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DEPARTMENT OF MINES
SOUTH AUSTRALIA

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Preliminary Report

on

THE DECLINING PRESSURE GROUNDWATER LEVELS

IN THE NORTHERN PORTION OF THE ADELAIDE PLAINS BASIN

WITH SOME INFERENCES AND RECOMMENDATIONS FOR FURTHER STUDY

by

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Geological Assistant

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PRELIMINARY REPORT ON THE DECLINING PRESSURE GROUNDWATER LEVELS IN THE NORTHERN PORTION OF THE ADELAIDE PLAINS BASIN WITH SOME INFERENCES AND RECOMMENDATIONS FOR FURTHER STUDY

ABSTRACT

The North Adelaide Plains has become an area of extensive use of groundwater from the underlying basin sediments which include upper non-marine sands and gravels and deeper marine limestone and fossiliferous sand aquifers. The hydraulic behaviour of the Basin is complex, intake occurring principally from two rivers, low salinity recharge waters moving westward leaving median, northern and southern zones of higher salinity.

An increasing rate of withdrawal has caused a definite decline in the Piezometric surface of the pressure waters from the marine aquifers which has become more apparent in the last three years. Since piezometric values are approaching, and sometimes temporary falling below, mean sea level; there is a possibility that with the present rate of increased pumping a reversal in gradient will tend to produce an eastward movement of saline waters which are presumed to occur in the marine aquifers under the Gulf. Additionally, since areas of low salinity groundwaters are much more heavily exploited, there is a probability of a change in gradient causing ingression from nearby areas which contain relatively saline groundwaters. Data is insufficient to give an approximate time prediction for these events at this stage, possibly some years being required for the ingression of Gulf waters to have an economic affect. Ingression from more saline portions of the basin are considered to constitute a more immediate but localized danger. Significant vertical contamination from overlying and also deeper more saline waters is also a distinct possibility.

The fall in levels of pressure water can be expected to be accompanied by further increases in cost in drilling, pumping equipment and power usage.

In order to be able to advise on the maximum safe yield from various parts of the Basin, problems suggested for further study are discussed.

1. INTRODUCTION

There has been a marked increase in the number of bores withdrawing irrigation supplies of groundwater from the North Adelaide Plains in the last ten years. Subdivision of grazing land into small allotments has accelerated the drilling rate in the last five years and a continuation of intensive drilling in the near future can be expected.

In addition to grazing, the North Adelaide Plains area to as far north as Two Wells has assumed great economic importance as a vegetable and lucerne producing area. Since these latter primary industries depend upon the groundwater resources of the Basin, the need to ascertain the extent of those resources is apparent.

Recognizing this need the Department of Mines has conducted surveys (Miles, 1952) and (Solomon, unpublished) to gather data on the nature of the Basin sediments, drilling conditions and the varying quality and hydraulic behaviour of the groundwater. A program of monthly measurements of water levels in a number of observation bores was instituted in 1953 and this program has recently been intensified.

The information obtained has already enabled considerable advice to be given to landholders and Government Departments regarding groundwater prospects, immediate and long term, and expected drilling conditions in particular areas. The Department has also acted on this information in making a press release warning the general public of areas doubtful for long term good irrigation quality water.

Despite the press release, lectures to local agricultural bureaus and many oral and written advices and discussions with land owners, the problems of the groundwater resources are generally poorly understood by the public, and some dangerous misconceptions exist. There is, for example, a widespread belief even expressed by a boring contractor, that the source of the groundwater is Gulf water, desalted in its movement through the sediments.

Although still further work is required before a comprehensive report can be completed, it is considered that certain facts about the response of the groundwater to heavy pumping as well as some inferences, conclusions and recommendations should now be set forth. This is appropriate since the writer has recently transferred to other work after a long association with the North Adelaide Plains Basin.

2. THE GENERAL NATURE OF THE BASIN

A. FORM OF THE BASIN

The area considered, about 200 square miles, is bounded on the east by a faulted contact with the ancient Precambrian rocks of the Adelaide Hills which can be inferred to underlie the Basin sediments on the down throw side to the west. The thickness of the overlying sediments has not been satisfactorily measured by boring but is known to be generally in excess of 500 ft., probably more of the order of 1500 ft. and deeper in places. Although the Basin sediments continue to the north and south, for this discussion the southern limit is taken as the continuation to the east of the boundary between the Hundreds of Port Adelaide and Yatala and the northern by an east-west line just north of Two Wells. These boundaries are natural in that higher salinity groundwaters, unfit for general irrigation, occur to the north and south of these limits. Although no sample data is available, the Basin sediments can confidently be inferred to continue westward under the Gulf. A hydraulic or elastic contact with Gulf waters is indicated by the sympathetic movement of water levels in bores to tidal fluctuations. This tidal response has been measured by automatic recorders installed in bores in the western suburbs of the Metropolitan area of Adelaide. Such hydraulic or elastic connection can be assumed to continue northward in parts of the

Basin being discussed.

B. AQUIFERS OF THE BASIN

The Basin sediments include various marine, lagoonal and terrestrial deposits. A marine sandy limestone persists throughout most of the area and is the most important aquifer. Its surface varies in depth from about 450 ft. near Salisbury to about 150 ft. near Two Wells. The limestone is not everywhere uniform in character and in some areas contains interbedded sands, silts and clays. On the eastern edge of the basin near Gawler, the limestone tends to give way to fine sands. Insufficient bores have penetrated through this limestone to generally define its lower limits and the deeper sediments which underlie it, but on present evidence, these deeper sediments may be fine grained and difficult to exploit as an aquifer.

Fine marine sands, containing shell beds, which occur above the limestone in southern portions of the area, form the important aquifer in the Waterloo Corner area, the underlying limestone being more saline. These sands wedge out south of Virginia.

The terrestrial sediments which overlie the marine beds already discussed, vary considerably laterally and with depth and although generally clayey, sand and gravel beds frequently occur. These irregular often lenticular coarser beds sometimes act as aquifers for irrigation supplies near the Rivers, particularly in the Angle Vale, Bolivar and, in part, the Virginia areas.

C. SEPARATION OF GROUNDWATERS AND INTAKE OF [illegible] WATERS

The aquifers of the Basin are then not homogeneous isotropic or in all respects continuous. This is particularly true of the non-marine sand and gravel beds whose aquicludes vary in their capacity to act as a barrier to the vertical and lateral movement of groundwater from one aquifer to another. The underlying marine aquifers, although continuous over large areas, also vary from area to area in their capacity to allow the ready movement of groundwater. In the middle and western portions of the Basin the aquicludes between the marine and non-marine aquifers act as effective seals, maintaining waters in the marine aquifers under pressure and preventing intake from shallow or surface supplies. However, these impermeable clayey confining beds are not continuous near the eastern margin of the Basin, and here intake of catchment waters to the deeper aquifers occurs in the vicinity of the outflow of the Gawler and Little Para Rivers.

Aquicludes between the upper and lower marine aquifers are apparently sufficiently effective to separate waters of different salinities under normal pressure gradient conditions. In the Waterloo Corner area good quality irrigation water in Pliocene sands is separated from more saline deeper waters by a fairly thin clay aquiclude which in places may be discontinuous. Such a discontinuity in the clay seal may allow mixing to occur between the two marine aquifers giving rise to a small area of higher salinity as shown on the accompanying deep water salinity plan.

