TENNANT CREEK WATER SUPPLY
1979 - 1980 SOURCE INVESTIGATION

THE NORTHERN TERRITORY OF AUSTRALIA
DEPARTMENT OF TRANSPORT AND WORKS
TENANT CREEK WATER SUPPLY

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Report on Water Division Project 91
Tennant Creek West - Groundwater

Prepared by T J Verhoeven & P W Russell
Water Division
Department of Transport and Works
Alice Springs

June 1981
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PREPARED BY T.J. VERHOEVEN AND P.W. RUSSELL
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ABSTRACT

The latest in a sequence of groundwater investigations to augment the Tennant Creek Water supply was conducted during 1979-1980. The investigation was carried out to provide additional hydrogeological information in the area of the existing borefields, a future borefield at Tennant Creek West, and in the area between the two. As part of the project a water balance model was developed to assess the inter-relationship of recharge, storage and yield for the existing borefields.

As a result of this investigation six additional production bores were drilled, constructed and tested in the Kelly Well and Kelly Well West borefields during 1980. For a planned 25% storage depletion in these borefields, a supplementary water source is not required until 1989-90. The supplementary source is identified as a borefield in the Tennant Creek West area 40 to 50km west-south-west of Tennant Creek.

The results of this and past investigations provide input to resource management. Direct management by the Tennant Creek Area Office of daily extraction from the borefields is specified. Broader management measures including the Control of Waters Act, monitoring, modelling and water conservation are detailed and recommended to make full use of surface water and groundwater resources.
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<table>
<thead>
<tr>
<th>Symbol</th>
<th>Description</th>
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<tbody>
<tr>
<td>AHD</td>
<td>Australian Height Datum</td>
</tr>
<tr>
<td>AMG</td>
<td>Australian Map Grid</td>
</tr>
<tr>
<td>BqL^{-1}</td>
<td>Bequerel per litre</td>
</tr>
<tr>
<td>km</td>
<td>kilometre</td>
</tr>
<tr>
<td>Ls^{-1}</td>
<td>litres per second</td>
</tr>
<tr>
<td>m</td>
<td>metre</td>
</tr>
<tr>
<td>m^2d^{-1}</td>
<td>square metres per day</td>
</tr>
<tr>
<td>m^3d^{-1}</td>
<td>cubic metres per day</td>
</tr>
<tr>
<td>mg L^{-1}</td>
<td>milligrams per litre</td>
</tr>
<tr>
<td>RN</td>
<td>Registered Number</td>
</tr>
<tr>
<td>S</td>
<td>Storage coefficient</td>
</tr>
<tr>
<td>SWL</td>
<td>Standing Water Level</td>
</tr>
<tr>
<td>T</td>
<td>Transmissivity</td>
</tr>
<tr>
<td>TDS</td>
<td>Total Dissolved Solids</td>
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CONCLUSIONS

1. Tennant Creek West Hydrogeology

1.1 Field investigation work conducted as part of this project has added greatly to the information obtained from previous investigations.

1.2 The sandstone member of the Point Wakefield Beds containing the major aquifer is not as extensive areally as previously surmised. It is restricted to a major fracture zone which underlies much of the area and has been preserved by block faulting.

It is this sandstone which will be the target aquifer for the future borefield development at Tennant Creek West.

1.3 Water quality and aquifer characteristics for the Point Wakefield Beds white sandstone aquifer remain unaltered from previous investigations. The water is of low to medium salinity but is unsuitable for human consumption because it contains marginally excessive concentrations of nitrate and fluoride. The aquifer has an average transmissivity value of 200 m²/d⁻¹. It is semi-confined and has a storage coefficient value of 5 x 10⁻⁴.

1.4 The reddish-purple sandstone unit previously hypothesised to contain a major aquifer was also investigated. It was found that this sandstone occurs only in isolated pockets and so, although the sandstone has good interstitial porosity it cannot be designated as a second, deeper major aquifer.

