

DEPARTMENT OF MINES  
SOUTH AUSTRALIA

*Section*  
RB 56/3

PROGRESS REPORT ON  
THE INVESTIGATION INTO THE EFFECTS OF THE INCREASING  
UTILIZATION OF THE PRESSURE GROUNDWATERS  
OF THE NORTHERN ADELAIDE PLAINS

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Rept. Bk. No. 56/3  
G.S. No. 2515  
D.M. 2193/61  
MYD. No. 1402

4th January, 1963.

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**I. INTRODUCTION**

The rapid expansion of the metropolitan area in the post war years has caused large areas of land, particularly in the western suburbs, to be sub-divided for housing. This land had previously been used for market gardening, and these activities were transferred to other districts where good quality groundwater was obtainable in close proximity to the metropolitan area. In these areas of the northern Adelaide Plains where the groundwater was of suitable quality for vegetable growing, land which had previously been used for cereal cropping and grazing was broken up into relatively small holdings each equipped with a bore or bores. Water quality and soil conditions not being everywhere suitable for general market gardening caused relatively close settlement in the more favourable areas, resulting in high bore densities in these areas. Initially groundwater consumption for each holding was relatively small, but in the past three or four years there has been a tendency towards potato growing and lucerne irrigation, both of which necessitate greater pumping rates over longer periods than the glass house tomatoes and other vegetables. Consequently groundwater consumption has increased steadily over the last ten years, and at this stage there are in excess of three thousand bores in the area.

Recognizing the need for a complete appraisal of the area the Department has conducted preliminary surveys to gather information on the nature of the basin sediments and the various aquifers which contain the pressure waters. Several reports on specific localities have been prepared since the initial survey by K.R. Miles in 1952, but to date no report incorporating the area as a whole has been issued.

A programme of water level observations, similar to those carried out in the metropolitan area has been undertaken since 1953, the number of bores observed being steadily increased since the inception. Consequently water level behaviour can be closely studied over the last ten years, and the effects of the increased groundwater utilization on water levels is particularly apparent.

This report is intended as a brief appraisal of the investigations to date, with an assessment of the effects of the greatly increasing groundwater consumption and the possible dangers associated therein. A reiteration of previous investigators conclusions is unavoidable as the problems associated with the area have been realized for many years.

## II. NATURE OF THE BASIN

### 1. Extent and Topography

The investigation covers an area of approximately 200 square miles embracing those portions of the Hundreds of Port Adelaide, Yatala, Munno Para, Port Gawler and Mudla Wirra, bounded to the north by an east-west line just north of Two Wells, and to the south by the easterly extension of the boundary between the Hundreds of Port Adelaide and Yatala. The eastern and western boundaries are physiographical, the westerly boundary being the coastline, the easterly the escarpment of the Para Fault occurring to the east of and parallelling the Adelaide - Gawler road.

The northern and southern boundaries are natural in that although the basin sediments and the pressure waters extend further in both directions, the salinities of the groundwaters outside of the boundaries mentioned are too high for general irrigation use and consequently have been little developed.

Topographically the area consists of the relatively flat coastal plain of the elevated and dissected plateau of the Para Fault Block. Drainage is to the west from the Para Fault scarp, consequent streams, but only two of these streams reach the sea,

the Little Para River, and the Gawler River, both of which drain a considerable area to the east of the fault. The remainder of the streams enter the plains from the escarpment but because of the limited and seasonal flows, do not penetrate far to the west before the waters are absorbed into the soils of the plains. Even the two major streams are not perennial, flowing to the sea only in times of heavy rain.

With the relatively low gradient of the area both the Little Para and Gawler Rivers are notable for the strong development of natural levee banks, particularly in the western limits, and local flooding had been prevalent prior to the construction of additional levees. Impeounding of the waters to the east of the scarp and cultivation of the soils of the plains has probably considerably lessened the volumes of water entering both rivers in recent years, and hence reduced the dangers of flooding.

The western or coastal area is characterized by a relatively wide strip of tidal and salt flats, extending up to four miles inland from the coast in some areas. It is in this region that the I.C.I. evaporation pans have been constructed.

## 2<sup>nd</sup> Geology

Bounded to the east by a faulted contact with the Pre-Cambrian rocks of the Adelaide System the area under consideration is portion of the St. Vincent Basin. The basin comprises a considerable thickness of Tertiary and Pleistocene sediments deposited on the structurally depressed block of the ancient peneplaned Pre-Cambrian land surface.

The depth of these later sediments is not known, as no bores in the area have penetrated the complete sequence. However seismic and gravity surveys indicate that the depth of the Tertiary and younger sediments is in excess of 1500 feet at Elizabeth, approximately 1400 feet at Virginia and Port Gawler, and approximately 1100 feet just north of Two Wells. These figures indicate that the basement slopes gently to the south and east, and this

is confirmed in part by the known bedrock depths in the Grange and Croydon bores, and in bores in the Mallala area.

A series of lagoonal, lacustrine and marine sediments ranging from early to late Tertiary age was deposited upon the Pre-Cambrian basement. Presumably a full Tertiary sequence is present throughout the area but bores have only penetrated to the Upper Eocene beds. The Miocene and Pliocene limestones and sands of the upper portion of the sequence constitute the aquifers for the pressure waters in the basin.

Overlying the Tertiary sediments is a series of Pleistocene to Recent fresh and brackish water, mottled clays with minor intercalated sand and gravel beds. A series of fine grained sands of probable Pleistocene age and terrestrial in origin occur in some areas underlying the clays and resting on the Pliocene sands. These younger sediments also thicken to the southeast, being approximately 150 feet thick in the Two Wells area, 200 feet in the Virginia area and 400 feet in the Salisbury area. The clays are generally impervious, and confine the water in the underlying Tertiary sediments, thus creating the pressure water or sub-artesian conditions.

The basin in this area may therefore be summarized as consisting of wedge-shaped deposits resting on an inclined basement. The thickening of the sediments to the south-east is probably indicative of subsidence of the eastern margin during deposition. Structure within the Tertiary sediments has not been determined, although there is some evidence of minor flexures within them. However whether these are depositional, erosional or structural cannot be evaluated at this stage.

### 3. Aquifers

The groundwaters can be divided into two main groups, the waters contained in the Pleistocene to Recent fresh water sediments, and those occurring in the Pliocene and Miocene marine sediments.

The Pleistocene to Recent aquifers are confined to the gravel and sand lenses which occur throughout the mottled clays, and because of their irregular distribution and variable water quality are not extensively used for irrigational purposes, except in the vicinity of the two rivers, and then only in isolated cases. Therefore it is considered that these aquifers are not particularly significant in the interpretation of the groundwater potential of the area, and for the purposes of this report will not be further discussed.

The pressure waters which are extensively used throughout the area are contained in the upper portion of the Tertiary marine sediments, and to a more limited extent in the fine sands at the base of the Pleistocene. By far the most important aquifer is a consolidated fossiliferous limestone and calc-arenite of middle Miocene age which extends over the greater portion of the area. The only area where the bed is absent as such is in a zone adjacent to and paralleling the Para Fault scarp. In this area the sediments in a similar stratigraphic position to the calc-arenite are unconsolidated, consisting of fine sands and silts, and it is presumed that close to the scarp the sedimentary environment was unfavourable for the formation of the limestones. A similar effect is observed in similar situations in the metropolitan area, and also in the Willunga Basin. The thickness of the bed is not known as bores have not as yet penetrated it, but in most areas it is in excess of 200 feet.

This limestone, known locally as "coral" is a good aquifer in that it is highly permeable and generally does not require casing, being sufficiently consolidated to stand unsupported, yet soft enough for high drilling penetration rates. Many bores obtain relatively large supplies from within it.

