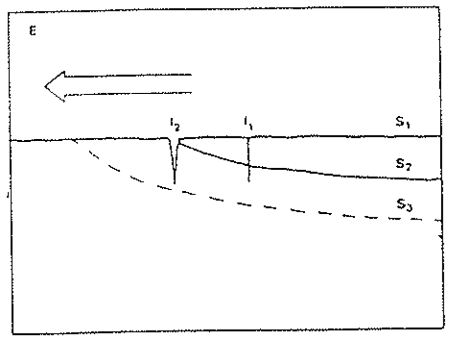
1B. Buried bedrock scarp



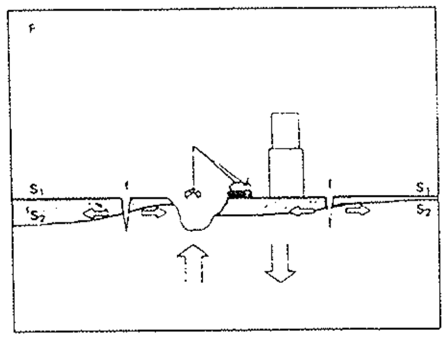
1C. Hinge-line



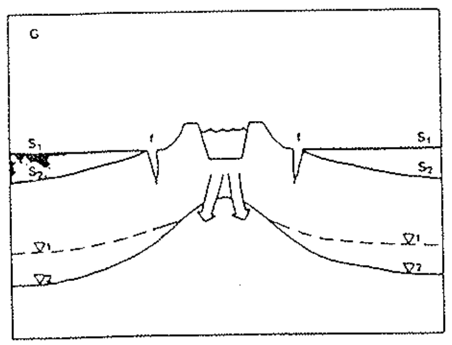
1D. Sedimentary facies changes



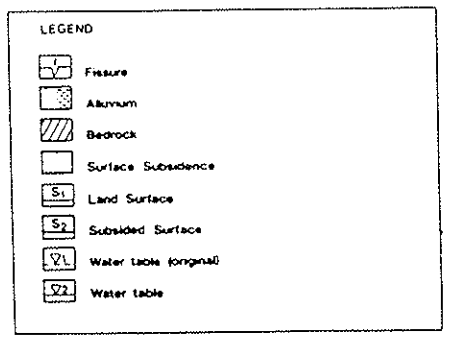
1E. Edge of advancing subsidence front



1F. Manmade changes in vertical loading



1G. Groundwater recharge mound



Geologic Environments of Fissuring.
(after Larsen, 1984)

FIG. 4

TABLE 2: GROUNDWATER USAGE SUMMARY - 1980/81 TO 1988/89 - GWMA004

Year	No. of Licensed Bores	No. of Bores in use	Volume of Water Pumped (ML/Year)	Volume of Water Authorised (ML/Year)	Total Area Irrigated (Ha)
1980/81	435	197	52263	n/a	11506
1981/82	478	206	39710	n/a	12606
1982/83	523	271	98958	n/a	21201
1983/84	572	184	24297	n/a	9492
1984/85	702	266	72605	240000*	19261
1985/86	760	330	76285	253000*	21221
1986/87	761	307	57668	249000*	15519
1987/88	775	282	66498	247000*	14204
1988/89	780	272	62820	252103	16784

Key

* No historical records have been retained. Figures quoted are best estimates.

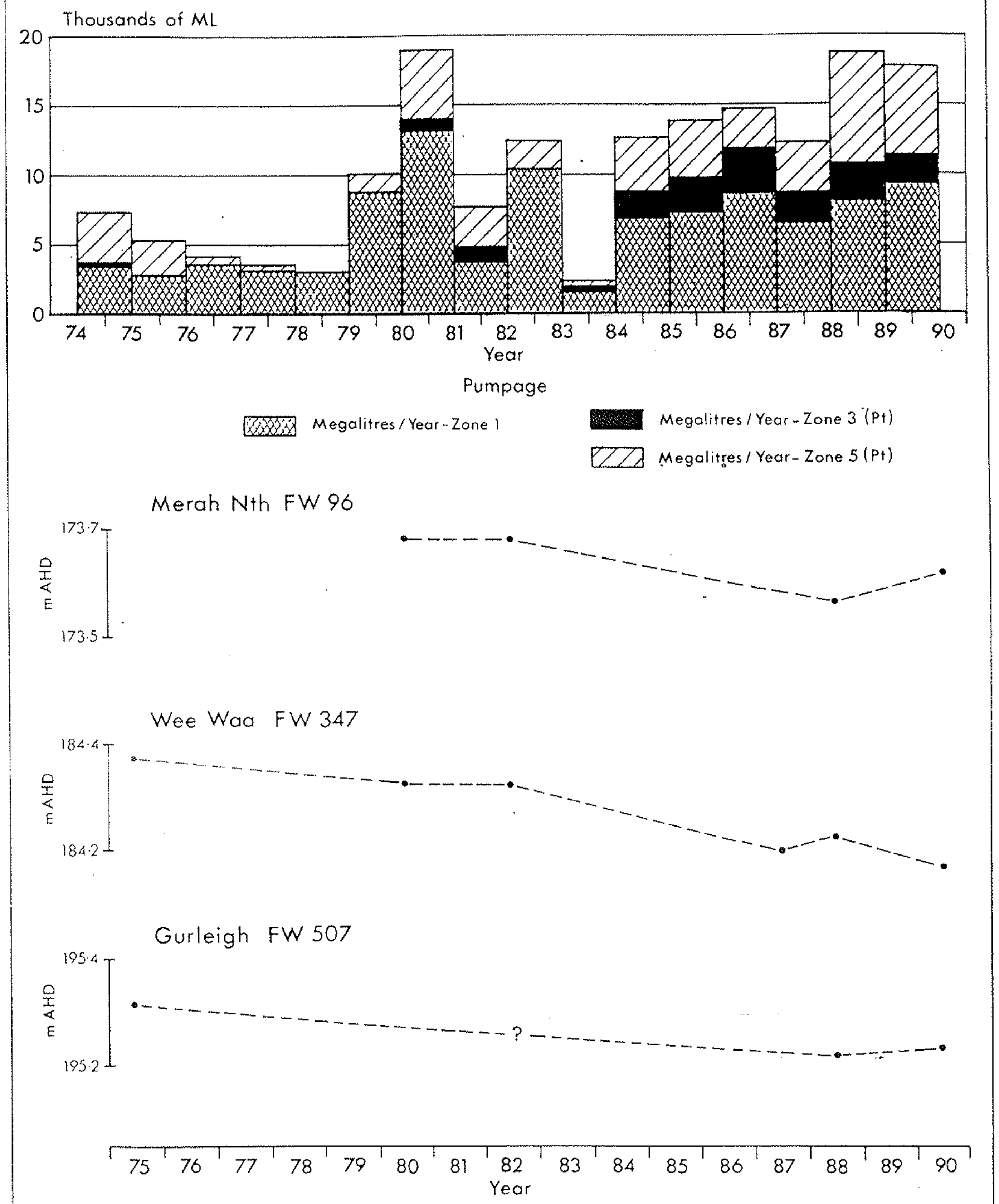
Looking at those areas subject of this report, the main usage and pumping trends are as follows:

Lower Namoi Valley - GWMA001 Zone 1, Parts Zone 3 and Zone 5

Pumpage data for the area north of the Spring Plain Road is shown in Figure 5. Water is used exclusively for irrigation, stock and domestic purposes in this area. The first irrigation bores were constructed in the late 1960s when it was discovered that deep alluvial sediments infilled an old Miocene palaeochannel that headed north west towards Rowena. Original static water levels for the deep productive aquifers below 60 metres in this area were between 20 and 25 metres but they are now typically between 45 and 50 metres. There was a shallow aquifer between 20 and 30 metres that was dewatered in the Zone 1 area by the late 1970's.

Seasonal water level variations for the 1974/75 and 1989/90 irrigation seasons are given in Figures 6, 7 and 8 for each of the Gurleigh, Wee Waa and Merah North Sections respectively. It is clearly evident that

- the pumping stresses have increased since 1979/80, and
- that static non-pumping water levels and irrigation season pumping water levels have both fallen dramatically since 1974/75. The bulk of this decline has occurred since 1979/80.



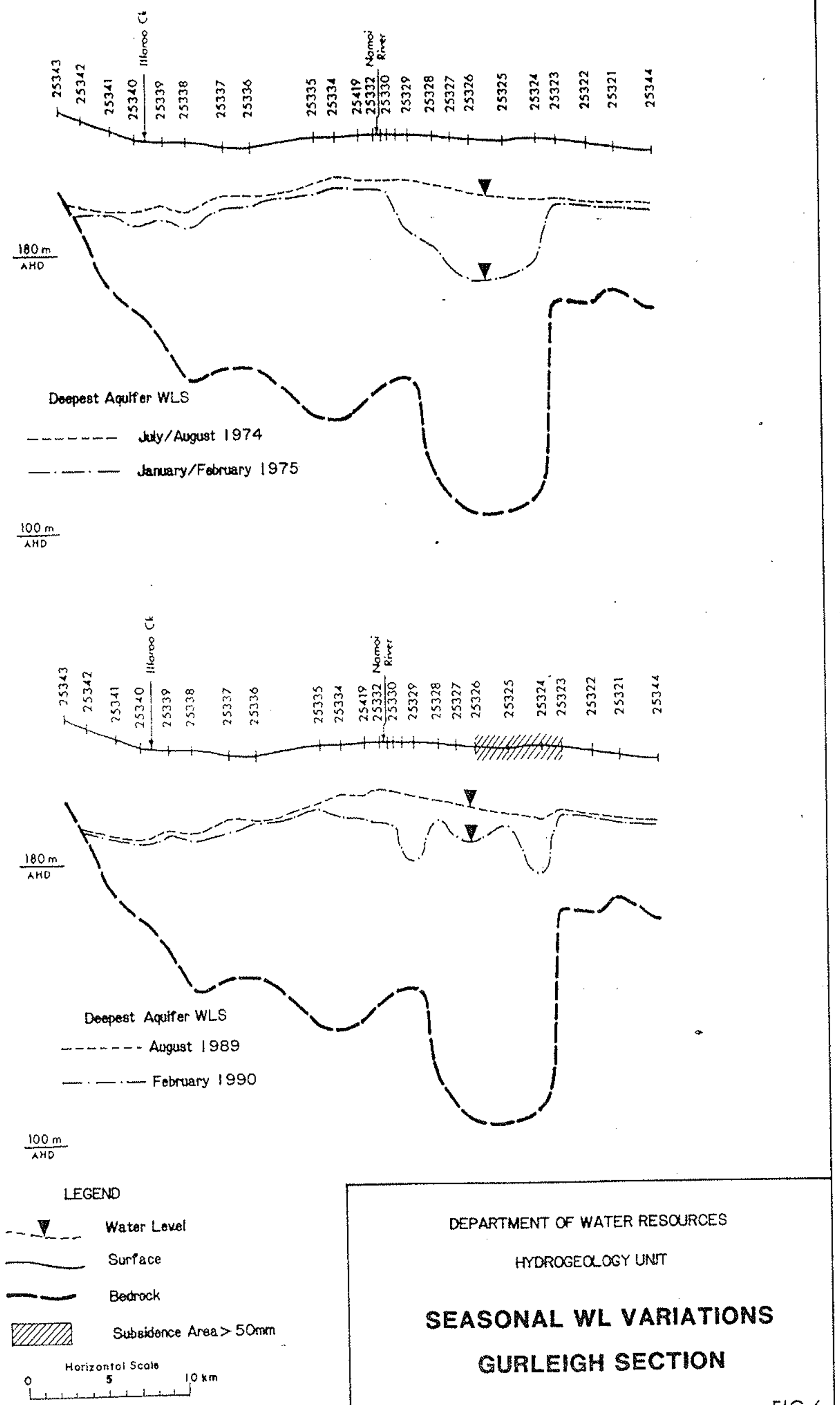
DEPARTMENT OF WATER RESOURCES

HYDROGEOLOGY UNIT

COMPARISON OF GROUNDWATER PUMPAGE AND MAXIMUM SUBSIDENCE

LOWER NAMOI VALLEY (GWMA 001)