1.5 Underflow in the area of the potential borefield is reassessed to be 1200 m³/day. Safe yield cannot be assessed because of insufficient information. The volume of water in storage which can be utilised has been reassessed to be 1.2 x 10⁶ m³.

1.6 Recharge to aquifers in this area is a combination of:

   (i) Groundwater underflow from Kelly Well West, confirmed by field investigation.

   (ii) Groundwater underflow from the south-east along the major fracture zone.

   (iii) Surface water recharge identified by Verhoeven and Knott (1979).

2 Present Borefield Hydrogeology

2.1 The areal extent and thickness of aquifers in the Kelly Well and Kelly Well West borefields has been defined.

2.2 The investigation confirmed the existence of a second major aquifer within a sandstone formation underlying the tubular siltstone aquifer from which the town supply is being pumped. Both aquifers are continuous and trend south-east to north-west. Formations containing aquifers do not extend south-west of Kelly Well West, as had been previously hypothesised.

2.3 There is no additional information to suggest that the previously calculated values of aquifer characteristics, underflow and safe yield need be altered.
2.4 The volume of water held in storage in the Kelly Well and Kelly Well West borefields has continued to change annually. Bore water levels rose to a peak in early 1979; the volume of water then held in storage in Cainozoic and Cambrian sediments was estimated to be 48 million cubic metres.

3. Future Water Demand and Supply

3.1 Future water demand for Tennant Creek, including town, abattoir and hobby farm components, has been estimated to 1999. Average daily demand increases from 3320 m$^3$ in 1979/80 to 11550 m$^3$ in 1998/99. Peak daily demand, including standby, is three times the average daily demand.

3.2 To meet increasing demand existing sources were upgraded in 1980. Bores P8 and P9 were test pumped and equipped to provide an additional 2160 m$^3$d$^{-1}$ (25 Ls$^{-1}$) standby capacity. Six new production bores were drilled, constructed and tested (P10 to P15 inclusive). The output of these bores when equipped will be 7258 m$^3$d$^{-1}$ (84 Ls$^{-1}$).

3.3 In the latter half of 1984 four older, shallow production bores in the Kelly Well area will need to be replaced with deeper, higher yielding bores.

3.4 With groundwater extraction continuing to increase above safe yield, aquifer storage is gradually depleted. It is concluded that the presently utilised aquifers can have their storage safely depleted by 25 percent. This level of depletion will occur between 1986/87 and 1990/91 (depending on precipitation and recharge) with the expected occurrence in 1988/89.

3.5 Based on the above a new borefield at Tennant Creek West will be required after 1988/89 to augment existing sources. However the results of a current recharge investigation and of improved management measures may delay this further.

3.6 The area of the proposed borefield at Tennant Creek West is shown on Figure 16. Attention will need to be paid to production bore drilling and construction. These bores will need to be drilled with mud, logged with geophysical tools, lined with stainless steel screens having a small aperture size, gravel packed and developed. Each bore is expected to yield between ten and twenty litres per second, with pump settings of between thirty and forty metres. An initial spacing between production bores of one kilometre should be considered.

4. Investigation and Management

4.1 It is concluded that when the results of Project 11 KELLY WELL INFILTRATION STUDY are published, the surface water and groundwater field investigations for the existing borefields and for the proposed borefield at Tennant Creek West will be completed. These results provide input to resource management.

4.2 Management of the water resources takes two forms; direct management of daily extraction, and the implementation of broader management measures including the Intcred of Waters Act, monitoring, aquifer simulation and water conservation.
RECOMMENDATIONS

1. **Groundwater Extraction**

1.1 It is recommended that daily management of extraction from the borefields be carried out under the supervision of the Regional Engineer Water, Tennant Creek. Pumping recommendations are listed in Chapter 6 (Section 6.2.1.)

2. **Control of Waters Act**

2.1 A water control district should be declared for Tennant Creek, to cover the areas of existing and future borefields (Section 6.2.2.).