Overlying the Miocene limestones in some areas is a wedge-shaped deposit of mainly unconsolidated, shelly sands, of Pliocene age, known as the Dry Creek sands. The northern boundary of these sediments is approximately on a line running through Pt. Gawler, Virginia and Penfield, the bed thickening and deepening

to the south. They consist of fine siliceous sands, calcareous and consolidated in parts, containing numerous large shells and shell fragments, and rest directly on the underlying Miocene limestones. Because of their nature they are not as good an aquifer as the limestones, there being some difficulty in developing the fine sands, and generally the supplies obtained from the sands are smaller than those obtained from the underlying limestones. They are extensively used in the Waterloo Corner and the Port Gavler areas, but elsewhere the Miocene sediments are generally preferred as an aquifer.

Hydrologically there is no separation between the Pliocene sands and the upper Miocene limestones, and with minor exceptions they can be considered as the one unit. However within the Miocene limestones there is a bed of blue-grey marine clay occurring at varying depths below the top of the limestones, but generally within 50 feet of the base of the Pliocene. This clay band in a considerable portion of the area acts as an aquiclude separating the Tertiary sediments into two aquifers, the upper comprising the Pliocene sands and a varying thickness of Miocene limestones, the lower composed entirely of Miocene sediments. In some areas these two aquifers contain water of similar salinity, whereas in others there is salinity variation between the waters above and below the aquiclude. The effect is most pronounced in those areas west of the Port Wakefield Road, and for a limited area east of Waterloo Corner. It is also believed that the separation of the two aquifers extends south of the Little Para River and presumably into the metropolitan area, but because of the deepening of the basin in this direction very few bores are of sufficient depth to penetrate to the lower Miocene sediments.

In addition it is obvious that in some areas the clay band is absent or not sufficiently impervious to act as an

aquiclude, and mixing of the two aquifers occurs. This probably accounts in part for some of the anomalous salinities recorded in some areas, but insufficient information is available to assess the full significance of the clay aquiclude.

#### 4. Intake, Groundwater Movement, and Outlets

A study of the hydraulic surface of the pressure waters indicates that intake into the marine aquifers occurs in the eastern margins of the basin, the water moving in a general westerly direction through the aquifers, eventually draining into the sea.

The actual mechanism of intake is not yet fully understood. Salinity zones and hydraulic contours indicate that the main intake points are where the Gawler and Little Para rivers enter the plains area from the dissected Para Fault block. To a limited extent the other smaller consequent streams also contribute. Two theories have been proposed for the mechanism of intake. The first is that the Tertiary sediments are in contact with the plane of the Para Fault and that water moves down the fault zone into the sediments. The second is that the Pleistocene to Recent sediments which overlie the aquifers, and which over the greater portion of the basin are impervious, are of a more sandy and permeable nature in the eastern zones, and thus could permit downward percolation of water into the marine sediments.

However in the region of the fault zone insufficient details of the nature and configuration of the Pleistocene to Recent sediments are available to assess the validity of either of the two proposed mechanisms. Present indications are that the intake is probably a combination of both, though which of the two has the greater influence is not known. Knowledge of the intake mechanism would be of vital importance should artificial recharge ever be considered, and an extensive testing programme in the critical areas would be required for a complete evaluation.

On entering the aquifers and being confined by the overlying impervious sediments the water moves westward under the

influence of the hydraulic head existing at the intake points. The gradient of the hydraulic surface varies throughout the area, depending on permeability and other factors, but in general is approximately 1 in 1000 in the winter months. Hence the rate of movement is probably slow, although it is not possible to estimate the rate because of the lack of information on porosities and permeabilities of the various aquifers. The gradient is considerably altered under the influence of the heavy summer pumping.

At some point in the western margins of the basin it may be assumed that the groundwaters have an outlet to the sea, and are in hydraulic connection with the seawater. This connection is indicated by the sympathetic movements of water levels in bores to tidal fluctuations. The tidal response has been measured by automatic water level recorders installed in bores in the western suburbs of the metropolitan area, and a similar effect can be assumed to continue northwards into the area under discussion, and has in fact been observed in some of the coastal bores in the Port Gawler area. The effect does not continue very far inland from the coast.

The saline water is under normal circumstances held back by the greater hydraulic head of the pressure waters contained in the aquifers, and under these conditions a salt-fresh water boundary is formed. The position of such a boundary is not definitely known in the northern Adelaide Plains, but it is fairly certain that one exists for each of the two divisions of the marine aquifers, and also that the position of the boundary is different in each aquifer. The upper aquifer is bounded by the overlying Pleistocene to Recent sediments, the westerly extension of which is not known, but it is possible that they do not extend in the form of impervious clays far westward of the present coastline. The lower aquifer is bounded by an aquiclude within the Miocene sediments, and it is possible that the aquifer extends further west than the Pleistocene to Recent sediments,

and hence the direct connection with seawater is further west for the lower aquifer. This has been verified in the coastal observation bores, and the significance will be discussed in greater detail in a later section of this report.

## 5. Salinities

The salinity of groundwater in this type of basin is dependent on three factors, the salinity of the intake waters, the solubility of the aquifer sediments, and the mixing or otherwise with waters previously contained in the sediments.

The aquifer sediments were deposited in a marine environment, and must have originally contained sea-water. This water known as "connate" water must have been replaced by low salinity water for the aquifer to contain today water of far lower salinity than seawater. The replacement of the saline water is attributed to the westerly movement of the intake waters flushing out the saline waters over a period of time, the action being more complete in some areas, thus in part causing the zones of varying salinity. There being a greater volume of water from the main intake areas of the Gawler and Little Para rivers there has been a greater freshening effect in these areas, resulting in zones of lower salinity extending westward from the intake points, and paralleling approximately the present day courses of the rivers. In the period of time required for the water to move from intake to outlet some of the soluble material contained in the aquifer sediments has also been incorporated into the groundwater, resulting in a slight rise in salinity in a westward direction. This effect is not as noticeable in the northern Adelaide Plains area as in some other basins, apparently due to the relative insolubility of the aquifer sediments.

The two low salinity zones widen towards the west and in the Waterloo Corner area merge in the upper aquifer, although not in the lower. The triangular area east of this point, and which includes Smithfield, Elizabeth, Penfield and Direk, is not in the direct path of the recharge waters, and with resultant

less flushing the aquifers contain higher salinity water.

To the north of the Gawler River the salinity of the water rapidly increases until in the Two Wells area the salinity is in excess of 200 grains per gallon, and increasing northward with the distance away from the recharge waters. A similar situation exists south of the Little Para River.

The approximate salinity zones are shown on the plan appended to this report. Lack of information in some areas prevents the accurate positioning of boundaries in these areas, and such boundaries are indicated on the plan.

As can be seen from the plan the salinity pattern in the Waterloo Corner area is complex. The upper portion of the marine aquifer contains water of approximately 60 grains per gallon, in contrast to the lower aquifer where the salinity is in excess of 100 grains per gallon. This is apparently due to greater permeability of the upper aquifer allowing more lateral spread of the fresh waters than occurs in the lower aquifer. This better quality water in the upper aquifer extends to the east of the Port Wakefield Road, but lack of suitable bores in the area does not permit a reliable estimation of the eastern limit, and the boundary as shown on the plan is tentative.

The westerly extension of the low salinity zones is not completely known. Recent bores in the coastal area have revealed that the upper marine aquifer contains highly saline water, whereas beneath the clay aquiclude the lower aquifer contains low salinity water. Therefore in the upper aquifer the westward movement of the low salinity water is halted at some point east of the present coastline, whereas in the lower aquifer the equilibrium point must occur further west of the coastline.

### III. PROBLEMS ASSOCIATED WITH INCREASED GROUNDWATER UTILIZATION

Situations similar to those encountered in the northern Adelaide Plains have been encountered in other parts of the world with the greater use of groundwaters as surface catchments have been found to be inadequate for the quantity of water required. In many cases it has been found necessary to implement some form of control on withdrawal so that serious deterioration of the groundwater resources does not occur. The investigation carried out by this Department has been aimed at determining whether or not the groundwater resources of the area are in danger of depletion, so that some form of effective control can be applied to safeguard the area.

