CONTENTS

Summary 1
Conclusions 1
Recommendations 2
1. INTRODUCTION 3
2. HISTORY 4
3. HYDROGEOLOGY 6
  3.1 General 6
  3.2 Town Basin 6
  3.3 Farm Area Basin 7
  3.4 Tertiary Sediments South of the Blatherskite Range 9
  3.5 The Bitter Springs Formation 9
  3.6 The Jay Creek Limestone 10
4. CURRENT SITUATION 11
  4.1 Town Basin 11
  4.2 Farm Area Basin 12
5. FUTURE USE 14
  5.1 Town Basin 14
    5.1.1 Availability 14
    5.1.2 Costs 14
    5.1.3 Nature of Consumption 15
    5.1.4 Possible Schemes 15
  5.2 Farm Area Basin 16
    5.2.1 Groundwater 16
    5.2.2 Sewage 18
6. MANAGEMENT 21
  6.1 Monitoring 21
  6.2 Control 22
APPENDICES

1. DISCUSSION OF SOME PAST STUDIES AND APPRAISALS .......................... 24
2. TOWN BASIN WATER BALANCE STUDY AND SAFE YIELD DETERMINATION ... 30
3. FARM AREA BASIN WATER BALANCE STUDY AND SAFE YIELD DETERMINATION 36
4. INVESTIGATION OF THE COMMONAGE AREA AND PROPOSALS FOR SEWAGE REUSE 41
5. REFERENCES ......................................................................................... 49

FIGURES

1. PROPOSED ALICE SPRINGS WATER CONTROL DISTRICT
2. TOWN BASIN STUDY - CHANGES IN SOLUTION WITH CHANGES IN ASSUMED VALUE OF Y
3. TOWN BASIN RECHARGE PROBABILITY CURVES
4. FARM BASIN STUDY - CHANGES IN SOLUTION WITH CHANGES IN ASSUMED VALUE OF L
5. EFFECT OF PROPOSED IRRIGATION ON WATER LEVELS EAST OF SEWAGE LAGOONS

PLATES

1. TOWN AND FARM AREA BASINS. POTENTIOMETRIC SURFACE CONTOURS FOR APRIL 1976
2. TOWN AND FARM AREA BASINS. POTENTIOMETRIC SURFACE CONTOURS FOR APRIL 1964
3. HYDROGEOLOGY OF THE ALICE SPRINGS COMMONAGE
4. TOWN BASIN WATER-LEVEL FLUCTUATIONS
5. FARM AREA BASIN WATER-LEVEL FLUCTUATIONS
6. ST. MARYS CREEK
SUMMARY

In the years since the development of the Mereenie Sandstone as a water source for Alice Springs, use of the water resources of the Town and Town Area Basins has dropped considerably. The present lack of management and control of these and other local aquifers is not compatible with water conservation objectives and has recently given rise to many problems. Clear management policies and effective control are required for the Alice Springs area.

CONCLUSIONS

1. Since 1964 there has been an over-emphasis on use of water from the Mereenie Sandstone, a comparatively expensive resource, while some more local resources are wasted.

2. Many problems and dangers can be attributed to the present lack of use of the Town Basin.

3. The Town and Farm Area basins should be managed so that the annual water consumption approximates the safe yield.

4. In the case of the Town Basin, the present consumption is about 420,000 kilolitres per annum below the safe yield of 600,000. Increased consumption could be achieved by the Council, the Golf Club or the Department of Education.

5. Other major aquifers in the area, the Tertiary sediments and Jay Creek Limestone, are not suited to large scale development but probably play an important role in relation to the Mereenie resources.

6. Effective monitoring and control of all the groundwater near Alice Springs is needed to co-ordinate requirements and to optimise utilisation of the resource. This can only be achieved by the declaration of a water control district under the Control of Waters Ordinance.

7. Sufficient data and understanding of the resource exists to manage a water control district, although an additional staff member would be required to handle the routine workload.

8. The present means of disposal of Alice Springs sewage effluent is unsatisfactory. Viable short-term solutions exist in an irrigation project and an infiltration scheme.

9. The use of sewage effluent to irrigate proposed recreation grounds west of the sewage lagoons is not feasible.

10. For the long term a major upgrading of the sewage treatment system is required to reduce public health problems and broaden the options for use of the reclaimed water.
RECOMMENDATIONS

1. Priority consideration must be given to the land tenure of the Alice Springs Golf Club to allow finalisation of the Club's irrigation proposals.

2. Pending the outcome of the above, detailed planning should commence on schemes for the Council and Department of Education to use Town Basin water.

3. A water control district should be established at Alice Springs.

4. The project advanced by the Regional Working Group to utilise sewage effluent for an irrigation project should be commenced as soon as possible. If this is not feasible, the infiltration proposal should be adopted.

5. Planning should commence for a major upgrading of the sewage treatment system at Alice Springs.
1. INTRODUCTION

After pumping commenced in 1964 from the Mereenie Sandstone 13 kilometres south of Alice Springs, interest rapidly waned in the groundwater resources closer to town. Pumping from the Town and Farm Area basins diminished to below the available yields and investigation of other potential aquifers ceased. 'The Mereenie' was regarded as a permanent source of all water supplies.

Increasing costs of development and pumping at the Mereenie, and water management problems which have arisen in the town area due to the lack of usage of local resources, indicate that the local resources must not be ignored.

This report is not concerned with the Mereenie Sandstone. It is concerned with re-appraising more local resources and aims to determine how these may be used and managed in the future.

Included in the scope of the report is discussion of Alice Springs sewage, itself a significant water resource.
2. HISTORY

The Town Basin provided water for Alice Springs from the time of the first settlement. The so-called springs from which the town derived its name were not springs but waterholes in the Todd River created by the exposure of the water table in holes scoured by river flows.

The basin was progressively developed with wells and bores, especially after World War II when the population began to increase rapidly. Eggington (1964) and Hamilton (1966) provide accounts of the pumping extractions during the late 1950s and early 1960s, when water levels dropped seriously and a search was commenced for a new source.

Pumping from the Mereenie Basin 13 kilometres south of town commenced in 1964 and withdrawals for public reticulation from the Town Basin were phased out within two years, except for a period in the late 1960s when the available Mereenie bores could not cope with the demand.

As a result of the reduced withdrawals the Town Basin recovered by 1967 and its behaviour since has been largely a function of the prevailing weather pattern.

Plate 4 shows the general water level movements from 1954 to the present and allows comparison with river flow occurrence and pumping extractions. Table 1 shows recorded and estimated extractions since 1954.

Pumping from the Farm Area commenced before the war but little is known of the extraction rates prior to 1950, and even since then the figures are not very reliable as there has been no requirement to submit returns. Water level records are also less complete than those of the Town Basin.

Plate 5 shows the water level trends in the Farm Area Basin. In the mid 1960s drawdowns were sufficient to put many bores out of action and subsequently interest in farming sharply decreased, despite the basin's recovery in 1967.

Table 1 shows the estimated Farm Area pumping extractions. The figures do not include farms removed from the area normally considered as the Farm Area, such as at Amoonguna or the A.I.A.S. farm.
TABLE 1
TOWN AND FARM AREA EXTRACTION FIGURES
Million kilolitres

<table>
<thead>
<tr>
<th>YEAR</th>
<th>Public A Reticulation</th>
<th>Other</th>
<th>Private B</th>
<th>Tot.</th>
<th>FARM</th>
</tr>
</thead>
<tbody>
<tr>
<td>1954</td>
<td>0.51</td>
<td>0</td>
<td>0.05</td>
<td>0.56</td>
<td>0.65</td>
</tr>
<tr>
<td>1955</td>
<td>0.49</td>
<td>0</td>
<td>0.05</td>
<td>0.54</td>
<td>0.65</td>
</tr>
<tr>
<td>1956</td>
<td>0.51</td>
<td>0.01</td>
<td>0.07</td>
<td>0.74</td>
<td>0.65</td>
</tr>
<tr>
<td>1957</td>
<td>0.64</td>
<td>0.06</td>
<td>0.07</td>
<td>0.70</td>
<td>0.65</td>
</tr>
<tr>
<td>1958</td>
<td>0.66</td>
<td>0.07</td>
<td>0.08</td>
<td>0.79</td>
<td>0.65</td>
</tr>
<tr>
<td>1959</td>
<td>0.73</td>
<td>0.04</td>
<td>0.08</td>
<td>0.86</td>
<td>0.65</td>
</tr>
<tr>
<td>1960</td>
<td>0.77</td>
<td>0.07</td>
<td>0.08</td>
<td>0.92</td>
<td>0.65</td>
</tr>
<tr>
<td>1961</td>
<td>0.91</td>
<td>0.10</td>
<td>0.08</td>
<td>1.09</td>
<td>0.65</td>
</tr>
<tr>
<td>1962</td>
<td>0.93</td>
<td>0.11</td>
<td>0.10</td>
<td>1.14</td>
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</tr>
<tr>
<td>1963</td>
<td>1.02</td>
<td>0.12</td>
<td>0.12</td>
<td>1.26</td>
<td>0.65</td>
</tr>
<tr>
<td>1964</td>
<td>0.57</td>
<td>0.14</td>
<td>0.14</td>
<td>0.66</td>
<td>0.49</td>
</tr>
<tr>
<td>1965</td>
<td>0.16</td>
<td>0.27</td>
<td>0.43</td>
<td>0.32</td>
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</tr>
<tr>
<td>1966</td>
<td>0.02</td>
<td>0.26</td>
<td>0.28</td>
<td>0.34</td>
<td>0.34</td>
</tr>
<tr>
<td>1967</td>
<td>0.03</td>
<td>0.25</td>
<td>0.28</td>
<td>0.31</td>
<td>0.31</td>
</tr>
<tr>
<td>1968</td>
<td>0.34</td>
<td>0.24</td>
<td>0.56</td>
<td>0.87</td>
<td>0.87</td>
</tr>
<tr>
<td>1969</td>
<td>0.43</td>
<td>0.23</td>
<td>0.66</td>
<td>0.90</td>
<td>0.90</td>
</tr>
<tr>
<td>1970</td>
<td>0.11</td>
<td>0.22</td>
<td>0.33</td>
<td>0.88</td>
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</tr>
<tr>
<td>1971</td>
<td>0</td>
<td>0.21</td>
<td>0.21</td>
<td>0.32</td>
<td>0.32</td>
</tr>
<tr>
<td>1972</td>
<td>0</td>
<td>0.21</td>
<td>0.21</td>
<td>0.30</td>
<td>0.30</td>
</tr>
<tr>
<td>1973</td>
<td>0</td>
<td>0.20</td>
<td>0.20</td>
<td>0.40</td>
<td>0.40</td>
</tr>
<tr>
<td>1974</td>
<td>0</td>
<td>0.19</td>
<td>0.19</td>
<td>0.28</td>
<td>0.28</td>
</tr>
<tr>
<td>1975</td>
<td>0</td>
<td>0.18</td>
<td>0.18</td>
<td>0.36</td>
<td>0.36</td>
</tr>
</tbody>
</table>

A - from Quinlan and Woolley (1969) and Hamilton (1966) and other WRB records.
C - from Baker (1967) and Jolly (1976) respectively. Other figures estimated.
D - from Albrecht (1965).
E - All other Farm Area figures estimated.
F - includes town reticulation from bore AR (RN 3513).
3. HYDROGEOLOGY

It is not intended in this report to present detailed hydrogeology of the Town and Farm Area basins, as previous authors have dealt with the subject almost exhaustively. Appendix 1 presents a discussion of various reports and papers. Quinlan and Woolley (1969) is recommended for a study of geology and geochemistry.