2.2 The existing Kelly Water Control District and Warrego Water Control District should be abolished at the time that the Tennant Creek Water Control District is declared.

3. **Monitoring**

3.1 The current programs of obtaining groundwater extraction, water quality and hydrographic data as outlined in Chapter 6 (Section 6.2.3. (1), (2) and (3)) should be continued.

3.2 It is recommended that bore water levels in 59 bores listed in Chapter 6 (Section 6.2.3. (4)) be measured regularly at intervals of six weeks. These bores are located in the Cabbage Gum, Kelly Well, Kelly Well West and Tennant Creek West areas. The water level on the lake should be measured regularly.

3.3 It is recommended that continuous water level recorders be maintained on bores RN 10167 and RN 10564 in the Kelly Well and Kelly Well West areas.

3.4 It is recommended that a new observation bore be drilled one kilometre south east of bore RN 10761 (Kelly Well area), to intersect the major Cambrian sediment aquifers. The water level recorder currently on bore RN 10761 should be moved to this new bore.

3.5 Bore RN 11626 in the Tennant Creek West area should be equipped with a continuous water level recorder.

4. **Aquifer Simulation**

4.1 Establishment and development of a computer model to simulate aquifer behaviour is recommended. Modelling packages to resolve a number of problems raised as part of this investigation are readily available.

4.2 The above model should be retained as dynamic management requires further verification and modelling as time progresses and input variables change.

5. **Water Conservation**

5.1 It is recommended that a local water conservation committee be established with the Tennant Creek Area Manager as its chairman. The committee would need to recognise the need for water conservation, identify losses and wastage, and examine mechanisms available to moderate consumption.

5.2 A water conservation program should be introduced.
During 1977/78 a field investigation was conducted to assess the groundwater potential in the Tennant Creek West area, as a future water supply for the town. The results of that investigation, together with information from other areas in the south-east corner of the Wiso Basin were presented and analysed in a report by Verhoeven and Knott (1979). As well as yielding local and revised regional interpretations of the hydrogeology the 1979 report recommended a program of continued monitoring and highlighted the need for investigation of surface recharge and for further groundwater investigation. Both investigations were recommended to be carried out during 1979/90 because of the need to fully develop the present interconnected borefields of Cabbage Gum, Kelly Well and Kelly Well West and to assess design parameters for a new borefield at Tennant Creek West.

The groundwater investigation was carried out in the second half of 1979. Preliminary findings were presented in an interim report by Verhoeven and Russell (1980), the report having limited circulation.

As this report supplements that by Verhoeven and Knott (1979) much of the interpretation will not be repeated. Geographical areas defined in that report are also used in this report (see Figure 1). Additional geological data modifies some local interpretation but regionally the picture remains unaltered.
There were four investigation objectives:

(i) At Tennant Creek West define the areal extent, thickness and hydraulic properties of the red sandstone aquifer which underlies the defined major aquifer of interest (Cambrian white sandstone). A successful outcome to this part of the investigation will result in the utilisation of both aquifers as water sources.

(ii) At Tennant Creek West drill, construct and test observation bores adjacent to future production bore sites to aid in production bore design.

(iii) In the area of the present borefields define the areal extent and total thickness of aquifers particularly south of Kelly Well West. This is required so that production bores can be sited to fully utilise the aquifers at present in use.

(iv) Define the areal extent and thickness of aquifers connecting Kelly Well West to Tennant Creek West. This may indicate areas suitable for expansion of the present borefields.
Field operations were carried out between July and November 1979.

3.1 Drilling and Bore Completion

Water Division Drilling Rig No. 21, a Portadril1 rotary drilling rig, was used throughout the investigation.