FIG. 5

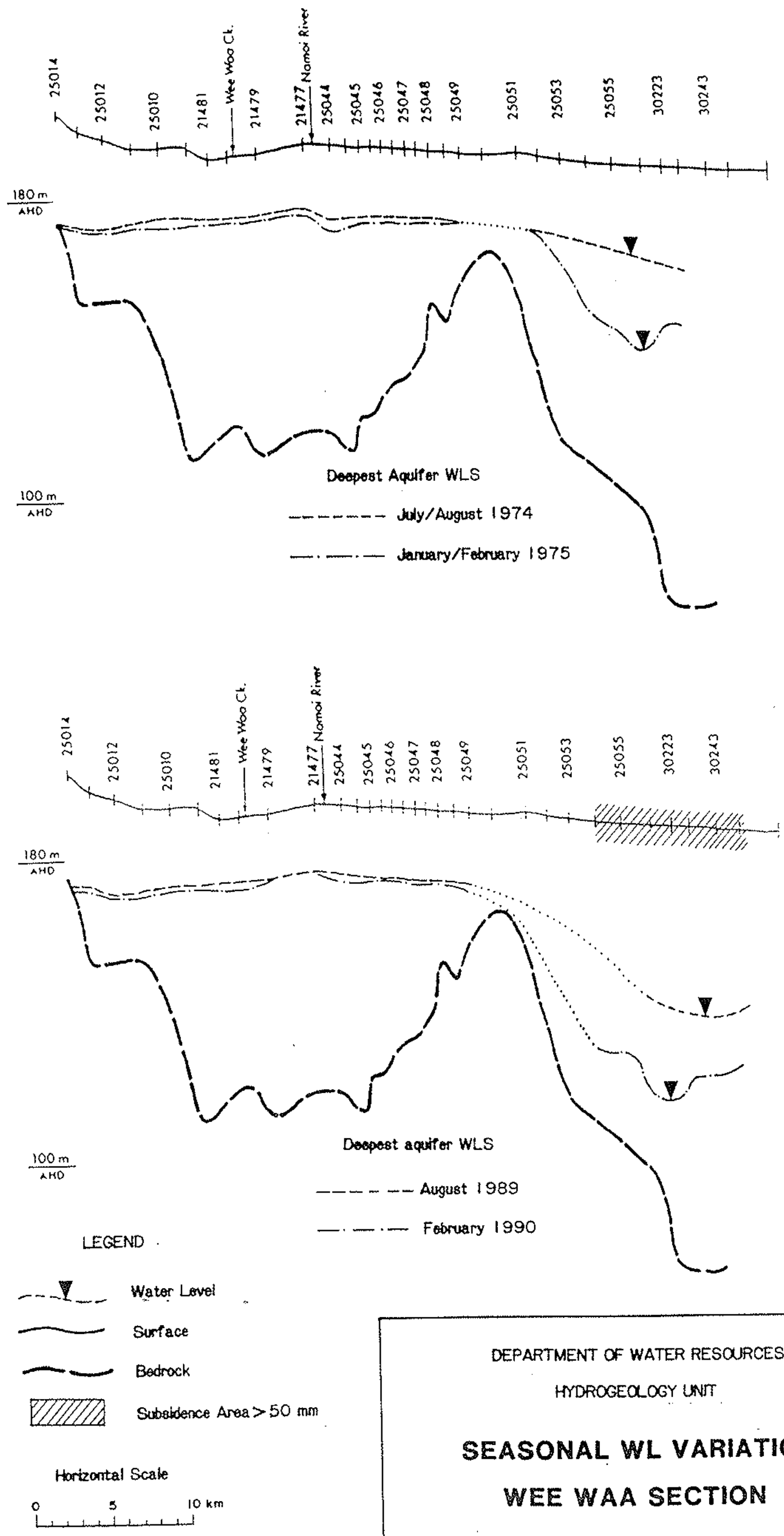


DEPARTMENT OF WATER RESOURCES

HYDROGEOLOGY UNIT

SEASONAL WL VARIATIONS
GURLEIGH SECTION

FIG. 6



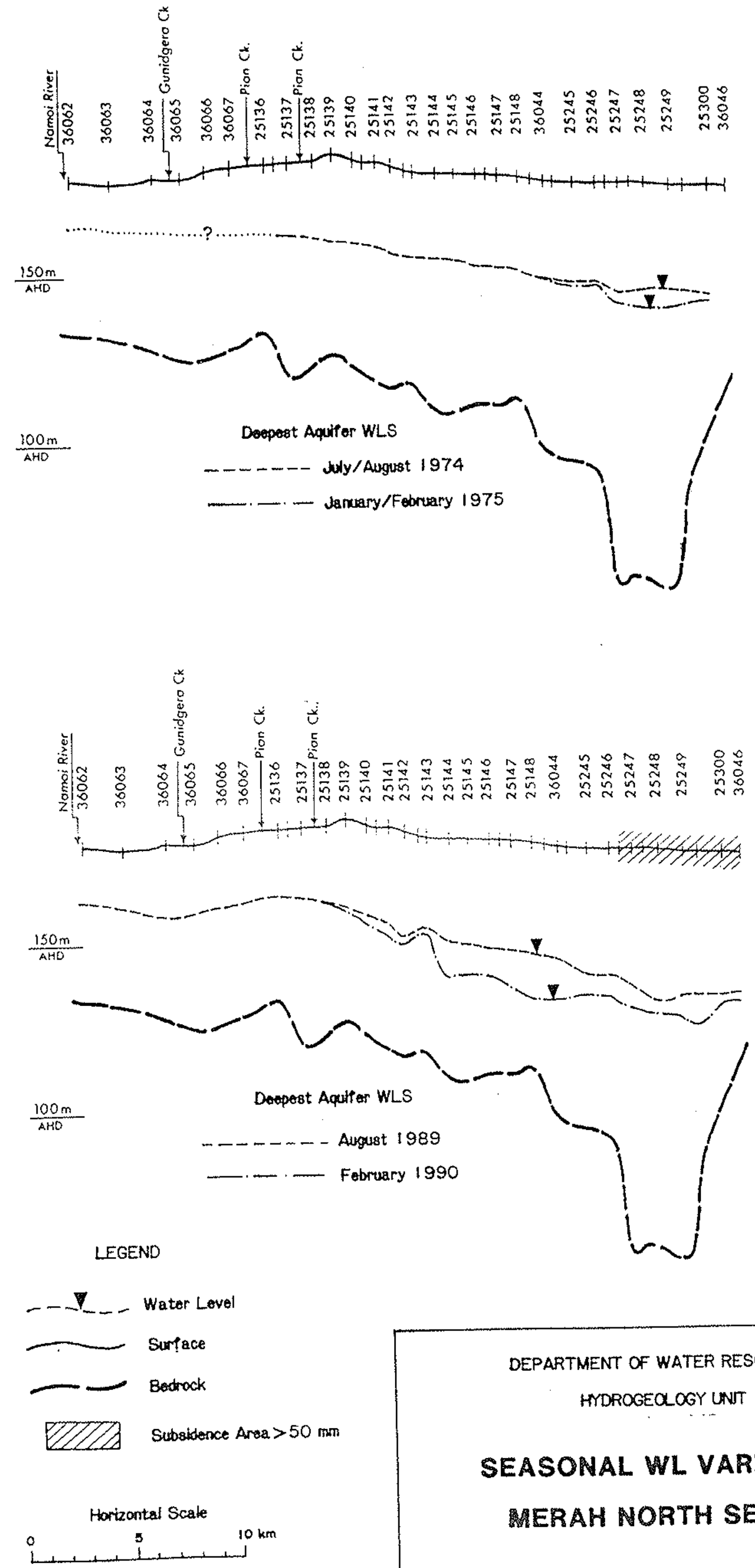
DEPARTMENT OF WATER RESOURCES

HYDROGEOLOGY UNIT

SEASONAL WL VARIATIONS

WEE WAA SECTION

FIG. 7



DEPARTMENT OF WATER RESOURCES

HYDROGEOLOGY UNIT

SEASONAL WL VARIATIONS

MERAH NORTH SECTION

FIG.8

Mooki Valley and Tributaries - GWMA004 Zone 1 and Zone 3

The main area of concern is the Zone 3 area from the Pine Ridge area to Gunnedah although subsidence survey marks have only been established in the Pine Ridge to Breeza area. Pumpage data is given in Figure 9. Water is used for town water supply, irrigation, stock and domestic purposes. The town water supply borefields (Quirindi and Curlewis) are remote from the subsidence survey marks. Water level declines are not as severe in the lower Namoi Valley. Typically seasonal variations are no more that ten metres but there have been permanent declines of more than five metres in the area north of Breeza [DWR (1991)]. Subsidence or bore problems have not been reported from this area to date.

4. BORE COLLAPSES

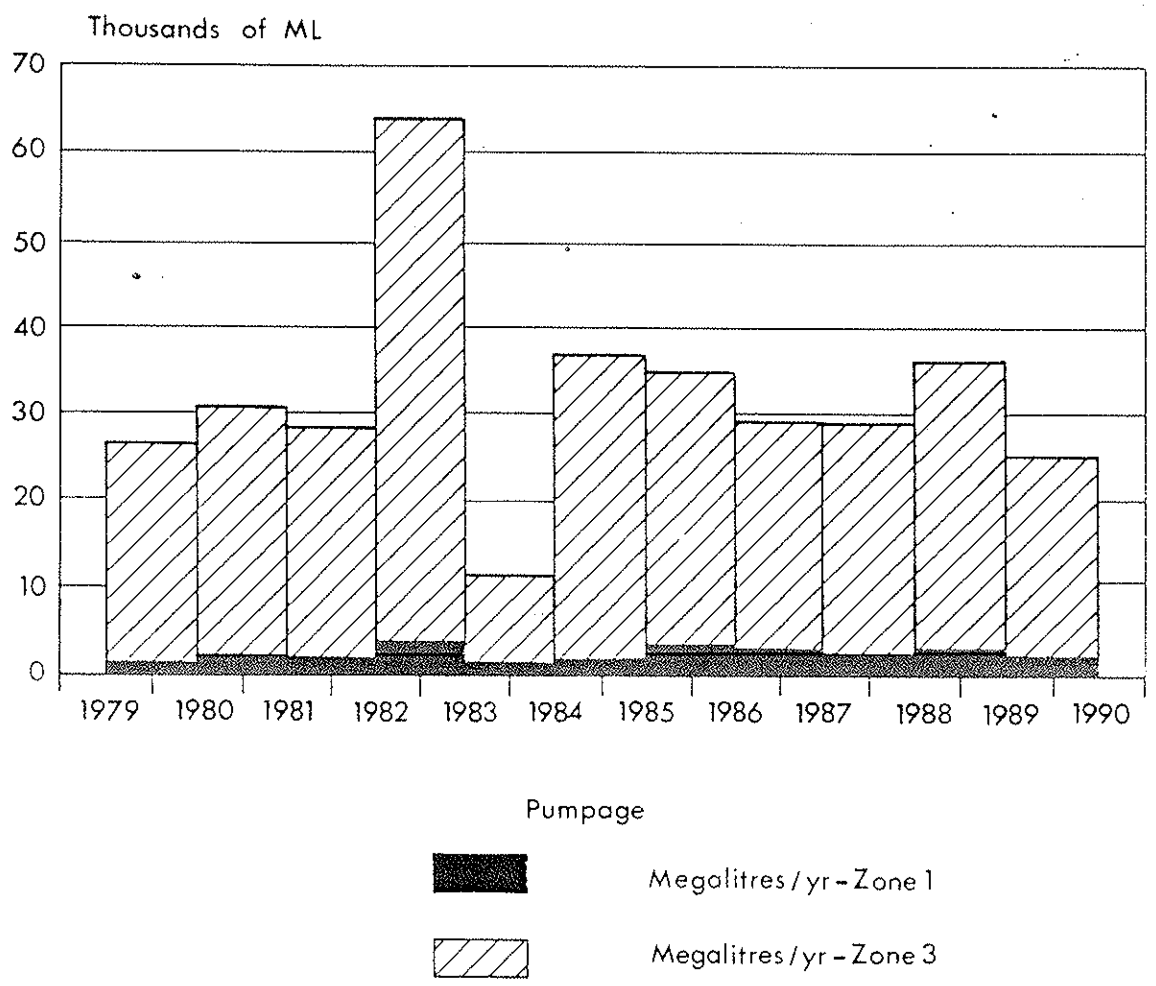
Replacement of production bores has to be expected with the passage of time as screens and slots corrode, casing becomes holed, and flood and mechanical damage occurs. However damage due to compressional forces is a new threat in areas with large water level variations. Bore life is expected to vary from 5 to 25 years depending on these and a variety of other factors.