The necessity of such an investigation is apparent when it is realized that the groundwater resources of the area are not unlimited, and should the situation arise whereby the productivity of the basin is exceeded, then deterioration of both the quality and quantity of the low salinity groundwater could occur, with consequent disastrous effects to this important primary producing area.

As is the case in all groundwater basins, the groundwaters of the aquifers underlying the northern Adelaide Plains are in equilibrium with various factors, and it is the continuance of these equilibria which enables low salinity water to be obtained in some areas and not in others. The increasing groundwater utilization has obviously upset the equilibria, and it has been the aim of the investigation to determine the effects of the disturbances, and to gauge the dangers associated with them.

Lacking factual data on both the annual intake and withdrawal from the basin it has been necessary to study the hydraulic behaviour of the aquifers. Unfortunately this does not at this stage provide positive information as to whether the basin is being overpumped, or as to when this situation will arise. However the investigation does reveal that as a result of the greatly increased groundwater consumption a set of conditions

has arisen which could lead to deterioration in both quantity and quality.

As previously mentioned the low salinity waters are bounded on several sides by zones of higher salinity, one to the north of the Gavler River, one to the south of the Little Para River, one in the Penfield, Direk area, and another in the western coastal region. Entry of these saline waters into the zones of good quality waters is under natural conditions prevented by the low salinity water having a greater hydraulic head, and provided this head is maintained, ingression of the saline waters is not possible.

Because of the high bore densities in the low salinity zones, there is much greater withdrawal in these zones, resulting in a general lowering of the piezometric surface in the better quality areas. Consequently the natural hydrostatic equilibrium is disturbed, and should the lowering of the piezometric surface be particularly severe, the natural hydraulic gradient can be reversed, and the saline water can move into the zones of better quality water. Upon cessation of pumping the "low" in the piezometric surface will recover, and if recovery is complete the saline water will be forced back to its original position. If however the gradient is reversed for a considerable period of the summer, and recovery to the original position is slow, then it is likely that upon recovery the saline water is not forced completely back, and so over a period of years will move into areas previously containing low salinity water.

The study of the reversal of the natural hydraulic gradient has been the prime consideration of the investigation to date. The investigation can be divided into three separate lines of study

1. Static Water Level Observations.
2. Salinity Observations.
3. Detection and Measurement of the Coastal Saline Water.

#### IV. INVESTIGATIONS

##### 1. Static Water Level Observations

Since 1953 water level measurements have been taken monthly in a series of bores throughout the area. Although confined initially to a few bores the programme has been steadily increased, until at present a total of 89 bores are measured.

The majority of these bores are privately owned and all measurements are taken with the permission of the landowner. In certain areas however no suitable bores were available for measurement, and to avoid a lack of information in these areas the Department constructed six additional bores. In this programme 2156 feet of drilling was involved at a cost of £8,500.

The selection of suitable bores for static water level observation is not easy. To enable regular and reliable measurements to be obtained it is necessary for a bore to be both accessible and not pumping continuously throughout the summer months. Accessibility is the most difficult problem as normally once a pump has been fitted bores are not accessible for measurement, and modifications to existing boreheads have been carried out in many cases by the Department. In addition the increasing use of the deep well turbine pump has created further problems. In this type of installation there is insufficient annular space between the bore casing and the pump column to permit the entry of any measuring device. The problem can be overcome by the attachment of an airline to the pump column when the pump is installed, thus enabling the head of water above the base of the airline to be measured by means of air pressure. This method is not as accurate as direct measurement, but has been the only means of obtaining water level information in certain areas. In the past two years additional observation bores have all necessitated airlines, with the airline material being supplied by the Department.

In the selection of suitable observation bores the Department is hampered by both lack of authority and the full co-operation of the landowners. As the owners are not bound to advise intention to construct a bore, or to advise when a bore has been completed, continual surveillance of the areas is required for the selection of additional observation bores. Even when a bore in a suitable location is recorded, the full co-operation of both the landowner and pump installation organization is required to install an airline, and unfortunately such co-operation is not always obtained.

An additional problem is that bores which have been observed become inaccessible through the installation of pumps, or a change in the type of pump installed in the bore, without the prior knowledge of the Department. Full co-operation of the landowners would prevent this, and enable more continuous water level information to be maintained, but many bores which had previously been observed for varying periods of time have been lost.

The locations of the existing static water level observation bores are shown on the plan appended to this report. Water levels are measured monthly by an officer of the Department, and all levels are recorded and related to a datum of L.W.O.S.T. Port Adelaide. This information is made available to any enquirer, and is often used as a guide in determining pump settings.

## **2. Salinity Observations**

During the period of the investigation random sampling of bores has been carried out. With the discovery of highly saline water in the upper marine aquifer in the coastal regions it was decided that more intensive sampling was required, particularly in the coastal areas. Accordingly bores adjacent to the known areas of saline water have been sampled at monthly intervals since early 1962 in an attempt to detect saline ingression.

Further inland a series of bores has been selected, and sampling at periodic intervals commenced. As saline ingression is not quite as serious a threat in these areas it was considered that sampling at three monthly intervals would be sufficient. It has not been possible to fully implement the inland sampling programme at this stage, mainly because of the lack of pumping in the winter months.

Locations of the bores selected for salinity observations are shown on the attached plan.

### **3. Detection and Measurement of Coastal Saline Water Ingression**

The discovery of the highly saline water in the marine aquifers in the coastal areas was considered to constitute an immediate threat to the groundwaters to the west of the Port Wakefield road. In addition to the regular sampling of existing bores in the area, a programme of test holes was initiated, firstly to detect a saline-fresh water interface, and secondly to measure the seasonal fluctuations of the interface under the influence of the heavy pumping. Funds for six test holes have been allocated, and construction of the holes is in progress.

Geophysical surveys of the critical areas were carried out in an attempt to discover the interface, but were not successful. Resistivity methods were used, but the presence of highly saline surface water prevented sufficient depth penetration by this method. It is believed that the recently acquired induced potential equipment may not be affected to such an extent, and it is intended that this equipment be used in the area in the near future.

V. INFERENCES FROM OBSERVATIONS TO DATE

1. Intake versus Withdrawal

Lack of precise information on both intake and withdrawal makes it very difficult to determine the relationship between these two factors.

So many approximations for run-off, infiltration and evapo-transpiration factors would be required for an estimation of the intake into the aquifers, that it is felt that such an estimation would not be valid, and could result in misleading interpretations. Installation of gauging stations to record annual stream flows, both into the plains area and into the sea would be the only method of obtaining a solid foundation for such an estimation.

Similarly the annual withdrawal cannot be determined. Very few landowners have any knowledge of how much water each bore produces, and also groundwater usage is governed to a large extent by climatic conditions. In addition new bores are continually being drilled, and established bores change in their function and production rate. Only by equipping individual bores with flow meters, and by taking regular readings could a full appreciation of the pumpage be obtained.

However it is interesting to compare estimations made by two previous investigators. In 1952 K.R. Miles estimated the average annual recharge into the artesian aquifers as 1,050,000,000 galls. per annum for the Little Para River, and less than 3,000,000,000 galls. per annum for the Gawler River. (Geology and Underground Water Resources of the Adelaide Plains Area, Geological Survey of South Aust. Bulletin 27). This implies a total average annual recharge of approximately 4,000,000,000 gallons for the northern Adelaide plains area.

In 1961 R.I. Chugg estimated the total pumpage for the year 1960 as 5,000,000,000 gallons (The Declining Pressure Groundwater Levels of the Northern Portion of the Adelaide Plains Basin. G.S. No. 1950).

As stated by both investigators these two figures involve too many approximations and assumptions to be regarded as conclusive, but they do indicate that two years ago there was a strong possibility that considerably more water was being withdrawn than could be replaced by natural recharge processes. The lowering of the water table because of the increased consumption could result in a larger intake during the winter months, provided sufficient water is available, and as a result the intake may also be increasing from year to year thus counterbalancing to some extent the increasing withdrawal. However, since the estimate by Chugg in 1961 considerably more bores have been constructed, (it is estimated that an additional two bores are constructed weekly throughout the area), and the withdrawal at this stage would be higher than estimated for the year 1960, and would need a corresponding increase in intake to maintain a balance between the two. It is unlikely that such an increase in intake is possible, and probably even at this stage withdrawal is exceeding the annual intake.