Some aspects of local hydrogeology, notably a re-appraisal of the yields of the Town and Farm area basins, are included herein.

3.1 General

Immediately north of Alice Springs groundwater is sparsely located in the Precambrian gneisses of the Arunta Complex. The Town Basin is formed of Tertiary and Quaternary sediments associated with the Todd River and overlying the Arunta Complex.

Between the town and the Mereenie Sandstone the hydrogeology is complex, and involves many different aquifers. These vary in age from Precambrian to Palaeozoic, with Tertiary and Quaternary sediments overlying. The groundwater flow pattern and quality distribution is not completely understood, but it may be stated that the general movement of groundwater is southwards. Woolley (1966) presents data for the region and describes various aquifers but does not adequately explain some aspects of the regional pattern. For instance, while the flow is generally to the south, the water quality, in some areas, also improves southward.

The Mereenie Sandstone does not represent a hydrogeological discontinuity, but is chosen as a convenient cutoff for this report; it does in effect act as a sump with respect to aquifers to the north.

3.2 Town Basin

Much of Alice Springs is underlain by unconsolidated sediments which receive recharge from the Todd River. The basin has been the subject of many reports, most of which are discussed in Appendix 1.

Several appraisals have been made in the past of the basin's 'safe-yield' and hydraulic properties, but a fresh study has been undertaken for this report to make use of more recent data. This study is summarised in Appendix 2.

Below are listed the main properties of the basin, as interpreted from the range of available investigations and studies.

(a) The most permeable part of the basin consists of a strip associated with the historical river course. It underlies the Todd in the area of the town centre but diverges westward in the Traeger Park area and does not reconverge with the river before Heavitree Gap. The transmissivity of this portion is of the order of 400 square metres per day, and the storage coefficient is about 0.10.
(b) The basin as a whole, as defined by saturated sediments, is some seven square kilometres in area and exhibits a storage coefficient of about 0.07. The aquifer is far from homogeneous, however, and several different aquifers have been defined.

(c) The storage available for 'economic' extraction is about 1.4 million kilolitres.

(d) The salinity of water in the basin varies from less than 400 milligrams per litre (total dissolved solids) in the more permeable area to over 2000 at the extremities.

(e) The major source of recharge is the Todd River and the most efficient recharge takes place along the northern portion of the basin. Recharge is a function of the duration of flow and of the depth to the water table, particularly in the vicinity of the river.

(f) Groundwater in the basin flows southward towards and through Heavitree Gap into the Farm Area Basin. The average subsurface discharge through the Gap is about 100,000 kilolitres per year.

(g) Bearing in mind that recharge and 'safe' yield are related to the state of the basin and thus the draft, the 'safe' yield (loosely defined as the rate for which impracticable or uneconomical pumping depths are expected with a return period exceeding 100 years) is about 700,000 kilolitres per year.

(h) The above figure includes the Heavitree Gap outflow which, unless induced by pumping at the Gap, reduces the yield available for pumping from the rest of the basin to 600,000 kilolitres per year.

(i) The area of basin to the north of Alice Springs Hospital is only half as large as the area to the south, although more favourable recharge conditions occur to the north. A compromise between recharge and storage considerations and an examination of past performance suggests that no more than 50% and 60% of the safe yield should be drawn from the northern and southern portions of the basin respectively.

3.3 Farm Area Basin

Because of the function of Heavitree Gap, aquifers between the Heavitree and Blatherskite Ranges and underlying the Farm Area cannot be regarded as independent of the Town Basin. From the point of view of yield the two basins should be considered as a hydrogeological unit.

The Farm Area Basin is however, much more complex and poorly defined than the Town Basin. Past workers have referred to the area north of the Blatherskite Range as the 'Inner Farm Area' and beyond as the
'Outer Farm Area'. The boundary is defined by a marked fall in the level of the pre-tertiary surface which is reflected in the modern pattern of the potentiometric surface.

Henceforth in this report 'Farm Area' refers substantially to the 'Inner Farm Area', as described above. The 'Outer Farm Area' is mainly located over the Tertiary sediments discussed in section 3.4.

Past workers have dealt in some detail with the Farm Area (Appendix 1) although none has provided a reasoned estimate of the available yield. Appendix 3 presents a study carried out to obtain such an estimate. Appendix 4 describes investigation work carried out on the Commonage in 1975/76 to complete the picture of the Farm Area and study any effect of the sewage lagoons.

Features of the basin as interpreted from the various studies and investigations, are summarised below:

(a) The key aquifers are those of the Tertiary and Quaternary alluvium, although these are very lacking in uniformity and no representative transmissivity can be computed.

(b) The underlying Precambrian Aquifers and associated major faulting play a significant role. The prime example is the Bitter Spring Formation (predominantly limestone) which occurs in both the north and south. While high-producing bores have been constructed in the Bitter Springs, the quality is unreliable and only acceptable where frequent recharge from unconsolidated sediments occurs.

(c) The area of the basin providing useful storage is about three square kilometres and the average storage coefficient is about 0.04.

(d) Recharge to the basin is derived from the groundwater flow through Heavitree Gap and direct recharge from the river.

(e) Flow is generally south-easterly through the basin. Beyond the Blatherskite Range this flow increases in gradient and descends to the deeper Tertiary aquifers to the south.

(f) The 'safe' yield of the basin is comprised of the 100,000 kilolitres per year which flows through Heavitree Gap and a component of direct recharge from the river which is about 230,000 kilolitres, providing a total of 330,000 kilolitres per year.

(g) The above figure assumes that there is no pumping at Heavitree Gap to reduce the throughflow, and includes any outflow from the basin. Therefore, to extract the full 330,000 kilolitres, a considerable proportion of pumping must take place at the outflow area. This was practised in 1954 when bore RN 3613 was pumped for the town supply, although the total withdrawals were well in excess of the safe figure and the water quality deteriorated.
(h) The combined 'safe' annual yield of the Town and Farm basins is 700,000 plus 230,000 kilolitres, or 930,000 kilolitres.

3.4 Tertiary Sediments South of the Blatherskite Range

About 100 bores have been drilled in Tertiary Sediments between the Blatherskite Range and the Mereenie Sandstone and Woolley (1955) presents much of the data thus obtained. Woolley found that holes drilled into the Tertiary Sediments generally obtained some water, but large supplies were not common. Few produced more than four litres per second and most could not produce two litres per second. Salinities were mainly in excess of 1000 milligrams per litre of total dissolved solids.

By virtue of their apparent thickness and extent, the Tertiary sediments contain a huge storage of groundwater but in general it is not possible to obtain large supplies from bores and the quality is poor for domestic or agricultural use.

Groundwater flow as described by the potentiometric surface is generally southwards although the quality also improves to the south. This apparent inconsistency is explicable in terms of the following:

(a) Unreliability of the sampling distribution; sampling of different aquifers of different depths may give rise to an incorrect interpretation.

(b) Direct recharge occurring over the plains and at the Todd floodout.

(c) Deeper and unsampled aquifers of Palaeozoic Age may be making contribution of superior quality water from a different direction, perhaps from the west where recharge could be associated with outcrops of Roe and Laura Creeks. One such contributing aquifer may be the Jay Creek Limestone.

The degree of importance and role played by each of the above cannot be assessed without a considerable amount of new investigation.

3.5 The Bitter Springs Formation

Of all the pre-Tertiary formations north of the Mereenie and Pacoota Sandstones, the Bitter Springs Formation (predominantly limestone) and the Jay Creek Limestone appear to be the only formations capable of producing supplies in excess of ten litres per second.

The Bitter Springs Formation is generally not a viable aquifer except in close proximity to a recharge source, as stated in Section 3.4. Elsewhere total dissolved solids concentrations are usually several thousand milligrams per litre, and are at best suitable for stock watering.

Under the Farm Area the Bitter Springs Formation could be described
as a permeable sump, allowing recharge water to be withdrawn at rates sometimes higher than from the overlying sediments.

Other recharged zones of the Bitter Springs exist at Roe Creek on Temple Bar property and probably elsewhere wherever a river traverses the formation.

The Bitter Springs Formation cannot be regarded as a major source of potable groundwater.

3.6 Jay Creek Limestone

Woolley (1966) observed that although this formation and the associated Hugh River Shale had not been investigated near Alice Springs, bores drilled through it at other locations had obtained large water supplies with salinities varying from 600 to 25,000 milligrams per litre. Woolley stated that testing in the Alice Springs vicinity was warranted.

Minor drilling investigations were commenced in 1975. The first results indicated promising conditions, and the investigations were expanded until a total of thirteen bores had been drilled. Pumping tests were performed on three of these.

Although the quality and quantity of water available from some individual bores in the formation is excellent, it appears that the long term safe yield is not sufficient to sustain, for instance, an extensive farming venture. However, the formation may play a significant role in the regional hydrogeology, and contribute groundwater to the tertiary aquifers and the Mereenie Sandstone.

It appears that the Jay Creek Limestone is closely associated with the Hugh River Shale, which may also have good production potential. Elsewhere in the Amadeus Basin the two formations are not distinguished and are defined as the Shannon Formation.

A more detailed assessment of the Jay Creek Limestone is currently in preparation.
4. CURRENT SITUATION

4.1 Town Basin

The total annual withdrawal from the Town Basin has reduced to about 184,000 kilolitres per annum, which is only about 30% of the safe yield, allowing for continuation of Heavitree Gap throughflow. Table 2 lists the various known consumers and their corresponding estimated annual extractions.

The combination of this under-usage with the current period of above average rainfalls has resulted in the basin being over-full. Plate 4 shows that levels now are about three metres above those which were considered the 'full' levels of 1957.

Many problems are attributable to the present state of the basin, some of which are listed below:

(a) A large number of waterholes and seepages have developed in the Todd River and town drains, particularly towards Heavitree Gap. These are a manifestation of the water table and pose a health risk due to mosquito breeding and potential direct pollution of the aquifer.

(b) At least three basements in the town are known to be partly flooded by groundwater. One is at the new Commonwealth Government Centre and another is at the new hospital.

(c) Excavations for pipes and other installations are encountering groundwater.

(d) Some recently completed large buildings in Alice Springs are believed to have been designed on the basis of the 'basin-full' levels as defined in the 1950s. The present higher water table may give rise to settlements in excess of design and, conceivably, a large subsidence (Terzaghi and Peck, 1967).

(e) The high water tables is encouraging the prolongation of baseflows in the Todd River, which represent a nuisance at river crossings such as the Heavitree Gap causeway.

(f) In some parts of Alice Springs there is a danger that swimming pools, if emptied, will be dislodged and float on the water table.

(g) The water quality in some bores has deteriorated, apparently due to solution of salts from the zone which is not normally saturated.

(h) There is probably a contribution to the sewerage system from the groundwater, by leakage.