In the Namoi Valley there are over 1200 large diameter production bores, of which 452 are in the lower Namoi Valley (see Tables 1 and 2). Of these, approximately 5% of bores are replaced in any year.

In recent years there has been a greater than average replacement rate of bores in the area north of the Spring Plains Road. There are no records of the reasons for failure, however sub-surface movement has been attributed to some of the bore collapses. Some of the symptoms reported are sub-horizontal casing sheers and screen collapses, and bell shape distortions in casings. These problems are symptomatic of gravitational compaction and large pressure differentials according to Indreland (1978). In some instances submersible pumps have been sealed in boreholes below caved-in sections.

One interesting aspect is the number of problems that have been reported in the 65 to 70 metre depth zone below surface. This corresponds to the disconformity between the Miocene Cubbaroo Formation and the Pliocene Gunnedah Formation which would be a natural plane of weakness in the alluvial sequence.

In future, thick walled casings or double casing liners may be necessary to overcome these compressional problems.



DEPARTMENT OF WATER RESOURCES
HYDROGEOLOGY UNIT

GROUNDWATER PUMPAGE
MOOKI VALLEY
(GWMA 004)

FIG. 9

5. SUBSIDENCE LEVELLING SURVEYS

Because of the large scale exploitation of groundwater in the Namoi Valley especially around Narrabri and Wee Waa, it was anticipated that there could be substantial falls in the water table which in the longer term could cause subsidence of the land surface. Therefore it was decided in the early 1970s to establish a means of detecting subsidence.

Accordingly a system of specially constructed bench marks was established.

Additional ground movement is known to occur because of the black soil floodplains that are dominant throughout the valley. These montmorillonite clay soils are subject to swelling and shrinkage as they gain and lose moisture.

5.1 Bench Marks and Reference Points

These marks vary from especially constructed bores to bench marks cut into trees. For the lower Namoi Valley, the observation bores, major control bench marks and subsidence bench marks are shown in Figure 2. Similar bores and marks in the Mooki Valley are shown in Figure 3. No such bench marks have been constructed in the Namoi Valley between Carroll Gap and Narrabri, or in the Mooki Valley between Breeza and Gunnedah.

Major control bench marks

These marks consist of 102mm bore casing drilled and cemented into bedrock. This bore casing is isolated from the alluvium by a larger diameter (152mm) bore casing extending to just above bedrock. (The only exception is BM FW157@ bore 30070. This was the first major control bench mark constructed and does not have the outer, 152mm, bore casing).

Further details of the construction of these major control bench marks and their reduced levels are given in Appendix 1.

Subsidence bench marks

These marks are used to detect subsidence due to groundwater withdrawals. The marks consist of a steel rod driven into the bottom of a 6 metre deep borehole. This borehole is lined with a P.V.C. tube to isolate the steel rod from the surrounding alluvium. A copy of a report, referring to the construction of these marks, is given in Appendix 2.

Tabulations of reduced levels obtained for such marks are given at Appendix 3.

General Discussion

Control levelling was carried out in stages between 1975 and 1981.

Major control bench mark FW157 at bore 30070 was the first control bench mark constructed. A value of 200.000 to A.H.D. was ascribed to this bench mark. This value being very nearly that obtained by connection to bench mark FW65 at bore 21263. (Bench mark FW65 had previously been connected to state marks during routine levelling of observation bore sections). Bench mark FW157 has been adopted as the origin for all subsidence surveys carried out by the Hydrogeology Unit.

It was considered that level changes of less than say 50mm over 20km (1 in 400 000)would be insignificant and so it was decided to adopt 0.008 √ km accuracy as appropriate. (35mm over 20km).

Related to the appropriateness of the accuracy adopted is the stability of marks. An indication of the variations in stability is provided by an examination of the situation at bore 30266. A subsidence bench mark was placed near the control bench mark at bore 30266. A bench mark was also cut in a tree in this vicinity. These bench marks and the protector casings and P.V.C.s at bore 30266 have been levelled from time to time. A tabulation of results is given at Appendix 4.

The most stable marks (given that this site is south of the observed subsidence area) are the major control bench mark, the subsidence bench mark, and the casing protectors (in that order). The PVC piezometers have all moved lower by slightly greater amounts, probably because of settling of the gravel pack and distortions in the flexible PVC pipe.

At other sites it appears that the PVCs are more stable than casing protectors. The major control and subsidence bench marks are the most stable marks.

Other bench marks and reference points

These consist of:

(i) Ramset nails in concrete at bore collars
(ii) Protector casings at bores
(iii) P.V.C. piezometers
(iv) Steel casings as piezometers (No P.V.C.)
(v) Bench marks cut in trees.

In the black soil plains which form the major soil type north of the Namoi River, surface movement due to swelling and shrinkage of clays occurs with wetting and drying during flood and drought seasons. This movement makes some of these less stable reference points unreliable.

Evidence of such movement is demonstrated by -

a. Tilting and cracking of concrete placed at bore collars. Larger concrete slabs seem most affected.

b. Movement upwards of concrete blocks and some 'short length' bore protectors. (See Appendix 5a). In this case the concrete block is attached to the protector casing which has concrete poured between the P.V.C. and the casing. The P.V.C. appears unaffected by the surface movement and can be seen below the surface of the inner concrete. This movement occurs as a result of the concrete block being jacked up by the swelling and shrinking clay soils and seems to occur only if the concrete block at the bore collar extends below the ground surface. Evidence of this effect is also illustrated at subsidence bench marks which have had concrete at their collars pushed up around the P.V.C. (See Appendix 5b).

In cases where the concrete blocks were attached to the protector casing but just sitting on the ground this degree of movement doesn't seem to have occurred.

Steel protector casings can also be unreliable as reference points if back filling is poorly carried out. The protector can sink into the drilled hole. The photograph at Appendix 5c is a good example. Longer lengths of protector casing, between 3 and 6 metres in length without concrete at the collar and properly backfilled, are usually the most stable.

Bores cased all the way to basement (no P.V.C.), don't seem to be effected by surface movement. Bench marks cut in established trees also appear to be satisfactory as subsidence bench marks.

Care must be taken when comparing R.L.s of bore casing, protector casing, or P.V.C. because of differential movement. Also, on occasion, bores have been physically modified by having casing blanks added or cut from the original completed bore.

Given all these possible variations, with all the different types of reference points, the DWR levelling surveys were designed to measure all bench marks, piezometers and protector casings so as to later identify the most reliable marks.

5.2 Lower Namoi Valley

Survey levelling to identify possible subsidence has only been undertaken on three observation bore profiles in the lower Namoi Valley (Gurleigh, Wee Waa and Merah North Sections) with some bores being levelled more often than others. The possible extent of subsidence based on the

1988 and 1990 surveys is given in Figure 10. Details for each profile are given below.

Gurleigh Section

Tabulations showing the results of the survey work from 1975 to 1990 are given in Appendix 6 with a summary based on the major control bench marks given at Appendix 7.

This area was considered to be least at risk from subsidence but increased groundwater use in recent years in the northern areas of Zone 5 (adjoining Zone 1) prompted the Department to resurvey this area in 1988 and 1990. Some minor subsidence of around 70mm has been identified between bores 25326 and 25323 with the maximum subsidence occurring at bench mark FW430 at bore 25324 (although this may be an unreliable mark). This area coincides with the area of concentrated groundwater use and maximum variations in water levels (see Figure 6).

A comparison of the subsidence at bench mark FW507 (subsidence BM) versus the total groundwater usage in this area since 1974/75 is given in Figure 5.

Wee Waa Section

Tabulations showing the results of the survey work from 1975 to 1990 are given in Appendix 8 with a summary based on the major control bench marks given at Appendix 9.

The northern end of the Wee Waa section is considered to be the region of greatest subsidence potential. Control levelling of this section was first carried out in 1975. The section was again levelled in 1980 but the changes observed were small (perhaps twice that which might be attributed to survey error). In 1982 the part of this section north of the Spring Plain road was again levelled. The results varied little from the 1980 survey.

The northern portion of the Wee Waa section was next levelled in 1987. From the results of this levelling it was concluded that minor subsidence of the surface had occurred at the very northern end of this section. The subsidence began at bore 25054 and extended to beyond bore 30243. Maximum subsidence of around 180mm had occurred at bench mark FW347 at bore 30238. This coincides with the area of highest groundwater extraction and largest declines in water level as shown in Figure 7.

After the 1987 levelling of the Wee Waa section which showed the first indications of subsidence, an expanded work program was undertaken in 1988. The work included installing a further subsidence bench mark on the Wee Waa section, north of bore 30243. This bench mark was established beyond the expected northern limit of any subsidence and is shown on Figure 2.

In 1990 reports of bore collapses in the region led to further levelling of all three sections north of the Spring Plain Road. No substantial difference from previous levelling was found.

In all areas there was evidence of a widespread rise in ground surface of around 40mm which is attributable to the swelling of the clays following two very wet seasons. However despite the general rise, there was evidence of further subsidence along the northern Wee Waa Section centred on bore 30238. Here the total amount of subsidence is now around 210mm.

A comparison of the subsidence at bench mark FW347 (subsidence BM) versus the total groundwater usage in this area since 1974/75 is given in Figure 5.

Merah North Section

Tabulations showing the results of the survey work from 1980 to 1990 are given in Appendix 10 with a summary based on the major control bench marks given at Appendix 11.

The northern end of the Merah North section was considered to be an area of potential subsidence. Control levelling for this section was first undertaken in 1980. The portion considered most likely to be effected (i.e. north of bore 36044 on the Spring Plain Road) was levelled again in 1982. No reasonable level variations were found.

With subsidence being identified along the Wee Waa section in 1987, it was decided to relevel the Merah North section north of subsidence bench mark FW1020 at bore 25142.

In the course of this levelling it was found that minor surface subsidence (around 120mm in 1988; 70mm in 1990) had occurred on the Merah North section centred on bore 25300. It was decided to establish a bench mark, cut on a tree, to the north of any anticipated effects of water level decline. Bench mark FW1227 was cut 2Km north of bore 36046.