## 2. Static Water Level Observations

### a. Behaviour of the hydraulic surface

Water level readings indicate to date that there has been a general lowering of the piezometric surface throughout the area. When considered individually the water level in any bore shows a seasonal variation with a minimum value corresponding to the drier months of the year when pumping is heaviest, and with a maximum value corresponding to the wetter cooler months. When plotted graphically an approximate sinusoidal curve is obtained, with the amplitudes representing the difference between the maximum and minimum. The maximum and minimum vary in time from bore to bore according to the proximity to the intake and bore densities. In individual bores there is a yearly variation in the times that the maximum and minimum water levels occur due to seasonal climatic conditions affecting both pumping requirements and recharge conditions.

Typical water level variations are appended to this report, and from these it may be seen that as a generalization water levels are at a maximum in September - October, and at a minimum in February - March.

As stated previously the difference between the maximum and minimum water levels vary throughout the area, increasing generally in a westerly direction, with marked increases in areas of heavy pumping. In the summer of 1961-1962 the variations between maximum and minimum levels were 50 feet in the Virginia area, 30 feet in the Salisbury area, 25 feet in the Waterloo Corner area, 12 feet in the Port Gawler area.

A more significant factor that is apparent from a study of individual water level records is that there has been a general lowering of the minimum water levels over the last few years, indicative of increasing withdrawal from year to year as is to be expected. In addition a decrease in maximum water levels is also apparent, indicating that conditions are not fully restored each year, and possibly that winter recharge is insufficient to completely replace the summer withdrawal. This is particularly noticeable in the below average rainfall years, and maximum water levels were decreasing from 1953 to 1959, rose again in 1960 with the wet winter, and have decreased again in 1961 and 1962 with the lower rainfall. Annual rainfall has an important bearing on water levels, but another factor equally as important is the spacing of the rain and the maximum temperatures, as the latter two factors dictate the commencement and duration of pumping. This is apparent in August 1961 when a period of dry weather with relatively high temperatures necessitated early pumping in some areas, with a resultant earlier drop in the piezometric surface in these areas.

#### **b. Effects of Water Level Variations**

The declining water levels have created (i) immediate economic effects and (ii) conditions for possible deterioration.

(i) All bores ceased to flow several years ago, and it is now necessary to install some type of pump in all areas. Initially

centrifugal pumps and airlift pumps were sufficient to obtain large supplies, but as the water levels have dropped still further the replacement by the expensive deep well turbine pumps has been necessary in most areas.

Increased competition between bores as bore densities have increased has resulted in a general lowering of pumps to maintain supplies, and in some instances construction of deeper bores has been undertaken. This has increased pumping costs, and according to reports of landowners throughout the area pumping costs have risen from year to year. Whether the costs are nearing the economic limit for market garden irrigation is not known, but if present trends are continued then such a limit must eventually be reached.

(11) When water levels are considered throughout the whole area, and the piezometric surface established at various times of the year, the serious nature of the present conditions can be seen. The piezometric surface in the winter months indicates that there is an overall hydraulic gradient from the intake points in the eastern portion of the basin to the coastal areas. This gradient is sufficient to maintain a barrier to the highly saline water in the coastal areas, and to that greater than 200 grains per gallon to the north and south.

However when the piezometric surface is plotted for the summer months it may be seen that in the areas of heavy withdrawal there is a marked lowering of the surface. The piezometric surface as at February - March 1962 is shown on a plan appended to this report, and it can be seen that the surface is below sea level in a large area, and has been lowered to 30 feet below sea-level in the Virginia area. This has the effect of reversing the natural westerly groundwater movement, particularly in the coastal areas where it is known that highly saline water occurs. The reversal is more marked when the greater specific gravity of sea-water is considered, sea-water being approximately 2-3% heavier than the low salinity water. For

example in a permeable aquifer 200 feet below the surface in which there is a salt - fresh water interface, the fresh water would need to have a head of 5 to 6 feet greater than the salt water for hydrostatic equilibrium to be maintained.

Consequently there must be some inland movement of the coastal saline water during the summer months when the hydraulic gradient of the pressure waters is reversed. It may be argued that such a situation has been recorded in the metropolitan area since 1947 with no resultant deterioration, but it is believed that in the northern Adelaide Plains area deterioration is more imminent because of the following reasons.

No saline coastal zone has been discovered in the metropolitan area, and presumably the salt-fresh interface is west of the present coastline, whereas in the northern Adelaide Plains area a zone of saline water has been discovered. The salt fresh interface must therefore be east of the coastline between St. Kilda and Port Gawler, and is closer to the areas of heavy groundwater utilization than would be the case in the metropolitan area.

Further confirmation of this is obtained when the sedimentary environment of the Pleistocene to Recent sediments is examined. In the Port Gawler area these sediments contain varieties of shell life remains, indicative of a brackish to saline water depositional environment, in contrast to the undoubted freshwater origin of the sediments further east. Therefore it is likely that to the west of Pt. Gawler, Pleistocene to Recent sedimentation may not have occurred or may have been under marine conditions, resulting in more permeable sediments than were formed in the contemporaneous fresh water deposition further inland. The artesian conditions would not be present without the confining nature of the Pleistocene to Recent sediments, and as the formation of a salt-fresh interface would still require some upper confining layers, then such an interface would occur only where the conditions for confinement still existed. Con-

sequently the position of the interface would be expected to be to the east of the western limit of the Pleistocene to Recent impervious sediments. This situation exists in the Port Gawler and St. Kilda areas, as in the upper aquifer the salt-fresh water interface is to the east of the coastline, and at the coastline itself the Pleistocene to Recent sediments act as a confining layer. In the lower aquifer the confining layer is a marine clay which probably extends considerably further west than the Pleistocene to Recent fresh water sediments, and consequently in the lower aquifer the salt-fresh interface is much further west than the corresponding interface in the upper aquifer.

No evidence of the saline water origin of the Pleistocene to Recent sediments has been encountered in the metropolitan area, and probably the impervious clays extend considerably further west of the coastline, than is the case in the St. Kilda and Port Gawler areas. This is a reasonable assumption when the distances of the present coastline from the elevated Para Fault block which must have been the source of derivation of the Pleistocene to Recent sediments are considered. In the Port Gawler area the coastline is 16 miles west of the Para Fault, whereas in the Henley Beach area it is only 5 miles. The Pleistocene to Recent coastal plain must have been of approximately constant width between Marine and Port Gawler under the similar erosional factors that would have prevailed in the elevated blocks, and consequently the western limit of freshwater deposition would be expected to parallel the western boundary of the highlands. On this coastal plain Henley Beach would occupy a similar position with regard to the western limits of the freshwater sediments as would a point midway between Angle Vale and Virginia.

A salt-fresh interface could by inference be several miles west of the coastline in the metropolitan area, and inland movement of the interface does not approach too closely the areas of groundwater utilization, and consequently no deterioration has been experienced. However in the northern Adelaide

plains area the interface is very close to areas of high withdrawal, within a mile in the Waterloo Corner area.

The seasonal reversal of the hydraulic gradient coupled with the proximity of highly saline water to areas of high production constitutes an ever present threat of deterioration to the groundwaters contained in the upper marine aquifer, particularly in the Waterloo Corner area. In the lower marine aquifer the danger of saline ingression is not as great, but as previously mentioned mixing of the two aquifers must occur in some localities because of the discontinuity of the clay aquiclude. Should the saline water move into the upper aquifer then it is probable that the lower aquifer would be contaminated locally, because of leakage where the clay is absent or of insufficient impermeability to act as a barrier between the two aquifers.

Similarly the more saline waters to the north and south may be expected to gradually ingress into the low salinity zones with the overall drop in water levels, and although the effects would not be as noticeable as with the highly saline coastal waters the final result would be a decrease in the total area at present underlain by water of low enough salinity for general market garden use.