These problems aside, the lack of usage of the basin is not compatible with the philosophy of water conservation. For a given amount of water not extracted from the basin, a similar amount is
not recharged but is lost to the Todd floodout, either to be evaporated or to recharge aquifers which are far more expensive to develop than the Town Basin.

<table>
<thead>
<tr>
<th>TABLE 2</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>ANNUAL ESTIMATED EXTRACTIONS FROM THE TOWN BASIN, 1975/76</strong></td>
</tr>
<tr>
<td>kilolitres</td>
</tr>
<tr>
<td>Council - Traeger Park</td>
</tr>
<tr>
<td>Council - Anzac Oval</td>
</tr>
<tr>
<td>St. Phillips College</td>
</tr>
<tr>
<td>Memorial Club</td>
</tr>
<tr>
<td>Royal Flying Doctor Service</td>
</tr>
<tr>
<td>Lutheran Mission</td>
</tr>
<tr>
<td>Melenka Hostel</td>
</tr>
<tr>
<td>Flynn Church</td>
</tr>
<tr>
<td>Griffiths House</td>
</tr>
<tr>
<td>Alice Springs Hotel</td>
</tr>
<tr>
<td>About 20 private consumers</td>
</tr>
<tr>
<td><strong>Total</strong></td>
</tr>
</tbody>
</table>

4.2 Farm Area Basin

Although extraction rates in the Farm Area have dropped to about 280,000 kilolitres per year, this still represents some 85% of the safe yield; and although the present wet period has raised the water to the highest levels on record, it cannot be said that the basin is being grossly under-used.

The basin's full state is not as fraught with problems as in the case of the Town Basin. The only known problem is that the water from many Farm Area bores has deteriorated slightly. As in the Town Basin, this is believed to be due to the solution and flushing of salts from sediments normally located above the water table.

To the west of the basin, in the Commonage, recent investigation has shown that the introduction of the sewage lagoons has modified the groundwater pattern. As stated in Appendix 4, this is not expected to significantly affect the main part of the basin, but could give rise to water management problems in the Commonage.

The sewage lagoons are creating other problems not directly related to groundwater. Inadequate evaporation area has led to frequent uncontrolled spillages into the Ilpapa Swamp Area. The new lagoons to the west are discharging continuously into the swamp, at the western end. This serves to maintain the levels in the swamp, which under natural conditions is ephemeral. Aesthetic, ecological and public health problems are apparent.

The most unsatisfactory aspect of the sewage treatment at Alice
Springs is the principle of disposal itself. Over one million kilolitres of water are evaporated annually, more than the combined safe yield of the Town and Farm Area basins. In an arid environment this must be regarded as wasteful.

In the long term, disposal by evaporation will require increasing areas of land. In ten years, an evaporation area of some two square kilometres could be required - a substantial proportion of the Alice Springs Commonage.
5. FUTURE USE

5.1 Town Basin

5.1.1 Availability

The initial policy question to be answered is whether the annual pumping rate should be constant (say at the safe yield figure) or varied according to the state of the basin. The latter would be preferable from the purely hydrologic point of view, but is of doubtful value in respect of cost and management considerations. It is assumed herein that the policy of adopting a constant annual withdrawal rate is to be preferred.

If the assumed objectives are that the basin should rarely be depleted in any portion, and that the natural flow through Heavitree Gap should be maintained near the natural rate, hydrologic constraints are as follows:

(a) The total annual pumping extraction should not exceed 600,000 kilolitres.

(b) Pumping from near Heavitree Gap should be minimal. Bore 59 (RN 7506) should not be used and bore 110 (RN 3096) should be pumped with discretion.

(c) Annual extractions from either the north or south of Alice Springs Hospital should not exceed about 300,000 and 360,000 kilolitres respectively.

Within these constraints, the areal pumping distribution must be determined on the basis of aquifer permeability, location of water and availability of land for the construction of bores and pipelines.

A modified pumping philosophy is possible, in which priority would be given to pumping from the potential recharge areas in the northern part of the basin, after river flows. The aim of this practice would be to optimise the availability of storage for recharge. The pumping schedule would be changed with time as these areas became depleted, but the overall annual extraction rate could still be held constant and the above constraints adhered to.

It is believed that if most of the 300,000 kilolitre annual draft in the northern portion is pumped from the recharge areas, then the objective discussed above would be largely satisfied without the need for temporal changes in pumping schedule. The marginal benefit to be gained by pumping the area at a much higher rate after recharge events is unlikely to justify the additional requirement of bores, reticulation and scrupulous management.

5.1.2 Costs

Roberts (1974) estimated that the costs to the Council of using Town Basin supplies were about $0.03 per kilolitre. This included
capital costs. Allowing for increased costs, a figure of $0.05 is more appropriate, but this still compares very favourably with the charge of $0.12 per kilolitre for water from the town supply, if excess rates are assumed.

These costs do not apply to all situations but are presented to indicate the likely economies in the use of Town Basin water by large-scale consumers. Detailed costing should be carried out for individual schemes. In the case of small-scale situations, such as domestic garden supplies, the capital costs become more significant and, unless the excess water charge is likely to be very high, the comparative advantage is lost.

5.1.3 Nature of Consumption

The various consumers of Town Basin water may be classified as follows:

(a) Existing consumers of all types. These have a right to continue pumping from the basin.

(b) Public water supply. The Town Basin was used conjunctively with the Mereenie supplies in the 1960s, and a resumption of this policy is possible. The principle objection to this is that the Town Basin water may require chlorination, especially during times of high water level, but unless considerable modifications were made to the reticulation system, a separate chlorinator would be required on each bore. Management difficulties would greatly increase.

(c) Private domestic consumers. Use by private consumers mainly on gardens will remain relatively uncontrolled and should not be encouraged. However, the problem is not a significant one as the proportion of the town area where bores are a viable proposition on small leases is relatively minor, particularly when modern drilling costs are considered.

(d) Public and private organisations. The amount of water usually consumed by various organisations for gardens and recreation areas usually provides economies in the use of Town Basin water compared with reticulated town water. Furthermore, consumption of this nature is relatively stable.

(e) Farming. Pak-Poy and Associates (1975) recommended in accordance with advice from Water Resources Branch that Town and Farm Basin groundwater be used conjunctively in a redeveloped farm area. The proposal was to employ most of the available yield. However, the redevelopment plan is not being implemented and a co-ordinated farming venture is not currently envisaged.

It appears that for the foreseeable future the most desirable method of increasing the draw on the Town Basin, is to encourage planned use by a small number of public and private organisations. However, regard must be shown for the rights of existing users. It must also
be recognised that new commitments in the town area will partly close the options to redevelop the Farm Area, in that the amount of water available to a co-ordinated farming venture would be reduced by over half. This is unavoidable because the time delay involved in planning and implementing a new farming venture is unacceptable in the light of the immediate requirement to develop the Town Basin.

Present annual consumption north of Alice Springs Hospital is about 88,000 kilolitres and hence an additional 212,000 kilolitres is available. South of the hospital, the current rate of 96,000 leaves an available 204,000 kilolitres per year.

In 1976 a plan was proposed for the Council to use Town Basin water for the swimming pool complex and Larapinta Park. Roberts (1974) presented various schemes for the proposal and established their economic viability. If fully implemented the plan would use about 50,000 kilolitres annually for the swimming pool and lawns and 60,000 for Larapinta and Newlands Park. The latter requirement could probably be satisfied by a bore in the railway reserve, near Milner Road.

A shortage of funds has so far prevented implementation of this plan, but provision should be made for it when considering the amount of water available for other consumers. This reduces the figure for the southern portion of the basin from 204,000 to 94,000 kilolitres per year.

The Department of Education has potential to use all the available Town Basin water on the various school grounds, and the economic viability in the long term is almost certain. However, there is no current proposal on these lines. The High School currently consumes Merenue water at an approximate rate of 150,000 kilolitres per year, most of which is used on the lawns. Gillen and Bradshaw Primary Schools use some 80,000 kilolitres each.

The Alice Springs Golf Club has applied to use about 240,000 kilolitres annually of Town Basin water, for irrigation of the course. In the light of the present undesirable state of the basin and the genuine nature of the proposal, the application is being supported by this Branch. If the scheme proceeds in full, only 66,000 kilolitres of the annual safe yield will remain unused. However, capital costs may be prohibitive and the adoption of a smaller scheme is possible, and the land tenure of the Golf Club remains in some doubt.

Further use proposals should be deferred until the Golf Club scheme is finalised. If the scheme proceeds only on a small scale or not at all, it appears that immediate consideration should be given to use by the Education Department.

5.1.4 Possible Schemes

Only outlines of possible alternatives are given. The intention is to demonstrate how the available resource may be allocated. The
basin is divided into the northern and southern portions, with assumed maximum yields of 300,000 and 360,000 kilolitres per annum respectively, totalling no more than 660,000. It is stressed that the consumption figures are approximate.

Scheme A - This assumes the Golf Club proposal goes ahead to full capacity, requiring three bores in the north and one in the south.

<table>
<thead>
<tr>
<th>Existing consumers</th>
<th>North (kilolitres per annum)</th>
<th>South (kilolitres per annum)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Council - Swimming Pool</td>
<td>88,000</td>
<td>96,000</td>
</tr>
<tr>
<td>Council - Larapinta and Newlands Parks</td>
<td>50,000</td>
<td>60,000</td>
</tr>
<tr>
<td>Golf Club</td>
<td>212,000</td>
<td>28,000</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td><strong>300,000</strong></td>
<td><strong>234,000</strong></td>
</tr>
</tbody>
</table>

Utilisation of basin - 85% of safe yield.

Scheme B - This assumes that the Golf Club proposal goes ahead at 80% capacity, involving only three bores, located in the north. This would possibly be the most economically attractive solution for the Golf Club, and would allow some water from the south to be used for the Department of Education. A conjunctive system could supply Larapinta and Newlands Parks, and Gillen Primary School, from one or two bores in the railway reserve near Milner Road.

<table>
<thead>
<tr>
<th>Existing consumers</th>
<th>North (kilolitres per annum)</th>
<th>South (kilolitres per annum)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Council - Swimming Pool</td>
<td>88,000</td>
<td>96,000</td>
</tr>
<tr>
<td>Council - Larapinta and Newlands Parks</td>
<td>50,000</td>
<td>60,000</td>
</tr>
<tr>
<td>Gillen Primary School</td>
<td>80,000</td>
<td>80,000</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td><strong>278,000</strong></td>
<td><strong>286,000</strong></td>
</tr>
</tbody>
</table>

Utilisation of basin - 94% of safe yield.

Scheme C - This assumes that the Golf Club proposal does not proceed. Instead, water from the north is used for the Sadadeen High School and Ross Park Primary School. For this project, a pipeline of about 0.5 kilometres from three bores near the Todd River would be required.

<table>
<thead>
<tr>
<th>Existing consumers</th>
<th>North (kilolitres per annum)</th>
<th>South (kilolitres per annum)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sadadeen High School</td>
<td>140,000</td>
<td>80,000</td>
</tr>
<tr>
<td>Ross Park Primary School</td>
<td>72,000</td>
<td>0</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td><strong>300,000</strong></td>
<td><strong>80,000</strong></td>
</tr>
</tbody>
</table>

Utilisation of basin - 98% of safe yield.
5.2 Farm Area Basin

5.2.1 Groundwater

As stated in Section 4.2, the present consumption rate is about 85% of the safe yield, although unusual seasons have raised the water table to a very high level.