As for the other sections, this area coincides with some (not concentrated) groundwater use and large variations in water levels (see Figure 7). A comparison of the subsidence at bench mark FW96 (ramset nail in concrete block) versus total groundwater usage in this area since 1974/75 is given in Figure 5.

5.3 Mooki Valley

In addition to the lower Namoi Valley, one major control bench mark and five subsidence bench marks were established in the Mooki Valley in the 1970s. The only levelling relative to these bench marks has been routine levelling of investigation bores. No control levelling for subsidence has been undertaken.

A tabulation of their date of survey and reduced levels is attached at Appendix 12.

6. CONCLUSIONS

1. Land subsidence is directly related to:

   - large groundwater withdrawals away from the major recharge source, the Namoi River and
   - areas with large seasonal variations in groundwater levels and a long term reducing water level trend.

2. An area of between 250 square kilometres (1990 survey) and 360 square kilometres (1988 survey) has been affected by subsidence of 50mm or more in the lower Namoi Valley. Maximum subsidence of:

   - 70mm has been recorded at bore 25325 on the Gurleigh Section
   - 210mm has been recorded at bore 30238 on the Wee Waa Section (the 200mm change over an 8km distance represents a change in gradient of 1:40000)
   - 70mm has been recorded at bore 25300 on the Merah North Section

3. There is an apparent time lag between large groundwater withdrawals and the first signs of subsidence.

4. No structural damage has been reported except for some collapsed irrigation boreholes.

5. Subsidence has occurred because of dewatering of shallow aquifers and aquitards above the main productive aquifers. Now that drainage of some deeper aquifers is occurring, the following trends can be expected:

   - increased drainage from the overlying aquitards followed by further subsidence
   - lower water level declines as the main productive aquifers become unconfined

6. The subsidence identified to date is minor. No predictive modelling of the amount of subsidence has been undertaken as part of this study. It is uncertain to what degree ongoing subsidence will affect the area. This should be the focus of further work together with more survey levelling in say 5 years time.

7. Management strategies adopted to date to deal with excessive groundwater depletion in area north of the Spring Plain area are:

- reduced entitlements compared to those that applied in the 1970s
- a total embargo on new entitlements and no groundwater transfers into the area
- more efficient use of water
- construction of farm storages to hold tailwater, rainfall and flood flows for further irrigation requirements

8. Future strategies that should be considered are:

- further reduction in entitlements
- artificial recharge schemes
- changes to the floodway scheme to redirect flood flows into the area
- substitution of groundwater entitlements by regulated surface water
- returning irrigation properties to dryland farming operations

7. REFERENCES

Cobb, MA (1982) - "Groundwater Resources of the Barossa Valley" SA Dept of Mines and Energy. Unpub Report 82/67, October 1982.

DWR (1988) - "Review of Groundwater Use and Water Level Behaviour in the Lower Namoi Valley, NSW - 1983 to 1988" - Status Report No. 7, 13p, November 1988.

DWR (1991) - "Review of Groundwater Use and Water Level Behaviour in the Upper Namoi Valley, and its Important Tributaries - 1984 to 1990" - Status Report No. 3, 9p, February 1991.

Evans, R (1986) - "Subsidence Estimates for Groundwater Development at Barwon Downs, Kawarren, and Gellibrand". Report to Natural Resources and Environment Committee by Rural Water Commission, 19p, January 1986.

Gloe, CS (1984) - "Case History 9.1 : Latrobe Valley, Victoria, Australia" pp145-153 in Guidebook to Studies of Land Subsidence due to Groundwater Withdrawal, Unesco, 1984.

Indreland, JB (1978) - "Failure and Aging of Water Well Casing and Screen by Compressive Rupture, Incrustation and Corrosion" Roscoe Moss, California

Larson, MK (1984) - "Potential for Subsidence Fissuring in the Phoenix Arizona USA Area" pp291-299 in Land Subsidence, IAHS Publication No. 151, 1986.

Lofgren, BE (1978) - "Changes in Aquifer System Properties with Groundwater Depletion" pp26-46 in Evaluation and Prediction of Subsidence Conference Volume, ASCE, 1978.

Prokopovich, NP (1984) - "Classification of Land Subsidence by Origin" pp281-290 in Land Subsidence, IAHS Publication No. 151, 1986.

WRC (1983) - "Licensing Policy for High Yield Bores in the Lower Namoi Valley, New South Wales" 9p, July 1983.

WRC (1984) - "Licensing Policy for High Yield Bores in the Upper Namoi Valley, Mooki Valley and Cox's Creek, New South Wales" 16p, October 1984.

APPENDICES

APPENDIX 1

MAJOR CONTROL BENCH MARKS (BEDROCK) - LOWER NAMOI VALLEY

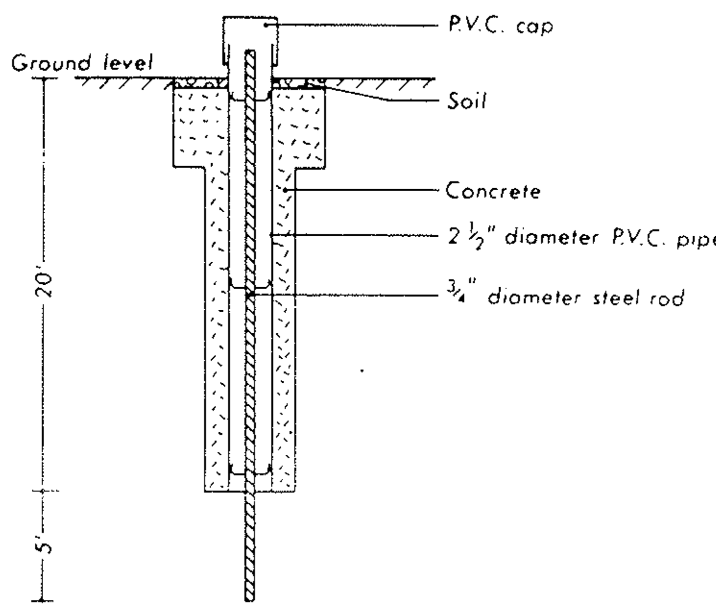
Bore	B.M. F.W.	Casing Length (m)	Original Survey Year	R.L.(mAHD)
30070	157	169.4	1974 -	200.000
30142	360	170.0	1981 -	204.670
30188	278	122.2	1974 -	193.283
30259	912	132.1	1981 -	209.680
30266	283	133.0	1974 -	194.966
30452	1005	80.8	1981 -	198.581
36036	1018	82.2	1980 -	182.420
36044	434	85.5	1980 -	177.245
36141	722	80.4	1981 -	171.699
36250	900	81.3	1981 -	159.431

APPENDIX 2

CONSTRUCTION OF SUBSIDENCE BENCH MARKS

1. Duration: From 15th August, 1972 to early 1973

2. Theory: Due to the movement of the surface structure in the Narrabri - Wee Waa area and therefore the difficulty of measuring static water tables, bench marks are being placed as described below throughout this district.



3. Method: Holes 20' deep are being drilled, the PVC being placed in the hole with the rod inside, the rod then being driven into the ground as far as possible or 5 feet with a post jumper and sledge hammer. The casing is then concreted into position and a PVC cap placed on top.

4. Access: The positions of these bench marks beside bores and access is quite good but only in fine weather.

5. Personnel: R.J. Taylor
   A. Whipps
   A.D. Ferguson

APPENDIX 3

SUBSIDENCE BENCH MARKS - LOWER NAMOI VALLEY

Bore	BM F.W.	Original Survey Year R.L	R.L. 1975	R.L. 1980	R.L. 1982	R.L. 1987	R.L. 1988	R.L. 1990
21263	279	1974 - 199.822						
21265	423	1975 - 198.994						
21269	420	1981 - 197.847						
21433	921	1981 - 201.028						
21435	922	1981 - 204.883						
21480	819	1978 - 190.190						
25048	275	1974 - 190.072	190.072	190.052	190.072	190.057	190.057	
25054	424	1975 - 186.721	186.721	186.686	186.701	186.660	186.664	186.641
25216	919	1981 - 203.736						
25220	898	1981 - 206.483						
25222	821	1981 - 209.554						
25136	1017	1980 - 182.272						
25138	1019	1980 - 182.485						
25140	1191	1980 - 182.268						
25142	1020	1980 - 181.724					181.762	
25144	1021	1980 - 180.066					180.096	
25146	1022	1980 - 179.796					179.831	
25148	1023	1980 - 178.411					178.411	
25244	435	1980 - 176.994		176.994	176.992		176.983	176.989
25246	436	1980 - 175.969		175.969	175.964		175.930	175.956
25248	439	1980 - 175.104		175.104	175.104		175.045	175.079
25321	433	1981 - 192.445					192.415	192.455
25323	431	1981 - 194.695					194.633	194.694
25325	507	1981 - 195.307					195.215	195.233

Bore	BM F.W.	Original Survey Year R.L	R.L. 1975	R.L. 1980	R.L. 1982	R.L. 1987	R.L. 1988	R.L. 1990
25328	282	1981 - 197.054					197.065	197.055
25335	1004	1981 - 197.078						
25337	920	1981 - 194.496						
30077	419	1981 - 198.646						
30101	913	1981 - 201.361						
30117	482	1981 - 209.136						
30121	483	1975 - 211.094						
30190	272	1974 - 191.700	191.700	191.691		191.690		
30222	425	1975 - 185.203	185.203	185.137	185.129	185.048	185.058	185.031
30238	347	1975 - 184.379	184.379	184.327	184.344	184.198	184.224	184.168
30266	421	1981 - 194.999	195.005	195.002	194.996	194.996		194.994
30288	822	1978 - 191.251						
30338	1048	1980 - 187.350						
30339	911	1980 - 183.286						
	1228	1988 - 182.796					182.796	182.786

APPENDIX 4

BENCH MARKS AND BORE DETAIL @ BORE 30266

Origin of Levels Major (Control) B.M. FW 283 - R.L. 194.966 to A.H.D.

	16.8.74	19.3.75	30.5.75	18.1.77	2.5.78	20.3.79	14.8.80	13.6.81	1.4.82	14.3.85	10.9.87	28.8.90
Outer Casing @ FW283	195.260	195.256	195.256	195.254	195.254	195.255	195.254	-	195.254	195.254	195.256	195.260
FW421 Subsidence BM	-	195.004	195.005	195.002	195.005	195.005	195.002	194.999	194.996	194.992	194.996	194.994
FW284 Box	195.129	195.116	195.110	195.109	195.100	195.110	195.100	195.095	195.094	195.092	195.097	195.117
Bore 30266 PVC 1	195.696	195.695	195.696	195.692	195.689	195.694	195.681	195.676	195.678	195.677	-	195.690
Bore 30266 PROT 1	195.746	195.743	195.746	195.741	195.739	195.746	195.736	195.731	195.734	195.734	-	195.748
Bore 30266 PVC 2	195.760	195.760	195.760	195.759	195.758	195.759	195.758	195.754	195.753	195.748	-	195.751
Bore 30266 PROT 2	195.845	195.843	195.844	195.842	195.844	195.843	195.842	195.839	195.836	195.832	-	195.835
Bore 30266 PVC 3	195.610	195.606	195.606	195.601	195.600	195.604	195.591	195.584	195.586	195.586	-	195.601
Bore 30266 PROT 3	195.693	195.689	195.691	195.387	195.686	195.690	195.678	195.671	195.671	195.672	-	195.686
226 EB Box					194.520						194.541	194.549