Twenty-five holes at twenty sites (Figure 2) were drilled into a number of formations and aquifers. Drilling results are included in Tables 1, 2 and 3:

(i) Holes RN 12128, RN 12129, RN 12130, RN 12131, RN 12132, RN 12133, RN 12134, RN 12135, RN 12136, RN 12142 and RN 12143 were drilled in the Tennant Creek West area to aid in defining the areal extent, thickness and hydraulic properties of the red sandstone aquifer. Holes were drilled on the 1977/78 investigation grid. Bores to be test pumped were cased with 152.4mm diameter casing, perforated opposite the major water bearing zones. Remaining holes were run with 50mm diameter galvanised water pipe, perforated opposite the aquifer of interest, for long term monitoring purposes.

(ii) Holes RN 12150, RN 12151 and RN 12152 were drilled at Tennant Creek West and completed as observation bores adjacent to future production bore sites. These bores were completed with screens and gravel pack material. Unfortunately the gravel pack material selected was unsuitable and poor test pump results were obtained (see Section 4.2.1.).

(iii) A number of holes were drilled in the area of the present borefields.

Holes RN 12140 and RN 12144 were drilled to provide geophysical control on traverse line A (see Section 3.2). Geophysical logging was carried out prior to running of 50mm diameter galvanized water pipe. Because of poor communication, hole RN 12144 was drilled on the wrong site; it should have been drilled 425 metres south east of its location.

Hole RN 12141 was drilled one kilometre south of Production Bore No 5 to investigate the hypothesised presence of a white sandstone aquifer underlying the siltstone aquifer at present being pumped. The bore was completed with 152.4mm diameter casing and screens suitable for test pumping.

Hole RN 12145 was drilled to investigate a possible south west trending extension of the aquifers at Kelly Well West.

Holes RN 12146, RN 12147, RN 12148 and RN 12149 were drilled at the request of Engineer Jolly (1979) to investigate a potential aquifer in weathered granite in the Cabbage Gum area. Results were inconclusive because of the use of incorrect drilling technique.
(iv) Holes RN 12138 and RN 12139 were drilled on traverse line B to provide geophysical control for that part of the investigation examining the interconnection between Kelly Well West and Tennant Creek West. Geophysical logging was carried out prior to running 50mm diameter galvanised water pipe. Those holes backfilled were marked with a steel star picket set in concrete. Each cased bore was securely capped, tagged with its RN, and surrounded by a concrete block.

3.2 Geophysics

Surface survey techniques and well logging of selected holes were programmed to be carried out commencing July 2 1979. The use of geophysics was programmed to reduce the amount of drilling required and to provide additional information to aid interpretation. This phase of the investigation has been documented by Braybrook (1980), and is outlined below.

(i) Traverse A

This traverse was included to investigate a possible south west trending extension of the aquifers at Kelly Well West. A Potential Drop Ratio Resistivity Depth Probe (P.D.R.) survey was first carried out. Control holes RN 12140 and RN 12144 (drilled for this investigation) and hole RN 10166 (drilled in 1971) were logged. The natural gamma ray log was used to provide stratigraphic control, drill log correlation and to aid in strata sample interpretation.

Braybrook (1980) notes that in a final analysis of accrued data a series of seismic refraction spreads 'shot' in the vicinity of site 79A6.0 to test an anomalous zone would prove beneficial.

(ii) Traverse B

 Traverse B was programmed to investigate the degree of interconnection between Kelly Well West and Tennant Creek West. Surface survey techniques including shallow refraction seismic (intercept time and method of differences), resistivity (P.D.R. depth probing and Normal Wenner Traversing) and magnetic traversing (total field intensity) were employed.

Control holes RN 12138 and RN 12139 were drilled and logged with the following probes: natural gamma, neutron-neutron, caliper, point resistance and self potential. Braybrook (1980) found excellent correlation between composite borehole logs and seismic refraction velocity data.

(iii) Tennant Creek West

Thirteen bores were logged in this area to aid in strata sample interpretation and to provide stratigraphic control. Probes run include natural gamma ray, caliper, neutron, point resistance, self potential and temperature.