Care must be taken that the public does not interpret the height of the water table as an indication of a continuing abundance of groundwater, and the general policy towards increased groundwater development should be one of discouragement. The existing equipped bores are capable of pumping well in excess of the safe yield.

The current land use trends in the Farm Area are largely uncontrolled and certainly not predictable, but it appears that an increasing number of lease-holders plan to run horses. In order to grow fodder and maintain the soil cover it can be expected that this activity will require increasing volumes of water. There has recently been an increase in the number of groundwater enquiries in the Farm Area, mainly by new lease-holders. A 'rush' on groundwater in an inevitable drought with a resultant depletion of the resource must be feared.

The best solution can only be found in the declaration of a 'Water Control District'. Pumping licences would be issued according to land use and/or seniority of land tenure, although under the Control of Waters Ordinance there can be no control over pumping for domestic purposes or at rates less than 0.63 litres per second on blocks of less than 2 hectares.

As an interim policy, no further 'Advice as to the Construction of a Bore', should be issued in the area at least until the overall amount of development is clear and groundwater can be allocated on a rational basis.

A co-operative or other co-ordinated water supply, using a small number of efficient bores, would provide best for an agricultural scheme in the Farm Area. As stated in Section 5.1.3, current use proposals in the town area will remove the possibility of using the Town Basin as well as the Farm Area Basin for such a scheme. On the other hand, any future upgrading of the standard of sewage treatment may allow reclaimed water to be used for a variety of agricultural purposes, and a co-ordinated farming venture could look to this source.

5.2.2 Sewage

The re-use of sewage has been the subject of a Regional Working Group in Alice Springs. A report entitled 'Reuse of Sewage Effluent - Alice Springs' was issued in June 1976. As an answer to short-term problems, the report presented two alternative schemes, as follows:

(a) An irrigation project to grow lucerne, barley, oats, and date...
palms in the area between the sewage lagoons and the Stuart Highway. The initial cost was estimated at about $164,000, which would be partly offset by the saving in new evaporation lagoons. Further details are provided in the above report and in Appendix 4 herein.

(b) A Water Resources Branch project to infiltrate the effluent, after primary settling, into the groundwater system south of Mt. Bletherskite. The initial cost was estimated at about $20,000. Further details are provided in Appendix 4.

Water Resources Branch favours the irrigation project despite the additional costs, because the benefits should be more immediate and the project could lead the way for further development of a similar nature.

However, if funding or administrative problems are to delay the irrigation project, the infiltration scheme should be given priority consideration.

While an irrigation project would normally require a seasonally varying rate of water application, the rate of sewage outfall does not vary seasonally, as stated in Appendix 4. Furthermore, extended wet periods may give rise to excessive quantities of water in the sewage lagoons compared with zero irrigation requirement. These inconsistencies could be readily solved by one or more of the following:

(a) The use of the storage of the existing ponds.

(b) Performing most of the soil leaching (see Appendix 4) in winter by overwatering in that season.

(c) The use of an existing Farm Area bore (such as Standpipe Bore) to make up the summer requirement.

(d) The conjunctive use of the infiltration scheme to handle excess quantities of effluent.

The draft report on the Alice Springs Commonage by D.J. Dwyer and Associates proposes an extensive sporting complex and golf course on and to the west of the site of the existing sewage lagoons. It is proposed to irrigate these facilities with partially treated sewage effluent.

It is unlikely that, under current financial conditions, the removal and replacement of the sewage lagoons can be considered. This question aside, the proposals are likely to cause serious problems.

Although the high salinity of the effluent water is acknowledged in the report, it is not recognised that a considerable amount of leaching of the soil would be required to prevent salt build-up. Probably at least 20% deep percolation by irrigation water is required. Except in the area to the east of the lagoons, the soils
are not structured to handle this infiltration, nor do groundwater aquifers exist to convey the infiltrated water away. This problem would only be solvable with the use of constructed sub-surface drainage, which would be an expensive operation.

The public health aspects of irrigating recreation grounds with effluent water are not adequately dealt with in the report. Either considerable time must elapse between watering and use, or the water must be of a guaranteed bacteriological standard. The existing treatment facilities cannot meet this standard.

For the long term, it is essential that a superior treatment process be adopted for Alice Springs sewage effluent. This would involve advanced secondary and tertiary treatment and, while removing most of the public health problem, would provide much wider options for the use of reclaimed water. These options would include more general agricultural applications, such as on private farms, and the possibility of direct sub-surface injection to recharge groundwater.
6. MANAGEMENT

6.1 Monitoring

The important parameters to be monitored in respect of Alice Springs groundwater resources are river flows, groundwater levels and pumping extractions.

In the case of the Town and Farm Area basins, flows in the Todd River are important. Roe Creek flows are probably related to the hydrology of the Jay Creek Limestone and the Mereenie Sandstone. Both rivers are monitored on a continuous basis.

A comprehensive groundwater level monitoring system was established in the early 1960s in the Town and Farm Area basins, although this lapsed from 1972 to 1975. The system has since been reinstated, mostly using the same observation bores, and the loss of record is fortunately not serious. The recording system has now been updated and rationalised by borefield management staff.

Every month, standing water levels are measured in 26 bores in the Town Basin and 33 in the Farm Area. Monitoring of the Commonage area or the region south of St. Marys will be intensified when a project to use sewage effluent for irrigation or groundwater infiltration proceeds. This will be of importance to prevent excessively high water tables and to ensure that unfavourable movements of chemically or bacteriologically undesirable groundwater do not occur.

At least one bore is to be established as a regular monitoring point on the Jay Creek Limestone.

There are no functioning flow meters installed on bores in either the Town or Farm Area Basins. Water extraction figures have been based purely on estimation since pumping for public water supply ceased. This is unsatisfactory if monitoring is to be useful and management effective, but there is no means of making the use of meters compulsory other than by creating a water control district. Even in this case, there would be no control over small private consumers, and it may be unreasonable to request existing consumers to install meters at their own expense.

Public and private organisations especially must be encouraged to use meters. The installation of meters should be requested in response to technical assistance provided by the government.

A rough means of monitoring groundwater usage would be the use of electricity meters on pumping circuits. To achieve this, the co-operation of the Electricity Supply Undertaking should be sought. While small domestic pumps are often single-phase and would thus be overlooked, larger installations are normally three-phase and meters should be installed as a matter of course. The electricity accounts could then be used to provide approximate figures for pumpage.
6.2 Control

Currently there is no control. Groundwater use in the Town and Farm Area basins is subject to the whim of the various private consumers.

The lack of control is serious because:

(a) if and where clear policies exist on the usage of groundwater, there is no clear means of supporting them;

(b) there is no protection for existing consumers against the inroads of new groundwater development;

(c) excessive development occurring in times of abundant groundwater will inevitably be followed by shortages in a drought; and

(d) any major unplanned developments in the Jay Creek Limestone or Mereenie Sandstone may adversely affect the future of the town supply and, in the case of the Jay Creek Limestone, result in eventual disaster for the project itself.

The only satisfactory means of exerting control lies in the declaration of a water control district, which should extend from the town area to a portion of the Mereenie Sandstone. A suitable boundary is shown on Figure 1, which also indicates the relative positions of the main groundwater resources.

A water control district would enable the prohibition of the construction or use of bores without a permit. Permits would include conditions requiring the installation of water meters (at least on new pump or bore installations) and submissions of returns. The latter, in cases of there being no water meter, would be in the form of hours of pumping or electricity consumption.

Under the existing Control of Waters Ordinance, bores for domestic use, and bores equipped to pump no more than 0.63 litres per second on leases of less than two hectares, would not be subject to the provisions of the water control district. This should not be a significant problem because (a) domestic consumption is relatively minor over the areas of available potable water; (b) most leases in the Farm Area are larger than two hectares; and (c) leases over the Town Basin are so small that the construction of bores for domestic or garden watering purposes is not normally viable.

There are several prerequisites to the setting up of a water control district. These are discussed below:

(a) Policy. Clear management policies must be established for the various areas. In the case of the Town and Farm Area Basins, the policy may be to maintain groundwater extraction near the safe yield level and protect the existing consumers. In the event of having to allocate further allowances, priority could be given firstly to government bodies and secondly to
private landholders with a seniority of land tenure. At the Jay Creek Limestone and Mereenie Sandstone, the policy should be of exclusion of most consumption other than for the town water supply. In the tertiary aquifers, control should be exercised to prevent any large-scale developments unless it can be shown that the effect on the Mereenie resources is insignificant.

Records. Comprehensive water resources records and data for the entire area of the water control district are necessary, as well as prior knowledge of ownership and usage of bores. It is believed that this office currently has adequate technical records for this purpose. Additional information could be obtained on the creation of the water control district by requiring, through a publicity programme, private consumers to submit details of pumping equipment and water consumption. The response to such a call would be enhanced by stressing a policy of protection for existing consumers.

Staff. An additional staff member would be required in Alice Springs to handle the routine monitoring and management requirements of a water control district.
APPENDIX 1

Discussion of Some Past Studies and Appraisals

Note on units: Although past reports have involved British units only, all figures have been converted to their metric equivalent in the discussions below. Regard has been shown in each case for the order of accuracy intended, by suitable rounding off of converted figures.


This paper is the first known to present a realistic general picture of the Town Basin, and uses data from as early as 1939. The general shape of the basin, recharge behaviour and role played by Heavitree Gap are correctly assessed. Owen estimates the total storage in the Town Basin, when full, to be of the order of four million kilolitres.


This paper refines the assessment of Owen, and introduces the Farm Area Basin. Figures for available storage of potable water are calculated, being 1.5 million kilolitres for the Town Basin and 3.3 million for the Farm Area.

No quantitative assessment of recharge or yield is given, but Jones instigated a monitoring programme for this purpose.


The objective was to determine more accurately the values of Town Basin parameters, and quite detailed, although at times questionable, calculations are contained. Rather than assessing the full potential of the basin, the report centres on supplying a given water requirement.

An important calculation is that of the sub-surface outflow rate at Heavitree Gap, which is calculated to vary from 2.4 to 5 litres per second, with an annual average of 4.15 litres per second or 130,000 kilolitres per year. The lower rate is said to occur after river flows,
when the gradient is found to be reduced.

These figures were derived from dye tests, gradient measurements, cross sections estimated from bore logs, and an assumed porosity. For the latter, a figure of 0.41 was used on the basis that the aquifer consists of coarse sands. This is very questionable; allowing for an inevitable percentage of fines (perhaps lost from bore samples), and the fact that not all the porosity is likely to be available for water seepage, a realistic figure would probably not exceed 0.30. Using 0.30, the figures above become 1.8, 3.6 and 3.0 litres per second, and 95,000 kilolitres per year.

Wilson's average outflow has been assumed in several subsequent reports.

Other calculations made bear out that the subsurface inflow to the basin (down the Todd River) is negligible, and recharge is, for practical purposes, entirely from surface flows through the town.

Wilson, H.

Department of Works Minute. 1959

This report questions and corrects several of the calculations made by T. Wilson, and the latter's concept of recharge from the river. It is argued that recharge is mainly dependent not on available lateral gradient from the river, but on the available volume below the river bed.