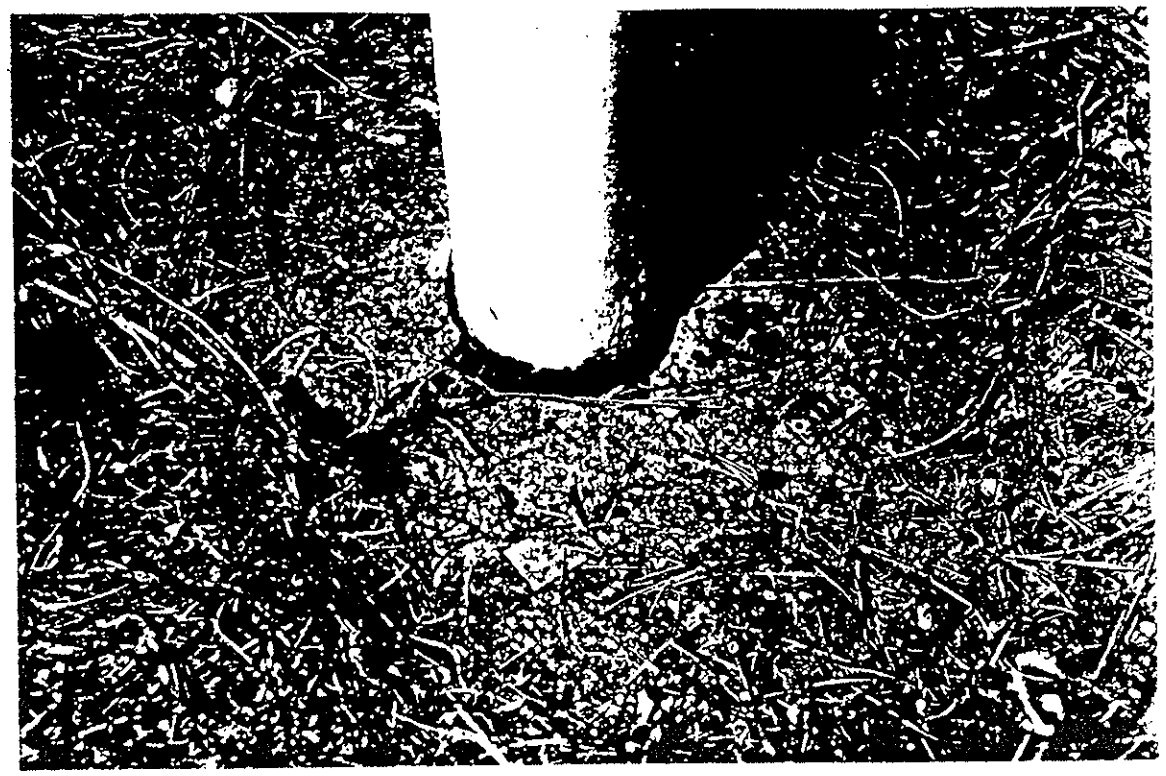
APPENDIX 5

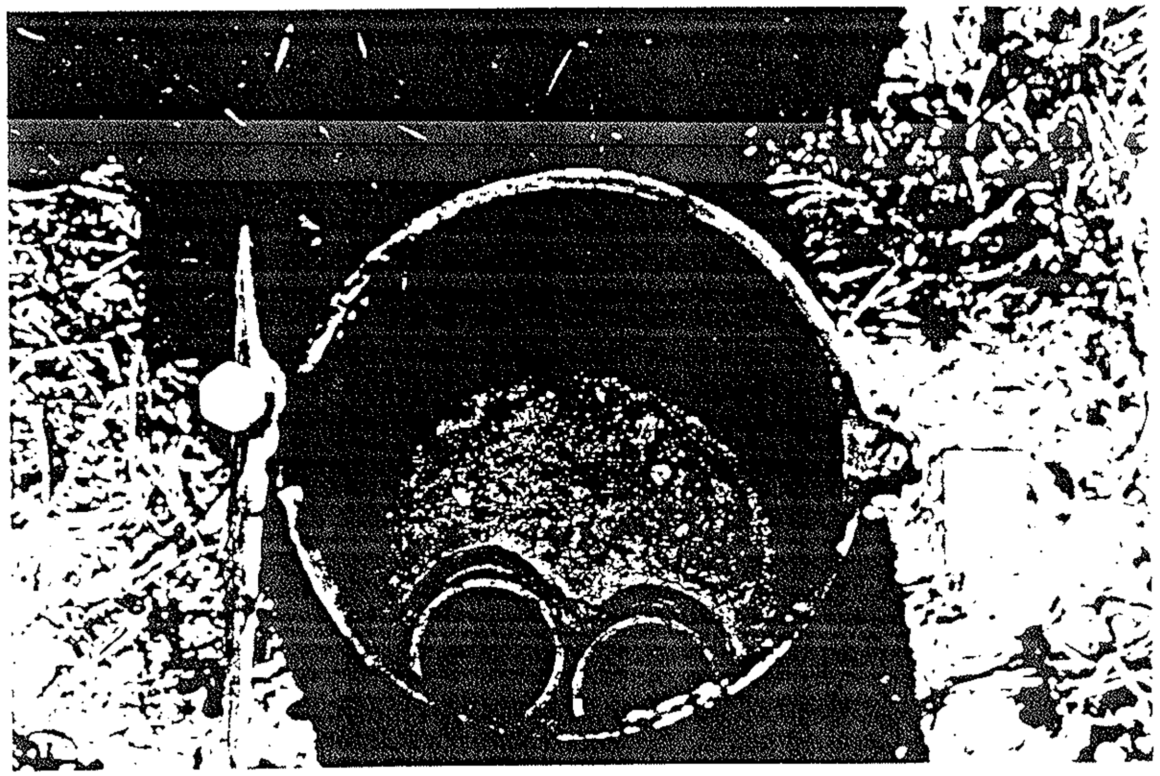
PHOTOGRAPHS

5a Upward Movement of Concrete Block and Bore Protector - Bore 25249

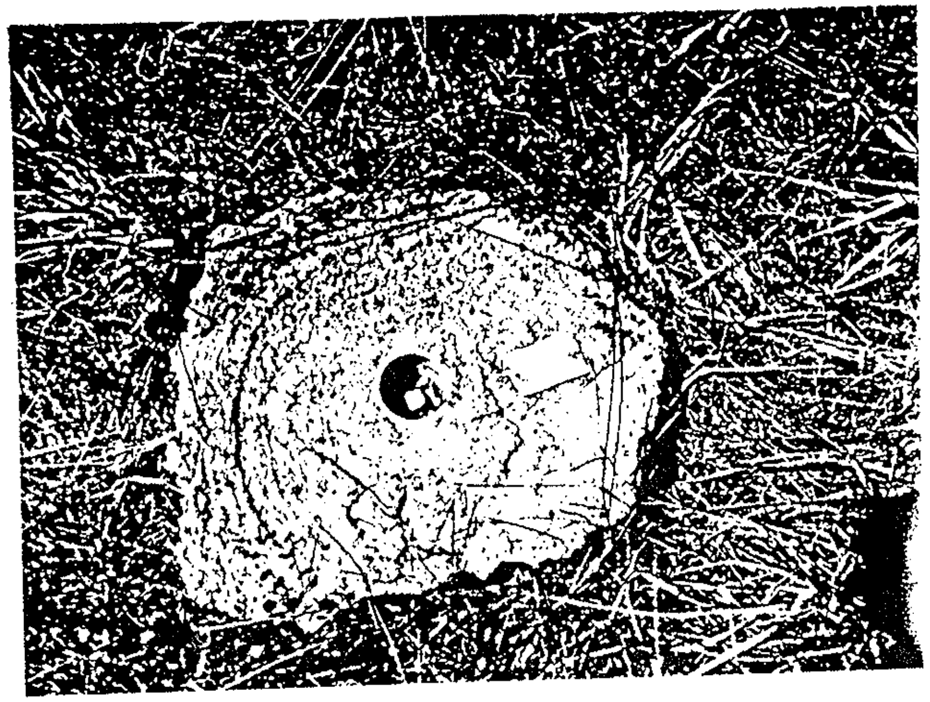
5b Raised Concrete Block around Subsidence Bench Mark - Bore 30063

5c Subsided Casing Protector - Bore 36168

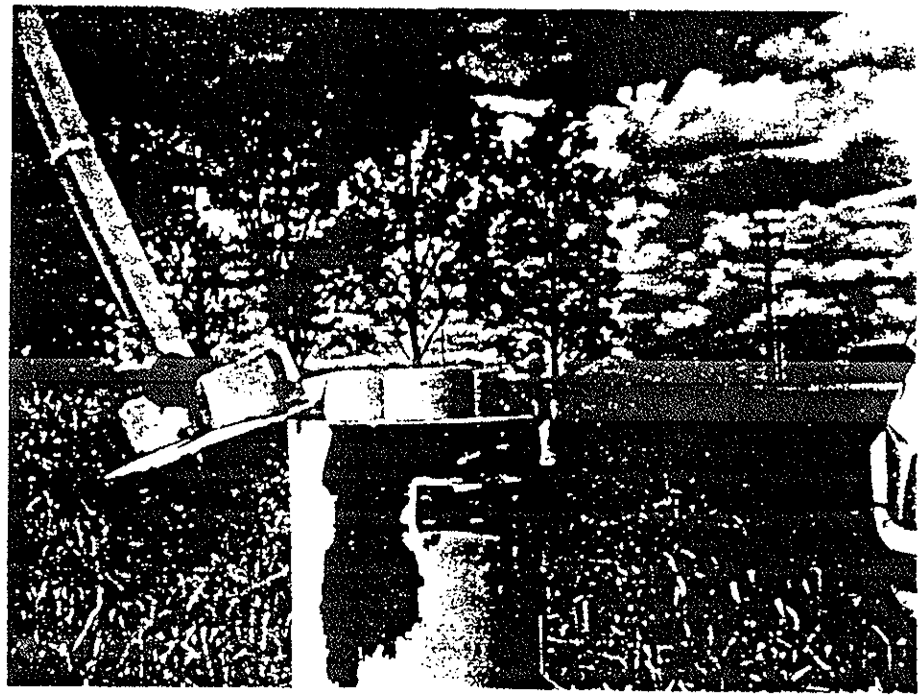




5a. Upward Movement of Concrete Block and Bore Protector - Bore 25249



5b. Raised Concrete Block around Subsidence Bench Mark - Bore 30063



5c. Subsided Casing Protector - Bore 36168

APPENDIX 7

GURLEIGH SECTION - SURVEY SUMMARY

Origin Major (Control) B.M. F.W. 283 - R.L. 194.966 to A.H.D

	R.L. 1975	R.L. 1988	Change	R.L. 1990	Cum Change
FW283 @ 30266	194.966	Origin	-		
FW282 @ 25328	197.054	197.065	+0.011	197.055	+0.001
FW507 @ 25325	195.307	195.215	-0.092	195.233	-0.074
FW431 @ 25323	194.695	194.633	-0.062	194.694	-0.001
FW433 @ 25321	192.445	192.415	-0.030	192.455	+0.010

	1975	1988	Change	1990	Cum Change
FW283 - FW282	+2.088	+2.099	+0.011	-	
FW282 - FW507	-1.747	-1.850	-0.103	-1.822	-0.075
FW507 - FW431	-0.612	-0.582	+0.030	-0.539	+0.073
FW431 - FW433	-2.250	-2.218	+0.032	-2.239	+0.011