3.3 Geological Logging

Strata samples collected at 3 metre intervals in each hole were logged by
Hydrogeologist Knott. Unfortunately logging was not completed until mid 1980, long after follow up drilling was possible.

3.4 Pump Test

The pump test program was commenced on 1 October 1979 and concluded in November. As less than half the number of bores drilled were to be tested only one crew was used.

Bore development work was followed by preliminary and constant discharge tests, the latter generally of 24 hours duration. These tests were used to aid in evaluating aquifer hydraulic characteristic values for aquifer transmissivity and storage coefficient.

Where possible bores were also given a five stage step test, to aid in predicting bore behaviour with pumping.

3.5 Survey

The survey program was commenced in July 1979. Prior to this traverse lines A and B had been cleared and a number of investigation hole sites pegged.

The survey crew established bench marks 20m from each bore or group of bores, and pegged the two traverse lines at 500m intervals. All bench marks and traverse line pegs were located to AGD co-ordinates and levelled to AHD, to tie in to the existing horizontal and vertical survey.

At the completion of drilling all bores were levelled and located relative to adjacent bench marks (bore survey data is summarised in Table 4).

3.6 Water Sampling

As in the 1977/78 investigation water samples representative of each aquifer encountered in each bore were analysed to ascertain chemical quality and suitability for human consumption. The variations in ionic concentration areally, with depth and with aquifer sampled are used to confirm the previously defined directions of groundwater movement and areas of recharge.

Investigation holes were sampled:

(i) during drilling, at each increase in supply; and,

(ii) at various intervals in time during each pump test, from a constant depth.

3.7 Water Level Monitoring

Water levels in bores drilled in past investigations have been measured at six weekly intervals. Standing water levels in bores drilled as part of this investigation have been measured annually. These levels are reduced to AHD and used to plot the potentiometric surface for each aquifer.

Areal and temporal variations in the potentiometric surface since the 1977/78 investigation are useful in confirming groundwater flow gradients and recharge. The monitoring network is assessed in Chapter 6 of this report.
CHAPTER 4  DATA INTERPRETATION

It is important to again stress that this report supplements that by Verhoeven and Knott (1979). As such, much of the information base will not be repeated in this report, especially as on a regional scale there is no change to interpretation. Only where recently acquired data adds to, or modifies local interpretation will it be discussed in this report.

4.1 Geology

4.1.1. Tennant Creek West

Drilling in this area added greatly to the information obtained from the previous investigation. While the stratigraphy remains unchanged the geological structure of the area has been found to be more complex. Knott (1980) has revised the geological interpretation along the traverse lines 1 to 6 (as shown in Figures 3 to 8). The former interpretation of a simplified shallow synclinal structure with its axis trending north-north west has given way to that of a major fracture zone, also trending north-northwest (see Figure 9).

The member containing the major potential aquifer, that is, the middle member of the Point Wakefield Beds, is not as extensive areally as previously surmised. It is restricted to the fracture zone which underlies much of the area (the areal extent of the subcrop of this member is plotted in Figure 9). Within the fracture zone block faulting has preserved this middle member. The location of this member is important as it determines the position of the future borefield for Tennant Creek.

Knott found that the middle member previously identified as a white sandstone occasionally exists as a silty sandstone. Extensive drilling failed to locate more of the reddish purple sandstone formation which occurs beneath the Montejinni Limestone. Knott concluded that this sandstone formation occurs only in isolated pockets. Thus, although the sandstone has good interstitial porosity it cannot be designated as a second, deeper, major aquifer.

4.1.2. Kelly Well - Kelly Well West

Geophysical resistivity work carried out by Braybrook (1980) on Traverse A indicated shallow depth (less than 20 metres) to bedrock. This was confirmed by hole RN 12140 on Traverse A and by hole RN 12144 between the borefield and Traverse A (see Figure 2 for location and Figure 9 for bedrock contours). However, hole RN 12144 intersected 27 metres of alluvial material. Knott concludes that the greater thickness of alluvium marks the extension of the fault zone that defines the north-western edge of the Cabbage Gum Basin. This development is not significant, there is no evidence to suggest a major groundwater outflow channel in a direction southwest of Kelly Well West.