The rate of ingress of the saline water under the reversed hydraulic gradient cannot be determined at this stage. Information on transmissibilities or permeabilities of the various aquifers would be required to evaluate the rate of groundwater movement under the influence of the present gradient, and such information is lacking.

Another disturbing feature of the declining water levels and resultant lowering of pumps is that in some areas, pumps have been lowered to such an extent that they are actually located within the marine aquifer. Thus when pumping the water levels are lowered with the drawdown to below the confining Pleistocene to Recent sediments, and the top of the aquifers

must be dewatered for limited periods. The effect of this dewatering is not known, but it could result in a rearrangement of particles within the aquifer causing a decrease in porosity and hence storage capacity, and also could create conditions for subsidence of the overlying confining layers.

Subsidence as a result of declining pressure water levels has been encountered in other parts of the world, and is not improbable in the Northern Adelaide Plains, although no evidence has yet been obtained.

### c. Salinity Observations

With one exception the random sampling to date has not revealed any definite instances of deterioration in groundwater quality. Minor fluctuations do occur in individual bores and as such are common throughout both the metropolitan area and the northern Adelaide plains. Such fluctuations are believed to be caused by any of several factors. The salinity of groundwater is directly proportional to the salinity of the intake waters, and consequently minor variations in intake salinities will result in sympathetic variations in groundwater salinities. The rate of groundwater movement probably being relatively slow, the time before such variations in intake would be recorded in bores could be many years, depending upon the distance from the intake.

Mixing of groundwaters from different areas due to the interference of the natural conditions would also cause minor variations. It has been found that the aquifers are not homogeneous in regard to water quality, there being minor vertical variation within the aquifer, apparently due to varying permeability as a result of the layering of the sediments. The salinity of water obtained from a bore is the resultant mixture of these varying layers, and oscillating water levels could disrupt the proportions drawn from each of the layers, with a resultant variation in the salinity of the output.

Imperfect bore construction with incomplete casing seals could also result in leakage of the upper saline groundwaters into the borehole in varying amounts.

Such variations are generally minor in character and also do not show seasonal fluctuations or total increases with time as would be expected if deterioration on a large scale was occurring.

Instances of rises in salinity from particular bores have been reported, but on investigation it has been found that the reports are false or that the rise is the result of obvious mechanical failure of the bore. The latter cases are becoming more prevalent as in the older bores the casing has corroded allowing highly saline shallow waters to enter the borehole.

The exception to the minor fluctuations in salinity has been a bore in Section 7531, Hd. Port Gawler. This bore is located in the westerly margin of the basin and has been sampled monthly since early 1962 and the results are tabulated below:

|         |                              |
|---------|------------------------------|
| 15.2.62 | 183.6 grains per gallon      |
| 14.3.62 | 136 A.T.S. grains per gallon |
| 30.4.62 | 198 A.T.S. grains per gallon |
| 13.6.62 | 124 A.T.S. grains per gallon |
| 19.7.62 | 88 A.T.S. grains per gallon  |
| 6.9.62  | 59 A.T.S. grains per gallon  |
| 9.10.62 | 88 A.T.S. grains per gallon  |

From the above results it can be seen that there is a seasonal salinity variation, the higher salinity corresponding to the time of the heavy summer withdrawal, and the lower salinity to the winter months. This could be indicative of saline ingress as the bore with a depth of 312 feet is deeper than the remainder of the bores in the area, and would be expected to record the inland movement of the heavier more saline water before the shallower bores.

However the bore in question is approximately 40 years old, and it is possible that the casing is holed, and that small amounts of saline water can enter the borehole when water levels are low as in the summer months, but are held back in the winter when water levels are high. A mobile pump unit to be used in conjunction with the Dionic probe will soon be available, and

it is hoped that should the salinity rise this summer the cause will be determined.

Salinity variations have also been noted in Section 28, Hd. Port Gawler where a bore constructed by the Department encountered highly saline water in the upper marine aquifer, to the east of previously recorded low salinity water in the upper aquifer. However the sediments in this bore were of a different facies to those in the surrounding bores, being indicative of a mangrove swamp environment, and the occurrence could be a local pocket of saline water which has not been flushed out because of varying permeabilities. In addition the salinity pattern of the immediate vicinity has been complicated by the possible faulty construction of a large production bore which could have permitted leakage of the upper saline waters into the marine aquifer.

d. The Detection and Study of the Coastal Saline Wedge

Proof of the existence of the saline zone in the coastal areas has only recently been obtained, and the investigation is still in the initial stages. Of the six bores proposed initially to detect the interface one has been completed and two are in progress at the time of writing. Results to date indicate that the saline water extends at least a mile inland in the St. Kilda area, but the precise position of the interface has not yet been determined. Complex aquifer configuration has been revealed in the test drilling and it is possible that the saline-fresh interface is not of the relatively simple type that has been encountered in other parts of the world.

The isohaline plan appended to this report indicates the known limits of the saline water, and the proximity of the zone to areas of high bore densities can clearly be seen.

## VI. CONCLUSIONS

At this stage the results of the investigation into the declining water levels of the northern Adelaide plains area do not reveal definite signs of deterioration of the groundwaters, deterioration being used as defined in the groundwater legislation and meaning deterioration in quality i.e. salinity. Instances of rises in salinity have been recorded, but as yet none can be proved to be the result of saline ingression.

Evidence of declining water levels is abundant in all portions of the area, the decline in some areas being sufficient to cause marked reductions in the output of bores, and increases in pumping costs. An improvement in these conditions does not appear likely, as development of the area is still taking place with a resultant increase in groundwater withdrawals, and a severe worsening of the present day conditions may confidently be expected. The increase in pumping costs must eventually reach a stage where the economics of groundwater irrigation will be seriously effected.

A more important feature of the drop in water levels is the reversal of the natural westerly hydraulic gradient in the summer months, coupled with the piezometric surface being lowered to below sea-level over a large area. The reversal of gradient is sufficiently great to create conditions suitable for the ingression of the more saline water surrounding the zones of low salinity. This situation is particularly serious in the coastal areas where highly saline water occurs in a similar stratigraphic position to the low salinity waters of the Virginia and Waterloo Corner areas. A seasonal inland migration of this saline water can be expected, and as in the Waterloo Corner area the saline water is within a mile of producing bores the danger of deterioration of the groundwaters is great.

The rate of ingression of the saline water cannot at this stage be calculated, although it is hoped that the current series of observation bores will locate the salt fresh interface and permit measurement of the seasonal fluctuation.

Although the present investigations reveal the existence of a set of conditions which could cause deterioration of the groundwaters contained in the area, the present lack of factual data on the aquifer characteristics does not permit a reasonable assessment of the effect of the disturbance of the natural conditions. Consequently the stage at which the maximum safe yield of the basin is exceeded to such an extent as to cause severe deterioration of the groundwaters cannot be predicted. Deterioration will be detected in the series of outpost observation bores at present utilized, but such a detection could be too late, as for deterioration to occur the capabilities of the basin could have been exceeded to such an extent, that at that stage remedial measures may either entirely fail to restore the initial conditions, or require considerable time to do so.

Should control of the groundwaters ever be obtained in the area, information on intake, withdrawal and aquifer characteristics will be necessary to determine the maximum safe withdrawal. Implementation of the groundwater legislation does not appear imminent, but it is suggested that consideration should be given to the determination of these fundamental statistics, so that the information is available when required.

Of prime importance is the measurement of the amount of water available for intake into the basin. The impounding of the run-off waters, coupled with the greater groundwater utilisation in the catchment areas of the Para and Eden Fault blocks must have decreased the natural discharge onto the plains, and to a certain extent restricted intake into the aquifers. The construction of the proposed reservoir on the Little Para River will further decrease the amount of water available for recharge. The necessity of such surface storage cannot be denied, but it is considered that with the limited rainfall of the area, a greater knowledge of the available surface water should be obtained.