D. PATTERN OF DISTRIBUTION, MOVEMENT AND VELOCITY OF GROUNDWATERS

Appended plans (Appendix E and F) show approximate boundaries of several salinity zones for both terrestrial and marine aquifers. Considerable vertical variation in salt content occurs within the upper, non-marine aquifers and hence the plan for these shallower groundwaters is generalized to show the overall pattern of salt content: very shallow often highly saline waters in small supply are not generally used as datum. There are also indications of variation of water quality with depth within one or other of the marine aquifers. A considerable variation of this type is apparent in some of the few bores which are sampled at various depths, such as the Elizabeth Oval bore[4].

The anisotropic nature of the layered sediments may allow preferential movement of recharge waters along the more permeable horizons and different waters may occur separated by weak permeability barriers.

The general pattern of distribution of different quality deep groundwaters is clear. From examination of salinity plans it is apparent that these deep groundwaters would be generally saline if it were not for intake of runoff waters from the Gawler and Little Para Rivers. For the deeper groundwaters the intake is in the vicinity of the Rivers in the eastern portions of the Basin where permeable sands occur to considerable depth. The low salinity recharge waters have a freshening effect in their movement westward through the aquifers forming somewhat wider zones of better quality toward the west. A similar pattern occurs to the south in proximity to the River Torrens and Sturt River as shown on ischalsine plans previously prepared (Miles, 1952).

A zone about midway between the Rivers which includes Smithfield, Elizabeth, Penfield and Dirok is not in the path of the movement of the bulk of the recharge waters and hence contains higher salinity deep groundwaters. This shadow zone of poorer quality waters narrows to the west and in the vicinity of the Port Wakefield Road the good quality waters appear to make contact.

The salinity pattern in the Waterloo Corner area, however, is complex. Where hachured on the plan (appendix F) the upper shelly sand marine aquifer contains about 60 grain water in contrast to the underlying sandy limestone whose water is over 100 grains per gallon. The occurrence of more saline water in the deeper aquifer may be considered as an extension of the more saline zone in the Dirok area. If so, the overlying, probably more permeable shelly sand may more readily allow the lateral spread of the fresher intake waters which are locally sealed off from the limestone aquifer by impermeable clays.

To the north of the hachured area there is an occurrence of more saline water in the shelly sand aquifer. Here mixing of the waters of the two marine aquifers may occur through a discontinuous clay aquiclude as previously suggested.

Insufficient data is available to approximate groundwater velocities in the various aquifers and areas of the Basin. In general the velocity is directly proportional to the permeability and hydraulic gradient and inversely proportional to porosity. With the present programme of water level measurements good gradient determinations in a number of directions should be possible. Considering only data readily at hand an east-west natural gradient of about 1 in 800 is estimated. No porosity or permeability determinations have been made. Since such parameters would be expected to be subject to considerable variation from area to area and since the natural gradient may be severely distorted near areas of heavy pumping the estimation of velocity is considered to be a matter for further investigation.

3. WATER LEVEL BEHAVIOUR

A. OBSERVATION BORE DATA

Suitable bores for periodic measurement are not plentiful throughout the whole area, many existing bores being either inaccessible or normally pumping through much of the year. Measurements from a number of early observation bores were curtailed for these reasons but additional bores have been added from time to time and a large number have recently been included in the observation programme.

Study of water level readings from some of the early established observation bores (Appendix D) clearly shows that there are seasonal minimum values corresponding to dry months of heavy pumping in November, December, January and February and seasonal maximum values corresponding to the wetter cooler months of June, July, August and September when pumping is small.

The times at which the maximum and minimum values occur in different bores vary according to the proximity of the observation point to sources of intake and to concentrations of pumping bores. For individual bores there is a variation from year to year in the values of the maxima and minima and the times that they occur. This variation is due to yearly differences in rainfall which influence both pumping requirements and recharge conditions. There is, however a noticeable overall trend, particularly apparent in the last few years, of a progressive lowering of these maxima and minima also the differences between the maxima and minima are tending to increase.

The higher rainfall of last winter has resulted in a general good recovery of the static water levels, better than the previous year. Water levels were significantly higher even in December of 1960 than the same time in 1959. That such recovery can still occur is encouraging in that it suggests that intake during a wet winter can substantially replace the water withdrawn from storage during the pumping season. This is further borne out by the fact that the differences in maxima and minima is increasing and it would appear likely that heavy withdrawal, lowering the water levels in the intake zone, would enable increased intake during the rainy season provided sufficient runoff water is available.

The response of the water levels to different weather conditions, which effect both pumpage and intake, should continue to be studied and many different variations to the general pattern can be expected. It is the writer's opinion that the slightly improved position from last year's good rainfall is only a temporary interruption to the progressive yearly decline in water levels and that even with fairly complete winter recovery the pumping season minimum can be expected to continue to decline. Unless actual withdrawal decreases or a succession of very wet years takes place it is unlikely that restoration to the high heads reported to exist 10 and 20 years ago will take place. The probability of further decline is increased by recent and proposed reservoirs on the South and Little Para Rivers.

It should be stressed that even with complete winter recovery, increased pumpage will result in an increased drop in the minimum summer levels.

D. REPORTS FROM LANDHOLDERS

A number of landholders were visited and asked to report on the behaviour of water levels in their bores. In most cases these bores were not accessible for observations and only indirect evidence was obtainable. Instances of replacement of centrifugal pumps by deep bore pumps and extensions to pump columns are taken as indications of a decline in water levels during the pumping season. Brief case histories of water level variations in a number of bores is appended (Appendix A).

The data obtained largely confirms the evidence from the observation bores but also shows that the fluctuations vary with location, the decline in levels being most pronounced westward i.e. down the hydraulic gradient, from areas of heavy pumping and vertically as different aquifers are concerned.

The general piezometric surface tends to be re-established through the winter months of relatively little pumping. This period of "rest" is also one of intake to ground-water storage in the eastern portion of the Basin which provides additional head. It would appear, from the fairly rapid recovery or partial recovery of water levels that the cessation of pumping is quickly followed by local readjustment of distorted gradients to the more static over all piezometric surfaces. A progressive yearly deficiency in recovery, however, indicates a net yearly draw on storage not made up by intake. Long term water level measurements and pumpage data supports this non-balance.

4. IMPLICATIONS OF FALLING WATER LEVELS

The decline in water levels has already had the following effects in considerable areas:-

1. Abandonment of irrigation and stock feeding from the natural overflow of bores.
2. Replacement of centrifugal and compressor pumps by more expensive deep bore turbine pumps.
3. Higher power costs.

If the drop in the piezometric surface should become sufficiently large, the following adverse results could be expected to occur:-

1. Increased competition for the available water, landholders vying with one another by deepening bores and lowering pumps with consequent increased pumping costs. This has already occurred to an appreciable extent in some areas.

2. Ingression of more saline waters from areas less heavily pumped, from the gulf and from one aquifer to another.

3. Loss of some of the elastic properties of the aquifers with possible permanent damage to the water bearing capacity of the sediments.