APPENDIX 9

WEE WAA SECTION - SURVEY SUMMARY

Origin Major (Control) B.M. F.W. 278 - R.L. 193.283 to A.H.D

	R.L. 1975	R.L. 1980	Cum Change	R.L. 1982	Cum Change	R.L. 1987	Cum Change	R.L. 1988	Cum Change	R.L. 1990	Cum Change
FW 278 @ 30188	193.283	Origin									
FW 272 @ 30190	191.700	191.691	-0.009	-	-	191.690	-0.010				
FW 275 @ 25048	190.072	190.052	-0.020	190.072	-	190.057	-0.015	Origin 1988	-		
FW 424 @ 25054	186.721	186.686	-0.035	186.701	-0.020	186.660	-0.061	186.664	-0.057	186.641	-0.080
FW 425 @ 30222	185.203	185.137	-0.066	185.129	-0.074	185.048	-0.155	185.058	-0.145	185.031	-0.172
FW 347 @ 30238	184.379	184.327	-0.052	184.344	-0.035	184.198	-0.181	184.224	-0.155	184.168	-0.211
Prot. 30243/2	184.003	183.939	-0.064	183.956	-0.047	183.847	-0.156	183.894	-0.109	183.894	-0.163
FW 1228								182.796	New	182.796	0

	Base 1975	1980	Change	1982	Cum Change	1987	Cum Change	1988	Cum Change	1990	Cum Change
FW278 - FW272	-1.583	-1.592	-0.009	-		-1.593	-0.010				
FW272 - FW275	-1.628	-1.639	-0.011			-1.633	-0.005				
FW275 - FW424	-3.351	-3.366	-0.015	-3.371	-0.020	-3.397	-0.046	-3.393	-0.042		
FW424 - FW425	-1.518	-1.549	-0.031	-1.572	-0.054	-1.612	-0.094	-1.606	-0.088	-1.610	-0.092
FW425 - FW347	-0.824	-0.810	+0.014	-0.785	+0.039	-0.850	-0.026	-0.834	-0.010	-0.863	-0.039
FW347 - 30243/2	-0.376	-0.388	-0.012	-0.388	-0.012	-0.351	+0.025	-0.330	+0.046	-0.274	+0.102
30243/2-FW 1228								-1.098	New	-1.108	-0.010

APPENDIX 11

MERAH N SECTION (N OF SPRING PLAINS ROAD) - SURVEY SUMMARY

Origin Major (Control) B.M. F W 434 - R.L. 177.245 to A.H.D.

	R.L. 1980	R.L. 1982	Change	R.L. 1988	Change	R.L. 1990	Change
FW434 @ 36044	177.245	Origin	-				
FW435 @ 25244	176.994	176.992	-0.002	176.983	-0.011	176.989	-0.005
FW436 @ 25246	175.969	175.964	-0.005	175.930	-0.039	175.956	-0.013
FW439 @ 25248	175.104	175.104	0.000	175.045	-0.059	175.079	-0.025
L1191	173.701	173.705	+0.004	173.616	-0.085	173.676	-0.025
*FW96 @ 25300	173.691	173.682	-0.009	173.569	-0.122	173.622	-0.069
*FW438 @ 36046	173.284	173.286	+0.002	173.183	-0.101	173.235	-0.049
FW1227				172.177		172.241	+0.064

	Base 1980	1982	Change	1988	Cum Change	1990	Cum Change
FW434 - FW435	-0.251	-0.253	-0.002	-0.262	-0.011		
FW435 - FW436	-1.025	-1.028	-0.003	-1.053	-0.028	-1.033	-0.008
FW436 - FW439	-0.865	-0.860	+0.005	-0.855	+0.010	-0.877	-0.012
FW439 - L1191	-1.403	-1.399	+0.004	-1.429	-0.026	-1.403	0
L1191 - FW96	-0.010	-0.023	-0.013	-0.047	+0.037	-0.054	-0.044
FW96 - FW438	-0.407	-0.396	+0.011	-0.386	+0.021	-0.387	+0.020
FW438 - FW1227				-1.006	New	-0.994	+0.012

* Because subsidence is occurring at the northern end of this section bench marks FW96 and FW438 are included. These marks are ramset nails in concrete at bore collars and don't have the reliability of the specially constructed subsidence bench marks.

APPENDIX 12

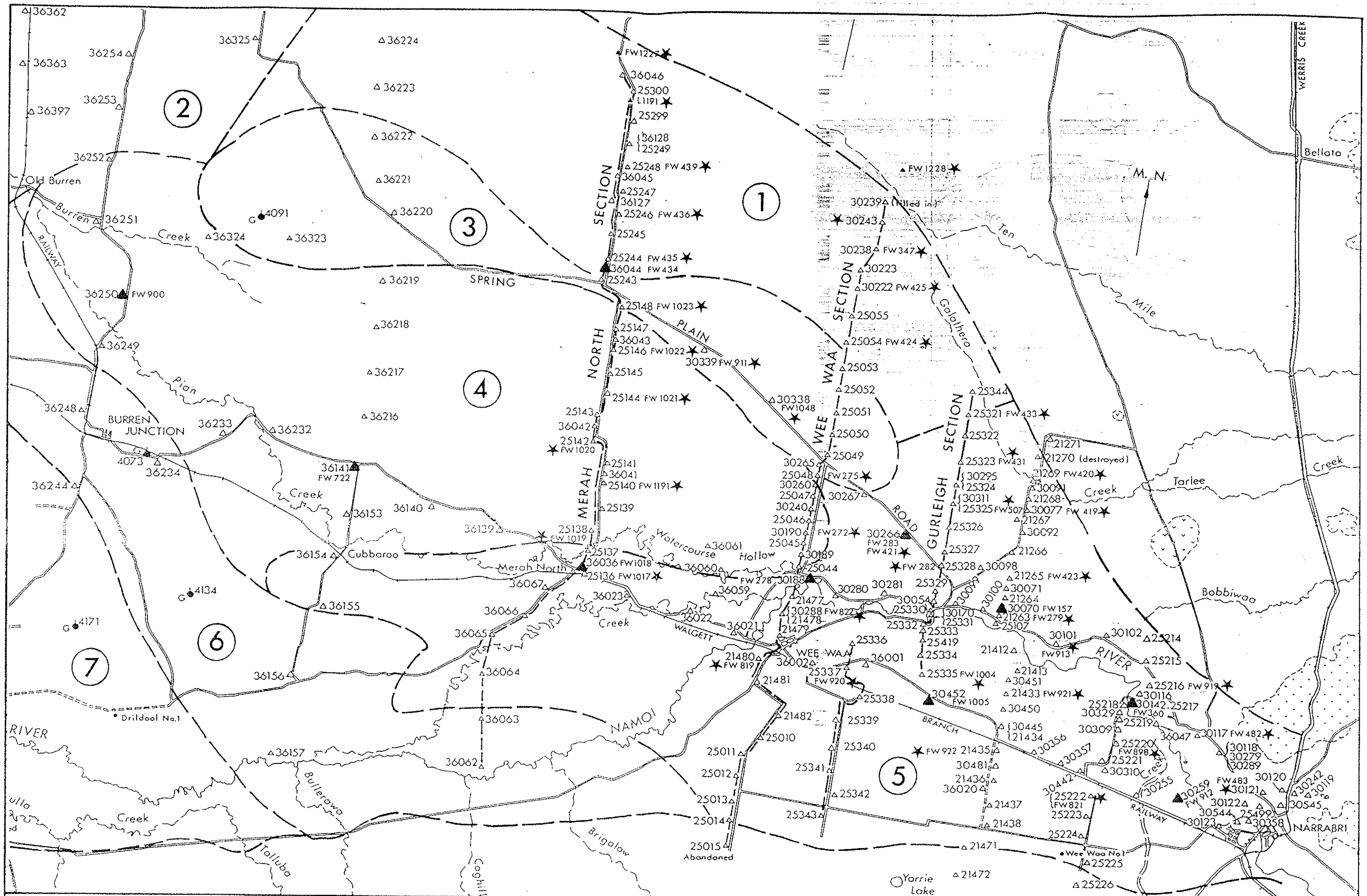
MAJOR CONTROL BENCH MARKS (BEDROCK)

MOOKI VALLEY

Bore	B.M. F.W.	Original Survey Year		R.L. (m AHD)
30063	627	1976	-	321.161

SUBSIDENCE BENCH MARKS - MOOKI VALLEY

Bore	B.M. F.W.	Original Survey Year		R.L. (m AHD)
30002	685	1976	-	286.873
30003	688	1977	-	286.726
30063	655	1976	-	320.939
30086	657	1976	-	328.506
30274	656	1976	-	323.646



LEGEND

▲ 36044 FW 434	Major (Control) Bench Marks (Bedrock)
✶ 25244 FW 435	Subsidence Bench Marks (C.T.)
(2) — — —	Zone Boundaries

DEPARTMENT OF WATER RESOURCES

HYDROGEOLOGY UNIT – TECHNICAL SERVICES DIVISION

LOCALITY PLAN – LOWER NAMOI VALLEY

Scale 1 : 250 000

5 0 5 10 15 Kilometres

FIG. 2

GURLEIGH SECTION

	TOP OF PROTECTOR					TOP OF PVC					B.M.				
BORE	GROUND	1975	1988	1990	CUM.DIFF.	BORE-PVC	1975	1988	1990	CUM.DIFF.	B.M.	1975	1988	1990	CUM.DIFF.
Origin of levels-major control B.M.F.W.283-R.L.194.966															
25328/1	197.1	197.697	197.716	197.709	+ 0.012	25328/1	197.678	197.697	197.686	+ 0.008					
/2		197.742	197.753	197.744	+ 0.002	/2	197.714	197.725	197.715	+ 0.001					
/3		197.728	197.737	197.729	+ 0.001	/3	197.711	197.719	197.710	- 0.001					
/4		197.807	197.814	197.805	- 0.002	/4	197.737	197.746	197.736	- 0.001	SUB.B.M.				
											FW 282	197.054	197.065	197.055	+ 0.001
25327/1	196.4	197.246	197.242	197.240	- 0.006	25327/1	197.231	197.227	197.225	- 0.006					
/2		197.116	197.113	197.112	- 0.004	/2	197.112	197.108	197.105	- 0.007					
/3		197.167	197.168	197.166	- 0.001	/3	197.066	197.066	197.063	- 0.003	FW 429	196.396	196.393	196.390	- 0.006
25326/1	195.7	196.399	196.383	196.390	- 0.009	25326/1	196.386	196.367	196.373	- 0.013					
/2		196.312	196.294	196.300	- 0.012	/2	196.279	196.264	196.270	- 0.009					
/3		196.378	196.364	196.374	- 0.004	/3	196.366	196.354	196.365	- 0.001					
25325/1	195.2	195.766	195.677	195.695	- 0.071	25325/1	195.737	195.647	195.666	- 0.071					
/2		195.842	195.750	195.769	- 0.073	/2	195.822	195.732	195.750	- 0.072					
/3,4		195.828	195.737	195.755	- 0.073	/3,4	195.814	195.723	195.742	- 0.072					
/5		195.782	195.693	195.710	- 0.072	/5	195.770	195.682	195.700	- 0.070					
/6		195.797	195.707	195.725	- 0.072	/6	195.788	195.697	195.714	- 0.074					
(30311)=/7		195.894	195.802	195.821	- 0.073	(30311)=/7	195.890	195.798	195.817	- 0.073	SUB.B.M.				
											FW 507	195.307	195.215	195.233	- 0.074
25324/1	194.6	195.199	195.086	195.107	- 0.092	25324/1	195.199	195.086	195.107	- 0.092					
/2		195.181	196.068	195.089	- 0.092	/2	195.181	195.068	195.089	- 0.092					
/4,5		195.134	195.020	195.042	- 0.092	/4,5	195.119	195.015	195.036	- 0.083	FW 430	194.625	194.513	194.535	- 0.090
30295/1		195.252	195.137	195.158	- 0.094	30295/1	195.232	194.948	194.969	- 0.263					
25323/1	194.3	195.191	195.128			25323/1	195.185	195.122							
/2		195.198	195.133			/2	195.194	195.131			SUB.B.M.				
Levels taken before protectors were cut down on 28.6.88 to allow passage of machinery											FW 431	194.695	194.633	194.694	- 0.001
25323/1	194.3		194.592	194.653	+ 0.061	25323/1		194.590	194.650	+ 0.060					
/2			194.582	194.643	+ 0.061	/2		194.575	194.634	+ 0.059	SUB.B.M.				
Levels taken after protectors were cut down											FW 431	194.695	194.633	194.694	- 0.001
25322/1	193.5	194.360	194.331			25322/1	194.340								
/2		194.457	194.426			/2	194.428				FW 432	193.635	193.601	193.656	+ 0.021
Levels taken before protectors were cut down on 28.6.88 to allow passage of machinery															
25322/1	193.5		193.745	193.802	+ 0.057	25322/1		193.740	193.797	+ 0.057					
/2			193.762	193.819	+ 0.057	/2		193.759	193.816	+ 0.057	FW 432	193.635	193.601	193.656	+ 0.021
Levels taken after protectors were cut down															
25321/1	192.3	193.364	193.362	193.410	+ 0.046	25321/1	193.342	193.335	193.383	+ 0.041					
/2		193.350	193.332	193.376	+ 0.026	/2	193.327	193.303	193.347	+ 0.020					
/3		193.438	193.414	193.457	+ 0.019	/3	193.420	193.398	193.440	+ 0.020	SUB.B.M.				
											FW 433	192.445	192.415	192.455	+ 0.010
25344	190.9	192.231	192.182	192.236	+ 0.005	25344	192.205	192.152	192.207	+ 0.002					
This bore is in the centre of an irrigation channel and its stability is in doubt															