Information of this type will only be obtained by continual stream gauging, and it is suggested the consideration be

given to the installation of permanent gauging stations on both the Gawler and Little Para Rivers, so that (a) the quantity of water entering the plains and (b) the quantity of water flowing out to sea can be measured.

A minimum of five gauging stations would be required for this, three on the Gawler River and its tributaries, and two on the Little Para River. Suitable sites for such stations would require further investigation.

From these stream flows a reliable estimate of the intake into the aquifers should be possible. Withdrawal figures do not appear possible without individual measurement of bores, and enforcement of this would require legislation.

The second important factor is a knowledge of the hydraulic characteristics of the aquifers. The total amount of low salinity water in the aquifer, the rate of movement of the water, and the effect of the reversal of hydraulic gradient are not known, and information on these factors will only be obtained when complete aquifer penetration has been made, and when the porosity, permeability and coefficient of storage have been determined for the various aquifers.

To obtain complete aquifer penetration construction of at least one, preferably more deep bores would be required, as to date the lower limit of the Miocene sediments containing low salinity water has not been reached in a borehole. Deepening of the existing observation bores, particularly in the Virginia area would supply this information at a relatively low cost.

Permeability figures can be obtained by several methods. Theoretical treatments involving a study of the tidal response of an aquifer in coastal areas have been carried out in other parts of the world, but the validity of this type of calculation has not been proved. In addition data on some of the aquifer characteristics are required, particularly porosity, and it is difficult to see how such figures can be obtained. Laboratory methods can be used to supply this information, and can also be used to

determine permeability, but do not appear applicable to the area because of the problem of obtaining representative samples, and also because of the extreme variation in aquifer composition and structure.

Field permeability tests overcome many of the disadvantages of the theoretical and laboratory methods, and appear to be the most applicable in the Northern Adelaide Plains. The particular method considered most suitable is one of the various discharging-well methods as described by Wenzel. These have the advantage in that the cone of depression generally extends over a considerable area, and takes into consideration the many horizontal and vertical variations of the aquifer sediments. However they have the disadvantage in that extensive drilling and observation is required for each test, and in an area such as the one under investigation more than one test would be required to allow for the considerable variation from place to place, and consequently the tests are expensive. However it is suggested that consideration be given to the implementation of such a testing programme in the near future.

It is realized that the lines of investigation suggested involve considerable expenditure, but in the opinion of the writer it would not be possible to assess the groundwater potential of the area without a complete knowledge of intake and aquifer characteristics, and it is difficult to envisage how effective control of the groundwaters could be maintained without such knowledge.

  
P.G. Miller  
Geologist  
HYDROLOGY

pgm;agk

1953 1954 1955 1956 1957 1958 1959 1960 1961 1962  
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# NORTHERN ADELAIDE PLAINS GRAPH SHOWING WATER LEVELS

Bore - Hd Munno Para, Sec. 2271

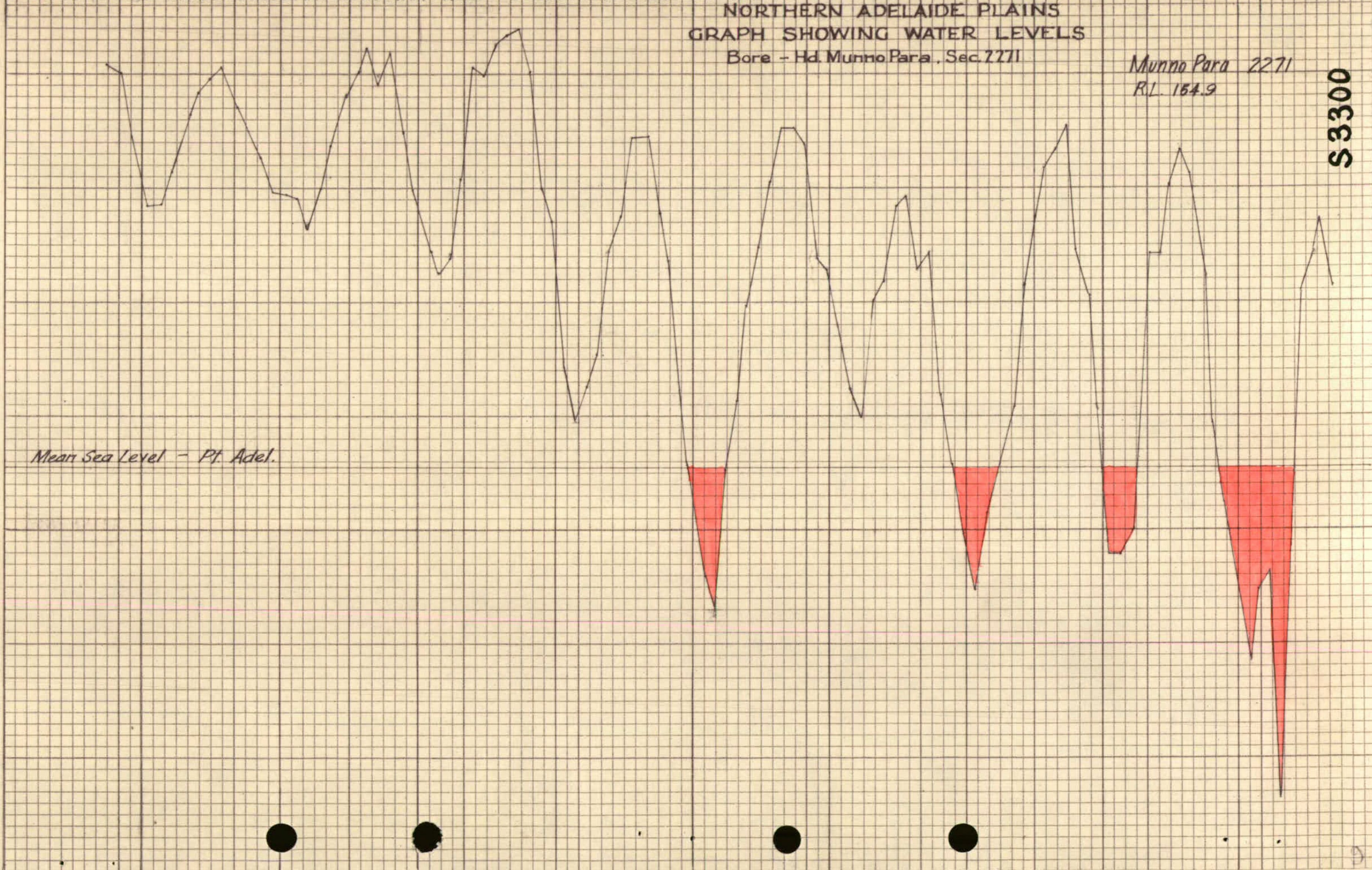
Munno Para 2271  
R.L. 154.9

S 3300

140  
130  
120  
110  
100  
90  
80

Reduced Level

Mean Sea Level - Pt. Adel.