Hole RN 12141 (Figure 2) confirmed the presence of a water bearing sandstone underlaying the major siltstone aquifer in the borefield.

The investigation confirmed the existence of a second major aquifer in the borefield area underlaying the tubular siltstone aquifer from which the town water supply is being pumped. The sandstone formation containing this aquifer lies within the narrow bedrock depression. The formation is continuous
beneath the bore field and trends south-east to north-west. Formations containing aquifers do not extend south-west of Kelly Well West, as evidenced by shallow bedrock.

4.1.3. Interconnection between Kelly Well West and Tennant Creek West

From the results of geophysical traversing and limited drilling on Traverse B, Braybrook (1980) identified two possible outflow areas from Kelly Well West:

(i) A shear zone located midway between holes RN 12138 and RN 12139 (see Figure 2) and trending north-west. The geophysical work indicated a possible northward vertical displacement of 25 metres.

(ii) A broad bedrock channel centred on hole RN 12138 (which intersected 36 metres of alluvium) and trending west toward a topographical low. This topographical low, when containing water, reflects the elevation of the water table.

The locations of both the above channels are plotted on Figure 9.

4.2 Groundwater Hydrology

4.2.1. Aquifers in Tennant Creek West

(1) Definition

The previous assessment of groundwater hydrology by Verhoeven and Knott (1979) remains much the same with one exception; the red sandstone unit is no longer considered a major aquifer as it is not areally extensive. Two major aquifers and four minor aquifers are defined in this area.

Of chief interest is the aquifer contained within the middle member of the Point Wakefield Beds. This friable white sandstone, discontinuous in extent and having variable water bearing properties will be the target aquifer for the future borefield development at Tennant Creek West. As mentioned in Section 4.1.1 interpretation of the structure of this sandstone unit has altered since 1979, however the aquifer characteristics and water chemical quality remain unaltered.

The second major aquifer, contained within the Montejinni Limestone formation, was not studied in this investigation. Minor aquifers include the siltstone members of the Point Wakefield Beds, the dolomitic siltstone of the Hooker Creek formation, the red sandstone unit, and the bedrock granites.

(2) Pump Test and Aquifer Characteristics

Of the 15 holes drilled in Tennant Creek West, only 5 were completed for pump testing; bores RN 12131, RN 12137, RN 12150, RN 12151 and RN 12152. The airlift yields of these and other bores drilled are included in Table 1.

Bore RN 12150, penetrating the major aquifer within the Point Wakefield Beds sandstone unit, was tested at low rates. The derived transmissivity value of 130m²/d is within the range previously obtained for the aquifer.

The results of the remaining tests were marred by high well losses, instability of water level readings, and poor development, all indicative of inappropriate bore construction. As concluded previously by Verhoeven and Knott (1979) construction of successful production bores will require the use of bore screens, artificial gravel pack material and development.
(3) Water Quality

The chemical quality of water from various formations varies little from the findings of the previous investigation documented by Verhoeven and Knott (1979). The major quality parameters used in that report (Total Dissolved Solids, Nitrate and Fluoride) are listed in Table 1 so that the relevant figures in the 1979 report can be updated.

In particular the chemical quality of water sampled from the major aquifer within the Point Wakefield Beds sandstone unit remains unaltered. Salinity ranged from 800 to 1200 mgL⁻¹ and is acceptable for human consumption. However nitrate (generally 50 to 60 mgL⁻¹) and fluoride (1.7 to 2.5 mgL⁻¹) exceed the permissible levels for human consumption (45 mgL⁻¹ and 1.5 mgL⁻¹ respectively; Department of Health/NHMRC/AWRC (1980)).