WEE WAA SECTION

	TOP OF PROTECTOR								TOP OF PVC								B.M.							
BORE	GROUND	1975	1980	1982	1987	1988	1990	CUM. DIFF.	BORE - PVC	1975	1980	1982	1987	1988	1990	CUM. DIFF.	B.M.	1975	1980	1982	1987	1988	1990	CUM. DIFF.
Origin of levels - major control B.M. F.W. 278 - RL 193.283																								
		m.p.rec			m.p.rec																			
30188/1	193.3	194.682			194.613			- 0.069	30188/1								FW 277	193.290	193.280		193.294			+ 0.004
/2		193.882	193.890		193.922			+ 0.040	/2	193.698	193.700		193.697			- 0.001								
/3		193.872	193.880		193.888			+ 0.016	/3	193.721	193.724		193.725			+ 0.004								
/4		193.857	193.869		193.922			+ 0.065	/4	193.680	193.668		193.674			- 0.006								
																	FW 278	193.283						
25044/1	192.7	193.170	193.138		193.124			- 0.046	25044/1	193.152	193.120		193.084			- 0.068	FW 97	192.898	192.868		192.857			- 0.041
/2		193.158	193.126		193.114			- 0.044	/2	193.150	193.116		193.103			- 0.047								
/3		193.180	193.150		193.144			- 0.036	/3	193.163	193.153		193.092			- 0.071								
30189	191.8	192.234	192.224		192.209			- 0.025	30189/1	192.060	192.040		192.022			- 0.038	FW 270	191.837	191.823		191.798			- 0.039
									/2	192.062	192.035		192.020			- 0.042								
									/3	192.064	192.043		192.024			- 0.040								
25045/1	191.0	191.678	191.654		191.650			- 0.028	25045/1	191.657	191.627		191.619			- 0.038	FW 98	191.247	191.223		191.222			- 0.025
/2		191.680	191.654		191.652			- 0.028	/2	191.640	191.614		191.616			- 0.024								
30190	191.6	192.170	192.155		192.134			- 0.036	30190/1	191.946	191.944		191.940			- 0.006	FW 271		191.630		191.608			- 0.022
									/2	191.942	191.940		191.934			- 0.008								
									/3	191.930	191.929		191.924			- 0.006	SUB.B.M.							
																	FW 272	191.700	191.691		191.690			- 0.010
25046/1	190.9	191.478	191.425		191.439			- 0.039	25046/1	191.460	191.411						FW 99	191.023	190.967		190.985			- 0.038
/2		191.470	191.421		191.434			- 0.036	/2	191.464	191.406													
30240	190.8	191.424	191.388		191.396			- 0.028	30240/1	191.150	191.122		191.130			- 0.020	FW 273	190.792	190.759		190.765			- 0.027
									/2	191.150	191.118		191.126			- 0.024								
									/3	191.124	191.095		191.104			- 0.020								
25047/1	190.4	191.424	191.400		191.354			- 0.070	25047/1	191.420	191.395		191.349			- 0.071	FW 100	191.047	191.018		190.979			- 0.068
/2		191.426	191.393		191.355			- 0.071	/2	191.430	191.394		191.361			- 0.069								
/3		191.420	191.381		191.350			- 0.070	/3	191.292	191.243		191.218			- 0.074								
30260	190.7	191.574	191.558		191.548			- 0.026	30260/1	191.324	191.301		191.289			- 0.035	FW 274	190.701	190.686		190.674			- 0.027
									/2	191.494	191.468		191.456			- 0.038								
									/3	191.556	191.518		191.508			- 0.048								
25048/1	190.0	190.399	190.386	190.381	190.378	190.395		- 0.004	25048/1		190.374		190.319	190.325		- 0.049	FW 101	190.112	190.081	190.080	190.072	190.089		- 0.023
/2		190.544	190.512	190.510	190.512	190.528		- 0.016	/2		190.296	190.294	190.292	190.311		+ 0.015								
																	SUB.B.M.							
																	FW 275	190.072	190.052	190.052	190.057	190.057		- 0.015
30265	189.9	191.099	191.080	191.080	191.080	191.088		- 0.011	30265/1	191.042	191.030	191.030	191.035	191.040		- 0.002	FW 276	189.915	189.892	189.891	189.899	189.931		+ 0.016
									/2	191.099	191.082	191.080	191.080	191.088		- 0.011								
									/3	191.042	191.026	191.030	191.046	191.051		+ 0.009								

25049/1	190.0	190.615	190.590	190.594	190.604	190.601		- 0.014	25049/1	190.615	190.590	190.592	190.596	190.593		- 0.022	FW 102	190.202	190.168	190.169	190.176	190.174		- 0.028
/2		190.585	190.543	190.537	190.546	190.544		- 0.041	/2	190.595	190.546	190.546	190.550	190.543		- 0.052								
/3		190.590	190.530	190.524	190.526	190.524		- 0.066	/3	190.547	190.510	190.508	190.520	190.514		- 0.033								
25050	189.3	190.070	190.022	190.005	190.027	190.028		- 0.042	25050	190.017	189.971	189.954	189.976	189.777		- 0.040	FW 103	189.562	189.514	189.497	189.515	189.515		- 0.047
25051	188.8	189.281	189.249	189.253	189.289	189.302	189.324	+ 0.043	25051	189.168	189.134	189.143	189.130	189.145	189.147	- 0.021	FW 104	188.871	188.844	188.853	188.889	188.901	188.926	+ 0.055
25052	188.1	188.660	188.628	188.643	188.649	188.676	188.678	+ 0.018	25052/1	188.608	188.573	188.584	188.584	188.598	188.598	- 0.010	FW 105	188.191	188.158	188.175	188.184	188.206	188.212	+ 0.021
									/2	188.600	188.568	188.580	188.577	188.591	188.592	- 0.008								
25053	187.4	187.830	187.830	187.839	187.831	187.860	187.865	+ 0.035	25053	187.783	187.782	187.789	187.786	187.812	187.820	+ 0.037								
25054	186.5	187.024	187.009	187.000	186.995	187.015	187.000	- 0.024	25054/1	186.946	186.909	186.896	186.878	186.885	186.855	- 0.091	FW 129	186.587	186.569	186.555	186.555	186.574	186.558	- 0.029
									/2	186.944	186.904	186.896	186.875	186.887	186.855	- 0.089	SUB.B.M.							
																	FW 424	186.721	186.686	186.681	186.660	186.664	186.641	- 0.080
25055	185.7	186.226	186.199	186.194	186.155	186.180	186.166	- 0.060	25055/1	186.141	186.086	186.076	186.028	186.057	186.018	- 0.123	FW 130	185.829	185.804	185.801	185.763	185.785	185.775	- 0.054
									/2	186.146	186.121	186.113	186.042	186.103	186.090	- 0.056								
									/3	186.141	186.096	186.087	186.076	186.063	186.051	- 0.090								
30222/1	184.9	186.039	185.972	185.942	185.883	185.892	185.864	- 0.175	30222/1	185.957	185.892	185.858	185.803	185.812	185.783	- 0.174								
/2		186.129	186.061	186.032	185.974	185.982	185.954	- 0.175	/2	186.027	185.958	185.927	185.868	185.876	185.850	- 0.177	FW 213	184.979	184.897	184.858	184.608	184.832	184.824	- 0.155
																	SUB.B.M.							
																	FW 425	185.203	185.137	185.109	185.048	185.058	185.031	- 0.172
30223/1	183.9	184.672	184.666	184.661	184.566	184.590	184.570	- 0.102	30223/1	184.322	184.308	184.242	184.152	184.160	184.112	- 0.210								
/2		184.605	184.614	184.614	184.510	184.542	184.538	- 0.067	/2	184.292	184.259	184.303	184.164	184.167	184.123	- 0.169	FW 214	183.962	183.968	183.969	183.864	183.898	183.892	- 0.070
30238/1	184.1	184.836	184.775	184.782	184.693	184.758	184.742	- 0.094	30238/1	184.598	184.523	184.518	184.386		184.469	- 0.129								
/2		184.706	184.653	184.654	184.570	184.621	184.588	- 0.118	/2	184.476	184.393	184.390	184.268	184.306	184.245	- 0.231	FW 215	184.139	184.084	184.084	183.998	184.049	184.015	- 0.124
																	SUB.B.M.							
																	FW 347	184.379	184.327	184.324	184.198	184.224	184.168	- 0.211
30243/1	183.1	183.951	183.891	183.886	183.797	183.838	183.788	- 0.163	30243/1	183.316	183.256	183.248	183.164	183.204	183.149	- 0.167								
/2		184.003	183.939	183.936	183.847	183.894	183.840	- 0.153	/2	183.710	183.649	183.643	183.554	183.596	183.551	- 0.159								
/3		183.836	183.779	183.774	183.686	183.727	183.678	- 0.158	/3	183.466	183.414	183.408	183.318	183.361	183.313	- 0.153	FW 216	183.146			182.994	183.038	182.990	- 0.156
30239	182.5	Abandoned -bore backfilled																						
	182.4																SUB.B.M.							
																	FW 1228					182.796	182.786	- 0.010