Based on the longest recorded periods of no river flow, a safe yield of 550,000 kilolitres per year is quoted, although the calculations are not presented. From this figure, 'private use, transpiration and other losses' must be taken.

This report is possibly the first to urge development of sources other than the town basin.

Forbes, C.F.


A large proportion of this report is involved in estimating annual surface discharge at Heavitree Gap, for later consideration for surface storages and conjunctive-use schemes.

With respect to groundwater, Forbes deals more
with the Inner Farm Basin than any predecessors, and establishes that there is negligible recharge to this basin other than that associated with the Todd. Further, he claims that the only significant recharge is subsurface flow at the Gap, and precludes direct recharge from surface flows. This is unreasonable. Evidence to the contrary includes T. Wilson's observations that the gradient and hence outflow at the Gap diminish after river flows, which implies recharge south of the Gap.

The safe yield for the combined Town and Inner Farm Basins are then calculated from the sum of the safe yield of the Town Basin and the natural average discharge through Heavitree Gap. For the latter, T. Wilson's figure of 130,000 kilolitres per year (probably too high, as previously mentioned) is chosen as a fait accompli. The safe yield of the Town Basin is derived using Hill's Method (reference Todd) and nine years of data. In this method, annual draft is plotted against decline obtained by extrapolation, a method not without considerable dangers in this situation. However, the figure obtained (550,000 kilolitres per year) equals the figure derived by H. Wilson using a totally different method.

There is an element of deception involved in calculations presented by Forbes to support his figures. For instance, the discharge at the Gap is added at one point and later subtracted. Nevertheless, the derived safe yield of the Basins (550,000 + 130,000 = 680,000 kilolitres per year) was effective in demonstrating that the basin was in fact being severely overpumped at the time.

Quinlan, T. and Woolley, D.R.


This report describes in some detail the geological history of the Town Basin.

Parameters for transmissivity and storage coefficient are derived, being 0.05 and 300 square metres per day.

Eggington, H.F.

'Pumping for the Alice Springs Water Supply', (unpub.) 1964.

This is the only report presenting a philosophical approach to the pattern of pumping, from the point of view of optimising the use of the basins.
and recharge to them.

No new data or calculations are provided, but a summary of available bores, existing and historical, is given.


Specific yield figures are given for the Town Basin: 5% for the aquifers as a whole, 8% for that part normally recharged and dewatered, and 13% for the sands associated with the river. Water available from storage is then computed as 1.15 million kilolitres for economic extraction or 1.40 at the very outside.

From available records Eggington assumed that the worst situation likely to occur is one of two consecutive years with no river flow, and thus derives a safe yield figure of 700,000 kilolitres per year, which is similar to the figure derived by Forbes (including Heavitree Gap sub-surface flow). Presumably implicit in the study is that the Heavitree Gap flow can be recovered.

Eggington estimates that recharge rates are 180,000 kilolitres for a one-day flow, 270,000 for a two-day flow, 450,000 for ten days of flow, and 2,700 kilolitres per day after ten days.

It is claimed that the safe yield could be increased to 1,550,000 or more kilolitres per year with the use of a Todd Dam to regulate flow. There are other papers on this subject but none is discussed here.

Woolley, D.A. 'Geohydrology of the Emily and Brewer Plains Area, Alice Springs', (unpub.) 1966.

This report is not specifically concerned with the Town or Farm basins, as the primary purpose was to present investigation data relating to the Mereenie Sandstone and the Tertiary aquifers south of the Farm Area.

Woolley's most important comment in respect of the report in hand was that further testing of the Jay Creek Limestone was warranted.

In discussing the Bitter Springs Formation, it is pointed out that bore AR (RN 3613) which is located at the outflow area of the ('Inner')
Farm Basin and is located in Bitter Springs Formation, produced water of increasing salinity while pumping for the Town Supply, in 1964.

This problem would have been partly a function of the lack of recharge and excessive drawdowns in the basin at the time.


In spite of an alluring title, this report contains little of practical significance: an aquifer model for a supposedly improved analysis of bore tests, using curved boundaries, is mooted only. In the later report by Quinlan and Woolley, the simple 'isotropic homogeneous unconfined aquifer of infinite lateral extent' is accepted.


Only conclusions are given, with unfortunately no background discussion. As such, the report offers nothing of modern use other than some drawings summarising data.

Ride, G. 'Availability of Groundwater in the Alice Springs Farm Area', (unpub.) 1968.

This report, in two volumes, contains a large quantity of hydrogeological information compiled from drilling investigations in the Farm Area, but is of limited value with respect to management of the basin. It is claimed that the area has 'only a limited capacity to accept recharge' (from the river), and that the safe yield of the 'Northern Area' is 130,000 kilolitres per year, provided by sub-surface flow at Heavitree Gap. The derivation of this figure is not given, but it is probably taken directly from T. Wilson. The safe yield of the 'Outflow Area' is given as 180,000 kilolitres, but it is not clear whether this is intended to be independent of or as an alternative to the Northern Area. To be consistent with the statement on recharge, the figures are probably not independent, implying that only 50,000 kilolitres is added annually by direct recharge.


Much of this report contains detailed geological...
and geochemical information, and in respect of this is probably the best account available. A discussion of bore construction techniques is provided.

For the Town Basin, using tests on several bores and the assumption of an isotropic homogeneous unconfined aquifer of infinite extent, an average transmissivity of 450 square metres per day and a storage coefficient of 7% are derived.

An adaptation of Hill's method, using change in storage instead of change in potentiometric water level, gives rise to a scatter diagram which, with the superposition of a variable 't', being the estimated number of days of a year without recharge (assuming recharge continues for 100 days after each river flow), gives rise through a multiple regression analysis to the equation:

\[ y = 10.5 - 7.64x - 0.038t \]

where 'y' is the annual change in volume of saturated alluvium in millions of cubic metres and 'x' is the annual draft in millions of kilolitres.

With possibly questionable reasoning and using depletion of the basin as a criterion, a safe yield of 713,000 kilolitres per year is given. Alternatively, a management policy is mentioned of withdrawing at 90,000 kilolitres per month for two months following each recharge, then reducing the rate by 15,000 kilolitres per month.

The basis of all the above calculations is in doubt, as there is no mention of the groundwater outflow at Heavitree Gap being taken into account.
APPENDIX 2

Town Basin Water Balance Study and Safe Yield Determination

Several versions of the model were examined and found to be unsatisfactory before the version described below was studied. These former attempts were similar in principle but less refined, and details are not provided here.

The model was based on an assumed annual water balance equation, viz,

\[ P + H + Y + \Delta h SA - d B \Sigma \log (t + 1) = 0 \]

where

- \( P \) = annual extraction by pumping (million kilolitres)
- \( H \) = groundwater outflow at Heavitree Gap (million kilolitres)
- \( Y \) = constant (million kilolitres) allowing for minor parameters, in particular evapotranspiration, direct recharge from rainfall and constant recharge
- \( \Delta h SA \) = change in storage (million kilolitres)
- \( \Delta h \) = change in height of potentiometric surface (metres)
- \( SA \) = storage coefficient times the area of aquifer (millions of square metres)
- \( d B \Sigma \log (t + 1) \) = function describing recharge from Todd River floods (million kilolitres)
- \( d \) = depth of the potentiometric surface below river flow level (metres)
- \( B \) = constant (millions of square metres per log days)
- \( t \) = duration of each river flow event (days)

It can be seen that the model treats the basin as a homogeneous unit, a simplification which is acceptable for longer time periods.

The equation was applied to fourteen 'water-years' of record, each water year commencing in September. Detailed discussion of the above parameters and variables follows:

(a) Pumping extraction (\( P \)). This is the most straightforward of the variables. Values have been recorded or estimated since the early 1950s. Both public and private usage is included. Values are given on Table 3.

(b) Groundwater Outflow (\( H \)). Wilson (1957) estimated the annual average groundwater discharge at Heavitree Gap, and although the permeability calculations were doubtful, no other study has been attempted. Factors affecting the outflow are height of potentiometric surface and hydraulic gradient, which in turn, is dependent on the relative potentiometric levels in the Town and Farm Basins. Owing to the complexity of the
relationship and the fact that this component is probably not a major one in the water balance, H was assumed to be constant under normal conditions. However, evidence suggests that when town production bores in and near Meavitree Gap were in use the discharge was almost totally cut off and this led to the assumption that the outflow was 0.2H in 1959/60, zero in 1960/61, 1961/62 and 1962/63, and 0.1H in 1963/64.

(c) Constant Y. The largest expected influences not specifically provided for are evapotranspiration, direct infiltration, and a constant recharge component, although none of these is expected to be of great significance. Y was arbitrarily defined as 'evapotranspiration minus infiltration minus constant recharge'. In real terms, the constant recharge component could be recharge down the Todd River sands.

(d) Potentiometric change (Δh). All observation bore records were examined to obtain changes between 1 September of sequential years. Δh was obtained by numerical average for each year, a positive figure indicating a rise in potentiometric surface. Prior to 1957/58 insufficient records were available to obtain reliable figures. The number of bores used in subsequent years varied from nine in 1957/58 to forty in 1966/69, and in every case were well distributed throughout the basin. The adopted values of Δh are given in Table 3. After 1971 inadequate records were kept and Δh values could not be obtained.

(e) SA. The true value of storage coefficient varies considerably throughout the basin, and the area of contributing aquifer is not well defined. However, for the purposes of the annual water balance SA may be treated as a constant describing the volume of water yielded per metre decline in potentiometric surface. The value of SA was treated as an unknown.

(f) Recharge. A function describing the recharge from one flow event was assumed, being dB = log (t + 1). This allowed that recharge depends on the initial potentiometric surface position and that the daily recharge decreases considerably with time. The latter phenomenon occurs because while recharge continues the available gradient for transmitting the recharge is being reduced. Eggington (1965) also assumed a logarithmic function. In reality, the value of 'd' is not uniform throughout the basin, and the value applicable to the portion of the basin directly beneath the river should have a higher 'weighting' than values at more remote locations. The compromise made in the model was to adopt values applicable to locations close to the river, as follows in (g).

(g) Depth of Potentiometric Surface below Flow Level (d). Values were obtained for each year by determining the depth of the potentiometric surface below the typical river flow level in the nearest part of the river at the commencement of each flow for bores RN 5810, 5807 and 5825. The assumed 'river flow level' values were respectively 578.5, 574.0 and 568.5 metres.
A.H.D. The values of 'd' assumed for each year are given in Table 3.

(h) Constant (B). This was treated as one of the unknowns.

(i) Time of Flow (t). Records provide the number of days of each river flow. For each flow the value \( \log (t + 1) \) was derived, and for the purposes of the annual total recharge the separate flows were added using \( \Sigma \log (t + 1) \). Prior to 1957 the flow duration records were unreliable.