A. SALINITY IMPLICATIONS OF FALLING WATER LEVELS

The contamination of groundwaters by saline ingressions is known to have occurred overseas in Basins having analogous features to the Adelaide Plains Basin. Studies of such ingression following a fall in the piezometric surface have been described in many publications elsewhere (2, 3, 7, 9, 10, 11, 13, 14) and it is apparent that saline contamination is a consequence of changes in the pressure balance of saline and fresh waters giving rise to lateral displacement and also the vertical movement between aquifers, the latter occurring particularly in the vicinity of boreholes.

1. Possibility of Ingression of Gulf Waters:

An important comparison of drawdown values of the pressure groundwaters can be made with respect to the mean sea level along the coast. A comparison using the maximum drawdown and minimum recovery readings in observation bores in 1959-1960 with the mean sea level is shown approximately in Table I. Of these bores only MP2271A had previously fallen below mean sea level.

Additional bores have not been read for a sufficiently long period to enable seasonal variations to be determined. The following data is, however, of interest.

TABLE II

Observation Bore Designation	Level of Maximum fall	Date
MP3076B	35' above M.S.L.	March 1959
PA153	13' " "	Sept. 1959
PA167	2" " "	Feb. 1960
PG26	4" below "	Jan. 1960
PA320	4½' " "	Jan. 1960
PA3901	16' " "	Jan. 1960

Previous observations by the owners over a long period of time indicate that the water levels in bores, PA167, PG26 and PG153 did not previously approach mean sea level.
It is apparent from Observation Bore Data that in the western portions of the Basin there is a small overall pressure gradient from E. to W. in the marine aquifers which opposes the ingression of saline waters inland from the Gulf into the "fresh" water aquifers of the Basin. There is evidence that this pressure gradient is temporarily reversed during peak pumping periods for some of the observation bores. This reversal is more marked when the greater specific gravity of salt water over sea water is considered, the difference being about 1 in 40. For example a permeable aquifer at 200 ft. common to the entry of saline

TABLE I

GROUNDWATER LEVELS COMPARED WITH MEAN SEA LEVELS

Observation Bores Designation	Summer Minimum Levels	Date	Winter Maximum Recovery Level	Date
Brooks A PA 122	9' above M.S.L.	February 1960	25' above M.S.L.	September 1960
Brooks B PA 122	2½' " "	January, 1960	17' " "	July 1959
Brooks C PA 123	10' below "	January 1959	11' " "	September 1960
A.B. Fuss MP 7569	18' below "	November 1959	30' " "	July 1960
Coates PG 256	40' above "	January 1959	47' " "	July 1959
Grayling MP 3226	17' below M.S.L.	November 1959	18' " "	June 1959
Pearson MP 2271	10' below M.S.L.	January 1960	24' " "	July 1959
	12' below M.S.L.			

Gulf water from the west and fresh intake waters from the east could be considered. Under these conditions on the fresh water side a head of fresh water would have to be five or six feet above mean sea level to be in a state of hydrostatic balance with the Gulf waters.

The velocity of movement of the water through the aquifer is directly proportional to the hydraulic gradient and the permeability of the sediments. Since the velocity of movement of the groundwater in the Basin is probably small, say less than 100 ft. per year, for normal gradients, temporary small reversals of gradient would tend to give an insignificant and temporary eastward shift of the saline Gulf waters. If, however, the decline in the piezometric surface should continue, as would appear likely from present indications, the point may be reached within even a few years whereby there is a net yearly reversal of gradient accompanied by an average eastward movement of saline Gulf waters into some areas. Such ingression would initially proceed at a very slow rate but would increase in velocity with continued heavy pumping and further fall in the piezometric surface inland.

The increased rate of fall of water levels is too recent a feature to enable time predictions to be made but it would appear that the effects of such ingression may quite possibly become economically important within the present generation if the present rate of increase in withdrawal from storage should continue.

2. Possibility of Ingression from Portions of the Basin containing more Saline Waters

Another aspect of saline ingression is that which may be expected from saline portions of the Basin adjacent to areas of heavy pumping in good quality water zones. Such more saline waters are known to exist in the Direk-Penfield-Smithfield-Elizabeth area and again in the Two Wells - Kangaroo Flats area as shown on the accompanying salinity plans. Near both areas, but particularly southwest from Direk in the Waterloo Corner area, there is a concentration of large producing bores in the zone of good quality water which is in contrast to the more saline areas. Such differential pumping must tend to establish a new and steeper hydraulic gradient favouring the movement of the more saline water toward the more heavily exploited groundwater of lower salt content. Movement of the saline water of only one quarter of a mile would be significant in this area where a steep salinity gradient from Dirck to Waterloo Corner exists. Although only tentative evidence of such ingression is at hand a tendency for it to occur is an inevitable consequence of the present trend toward increased withdrawal. Effects of ingression from these areas might be expected to be possibly not so severe but to become apparent more quickly, than that from the Gulf.

3. Possibility of Vertical Contamination from Saline Water Horizons

Saline groundwaters commonly occur at shallow depth throughout most of the Basin area. These waters are normally contained from downward percolation by impermeable clays. Some known old bores act as a means of intake of these apparently corrosive upper salt waters to deeper better quality zones by means of corroded holes in the casing. The amount of this intake would be accelerated by nearby bores pumping from the deeper aquifers. Similarly bores constructed with oversize holes through the aquicludes may allow vertical leakage down the outside of loosely fitting casing. Vertical contamination as described has become severe and caused the abandonment of important areas of groundwater usage overseas.[3] Some such contamination is unquestionably occurring to some small extent in the North Adelaide Plains at the present time. There is no evidence to indicate that this condition now is serious, but unless bores showing signs of such leakage are properly sealed or rehabilitated, an increase in this type of contamination will occur with time as more casings become corroded.

An additional possible source of vertical contamination is from underlying more saline waters. In the Waterloo Corner area, for example, market garden quality water is being pumped from shelly sands which occur from about 200 to somewhat over 300 ft. in depth. Below these sands water too saline for gardening occurs in permeable sandy limestone. With declining water levels there may be a tendency to install deep bore pumps at greater depth which may eventually cause mixing of these waters through any points of weakness in the sometimes rather thin aquicludes which separate the aquifers.

B. SUPPLY AND PUMPING COSTS AND FALLING WATER LEVELS

It has been noted that the decline in water level has necessitated fitting pumps to previously flowing bores and replacing centrifugal pumps with the more expensive deep bore pumps. With a further fall in water levels, pumps will have to be installed at greater depths if the yield is to be maintained and in some cases bores may have to be deepened. Aside from these additional expenditures there is an increased power cost entailed in pumping against greater heads following falls in water levels.

One criterion for determining the "safe yield" in studies of the groundwater resources of Basins is based on the economics of pumping costs and crop value. Because of the lack of data available from users on pumping schedules and rates of withdrawal and the fact that most irrigation bores are inaccessible for measurement, the use of this criterion would be very difficult to apply in this area. It is known, however, that a decline in the static water level and hence the pumping level in a bore of say 30 ft. requires an appreciable greater power expenditure, the amount varying with the particular equipment installed. Following from discussion with officers of the E.T.S.A. it would appear that such costs increases may already be significant in some cases.