Three bores (RN 11601, RN 11602 and RN 11606) in the potential borefield area were sampled for heavy metals and radiological analyses. Concentrations of Copper, Lead, Zinc, Manganese, Cadmium and Arsenic were well within designed criteria. The concentration of Radium 226 was found to range from less than 0.04 BqL⁻¹ to 0.2 BqL⁻¹ with a median of 0.04 BqL⁻¹. These values are within the desirable current criteria of 0.4 BqL⁻¹ (Department of Health/NHMRC/AWRC (1980)).

4.2.2. Aquifers in Cabbage Gum Kelly Well and Kelly Well West

(1) Definition

Two major aquifers are identified in the Kelly Well, Kelly Well West areas; the siltstone aquifer currently being pumped from and an underlying sandstone aquifer which is only being utilised to a limited extent. Both aquifers are contained within the narrow bedrock depression which trends south-east to north-west, extending outward from the existing production bores. The aquifers underlie the floodout of Kelly Creek.

No major aquifers were located within the Cabbage Gum Granite Complex.

(2) Pump Test and Aquifer Characteristics

Bore RN 12141 was tested at a constant discharge rate of ten litres per second. Although bore construction was poor the results obtained indicated an efficient bore. The indicated aquifer transmissivity value of 350 m²d⁻¹ supports previously obtained values.

Bores RN 12147, RN 12148 and RN 12149 in the Cabbage Gum Granite Complex were not tested. Airlift estimates of supply are generally less than one litre per second (included in Table 2). Three previously drilled bores were tested; bores RN 5230, RN 5264 and RN 6517. Discharge varied from 0.8 to 2.0 litres per second, and the tests indicated aquifer transmissivity values averaging 20 m²d⁻¹.

(3) Water Quality

The chemical quality of water from bores drilled in these areas does not vary from previous findings. In particular the isochaline, isonitrate and iso-fluoride contours previously constructed by Verhoeven and Knott (1979) serve as a useful predictive tool and have been verified by these later analyses.
Three production bores (P5 and P7 at the extremes of the Kelly Well - Kelly Well West borefield, and RN 1736 in the Cabbage Gum borefield) were sampled for heavy metals and radiological analyses. Concentrations of Copper, Lead, Zinc, Manganese, Cadmium and Arsenic were well within desired criteria. The concentration of Radium 226 in each bore sampled was less than 0.04 Bq L\(^{-1}\), well within the desired current criteria.

### 4.2.3. Groundwater Movement

Bore water levels, monitored since the late 1960's have continued to be monitored since the 1977/78 investigation. The shape of the potentiometric surface as plotted for April 1981 (Figure 10) remains unaltered to that plotted by Verhoeven and Knott (1979), although water levels at bores have changed.

Briefly, groundwater inflow is south-east of Kelly Well, being recharged by the Kelly Well and Edinburgh Creek systems. The potentiometric gradient slopes north-west beneath Kelly Well and Kelly Well West, with a small groundwater input from Cabbage Gum. The flow is then north-west towards Tennant Creek West and does not contain a south-west component as previously hypothesised. The shape of the potentiometric surface in Tennant Creek West is controlled by the major north-north-west trending fracture zone which contains permeable aquifers within the Point Wakefield Beds.

In the Kelly Well - Kelly Well West areas bore water levels continued to rise during 1978, indicating additional surface water recharge and groundwater inflow (see figure 11). Levels peaked in early 1979, this representing a rise of six metres in some bores in the centre of the borefield. Levels remained constant in the first half of 1979 and have since started to fall because of increased pumping and a reduction of recharge. In the present borefields water levels are one to two metres below those measured in 1978, but still generally three metres above the pre-pumping levels measured in the late 1960's.

The shallow lake between Kelly Well West and Tennant Creek West identified as a window on the water table had by early 1980 dried by evaporation and by the regional lowering of the potentiometric surface (Verhoeven and Russell (1980)). The lake has since refilled following high rainfall events in January 1981 (Figure 10).