### Table 3

<table>
<thead>
<tr>
<th>Water-Year</th>
<th>( P )</th>
<th>( \Delta h )</th>
<th>( d )</th>
<th>( t )</th>
<th>( \Sigma \log )</th>
</tr>
</thead>
<tbody>
<tr>
<td>1954/55</td>
<td>0.55</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>55/56</td>
<td>0.55</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>56/57</td>
<td>0.65</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>57/58</td>
<td>0.73</td>
<td>0.22</td>
<td>4.8</td>
<td>4,2,2</td>
<td>1.66</td>
</tr>
<tr>
<td>58/59</td>
<td>0.81</td>
<td>-0.96</td>
<td>5.1</td>
<td>1,4,1</td>
<td>1.30</td>
</tr>
<tr>
<td>59/60</td>
<td>0.89</td>
<td>-0.44</td>
<td>6.0</td>
<td>1,2,2,1,1,1</td>
<td>2.16</td>
</tr>
<tr>
<td>60/61</td>
<td>1.03</td>
<td>-0.10</td>
<td>6.4</td>
<td>1,1,1,4</td>
<td>1.60</td>
</tr>
<tr>
<td>61/62</td>
<td>1.12</td>
<td>-0.32</td>
<td>6.7</td>
<td>2,5,4,2</td>
<td>2.50</td>
</tr>
<tr>
<td>62/63</td>
<td>1.22</td>
<td>-0.31</td>
<td>6.8</td>
<td>4,2,2,4,6</td>
<td>3.20</td>
</tr>
<tr>
<td>63/64</td>
<td>0.96</td>
<td>1.41</td>
<td>7.5</td>
<td>2,2,2</td>
<td>1.44</td>
</tr>
<tr>
<td>64/65</td>
<td>0.57</td>
<td>0.16</td>
<td>8.1</td>
<td>2,5,2,1,2,2</td>
<td>3.00</td>
</tr>
<tr>
<td>65/66</td>
<td>0.33</td>
<td>1.92</td>
<td>7.3</td>
<td>2,2,3,7,7,4,5,9</td>
<td>5.64</td>
</tr>
<tr>
<td>66/67</td>
<td>0.26</td>
<td>0.98</td>
<td>5.4</td>
<td>4,4,4,8,9,6,3</td>
<td>5.50</td>
</tr>
<tr>
<td>67/68</td>
<td>0.44</td>
<td>0.65</td>
<td>5.2</td>
<td>2,2,4,4,7,4</td>
<td>3.96</td>
</tr>
<tr>
<td>68/69</td>
<td>0.67</td>
<td>-0.68</td>
<td>5.3</td>
<td>2,3</td>
<td>1.08</td>
</tr>
<tr>
<td>69/70</td>
<td>0.25</td>
<td>-1.05</td>
<td>6.6</td>
<td>2</td>
<td>0.48</td>
</tr>
<tr>
<td>70/71</td>
<td>0.21</td>
<td>0.35</td>
<td>6.6</td>
<td>4</td>
<td>0.70</td>
</tr>
<tr>
<td>71/72</td>
<td>0.20</td>
<td>-</td>
<td>-</td>
<td>4,4,3</td>
<td>2.00</td>
</tr>
<tr>
<td>72/73</td>
<td>0.20</td>
<td>-</td>
<td>-</td>
<td>2,2</td>
<td>0.96</td>
</tr>
<tr>
<td>73/74</td>
<td>0.20</td>
<td>-</td>
<td>-</td>
<td>3,1,9,8,31,195</td>
<td>6.65</td>
</tr>
<tr>
<td>74/75</td>
<td>0.20</td>
<td>-</td>
<td>-</td>
<td>(195+255),7,3,3,4,3</td>
<td>3.52</td>
</tr>
</tbody>
</table>

The available data thus allowed the water balance equation to be applied to fourteen water-years of record, yielding the following fourteen equations in four unknowns:

\[
\begin{align*}
0.73 + H + Y &+ 0.22 S_A = 7.97 B = 0 \\
0.81 + H + Y &+ 0.96 S_A = 6.63 B = 0 \\
0.89 + 0.2H + Y &+ 0.44 S_A = 12.96 B = 0 \\
1.03 + 0 + Y &+ 0.10 S_A = 10.24 B = 0 \\
1.12 + 0 + Y &+ 0.32 S_A = 16.73 B = 0 \\
1.22 + 0 + Y &+ 0.31 S_A = 21.78 B = 0 \\
0.99 + 0.1H + Y &+ 1.41 S_A = 10.89 B = 0 \\
0.57 + H + Y &+ 0.16 S_A = 24.30 B = 0 \\
0.33 + H + Y &+ 1.92 S_A = 42.63 B = 0 \\
0.25 + H + Y &+ 0.98 S_A = 25.70 B = 0 \\
0.44 + H + Y &+ 0.65 S_A = 20.55 B = 0 \\
0.67 + H + Y &+ 1.05 S_A = 5.72 B = 0 \\
\end{align*}
\]
Unless the model is perfect, no set of the four unknown parameters can be found to satisfy all fourteen equations. It was therefore assumed that the best solution would correspond to the 'least squares' solution, that is the parametric values which would give the smallest sum of the squares of the values of the fourteen equations.

The problem could be solved by an iterative process or by calculus, and the latter method was chosen.

The equation describing the sum of the squares is:

\[
F = 28.023 + 9.05H^2 + 14Y^2 + 10.1(SA)^2 + 5030 B^2 + 9.11H + 19.06Y \\
-5.27SA - 2608 + 16.5 HY + 2.72 H(SA) - 258 HB - 1.98Y(SA) \\
-436 VB - 165 (SA)B.
\]

This is the function to be minimised. The lowest value of \( F \) corresponds to the point where the four partial derivations are equal to zero. Thus four equations in four unknowns were obtained and the solution was:

\[
\begin{align*}
B &= .00381 \\
SA &= .126 \\
Y &= -.967 \\
H &= .534
\end{align*}
\]

The value of \( F \) given by these values was 0.37. However, the solution was an absurd one: neither the \( Y \) nor \( H \) value were realistic. The poor solution would be explained by inaccuracies in the model.

Further consideration was then given to the value of \( Y \). Evapotranspiration has been estimated by Wilson and Forbes to be of the order of 0.1 million kilolitres per year. On the other hand, if infiltration from rainfall was 5% to 10%, a similar value is conceivable for direct infiltration. Constant recharge is unlikely to exceed 0.1 million kilolitres per year.

It was therefore decided that \( Y \) should lie between -0.2 and +0.1, with a most likely value between -0.1 and zero. Hence, by setting \( Y \) equal to various values, a forced solution was obtained using the other three partial derivatives. That is, the minimum value of \( F \) was obtained under the constraints \( Y \) equals -0.1, zero and 0.1.

The results were:

<table>
<thead>
<tr>
<th>( Y )</th>
<th>B</th>
<th>SA</th>
<th>H</th>
<th>( F )</th>
</tr>
</thead>
<tbody>
<tr>
<td>-0.1</td>
<td>.0354</td>
<td>.531</td>
<td>.102</td>
<td>1.09</td>
</tr>
<tr>
<td>0</td>
<td>.0390</td>
<td>.576</td>
<td>.0519</td>
<td>1.27</td>
</tr>
<tr>
<td>0.1</td>
<td>.0426</td>
<td>.592</td>
<td>.0053</td>
<td>1.48</td>
</tr>
</tbody>
</table>
The results are shown graphically on Figure 1. Bearing in mind the constraints that $Y$ probably lies in the range $-0.1$ to zero and that $H$ is probably slightly less than 0.13 (see Appendix 1) and that the basic objective in solving the model is to minimise $F$, the solution for $Y = -0.1$ was selected.

The flatness of the $B$ and $SA$ curves on Figure 1 shows that these values are not very sensitive to the accuracy of the above decision. That is, their chosen values are probably fairly reliable. It is these parameters which are critical for the safe yield determination.

In the resulting model, recharge (after deducting evapotranspiration) may be described as comprised of a constant component equal to minus $Y$ (that is, 0.1) and a variable component $0.35 \cdot \log(t + 1)$. The average groundwater flow through Heavitree Gap is 0.10 million kilolitres per year, and the storage coefficient times the area of contributing aquifer is 0.53. This would give (say) an average storage coefficient of 0.07 and an area of contributing aquifer of 7.5 square kilometres, both realistic figures. It is pointed out that the area of contributing aquifer is much larger in the long term than the area of highly permeable sands which is often considered as the aquifer.

Based on the true starting value of 'd' and assuming that all annual recharge occurs on 1 January each year, the model was used to simulate the aquifer level since 1957. The closeness with which the simulated result approximates the real trend is an indication of the quality of the model. Examination of Plate 4 suggests that the model is in fact very satisfactory. The 'peakedness' of the simulated graph is due to the 'instant recharge' assumption.

A statistical analysis was carried out with the aim of determining the 'safe' yield.

(a) On the basis of past basin performances, the assumption was made that the basin was 'full' at $d = 3$ metres and 'empty' at $d = 9$ metres, values which are not intended to be conclusive but to represent a practical range with regard to economic pumping extraction.

(b) Using $B = 0.035$ the annual values of $dB \cdot \log(t + 1) + 0.1$ were computed for 1957/58 to 1974/75, assuming 'd' values of 3, 6 and 9 metres. The mean annual recharges for the three values were 0.38, 0.65 and 0.93 million kilolitres respectively. From this it appeared that the 'safe' yield could be in the vicinity of 0.6 to 0.7.

(c) The values were ranked; the derived probability curves are shown in Figure 2.

(d) For two values of extraction rate ($P + H$), probabilities of dewatering the basin were estimated. This was accomplished by (for a given rate) assuming a starting point equal to the level in the basin which would provide the rate as an average, and summing the probabilities of the basin being emptied in
Changes in solution with changes in assumed value of $Y$.

**FIGURE 2**
one, two, three, etc. years. The value of SA was employed to provide the available storage figures.

(e) The return periods obtained by this analysis were about 3000 years for a rate of 0.65 kilolitres per year and about 25 years for a rate of 0.75.

(f) This study concluded that the maximum 'safe' yield is about 0.70 kilolitres per year. This figure must include Heavitree Gap outflow; if the figure of 0.10 is accepted for the outflow, then 0.60 million kilolitres are available for other use. The average operating level of the basin at this rate would be slightly less than half-full. The basin appears from the above to be very sensitive to exceedence of the safe yield.

The above yield figures are similar to those derived by Forbes, Eggington and Quinlan and Woolley, each using different methods.
Appendix 3

Farm Area Basin Water Balance Study and Safe Yield Determination

The approach and methods employed in this study were similar to those used in the Town Basin study.

The area under study was not well defined hydrogeologically, but was arbitrarily defined to be bounded at the upper extremity by Heavitree Gap and at the lower extremity by the west-south-westerly prolongation of the eastern abutment of the Blatherskite Range. This excludes most of the area once referred to as the Outer Farm Area. However, the principal objective of the study was to provide an estimate of the safe yield, and as hydrogeological conditions suggest that the majority of recharge would occur more upstream, this omission is not considered to be significant.