C. ELASTIC RESPONSE OF THE AQUIFERS

One further possible adverse consequence of falling water levels should be considered. It is known that both aquifers and aquicludes in basins containing pressure waters have an elastic response to pressure changes.(5) With the relief of hydraulic pressure within an aquifer, basin sediments have been known to compress. Elsewhere under extreme conditions of withdrawal this has resulted in an actual subsidence in the surface level of the ground of as much as ten feet.(10) Although perhaps possible, an expansion of the sediments with a recovery of the hydraulic pressure within the aquifer has not been observed elsewhere and a loss in the specific capacity of the aquifer from such compression may result in irreparable damage to the storage capacity of the aquifer.(10)

Although the hydraulic pressure decline which is reflected by the water level in bores, is not considered to have been sufficient to cause significant compression of the sediments in the North Adelaide Plains, this study has not been actively undertaken.

5. RECOMMENDATIONS FOR FURTHER STUDY

In order to preserve and to increase to a safe maximum the area's large and still growing importance in market gardening and pasture irrigation, conservation and intelligent usage of the groundwater resources, upon which the area is dependant, is indicated. Decisions on helpful conservation measures in such a large complex Basin require considerable knowledge and understanding of the problems peculiar to the Basin, to its catchment area and to other areas using waters from its catchment. In an effort to obtain a thorough knowledge and understanding, a very extensive and intensive investigation could be undertaken. It becomes a difficult problem to draw the limits for such an investigation which could easily become so large as to drain investigation facilities from other important areas in the State which also require study. A discussion of various possible lines of investigation is given below.

A. VARIATIONS IN THE PIEZOMETRIC SURFACE

The greatly extended programme of water level measurement recently introduced is probably the most useful and practicable line of investigation. Extended period observation should enable a pattern of water level variation to be determined which may assist in making at least four important predictions.

1. Whether or not there is a tendency for the movement of saline water and the magnitude and direction of such movement.
2. Whether or not storage is being depleted from year to year.
3. Whether or not water levels are falling during the pumping season to near the bottom of the aquifers or to levels too deep for economic pumping.
4. Whether or not pump settings in individual bores are sufficiently deep.

B. CHEMICAL STUDY OF THE GROUNDWATER

Two lines of study are suggested.

1. Periodic water analyses

As has already been recognised a more extensive and systematic programme of periodic sampling from a grid of bores is desirable so that any variations in salt content can be studied. Provided sufficient personnel are available, such sampling should be reasonably straightforward as numerous pumping bores are generally available. However the drilling of outpost bores on the extreme western portions of the plains or in the Gulf itself might be considered. Such drilling is discussed later in the report. Bores should be selected from both marine aquifers and particularly at sites adjacent to the more saline zones and near areas of heavy pumping. If such sites are located on a steep salinity gradient, some seasonal oscillations in in water quality may occur. A possible example of this is a bore in Sect. 4263, Hd. of Munno Para where analyses have varied as follows:-

19/11/57	? 100 grains/gall.	Horwood Bagshaw analysis.
30/4/59	125.6	111/232
17/7/60	164.0	119/363
15/8/60	168	123/1504
18/11/60	131	123/1789

A programme of periodic analyses backed by active public co-operation in reporting suspected salinity changes should indicate any significant shift in salinity boundaries.

2. Chemical Nature of the Groundwaters and their Distribution

Considerable preliminary study was initiated with the plan of characterizing the chemical nature of the various groundwaters so that they could be treated statistically or graphically. It was hoped that such an empirical treatment would enable a better understanding of the movement, separation and intake of the groundwater. It was also hoped that such characterization and study would enable the typing of the waters and aid genetic interpretation of the history of the groundwaters.

Some hundreds of full analyses were recalculated, with the help of computers of the Geophysical Section, in terms of reacting values (the reciprocals of the equivalent weights). By using percentages of these reacting values it was then possible to represent each analysis by two points, one each on anion and cation ternary diagrams. In this way many different waters of common depth, aquifer or location can be represented on single diagrams. (Appendix O) Analyses of the data had not progressed sufficiently to enable conclusions to be drawn, but the following seemed to be suggested.

(a) The spread of the points on the diagrams although not large suggested that some possible characterization in this manner was possible.

(b) The density of the points appeared to fall into groups, the significance of which has not been studied.

(c) The marine aquifers water appears to be generally richer in calcium and carbonate ions than the shallower waters.

The results seem sufficiently encouraging to warrant further study.

C. WATER INVENTORY

There are so many variables of unknown magnitude that a water inventory of the area is difficult to approximate with even reasonable accuracy. A sufficiently thorough investigation to satisfactorily determine all the values required may not be considered warranted at this stage. However, some data is readily available and some helpful approximations could possibly be made with care.

1. Pumpage Data

The amount of water pumped for a given period of time is not known with any precision. This is true even though nearly all of the bores in the area have been recorded together with some comment on supply. The problem, however, is not a static one as new bores are continually being drilled for different purposes and established bores change in their function (and hence their production) or become abandoned. By in large, logs of pumping rates and times are not kept and the average withdrawal of most of the bores can only roughly be approximated. It would seem that the individual co-operation of landholders in providing pumpage data would be helpful and log forms for entry of such data might be made available.

In order to obtain some approximation of withdrawal from groundwater storage an estimation of pumping rates of all known functioning bores for the year 1960 was made by the writer. Considerable personal interpretation was required to obtain a total pumpage estimate of about 5 x 10^9 gall.

Additional water is lost from storage from some bores which still overflow through part of the winter period. Pumpage from water holes in the rivers is another source of water loss.

2. Intake

Intake for the area must first be defined before quantitative estimates can be considered. From previous discussion it may be understood that most of the intake into the marine aquifers occurs in the vicinity of the discharge of the two main rivers on to the plains. Since the marine beds do not actually outcrop in the intake area, recharge is by way of the overlying non-marine sediments which are of a sandy nature along much of the eastern margins. A number of drainages including Smith's Creek make some contribution to intake between the rivers. The shallower, non-marine aquifers have a more extended intake system which, although most active along the two major rivers would include intake from minor drainages on the plains area where the shallow sediments are sufficiently permeable.

Except in the eastern intake zone, sufficiently continuous and thick clay aquicludes occur to prevent the hydraulic contact between the non-marine and marine aquifers. In some areas irrigation waters may partly infiltrate and to some extent recharge the shallow groundwaters where water table conditions exist.

A study to determine the total water inventory of the catchment area using approximations for infiltration, evaporation, transpiration and runoff may involve too many doubtful parameters for satisfactory approximations of intake to groundwater storage and outflow of surface and groundwaters. Before water is discharged onto the plains it is used and reused as it is pumped from rivers and groundwater storage for irrigation and so exposed to repeated evaporation, transpiration and infiltration.

It is considered that the only satisfactory approach to quantitative intake determinations is by a system of river gaugings measuring the flow into the Plain area. If possible further gauging stations could be constructed in the Plains area so as to measure infiltration loss. Such constructions would be difficult and expensive and further work would be required to determine feasibility and siting. For sites on the Plains allowance for rainfall incident to the plains and for pumping from the two Rivers would have to be made.