MERAH NORTH SECTION

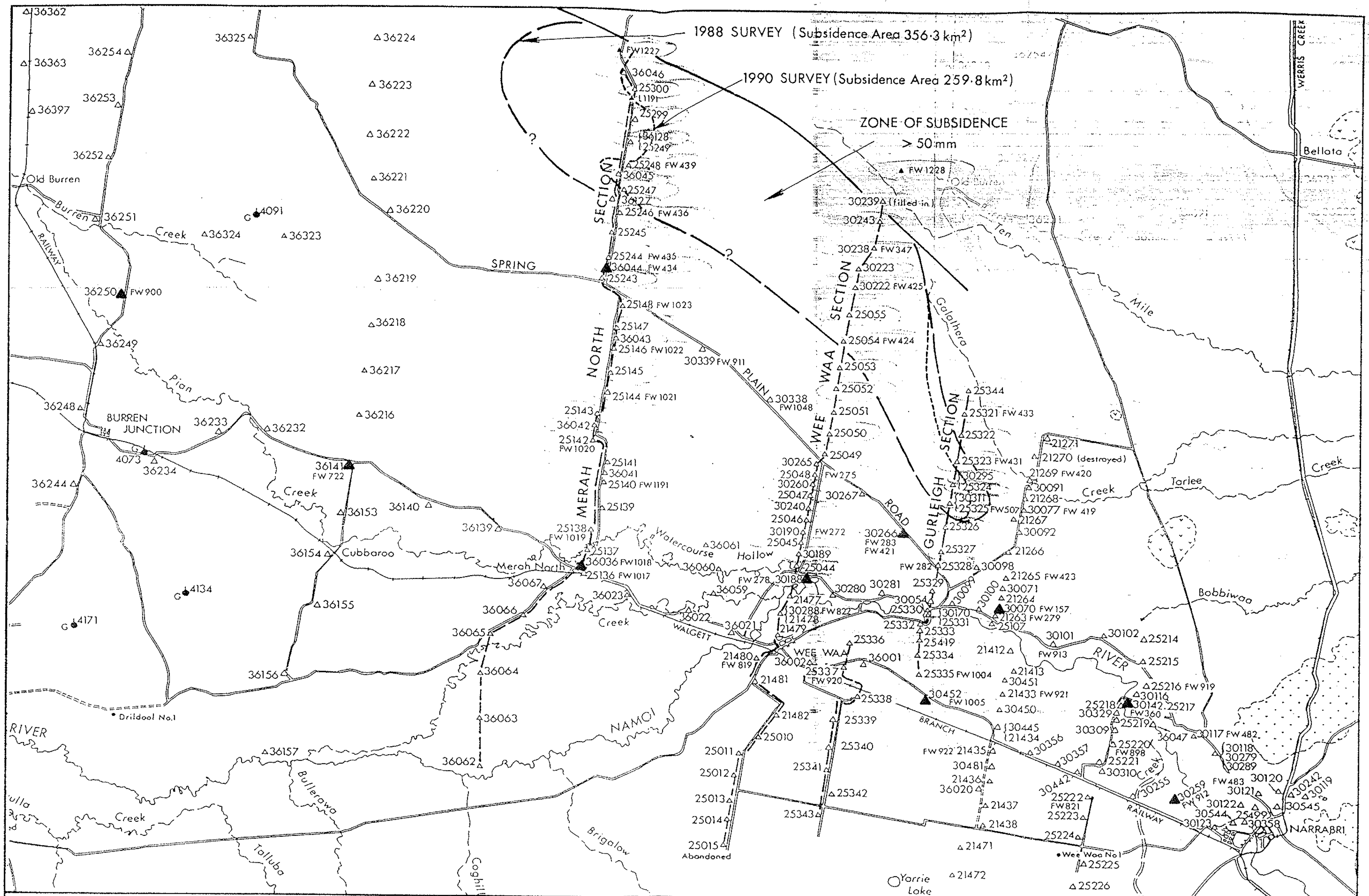
Appendix 10a

	TOP OF PROTECTOR						TOP OF PVC						B.M.					
BORE	GROUND	1980	1982	1988	1990	CUM.DIFF.	BORE-PVC	1980	1982	1988	1990	CUM.DIFF.	B.M.	1980	1982	1988	1990	CUM.DIFF.
Origin of levels - major control B.M. F.W. 434 - R.L. 177.245																		
25142/1	181.5	182.119		182.158		+ 0.039	25142/1	182.105		182.146		+ 0.041	FW 83	181.574		181.619		+ 0.045
/2		screw on lid, could not be removed					/2											
/3		182.028		182.065		+ 0.037	/3	NO PVC	(102mm CAS)									
													SUB.B.M.					
													FW 1020	181.724		181.762		+ 0.038
36042/1	180.8	181.678		181.708		+ 0.030	36042/1	181.658		181.691		+ 0.033						
/2		181.700		181.741		+ 0.041	/2	181.684		181.717		+ 0.033						
25143/1	180.5	181.015		181.050		+ 0.035	25143/1	180.902		180.889		- 0.013	FW 84	180.580		180.615		+ 0.035
/2		180.795		180.828		+ 0.033	/2	NO PVC	(102mm CAS)									
/3		180.935		180.967		+ 0.032	/3	NO PVC	(102mm CAS)									
/4		181.070		181.105		+ 0.035	/4	NO PVC	(102mm CAS)									
													B.M.L1047 C'BAH			180.530		
25144	179.8	180.581		180.620		+ 0.039	25144/1	180.353		180.393		+ 0.040	FW 85	180.014		180.058		+ 0.044
							/2	180.352		180.392		+ 0.040						
							/3	180.353		180.390		+ 0.037	SUB.B.M.					
													FW 1021	180.066		180.096		+ 0.030
25145/1	179.8	180.494		180.572		+ 0.078	25145/1	180.349		180.398		+ 0.049	FW 86	179.882		179.969		+ 0.087
/2		180.297		180.378		+ 0.081	/2	180.175		180.209		+ 0.034						
/3		180.334		180.420		+ 0.086	/3	180.214		180.246		+ 0.032						
/4		180.338		180.424		+ 0.086	/4	180.197		180.244		8						
25146/1	179.5	180.109		180.190		+ 0.081	25146/1	179.994		180.068		+ 0.074	FW 87	179.670		179.733		+ 0.063
/2		180.087		180.148		+ 0.061	/2	179.964		180.033		+ 0.069						
/3		180.087		180.152		+ 0.065	/3	197.934		179.968		+ 0.034	SUB.B.M.					
													FW 1022	179.796		179.831		+ 0.035
													BML 1050 C'BAH			179.535		
36043/1	179.3	179.845		LUG REC.BOX 179.882 M.P.REC 180.052		+ 0.037	36043/1	179.817										
/2		179.912		LUG REC.BOX 179.965 M.P.REC 180.150		+ 0.053	/2	179.712					FW 779	179.348		179.422		+ 0.074
25147/1	178.8	179.339		179.398		+ 0.059	25147/1	179.230		179.253		+ 0.023	FW 88	178.864		178.913		+ 0.049
/2		179.259		179.300		+ 0.041	/2	179.106		179.137		+ 0.031						
/3		179.304		179.343		+ 0.039	/3	179.179		179.213		+ 0.034						
25148	178.2	178.920		178.940		+ 0.020	25148/1	178.792		178.780		- 0.012	FW 89	178.336		178.361		+ 0.025
							/2	178.792		178.776		- 0.016						
													SUB.B.M.					
													FW 1023	178.411		178.411		0.000

25243	177.3	177.689	CAS. DAMAGED				25243											
36044	177.2	177.610	177.604	177.625	177.661	+ 0.051	36044	177.272	177.249	177.246	177.280	+ 0.008	MAJOR CONTROL					
													FW 434	177.245	177.245	177.245	177.245	0.000
25244/1	176.9	177.560	177.558	177.548	177.556	- 0.004	25244/1	NO PVC (102mm CAS)										
/2		177.424	177.423	177.413	177.421	- 0.003	/2	NO PVC (102mm CAS)										
													SUB.B.M.					
													FW 435	176.994	176.992	176.983	176.989	- 0.005
25245/1	176.8	177.367	177.369	177.340	177.367	0.000	25245/1	NO PVC (102mm CAS)										
/2		177.358	177.362	177.333	177.360	+ 0.002	/2	NO PVC (102mm CAS)										
/3		177.538	177.544	177.527	177.564	+ 0.026	/3	177.363	177.366	177.336	177.366	+ 0.003	FW 780	177.008	177.012	176.996	177.029	+ 0.021
													B.M. L1186	177.053	177.055	177.032	177.057	+ 0.004
													- STUMP					
25246/1	175.9	176.419	176.402	176.398	176.430	+ 0.011	25246/1	176.124	176.117	176.088	176.116	- 0.008						
/2		176.374	176.365	176.361	176.398	+ 0.024	/2	176.181	176.173	176.156	176.181	0.000	FW 91	175.974		175.956	175.997	+ 0.023
													SUB.B.M.					
													FW 436	175.969	175.964	175.930	175.956	- 0.013
36127/1	176.0	176.886	176.887	176.828	176.858	- 0.028	36127/1	176.866	176.856	176.799	176.838	- 0.028	FW 781	176.013	176.012	175.956	175.984	- 0.029
/2		176.913	176.914	176.859	176.890	- 0.023	/2	176.883	176.883	176.830	176.860	- 0.023						
25247/1	175.8	176.260	176.256	176.196	176.224	- 0.036	25247/1	NO PVC (102mm CAS)					FW 92	175.972	175.971	175.910	175.935	- 0.037
/2		176.420	176.416	176.376	176.428	+ 0.008	/2	176.240	176.236	176.181	176.214	- 0.026						
/3		176.257	176.256	Damaged (bent over)			/3	NO PVC (102mm CAS)										
													SSM NO No.	175.643	175.642	175.590	175.634	- 0.009
		M.P.REC.		M.P.REC.														
36045/1	174.8	175.908		175.868	175.922	+ 0.014												
				LUG REC.BOX														
				175.708	175.762					175.671	175.702							
/2		175.751	175.748	175.692	175.721	- 0.030	36045/2	175.738	175.734	175.677	175.707	- 0.031						
/3		175.766	175.760	175.704	175.732	- 0.034	/3	175.741	175.736	175.680	175.709	- 0.032	FW 437	174.908	174.884	174.832	174.857	- 0.051
25248/1	174.9	175.430	175.430	175.373	175.407	- 0.023	25248/1	NO PVC (102mm CAS)										
/2		175.421	175.422	175.362	175.398	- 0.023	/2	NO PVC (102mm CAS)										
/3		175.397	175.396	175.339	175.373	- 0.024	/3	NO PVC (102mm CAS)										
													SUB.B.M.					
													FW 439	175.104	175.104	175.045	175.079	- 0.025
25249	173.6	174.167	174.173	174.150	174.210	+ 0.043	25249/1	173.958	173.956	173.891	173.928	- 0.030	FW 94	173.648	173.648	173.621	173.659	+ 0.011
							/2	173.957	173.960	173.891	173.932	- 0.025						
				LUG REC.BOX														
				174.507	174.550													
		M.P.REC.		M.P.REC.														
36128	173.6	174.714		174.637	174.682	- 0.032												
25299	173.5	173.970	173.972	173.958	173.986	+ 0.016	25299/1	173.889	173.892	173.806	173.858	- 0.031	FW 95	173.550	173.548	173.501	173.528	- 0.022
							/2	173.892	173.895	173.808	173.863	- 0.029						
													B.M.					
													L 1191-BOX	173.701	173.705	173.616	173.676	- 0.025

Appendix 10 c

25300	173.7	174.112	174.102	173.998	174.049	- 0.063	25300	174.088	174.076	173.960	174.014	- 0.074	FW 96	173.691	173.682	173.569	173.622	- 0.069
36046/1	173.3	174.169	LUG REC.BOX 174.165 M.P.REC. 174.337	174.060	174.115	- 0.054	36046/1	174.159		174.051	174.108	- 0.051	FW 438	173.284	173.286	173.183	173.239	- 0.049
/2		174.194	LUG REC.BOX 174.186 M.P.REC 174.366	174.084	174.140	- 0.054	/2	174.180		174.072	174.128	- 0.052						
													FW 1227-BOX			172.177	172.241	+ 0.064



LEGEND

▲ 36044 FW434 Major (Control) Bench Marks (Bedrock)

25244 FW435 Subsidence Bench Marks (C.T.)

— — 1988 Survey

- - - 1990 Survey

DEPARTMENT OF WATER RESOURCES

HYDROGEOLOGY UNIT – TECHNICAL SERVICES DIVISION

SUBSIDENCE AREA – LOWER NAMOI VALLEY

Scale 1 : 250 000

5 0 5 10 15 Kilometres

FIG. 10