After some preliminary analysis, the model was based on the following annual water balance equation:

\[ P + k \cdot L \cdot t = H + \Delta h \cdot S \cdot A + d \cdot B \cdot \log (t + 1) = 0 \]

where

- \( P \) = annual extraction by pumping (million kilolitres)
- \( k \cdot L \cdot t \) = function describing the groundwater outflow (million kilolitres)
- \( k \) = height of potentiometric surface above 520 metres A.H.D. in bore RN 3666 (metres)
- \( L \) = constant (million metres)
- \( H \) = groundwater inflow at Heavitree Gap (million kilolitres)
- \( \Delta h \cdot S \cdot A \) = change in storage (million kilolitres)
- \( \Delta h \) = change in height of potentiometric surface (metres)
- \( S \cdot A \) = storage coefficient times the area of aquifer (millions of square metres)
- \( d \cdot B \cdot \log (t + 1) \) = function describing recharge from the Todd River (million kilolitres)
- \( d \) = depth of potentiometric surface below R.L. 554 metres in bore RN 3613 (metres)
- \( B \) = constant (millions of square metres per log days)
- \( t \) = duration of each river flow event (days)

A variable such as the \( Y \) of the Town Basin study was not employed. The reasons for this were that (a) the constant recharge in this study is described by \( H \) and the only parameters covered by a variable \( Y \) would be evapotranspiration and rainfall infiltration; (b) a new variable \( L \) introduced into the study had rendered it already as complex as the Town Basin study; and (c) \( Y \) was not critical to the Town Basin study in terms of the final safe yield answer, as other parameters were capable of 'absorbing' it with little change in the overall result.
The equation was applied to ten 'water-years' of record, each water year commencing in November. November was chosen rather than September in order to make fullest possible use of available data.

Detailed discussion of the above parameters and variables follows:

(a) Pumping Extraction (P). No records have been maintained of Farm Area water usage, and figures used are based on Albrecht's estimates for 1962, 1963 and 1964, and Jolly's estimate for 1976, with other figures obtained mainly by interpolation. Values are given in Table 4.

(b) Groundwater Outflow (k^2L). In the vicinity of the outflow point the hydraulic gradient increases and the groundwater descends to deeper tertiary aquifers where the potentiometric surface is relatively more stable. The actual outflow is effected chiefly by the saturated cross section of aquifer and by the hydraulic gradient. It was decided that each of these aspects could be described, proportionately, by the height of the potentiometric surface above the effective aquifer base at the outflow area. Hence, 'k' was adopted as the height of the potentiometric surface above 520 metres A.H.D. in bore RN 3666. 'L' is an overall constant allowing for both the area and gradient effects. 'k' values are shown in Table 4. An important modification was made for 1953/64, for which the outflow was set at zero because of pumping from bore RN 3517 for the town supply. There was insufficient data to directly substantiate this assumption, but in view of the relative volumes of water involved and the location of the bore, it was considered that the potentiometric surface was probably modified sufficiently to effectively prevent outflow.

(c) Groundwater Inflow (H). This corresponds to the H in the Town Basin study, which yielded a value of 0.10 kilolitres. By comparison with the Town Basin, H was set at zero in 1961/62 and 1962/63 and 0.03 in 1963/64.

(d) Potentiometric Change (Δh). All observation bore records were examined to obtain changes between 1 November of sequential years. Δh was obtained by numerical average for each year. Insufficient records for reliable figures were available prior to 1961/62 and after 1970/71. The number of record-providing bores in the intervening years varied from 11 to 17, and in every case the bores were well distributed throughout the basin. The adopted values of Δh are given in Table 4.

(e) SA. The true value of storage coefficient varies considerably throughout the basin, and the area of contributing aquifer is not well defined. However, for the purposes of the annual water balance SA may be treated as a constant describing the volume of water yielded per metre decline in potentiometric surface. The value of SA was treated as an unknown.

(f) Recharge. The same type of function was assumed as for the Town
Basin, although the 'd' value was based on only one bore (RN 3613) and was defined as the depth below 564 metres A.H.D. The reason for only one bore being chosen was that the Farm Area exhibits a much wider range of standing water levels than does the Town Basin, and mean value would have been difficult to obtain. Any discrepancy associated with the use of only one bore however, would be largely absorbed by the constant B.

**TABLE 4**

VALUES OF KNOWN VARIABLES

<table>
<thead>
<tr>
<th>Water-Year</th>
<th>P</th>
<th>k</th>
<th>H</th>
<th>Δh</th>
<th>d</th>
<th>10 log (e + 1)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1957/58</td>
<td>.50</td>
<td>21.6</td>
<td>0</td>
<td>-0.45</td>
<td>9.7</td>
<td>3.20</td>
</tr>
<tr>
<td>58/59</td>
<td>.46</td>
<td>21.1</td>
<td>0</td>
<td>-0.62</td>
<td>10.4</td>
<td>2.98</td>
</tr>
<tr>
<td>59/60</td>
<td>.39</td>
<td>18.5</td>
<td>.03</td>
<td>-1.16</td>
<td>11.6</td>
<td>2.65</td>
</tr>
<tr>
<td>60/61</td>
<td>.34</td>
<td>17.8</td>
<td>.10</td>
<td>3.49</td>
<td>12.3</td>
<td>5.36</td>
</tr>
<tr>
<td>61/62</td>
<td>.36</td>
<td>22.0</td>
<td>.10</td>
<td>0.22</td>
<td>9.2</td>
<td>5.20</td>
</tr>
<tr>
<td>62/63</td>
<td>.35</td>
<td>21.6</td>
<td>.10</td>
<td>1.05</td>
<td>9.4</td>
<td>3.96</td>
</tr>
<tr>
<td>63/64</td>
<td>.34</td>
<td>21.1</td>
<td>.10</td>
<td>-2.17</td>
<td>9.0</td>
<td>1.36</td>
</tr>
<tr>
<td>64/65</td>
<td>.33</td>
<td>18.0</td>
<td>.10</td>
<td>-2.00</td>
<td>10.0</td>
<td>0.46</td>
</tr>
<tr>
<td>65/66</td>
<td>.32</td>
<td>16.2</td>
<td>.10</td>
<td>-1.01</td>
<td>11.0</td>
<td>0.70</td>
</tr>
<tr>
<td>66/67</td>
<td>.31</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>2.00</td>
</tr>
<tr>
<td>67/71</td>
<td>.30</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>0.96</td>
</tr>
<tr>
<td>68/69</td>
<td>.29</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>6.49</td>
</tr>
<tr>
<td>69/70</td>
<td>.28</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>3.66</td>
</tr>
</tbody>
</table>

The available data thus allowed the water balance equation to be applied to ten water-years of record, yielding the following ten equations in three unknowns:

\[
0.50 + 457L - 0.45 SA - 31.04 B = 0
0.49 + 445L - 0.52 SA - 30.99 B = 0
0.47 + 0.13 SA - 25.63 B = 0
0.25 + 253L - 1.04 SA - 25.53 B = 0
0.24 + 317L + 3.49 SA - 55.89 B = 0
0.26 + 484L + 0.22 SA - 56.10 B = 0
0.25 + 467L + 1.05 SA - 37.22 B = 0
0.24 + 445L + 2.17 SA - 9.72 B = 0
0.23 + 353L - 2.00 SA - 4.80 B = 0
0.22 + 282L - 1.01 SA - 7.70 B = 0
\]

The 'least squares' equation obtained was:

\[
F = 1.110 + 1.424,000 L^2 + 26.1(SA)^2 + 12,280 S^2 + 2154 L - 2.75 SA - 157.3 B - 1968 L (SA) - 216,000 LS - 307.4 (SA) S
\]
For the best mathematical solution this function is to be minimised. The lowest value of $F$ corresponds to the point where the three partial derivatives are equal to zero. Thus three equations in three unknowns were obtained and the solution was:

$$
B = 0.00065 \\
SA = 0.1025 \\
L = -0.000294
$$

The value of $F$ given by these values was $0.125$. However, the value of $L$ was absurd and consideration was then given to 'forced' values of $L$.

Under natural high water table conditions, with no pumping, it would be expected that the basin would be full and the outflow rate would approximate the inflow rate. The full level would correspond to a $k$ value of about 32 metres, and hence $L$ is given by:

$$
k^2 L = 0.13 \text{ where } k = 32 \\
i.e. L = 0.000127
$$

Assuming this value and taking the partial derivatives of $F$ with respect to $SA$ and $B$, the following result was obtained:

$$
L = 0.000127 \\
B = 0.0102 \\
SA = 0.118
$$

These values give the value of $F$ as $0.135$, only marginally greater than the $F$ value for the previous solution. It can also be seen that the $B$ and $SA$ values are not greatly changed from the previous solution.

This solution was adopted. A brief sensitivity analysis was carried out, involving the further assumption that $L = 0.0003$, and the result is summarised graphically in Figure 3. It was concluded that the $B$ and $SA$ values were fairly reliable (perhaps within 10% or 20% of the true value), but that the $L$ value is not reliable.

The $SA$ value appears realistic: if the area of contributing aquifer is 3 square kilometres then the average storage coefficient would be about $0.04$. The $B$ value is only one quarter of the $B$ value obtained for the Town Basin, but the length of river capable of providing recharge in the Farm Area is only about half that applicable to the Town Basin, and the recharge characteristics would be expected to be lower in the Farm Area owing to the poorer aquifers and relative lack of homogeneity.

Based on the true starting values of $d$ and $k$ and an assumed direct relationship between $d$, $k$ and $L$ (an oversimplification), and assuming all recharge occurs at the start of each water year, the model was used to simulate the aquifer level since 1961. Examination
FIGURE 4

Changes in solution with changes in assumed value of L
of Plate 5 suggests that the model is satisfactory. The 'peakedness' of the simulated graph is due to the 'instant recharge' assumption.

A statistical analysis was carried out with the aim of determining the 'safe' yield:

(a) On the basis of past basin performances, the assumption was made that the basin was 'full' at $d = 4$ metres and 'empty' at 12 metres, values which are not intended to be conclusive but to represent a practical range with regard to economic pumping extraction.

(b) Using $B = 0.010$, the annual values of $d B \log (t + 1)$ were computed for 1957/58 to 1974/75, assuming $d$ values of 4, 8 and 12 metres. The mean annual recharges for the three values were 0.107, 0.216 and 0.323 million kilolitres respectively.

(c) By analogy with the Town Basin study the 'safe yield' component accruable from river recharge is 0.23 kilolitres per year.

(d) Hence, the 'safe yield' for the Farm Area was obtained by adding this figure to the Heavitree Gap inflow, giving $0.23 + 0.10 = 0.33$ kilolitres per year. This figure includes the system outflow, and to make full use of it pumping must be concentrated sufficiently at the outflow area to reduce the outflow to a negligible rate.
Investigation of the Commonage Area and Proposals for Sewage Reuse

1. 1975/76 Investigations

After concern arose about various aspects of the sewage treatment and disposal system, it was determined in 1975 to conduct minor hydrogeological investigations with the objectives of (a) extending westward the knowledge of the Farm Area Basin; and (b) examining any environmental effects of the lagoons, with regard especially to groundwater.

Eighteen holes were drilled mainly with a percussion rig in the region between the railway and the new sewage lagoons, to delineate aquifers, map the potentiometric surface, and determine groundwater quality. Pumping tests were performed on six of these bores to obtain transmissivity figures.

The locations of the bores and some interpreted hydrogeology are shown on Plate 3. Table 5 summarises the bore data.