At present River gaugings are inadequate. One station is located on the North Para River downstream from the Barossa Valley which would probably be useful. Also it is understood that some readings are taken on the South Para Reservoir. The applicability of the South Para readings to the investigation requires further discussion with the E. & W. S. Department. Gaugings of the Little Para River are not yet known but are highly desirable, particularly in view of the proposed reservoir at the junction of Gould's Creek.

Some estimation of run-off from the small drainages discharging onto the Plains between the two main rivers should be made - particularly Smith's Creek.

3. Outflow

The bulk of the water lost to the Gulf from the Plains area is surface water from the two main watercourses. The proposed drainage through the Bolivar Treatment Works, however is expected to discharge considerable runoff waters from rainfall incident to the Plains between the Gawler and Little Para River. The determination of the total surface outflow to the Gulf would be a valuable contribution to the understanding of both surface and groundwater resources of the area and would be necessary to any comprehensive programme of water management. This outflow represents a loss of low salinity water, a commodity not in over abundance in the area.

A determination of the outflow of groundwater cannot be reasonably estimated at the present time as neither the vertical dimensions or the water characteristics of the marine aquifers are known. A better appreciation of this loss may follow from a period of measurement of the increased number of observation bores. Deep outpost bores would be particularly helpful in determining pressure gradients and the thicknesses of the deep aquifers and hence evaluating outflow.

In general outflow through the aquifers can be expected to decrease with falling water levels and at peak periods of pumping, to be reversed with the inland movement of saline Gulf waters.

D. CHARACTERISTICS OF THE AQUIFERS

Knowledge of the permeability, porosity and coefficient of storage for the aquifers is necessary for a good understanding of the groundwater resources of the area but the obtaining of useful values for these parameters in the North Adelaide Plains may entail a greater expenditure of investigation resources than are available.

The value of these parameters is indicated in the following relations:

$$Q = PIA$$

$$Q = vIAp$$

where Q is the quantity of groundwater flowing through a cross section of the Basin of area A with a permeability P, porosity p, hydraulic gradient I and velocity v.

Evaluation of the coefficient of storage is almost equivalent in importance to permeability determination. The coefficient is defined as the water released from or taken into storage in response to a charge in head. Satisfactory evaluation of these factors would facilitate determination of the rate of movement of saline waters and the outflow from the Basin.

1. Field Pump Tests

The more approved methods of permeability and coefficient of storage determinations are by various field pump tests, sample analyses being widely held as unreliable. However, it is considered that such pump tests are not at present readily or generally applicable to the marine aquifers in the North Adelaide Plains for the following reasons:

a. The lower limits of the sandy limestone aquifer are not determined as present bores are too shallow.

b. The horizontal boundary conditions are often not easily defined due to changes in facies; this would necessitate many separate determinations before the permeability variations could be understood.

c. Vertical boundaries are often vague, the difference in the layered sediments giving anisotropic behaviour.

d. Drilling depths required are of the order of from 250 ft. to over 500 ft. for pumping and observation bores. Since a number of observations would be required, each necessitating several bores, a testing programme would be costly.

e. Existing bores are not generally satisfactory for such tests since

(i) Removal of pumps for observation would be required.

(ii) Depths and distribution of bores are not generally suitable.

(iii) Description of the sediments encountered in the bores is often not sufficiently detailed.

f. The upper marine, sandy aquifer, although marked by more clearly defined boundaries, is almost always developed by blowing with compressed air which means that there is a large and undefined area of disturbance around the bore. Considerable error in using such bores in pump tests would be introduced.

Despite these difficulties some field pump tests may be warranted under particularly favourable conditions where there is likelihood of obtaining useful information.

Other methods of determining the aquifer characteristics should be considered in view of the difficulty of pump test methods.

2. Laboratory Determination

Conversations with Mr. Moss of the C.S.I.R.O. indicate that it might be possible to work out a programme of laboratory porosity and permeability testing if suitable samples can be obtained. Generally sludge samples are not sufficiently reliable for this work even though compaction equipment is available. It is suggested that in the course of Departmental drilling that boring be interrupted at favourable depths and that tube or core sampling be undertaken at Departmental expense. If sufficient samples could so be obtained from various aquifers and positions in the plains and tested, the resulting data may give a truer picture of the characteristics of the aquifers than a very limited number of expensive pump tests. From previous trial it would appear that the sandy limestone aquifer may be sometimes too hard for tube sampling and coring would be required. Although difficult, the shelly sand aquifer under some conditions may possibly be sampled, but this would require trial. Although undisturbed samples may not be obtainable from these sands, sufficiently representative material may be recovered so that by compaction the order of permeability or, at least, the relative permeability from area to area might be determinable.

3. Instrument Logging of Bore Holes

Electric and radiometric logging methods discussed in D.M. 1574/58 appear to be promising methods for in situ porosity determination as well as obtaining stratigraphic information. Such logging is expected to give porosity information for the entire length of the hole which may be much more useful than porosity tests of samples taken from arbitrary depths, particularly if undisturbed samples are difficult to obtain. Some appreciation of permeability may also be possible from these logging methods. The radiometric logging can under some circumstances be done in cased holes.

4. Elasticity Study

It is considered pertinent to quote from the Ground-Water Hydraulics, Part 1, ground-water notes of the U.S.G.S., page 8, as follows:

"For an artesian aquifer, regardless of its attitude, the water released from or taken into storage, in response to a change in head, is attributed solely to compressibility of the aquifer material and of the water."

Although considerable theoretical study remains to be done on the elastic behaviour of artesian aquifers some relationships between coefficient of storage and elasticity of aquifers have been determined.(5) These relationships may be applicable to the study of the marine aquifers on the western margins of the Plains and useful data may possibly be obtainable by means of an extension and refinement of water level observations.

Such study is largely dependant upon water levels in the artesian aquifer showing a response to tidal and barometric fluctuation, tidal response having already been proven in the aquifers further south, the relations being:-

a. $B.E. = \frac{Sw}{Sb}$

where BE is the barometric efficiency

Sw = net change in water level in the bore tapping the aquifer

Sb = corresponding change in atmospheric pressure.

B.E. is determined by measuring the slope of the plot of Sw against Sb.

b. $TE = \frac{Sw}{St}$

where St = range of the tide in ft. corrected for density.

c. Relations between tidal and barometric efficiencies and elasticity of artesian aquifers.

$$T.E. = \frac{\alpha/\theta\beta}{1 + \alpha/\theta\beta}$$

$$B.E. = \frac{1}{1 + \alpha/\theta\beta}$$

$$B.E. + T.E. = \frac{\quad}{1 + \alpha/\theta\beta} + \frac{1}{1 + \alpha/\theta\beta} = 1$$

where α = bulk modulus of compression of the solid skeleton of the aquifer.

β = bulk modulus of compression of water (reciprocal of bulk modulus of elasticity).

θ = porosity of the aquifer

d. The coefficient of storage is a function of the elasticity of an artesian aquifer.