1956 1957 1958 1959 1960 1961 1962  
J F M A M J J A S O N D J F M A M J J A S O N D J F M A M J J A S O N D J F M A M J J A S O N D

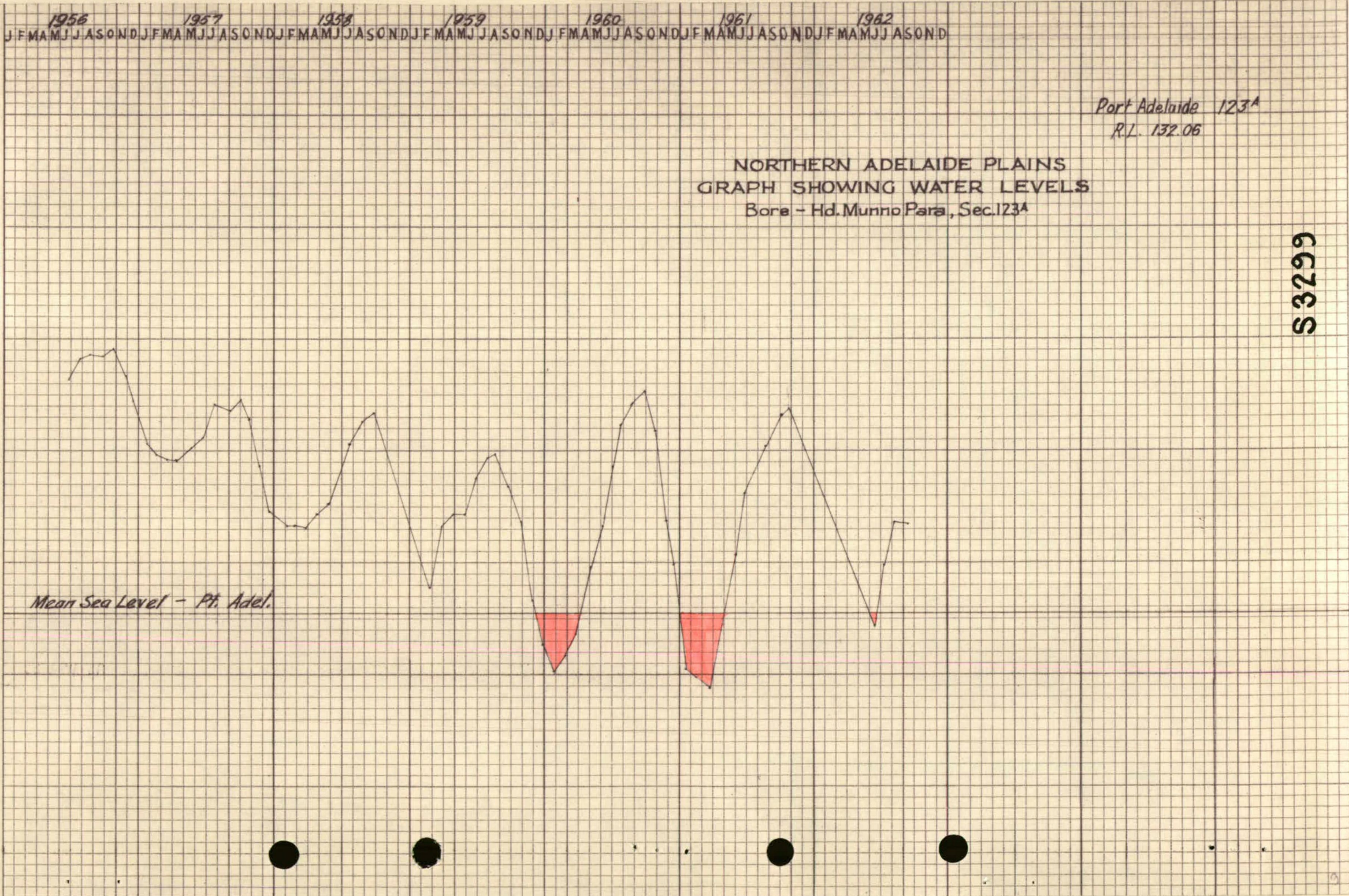
Port Adelaide 123<sup>A</sup>  
R.L. 132.06

NORTHERN ADELAIDE PLAINS  
GRAPH SHOWING WATER LEVELS  
Bore - Hd. Munno Para, Sec. 123<sup>A</sup>

130  
Reduced Level  
120  
110  
100  
90

Mean Sea Level - Pt. Adel.

S3299



150  
140  
130  
120  
110  
90

BRITISH MADE ATTITUDE

Reduced

1953 1954 1955 1956 1957 1958 1959 1960 1961 1962

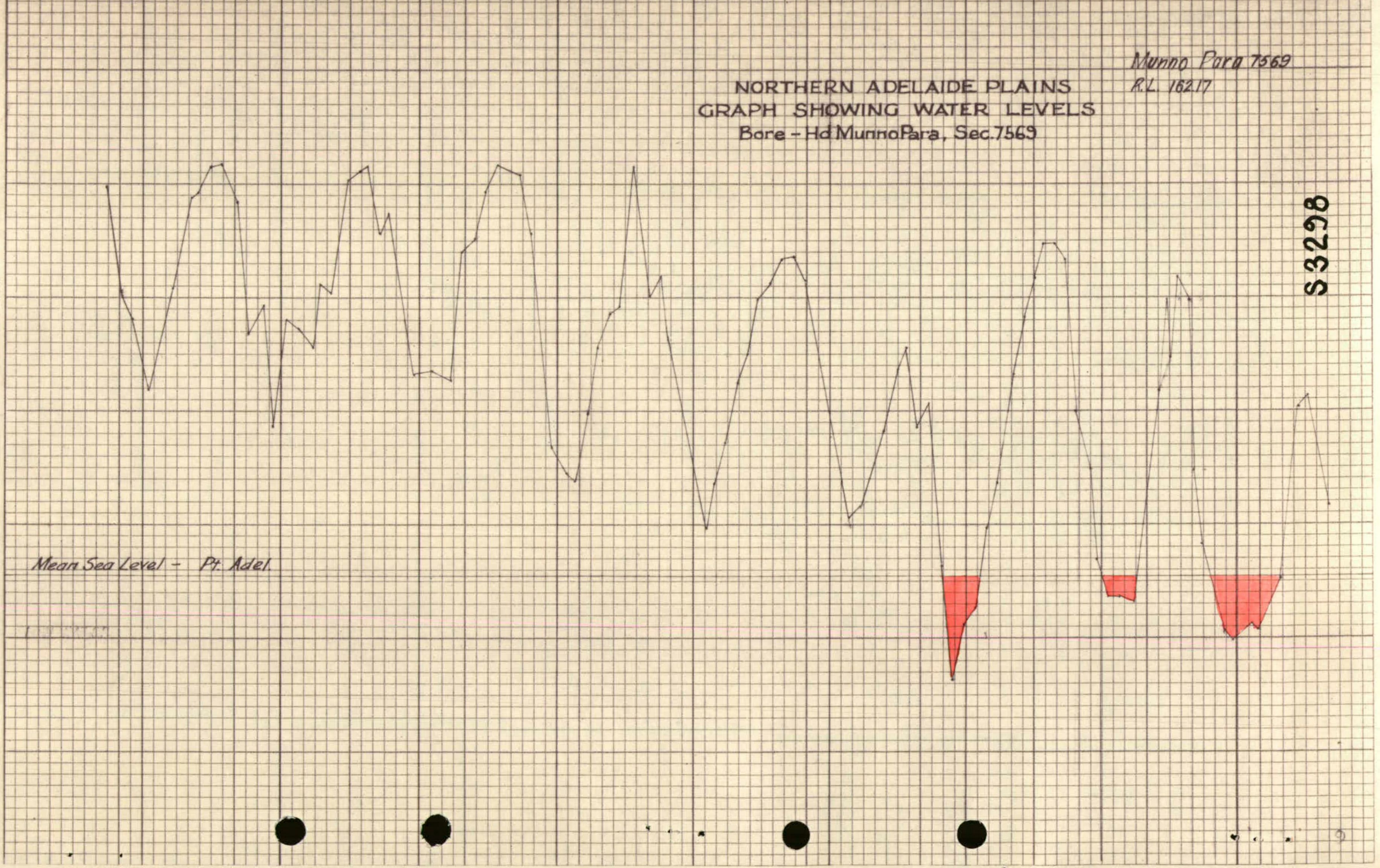
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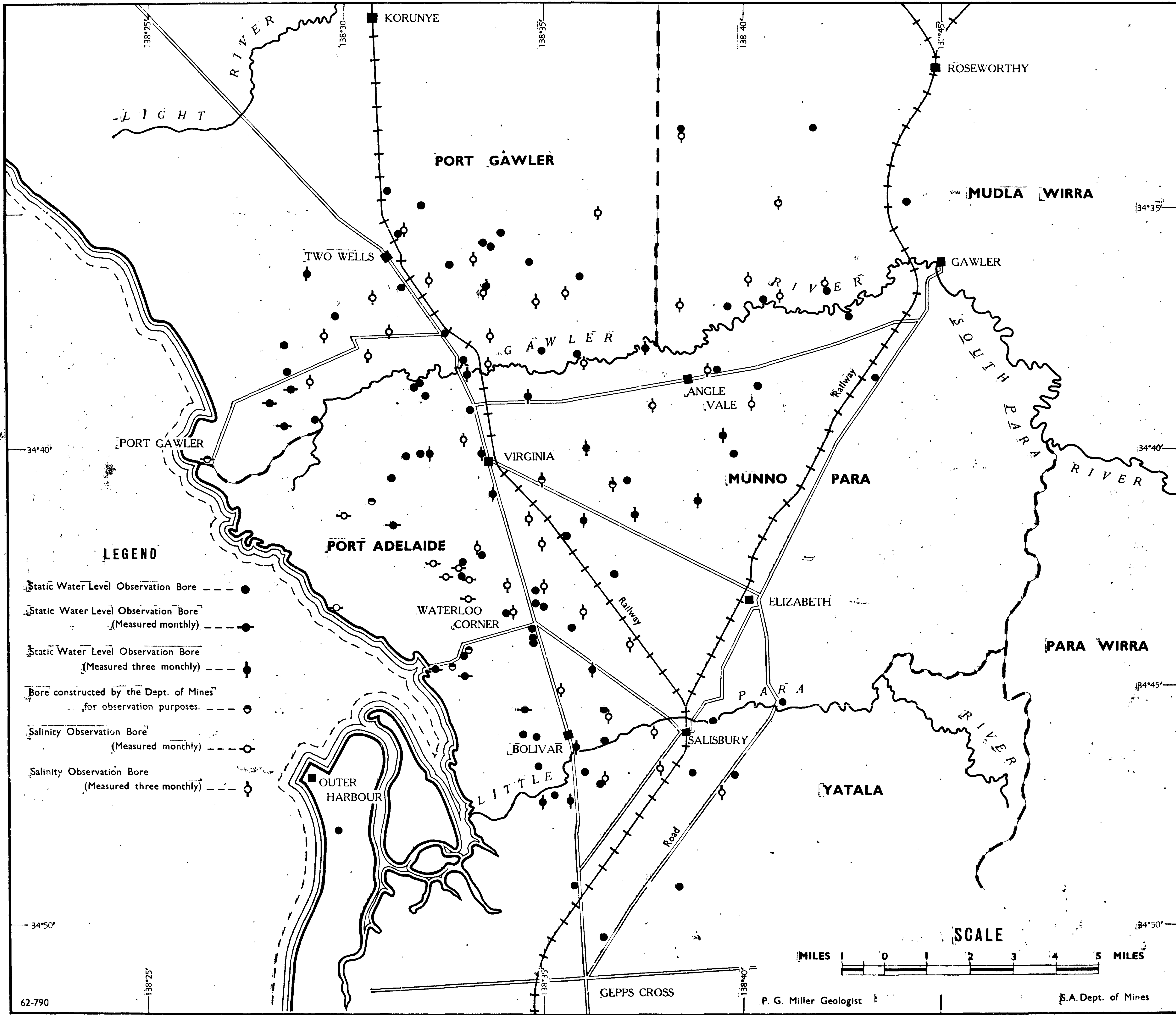
NORTHERN ADELAIDE PLAINS  
GRAPH SHOWING WATER LEVELS  
Bore - Hd Munno Para, Sec. 7569