Although data is not available for the period prior to the establishment of the lagoons, it is certain that the lagoons and the artificially prolonged water levels in Ilpapa Swamp have created a local groundwater 'recharge mound'. This is indicated by the shape of the potentiometric surface, although the effect has been partly masked by the river flows of 1975/76. From the mound, groundwater flows both eastward into the Farm Area Basin and apparently westward towards Roe Creek.

Under natural undisturbed conditions a 'groundwater divide' probably existed in the same area, and the role of the lagoons has been to raise this divide.

The effect of this modification can be shown to be less significant than it at first appeared. Pumping tests carried out on the immediate eastern side of the lagoons yielded transmissivities of about five square metres per day. When the groundwater gradient of about 1 in 200 was also considered, the derived figure for the total eastward flow from the commonage was of the order of only 25 kilolitres per day or 10,000 kilolitres per year. This represents only 3% of the safe yield of the Farm Area Basin, and may be taken as an indication of the degree of effect on the natural balance in that basin.

Water analyses have indicated little or no intrusion by effluent water. Bore RN 11190 and 11193, which are close to the lagoons, exhibit much higher salinity and a very different bicarbonate/chloride ratio to the effluent water. Water from bore RN 11003 however, very likely contains sewage effluent. This may be substantiated by the drillers' and test pumpers' reports that the water 'stank'. The bore is located in the Bitter Springs Formation.

On the whole, then, the effluent appears to have intruded very little.
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Sewage effluent (for comparison) 1,200 2.6
distance from the lagoons. Higher bicarbonate/chloride ratios closer to the river are due to proximity to the more permeable parts of the Farm Area Basin, within reach of recent recharge water.

If the aquifer were homogeneous and had a porosity of 0.1, then the flow rate would be only some five or ten metres per year through the aquifer. In reality, there is more than one aquifer and intrusion may have taken place to a greater extent in some areas. For instance, the Bitter Springs Formation, which runs under the northern end of the lagoons, may convey the water at a faster rate (viz. RN 11003 above), although no evidence of this has been discovered closer to the Todd River.

If any aspect of the eastward groundwater movement is of concern, it is not the movement of sewage effluent (which would be filtered by the aquifer) but the movement of saline groundwater being 'pushed' before it. Salinities as high as 20,000 milligrams per litre have been recorded. This indicates that under natural conditions the groundwater flow rates were extremely slow, allowing a salt build up probably enhanced by Ilpapa Swamp. Although the swamp is 'perched' above the groundwater table on a clay base, gradual solution and infiltration of evaporites would create this effect.

Even considering the high salinities, the low rate of eastward movement means that the effect on the Farm Area Basin is probably negligible.

The local effect is more significant. The effect on flora of the raised saline water table is unknown but several species of trees in the area could be at risk.

Further west, it is likely that the rise in water table could be more severe particularly with the introduction of the new lagoons. Aquifers between the old and new lagoons, and probably further west, are either non existent or have very low transmissivity, with the exception of the Bitter Springs Limestone. Thus the westward groundwater gradient in the area is associated with a negligible flow rate. In effect, water seeping from the swamp or lagoons can only raise the groundwater table, until an equilibrium is reached with the evapotranspiration rate.

2. Reuse Proposals

2.1 Irrigation Project

This project is detailed in the report 'Reuse of Sewage Effluent - Alice Springs' by the Regional Working Group. It is proposed to irrigate lucerne, barley, oats and date palms in the area between the sewage lagoons and the Stuart Highway.

Owing to the salinity of the water and nature of the soil, Animal Industry and Agriculture Branch estimates that there will be a leaching requirement of about 0.5 metres of water annually. This water has to be carried away by the groundwater system, or problems will arise of waterlogging and salinity increases.
Using the results obtained during the 1975/76 investigation, a calculation was made to establish that the groundwater system could in fact handle the surcharge. This calculation is shown on Figure 5. It can be seen that the expected effect of the irrigation would be to raise the water table by about 3 metres on the western side adjacent to the lagoons. Under current water table conditions, this situation could just be tolerated.

The assumptions used in the above are conservative because the irrigation proposal does not involve continuous cultivation of the entire area: if only one third of the area is irrigated in any one year, groundwater storage effects will attenuate the impact of the infiltration and the long term water table profile would be raised by only about one third of the calculated amount.

It is clear from the calculations however, that irrigation further west (where the transmissivity is lower) would not be possible in the long term without constructed drainage.

2.2 Infiltration Scheme

Alternative or supplementary to the proposal to use Alice Springs sewage effluent for agricultural purposes, is a project to infiltrate the water to enhance the groundwater resource.

Groundwater in the Farm Area is located close to the surface especially in years of above-average rainfall conditions. However, after it flows south of the confines of the Blatherskite Range, the groundwater enters deeper, tertiary sediments. The water table falls from about 10 metres below the surface near St. Marys Village to over 30 metres at the A.I. & A.B. farm, and the downward trend continues as far as the Mereenie Sandstone six kilometres to the south.

As stated elsewhere in this report, in general groundwater flowing south from Alice Springs is eventually destined for the Mereenie Sandstone.

The area to the south of Mt. Blatherskite provides an attractive area to undertake groundwater recharge with partially treated sewage effluent, in terms of benefit to the groundwater resource and proximity to the treatment area.

General Proposal

Overflow from Ilpapa Swamp flows into a watercourse sometimes described as St. Marys Creek, the route of which proceeds under the railway and highway before heading southwards through the south-west corner of the St. Marys block, the new racecourse block and the A.I. & A.B. block. The creek eventually floods out on blocks 429 and 422 north of the airport (see Plate 6).

Approximately one week after the March 1976 flood, a flow at the highway culvert estimated at 200 litres per second was found to be infiltrating into the sands of the creek bed within a distance of
NOTE: This assumes an infiltration rate of 500 mm/yr over a strip one metre wide.
1200 metres. No water at that time was flowing as far as the A.I. & A.B. block, although the 'end-point' of flow was clearly receding in accordance with the recession of the rate of inflow from the swamp area.

Hydrogeological records indicate that the water would have been infiltrating into permeable quaternary and tertiary sediments, to recharge the groundwater table 10 to 30 metres below.

The length of St. Marys Creek exceeds 3 kilometres, and it is expected that the infiltration capacity of the stream as a whole, but not including the floodout, is at least 500 litres per second.

The average rate of sewage discharge at Alice Springs is of the order of 40 litres per second, or one twelfth of the above infiltration capacity.

Even allowing for a significant decrease in infiltration characteristics due to chemical and organic material in the effluent, the potential should exist to infiltrate part or all of Alice Springs sewage effluent, after primary settling. This would be accomplished by piping or channeling the effluent into the creek in the vicinity of St. Marys, or further south. The flow would constitute only a small stream of water. Alternatively, recharge ponds could be constructed in the area. This would probably be less efficient, as the infiltration area would be more concentrated and there would be no cleansing action on the sands by flowing water.

Records indicate that the rate of sewage outfall at Alice Springs, while varying diurnally, does not fluctuate seasonally to any significant extent. Thus, a flow rate into the creek corresponding to the average outfall rate could be maintained with the aid of the storage available in existing lagoons.

The process would be continued throughout wet periods; any natural runoff into St. Marys Creek would tend only to dilute the effluent.

Occasional drying out of the creek bed, possibly followed by mechanical scouring, may be necessary to reduce clogging of the sand by algae and other organic matter. This operation, which could take a week, would require reserve storage capacity in the lagoons of about 24,000 kilolitres. Again, the existing lagoons should be capable of handling this if the system is adequately managed.

Benefits

The potential benefits of the proposal are listed as follows:

(a) Compared with the alternative of evaporation by lagoons or agriculture, the proposal would involve a very small amount of land.

(b) Bore water at St. Marys, the C.S.I.R.O. and A.I. & A.B. blocks would benefit quickly from such a scheme due to the resultant rise in water table.
(c) In the medium term, bores in the Alice Springs Farm Area would benefit, particularly during drought, because of a reduced rate of groundwater outflow from the Farm Area Basin.

(d) In the long term a significant contribution would be made to groundwater aquifers as far as the Mereenie Sandstone. The operation would replace some 25% of the extractions at Mereenie. Although the recharged water itself may take hundreds of years to reach the Mereenie Sandstone, benefits should be gained within a few years due to the increase in hydraulic gradient and hence flow rate.

Public Health Aspects

(a) Surface. There should be no public health problems if (1) direct contact with the water by humans or animals is prevented; and (2) the water is not permitted to become stagnant and thus promote mosquito breeding.

The contact problem must be overcome by fencing wherever the water is exposed and easily accessible, as in the portions of the creek located on the St. Marys and racecourse blocks. Stagnancy and ponding would be prevented by ensuring the creek had adequately formalised banks, and that the input rate was managed to avoid causing the creek to "flood-out".

Occasional clearing of weeds and deposited material would also be desirable, to assist the infiltration process in addition to removing any health risk. This operation would be accomplished using small plant, and would be partly aided by natural creek flows.

(b) Subsurface. The filtering action of sand on sewage effluent is well known. Nevertheless, bacteriological contamination of groundwater in close proximity to recharge is a possibility. The only bore likely to be affected by any such contamination is the St. Marys bore, which is used only for watering the grounds. If contamination were found, it could be overcome with a chlorinator. No contamination would occur if the infiltration were to start to the south of St. Marys.

Because of the southward groundwater movement, there is no risk of contamination of Farm Area bores to the north and east.

Design

The distance from the aerobic lagoons at the northern end of the older treatment works to the area of formation of St. Marys Creek near the railway, is about 1600 metres. If a slightly curved path is taken, there is a constant downward gradient of 1 in 390 (see Plate 6).

The creek itself maintains an average gradient of 1 in 440 for its course of 3.5 kilometres, with vertical variations from the mean gradient line of only 0.4 metres.
Consideration for the St. Marys and Racing Club people will be necessary in design. Aesthetic aspects may preclude the use of an open channel through these blocks. South of the racecourse, where the creek traverses a vacant block next to the C.S.I.R.O. block, the A.I. & A.B. block and block 427, this problem should not exist.

Some design options are considered below:

(a) The cheapest means of conveying the settled effluent from the lagoons to the creek would be an open channel. A grader-cut channel of about 0.75 metres depth would handle the present average discharge rate of about 40 litres per second. (The storage provided by the lagoons would enable the rate of discharge to the creek to be maintained at the average rate of raw effluent discharge.)

The cost of such a channel, and some minor formalisation of banks in the creek itself near St. Marys, should be less than $1000. However, it would be almost imperative to construct a man-proof fence on either side, at least from the Ilpepe access road to the lower boundary of the racecourse block, a distance of about 1400 metres. At about $12 per metre the cost of this work would be some $34,000, bringing the total cost of this plan to about $35,000.

(b) A 12" concrete or asbestos-cement pipe could be used to convey 40 litres of effluent water per second (flowing full) the entire 3 kilometres from the lagoons to the southern boundary of the racecourse block. The pipe would be laid in a one metre deep trench alongside the creek.

Assuming a cost of $40 per metre for the pipe, trench and laying, the total cost would approximate $35,500.

(c) The effluent could be conveyed by channel to the creek, but then fed into a 12" pipe which would carry it to the south of the racecourse.

This plan would involve 1400 metres of pipeline, and the total cost should be about $50,000. About half this expenditure could be deferred until the Racing Club actually moves into their block.
APPENDIX 5

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