$S = \gamma_0 \theta m (\beta + \alpha/\theta)$

where γ_0 = specific weight of water at a stated reference temperature ($62.4\ lbs/ft^3 = 0.0361\ lb/in^3$)

m = thickness of the aquifer

$$\beta = \frac{1}{300000} = 3.3 \times 10^{-6} in^2/ft.$$

and where loss through the confining layer is small,

S = specific yield = $\gamma_0 \theta m \beta \left[\frac{1}{B.E.}\right]$

and $BE = \frac{1}{1 - T.E.}$

Elsewhere specific yield determinations from elasticity study have compared closely with values obtained from pump tests.[5]

It is considered that provided suitable tidal response can be obtained, that a study of the above nature would not be overly expensive and would be compatible with present water level studies. The method offers a determination of specific yield independent from any pump tests evaluations which might be undertaken. Porosity determinations would be required which possibly could best be done by instrument logging as discussed in the previous section.

E. CONSTRUCTION OF OUTPOST OBSERVATION BORES

A continuation of the marine aquifers of the Basin under the sea water of the Gulf must occur. Sediments of similar stratigraphic age outcrop on the eastern margin of Yorke Peninsula. Folding and faulting of these marginal sediments and observed outcrop of aquifer material in littoral zones of the Gulf strongly suggest that saline Gulf waters have access, over some if not large areas of the Gulf for infiltration and percolation into the marine aquifers which underlies the Plains area.

This being the case, the head of water in the Gulf would tend to force the Gulf water through the aquifers well inland under the plains area. There has been however, a build up of fresh intake waters in the eastern portion of the aquifer over a long period of time resulting in a higher head of fresh water and a net movement of the fresh groundwater into the Gulf.

Since there is a tendency for this gradient to be reversed at times of heavy pumping inland, as has previously been discussed, the determination of the position of the zone of fresh-saline water contact in the aquifers and the movement of this zone becomes important. Neither determination can be made until such time as suitable observations are made on bores which penetrate or bracket this contact. The zone of contact, probably mixed and diffused, may occur just inland from the coast or well out into the Gulf and is probably in different positions for the different aquifers. The occurrence of 1400 grain water in the Pliocene sands at St. Kilda may indicate such a zone or an anomaly. A report of 685 grains water in Section 231, Hd. of Port Gawler is also uncertain.

Such contacts have been studied in some detail elsewhere (3, 10, 14) where encroaching saline water has been observed to toe under the fresher water in such a way as to give a balanced head within the aquifer, Ghyben-Herzberg Relationship. Where the contact is undergoing movement a more general form of the Relationship can be used.

$$z = \frac{Ps}{Ps-Pf} - hs - \frac{Pf}{Ps-Pf} - hf$$

Where z = altitude of a point on the fresh-salt water contact.

hs = altitude of the water level in a well filled with salty water of density fs and terminates at the contact at the depth z.

hf = altitude of the water level in a bore filled with fresh waterof density Pf and also terminates at the depth z.

If the position and movement of such a contact is to be determined there would appear to be no alternative to the drilling of outpost observation bores. Three such bores could initially be tried, which if at all possible should be drilled to basement, useful positions being on the extreme western margins of the Plains at Port Gawler, St. Kilda or to the south on the Le Fevre Peninsula near the Outer Harbour.

Three general possibilities exist.

1. If the bores penetrate only fresh water in the aquifers, then they would be valuable as warning outposts should encroachment occur.

2. If the bores penetrate the salt-fresh contact, then periodic observations could be made to determine the rate of movement of the contact in accord with the above equations. To do this two bores per site would be required, one to the fresh and one to the saline regions.

3. If such bores penetrated only saline Gulf waters, then this would indicate the dangerous proximity of the salt waters to areas of groundwaters use and such bores could be used in determining the rate and direction of movement of the saline water.

In the first case discussed, the only additional step to locate the contact would be the drilling of off-shore bores, perhaps utilizing the end of the breakwater at Outer Harbour. The drilling of off shore bores under the circumstances described may be considered prohibitively expensive and probably premature unless further water level drops indicate a significant landward gradient of the piezometric surface. However the importance of such bores is indicated by the following quotation. "Where a salt water body lies entirely offshore and there is reason to believe that it is encroaching, obviously there is no alternative except to construct outpost wells at or beyond the shoreline as a preliminary measure."(14)

Aside from their function in the study of encroachment, several other important uses strongly support deep outpost bore construction at least on the western limits of the Plains.

1. To provide a means for correlating and evaluating seismic data so that velocity coefficients of wave travel in the sediments can be computed and hence applied to the Adelaide Plains Seismic Survey as a whole.
2. To determine the depth to basement rock and hence the thickness of the Basin on its western margins.
3. To determine the thickness, nature and water characteristics of the deeper Basin Sediments, information which is unknown in the area. This is particularly important with regard to the aquifers, the storage and outflow from which cannot at present be computed.
4. To determine the distribution of various salinity waters with depth, data which is not at present available.
5. To advance the understanding of the stratigraphy of the deeper Basin sediments.

If such bores are to be drilled, it is recommended that casing be preceded by electric and other logging for stratigraphic correlation, porosity determination and permeability implications. Core and tube samples from such drilling would be desirable. It is suggested that the use of a rotary plant be seriously considered from the point of view of cost (possibly cheaper for a 1500 foot hole), coring of limestone samples, and facility for geophysical testing, down-hole shooting for velocity measurements and instrument logging of the hole. With a mudded hole a greater length of uncased hole could be left for longer periods of time to facilitate geophysical testing.

F. RECHARGE AND WATER USAGE

From the discussion of intake it follows that the amount and distribution of yearly run-off waters is not adequately known and that the available water for intake or recharge can be expected to decrease with the function of the South Para Reservoir and the proposed Little Para Reservoir. Certainly at times of prolonged strong precipitation, considerable water is lost to the Gulf along the two main rivers - quite strong flow having been observed during the last rainy season. The capacity of the drain through the Bolivar treatment Works is also large but expected to have a very short duration of flow occurring only after fairly heavy rains.

Since available low salinity water is not abundant the utilization of outflow waters to the Gulf, both surface and groundwater should be carefully considered.

Outflow loss through the aquifers can be minimised by sufficient inland pumping, to arrive at a hydrostatic balance of head of fresh water against equivalent head of Gulf water. Some net outflow should, however, occur as a safety margin to ensure against ingression of saline water inland along local steep inland gradients toward restricted areas of excessive pumping. Short seasonal periods of reversed gradients of low magnitude would cause only small oscillations of the saline-fresh water contact in the aquifers.

Surface waters on the Plains would be difficult to impound, desilt and introduce into the marine aquifers, particularly in the western portions of the plains. Some discussion of utilization of various surface waters in the western portion of plains is given in reference to the proposed Bolivar Treatment Works, D.M. 769/60.

Although much study would be required, it is considered important that some investigation should be given to diverting excess run-off waters, when they may be available, from the Little Para and North and South Para Rivers to soakage ponds in zones along the eastern margins of the Plains. Here the permeability of the underlying sediments may allow infiltration and percolation to a free water table some 50 to 100 feet or more in places belowthe ground surface in positions east from the Gawler-Adelaide Road. Such infiltrated waters would be expected to percolate downward and to the west and to build up the hydrostatic head in the marine aquifers and to transmit this head through the aquifers to the western portions of the Basin.

Such introduced waters would also be expected to have a slow progressive freshening effect on the groundwaters westward from points of infiltration.