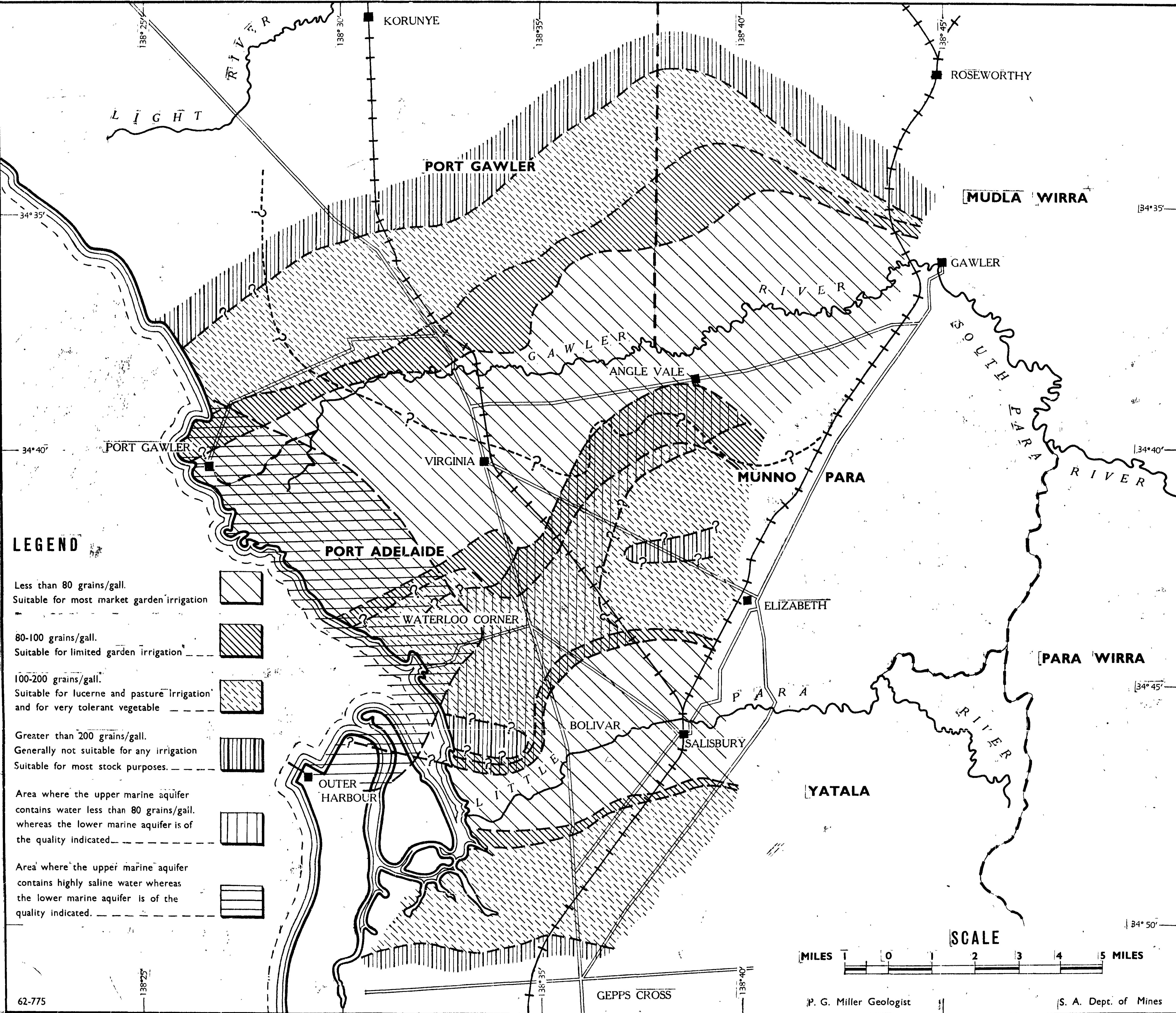
Munno Para 7569  
R.L. 162.17

Mean Sea Level - Pt. Adel.

S3298







- LEGEND**
- Less than 80 grains/gall.  
Suitable for most market garden irrigation
  - 80-100 grains/gall.  
Suitable for limited garden irrigation
  - 100-200 grains/gall.  
Suitable for lucerne and pasture irrigation  
and for very tolerant vegetable
  - Greater than 200 grains/gall.  
Generally not suitable for any irrigation  
Suitable for most stock purposes.
  - Area where the upper marine aquifer  
contains water less than 80 grains/gall.  
whereas the lower marine aquifer is of  
the quality indicated.
  - Area where the upper marine aquifer  
contains highly saline water whereas  
the lower marine aquifer is of the  
quality indicated.