G. ADDITIONAL REMEDIAL MEASURES

Some helpful measures could possibly be initiated with a minimum of investigation, these include.

1. An appeal could be made to landowners, drilling contractors and pump distributors to co-operate still further in making drilling data, water samples and pumpage records available to the Survey. Pumpage log forms could be supplied to landowners interested in co-operating, particularly those with bores near to observation bores. Pumpage records would assist in interpreting static water level variations and might enable some quantitative determinations of coefficients of storage.

2. The desirability of plugging old bores before their abandonment and the repair of corroded casing should be stressed to the public. If sufficient authority is available it would seem desirable to require that bores should be so treated.

3. A programme of preventing groundwater waste should be popularised and if possible enforced. It is suggested that the application of legislation (if this is possible) to prevent the wasteful overflow of bores would not generally be unpopular to users, many of whom have expressed concern at water level falls.

6. CONCLUSIONS

Although undefined, the total groundwater storage is large but much of this storage is too saline for irrigation purposes. Withdrawal from the better quality zones in excess of intake can result in depressed water levels to the point where reduced supplies and increased pumping cost may make some areas uneconomic for irrigation on the scale suggested by present land subdivisions.

Additionally, there is a danger of encroachment of saline groundwaters into some areas of high productivity. Unequal distribution of pumpage, large in areas of low salinity groundwater and small in the more saline areas, causes a change in the natural hydraulic gradients and such changes would favour the movement of saline waters to areas of highest production. Such movement may first become apparent in restricted areas where the gradients become particularly steep but a more general encroachment could follow a continuation of the present yearly trend of increased fall in water levels by the slow movement of saline Gulf waters inland.

The availability of good quality groundwaters to serve the irrigation requirements of a growing population of the "Greater Adelaide" area is sufficiently limited to make full utilization of the Basin's groundwater resources desirable. Consequently better definition of safe yield from the Basin is important.

The groundwater resources and their response to usage are sufficiently complex to necessitate consideration of portions of the Basin as well as the area as a whole. The limits of the aquifers, intake, pumpage, outflow and hydraulic characteristics of the aquifer are not adequately understood and further investigation is required before a definition of maximum safe yield can be given.

Since other important areas in the State also require study a sufficiently comprehensive investigation to enable full quantitative determination of the groundwater resources would probably overtax present investigation facilities. It is then probably necessary to critically examine possible lines of investigation such as have been discussed in this report in terms of facilities and objectives.

A division of the water resources of the area into groundwater and surface water categories is not always possible and both of these interdependent forms of water supply should be considered together in overall water management planning. Recent and proposed reservoir construction must act deleteriously on intake to the Basin aquifers. Problems of use and reuse of available waters should be studied and possibilities of artificial recharge of the groundwater aquifers be considered. Even greater efforts should be made to explain the groundwater problems to the public so that greater and more intelligent co-operation may be possible.

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1st March, 1961
RIC:AGK

REFERENCES

1. ALTOVSKY & KONOPLYANTSEV, 1959. Manual for the systematic study of the regime of underground waters. Foreign Languages Publishing House, Moscow.

2. BEAN, R.T., RICHTER, R.C. & McCLURE, C.R. 1957 Groundwater resources of California, Directory Am. Geoph. Union, Reviews and Abstracts, 1957, p. 415.

3. BENNETT, R.R. 1945. Groundwater situation at Baltimore badly confused, Water Works Engineering Aug. 8, 1955.

4. CHUGG, R.I. 1958. Bore at Elizabeth Oval and its hydrological significance, Mining Rev. No. 108, Dept. Mines, S.A.

5. FERRIS, JOHN G. 1955. Groundwater hydraulics, Part 1 theory. Groundwater notes, U.S.G.S. Groundwater Branch.

6. HALL, W.A. 1957. Perched water table under an artificial groundwater recharge system. Trans. Am. Geophy. Union. Vol. 38, No. 3.

7. JACOB, C.E. 1957. Full utilization of groundwater reservoirs, Trans. Am. Geoph. Union, Vol. 38, p. 417.

8. JACOB, C.E. 1937. Groundwater underflow in Croton Valley, N.Y. A comparison of field and laboratory methods. Trans. Am. Geoph. Union, 1937-38, p. 419.

9. KAZMANN, R.G. 1956. "Safe Yield" in groundwater development, reality or illusion?, Irr. and Drain. Div. A.S.C.E. Vol. 82, Nov.

10. LINSLEY, R.K. Jr., KOHLER, M.A. & PAULHUS, J.L. 1958. Hydrology for engineers, McGraw-Hill Book Co. Inc., N.Y. Toronto, London.

11. McGUINNESS, C.L. 1947. Recharge and depletion of groundwater supplies, Trans. A.S.C.E., Vol. 112, p. 972-998.

12. MILES, K.R. 1952. Geology and underground water resources of the Adelaide Plains area, Bull. 27, Geol. Surv. South Aust.

13. NACE, R.L. 1959. Water use and resources in U.S.A., Water and Water Engr., Vol. 63, No. 766, Dec.

14. PERLMUTTER, N.M., GERAGHTY, J.J. & UPSON, J.E. 1959. Relation between fresh and salty groundwater in Southern Nassau and S.E. Queens Counties, Long Island, N.Y.
Economic Geology, Vol. 54, p. 416-435.

15. WENZEL, L.K. 1942. Methods for determining permeability of water bearing materials. Water Supply Paper 887, U.S.G.S.

APPENDIX A

DATA ON DECLINE IN WATER LEVELS IN BORES IN THE NORTH ADELAIDE PLAINS

from

REPORTS FROM LANDOWNERS INTERVIEWED IN 1959

Hundred Port Gawler

Section 7532 Buckland Park.

S.W.L. was 13 ft. above ground level
S.W.L. was 11 ft. " " " in 1957
S.W.L. was 3 or 4 ft. " " " in 1958
S.W.L. was 1 ft. " " " Feb. 1959.
S.W.L. was measured April, 1959 at 2 ft. 3 in. below ground level.

A windmill was installed in 1959.

Section 7543 Buckland Park.

Bore overflowed summer and winter to a height of 4 or 5 ft. above ground level but stopped flowing in the last 2 or 3 years.

Section 26 Buckland Park.

This bore did overflow from a pipe 3 ft. above the surface but stopped six years ago and was then equipped with a windmill. The S.W.L. was measured April, 1959 to be 9½ ft. below the ground level.

Section 68

Mr. Fantasia and Mr. Fuse have noted a progressive decrease in supply in summer months. Mr. Fuse's bore and Mr. Sharpe's bore across the Gawler River in Section 7569, Hd. Munno Para affect one another when pumping.

Section 68

Mr. A. Canala reports that his 350 foot bore has decreased in yield by ¼ while pumping with an air compressor. This has caused him to discontinue the use of his compressor and to equip his adjacent deep bore with a deep bore pump.

Section 215

Mr. C.K. Badman reports that his 40 years old bore which used to overflow summer and winter ceased flowing after the winter of 1956 and has not overflowed since.

Hundred Munno Para

Section 4250

Mr. H.K. Briggs reports that he was successfully using a centrifugal pump on a 250 ft. bore until 12 months ago when his supply fell off severely owing to a drop in the water level in the bore.

In April-May 1955	S.W.L.	18'
In April-May 1958	S.W.L.	43'

The S.W.L. used to rise to the surface in winter.

Mr. Briggs reports that centrifugal pumps are no longer used for the deep bores (below 200 ft.) in the area.

Section 7585

F. & R. Trimboli report that they can now pump only 9,000 g.p.h. from their three year old bore whereas initially it yielded 11,000 to 12,000 g.p.h. with prolonged pumping. They attribute the decrease to a drop in the S.W.L. The bore is not accessible for direct measurement.

Section 7573

Mr. L. Cecci obtains 3,000 to 4,000 g.p.h. maximum yield from Oct. to Jan. in his 320 ft. bore, whereas in winter he can pump 7,000 gallons per hour. He attributes this to the competition of neighbouring bores pumping through the summer.

Section 3876

Mr. E. Chinner, eastward from the above, has observed when removing his pump on occasions that there has been no noticeable overall or seasonal variation in the S.W.L. in his 325 ft. bore.

Section 4263

Mr. Coad irrigating extensively from a deep bore (approx. 400 ft.), has been forced to use fewer sprinklers in summer than winter and has noted that falling pressures in his sprinkling system coincides with competitive pumping from neighbouring bores.

Section 4258

Lucerne Limited have recently replaced a centrifugal pump with a deep bore pump owing to a decrease in supply and presumably a drop in the S.W.L.

Section 7569

Mr. A.B. Fuss has noted a decrease in supply similar to that which has occurred with Mr. Carola's bore. Mr. Fuss intends installing a deep bore pump.

Hundred Munno Para (Contd.)

Section 3054

The S.W.L. in a bore drilled to 307 feet two years ago has been measured periodically by Mr. A.J. Taylor as follows:

Spring 1957: S.W.L. 4 to 5 ft. below surface. A supply of 4,000 to 5,000 g.p.h. was obtainable, with a centrifugal pump at the surface.

Summer 1957-58: With the pump still at the surface, the supply fell to about 3,000 g.p.h.

Winter 1958: The standing water level came up to 5ft. from the surface.

Summer 1958-1959: The S.W.L. fell to 25ft. by February and only 900 g.p.h. was obtainable with the pump at the bottom of an 8 ft. shaft.

June 1959: S.W.L. 24 ft.

Hundred Port Adelaide

Section 3034

The owner of a bore which produces up to 12,000 to 13,000 g.p.h. has observed a fall in S.W.L. from 8 ft. in winter to 20 ft. in summer.

Section 3051

Mr. Jones reports that his 200 ft. bore did overflow 10 feet above ground level 6 or 7 years ago. Although he does not pump a great deal the bore stopped flowing in the summer of 1957 and the S.W.L. dropped to 14 ft. below ground level. The following winter the bore just flowed at ground level. This summer the S.W.L. was 19 ft. below ground level and by June rose to within 8 ft. of the surface.

Section 122 Ilya Past. Co.

A bore and well about 200 ft. deep, constructed in 1901 overflowed summer and winter until the summer of 1954. See graph appended.

Section 123 Ilya Past. Co.

A bore over 300 ft. deep although not pumped since 1939 to 1940 ceased overflowing in summer of 1953.

Section 121 Bore A Ilya Past. Co.

This bore has a record of overflowing in 1949. It stopped in the summer of 1953 although it had not been used for irrigation after 1939.

Section 121 Bore B Ilya Past. Co.

Although never used for irrigation, this bore stopped its winter overflow in 1954.

Section 166 Ilya East. Co.

A bore did overflow at the rate of 170 g.p.h. into a tank but stopped in the summer of 1957. The S.W.L. was measured 27.4.59 at 1½ ft. below ground level.

Section 154 Ilya East. Co.

A bore about 300 ft. deep did have water standing at ground level. It was measured 27/4/59 at 2 ft. 8 in. below the surface.

Section 168 Ilya East. Co.

A very old (early 1900's) deep bore used to overflow at about 200 g.p.h. at a height of 8 ft. above the surface. It stopped in the summer of 1957 and a windmill was installed. It was measured 24/4/59 at 4 ft. 3 in. below ground level.

Section 7523 Buckland Park

A 160 ft. bore overflowed to a height of 1 ft. above ground level in 1957, stopped flowing in 1958 and was measured at 9 ft. below ground level on 24/4/59.

Section 7598

Mr. Snell Senior reported that a 320 ft. bore was pumped at 14,000 g.p.h. from 1955 to 1957 with a centrifugal pump. The bore did overflow summer and winter but in 1957 the S.W.L. was found to be 13 ft. below the surface. A deep bore pump was then installed. This bore has been noted to compete with Mr. Snell's son's bore on Section 3503.

Mr. Snell reports further that up to within 10 years ago he had 8 to 10 bores all 180 ft. deep all of which overflowed. These bores have all stopped flowing in the summer and all now require pumps.

Section 3503

Mr. J.B. Snell's bore, 108 ft. deep did overflow but with a fall in the S.W.L. the bore was deepened to 306 ft. From the deepened bore a supply of 12,600 to 14,000 g.p.h. was obtained with a centrifugal pump at a depth of 12 ft. in a shaft. In 1957 the supply decreased to ½ the yield and it was then noted that the S.W.L. fell to 26 ft. below ground level in the summer but filled the shaft in the winter. A deep bore pump was then installed. The bore does now still overflow in winter but last year this flow was very small.

Section 5025

Mr. Capaldo reports that the winter S.W.L. in his bore has been the same for the last three seasons at 7 ft. In December 1957 he noted that his S.W.L. was 14 ft. from ground level. Mr. Capaldo says that the remaining centrifugal pumps were replaced by deep bore pumps last year in his area.

Hd. Port Adelaide (Contd.)

Section 5001

Mr. Robinson did have a centrifugal pump at ground level with no suction pipe. A fall in the S.W.L. caused him to install a tail pipe on his pump two years ago.

In March 1950 the bore overflowed 2500 g.p.h. in the summer with a larger unmeasured flow in the winter.

In 1956 the bore still overflowed with a sufficient yield for stock (approx. 200 g.p.h.)

At present the bore still overflows in winter but the summer S.W.L. is about 15 ft. below the surface.

Section 5021

Mr. Robinson reports that in the summer 1957-58 the yield from a 250 ft. bore became very small using a centrifugal pump. A compressor was then installed the S.W.L. then being 33 ft.

Section 107

In 1957 a bore ceased to flow and a windmill was installed.

Investigation has shown that shallow bores (about 100 ft. deep) in the N.W. portion of the Hd. of Port Adelaide have had a fairly constant S.W.L. and no noticeable decline in supply. Deeper bores here, however, have been affected by the large withdrawals to the east.

Section 245

It has been noted by Mr. F.M. Trimbell that his 305 feet bore which produces 8000 to 10,000 g.p.h. at the start of summer yields only 6,000 to 7,000 at the close of the season.

APPENDIX B

TERNARY DIAGRAMS FOR PLOTTING TO REACTING VALUES

HUNDRED ....

SECTION ....

ANALYSIS Nº ....

TOTAL SALTS (gms/gall) ....