In Tennant Creek West groundwater levels generally have fallen since 1977, in some bores by up to one metre. This is attributed to high evapotranspiration and a reduction in the volume of surface recharge locally.

### 4.2.4. Underflow and Storage

(1) Tennant Creek West

Of the major aquifers in this area only that within the Point Wakefield Beds white sandstone member is a potential borefield source. Although the water from this aquifer is of marginal quality for human consumption it is suitable for agricultural and industrial uses and is of better quality than water from other aquifers in the area.

Underflow is calculated using equation (1) and the potentiometric surface for April 1981 (see Figure 10).
\[ Q = T \frac{A}{l} h \]  

where  
\( Q \) = underflow  
\( T \) = average aquifer transmissivity of 200 m\(^2\) d\(^{-1}\).  
\( h \) = height difference between four equipotential contours (6 m).  
\( l \) = distance between four equipotential contours (8000 m).  
\( w \) = aquifer width of 8000 m.

Then underflow is calculated to be 1200 m\(^3\) d\(^{-1}\) which is of the same order as that (1000 m\(^3\) d\(^{-1}\)) obtained by Verhoeven and Knott (1979).

The safe yield cannot be assessed because surface water level measurements are not available. The above calculated value of underflow provides a lower bound value of safe yield.

Storage which can be utilised is calculated for that portion of the Point Wakefield Beds which includes the white sandstone middle members and most of the upper and lower siltstone members. Reference to Figure 9 shows this area within the fracture zone; 8000 metres wide on lines 4 and 1, and approximately 5000 metres wide on lines 2 and 6. The average aquifer thickness of 50 m is saturated. A value for specific yield of 0.03 is assumed, this value having been derived for a similar aquifer in the Kelly Well area (Verhoeven and Knott (1979)). Storage is calculated using:

\[ \text{Storage} = A l s \]  

where  
\( A l \) = volume of aquifer (4 x 10\(^9\) m\(^3\)).  
\( s \) = specific yield (0.03)

Then storage is 1.2 x 10\(^8\) m\(^3\).

(2) Kelly Well - Kelly Well West

There is no additional information to suggest that the parameter values used by Verhoeven and Knott (1979) need be altered. Bore water levels rose to a peak in early 1979 as a result of continuing recharge. The volume of water then held in storage in Cainozoic and Cambrian sediments was estimated by Verhoeven and Russell (1980) to be 4.8 x 10\(^6\) m\(^3\).

Underflow for the Kelly Well area is 2000 m\(^3\) d\(^{-1}\) (Verhoeven and Knott (1979)). Combining this with the 500 m\(^3\) d\(^{-1}\) underflow for the Cabbage Gums area, (Eggington (1965), Sinch (1966)), the total underflow in the existing borefields is 2500 m\(^3\) d\(^{-1}\).
5.1 Tennant Creek Water Demand

Future water demand to 1999 was estimated by Verhoeven and Russell (1980):

(i) Average annual demand, used in the assessment of aquifer behaviour.

(ii) Peak daily demand, used to assess the number of production bores and the sizes of rising main and pumps required.

The average long term demand trend has been estimated to increase at eight percent per annum. This value, which includes both increasing per capita demand and increasing population, is based on:

(i) Three years of pumping statistics for Tennant Creek from 1977 to 1979, this period being uninfluenced by the effects of restrictions, large rainfall variations, or abattoir water demand.

(ii) A similar increasing consumption trend for Alice Springs in the same climatic region, and over a much longer time span.

Superimposed on this demand trend are:

(i) Abattoir water demand, which was estimated to be 140 thousand cubic metres in the year of its establishment (1979/80) and 280 thousand cubic metres annually thereafter (pers. com. Tennant Creek Area Manager).

(ii) Hobby farm water demand, which was estimated to be 52 thousand cubic metres in 1979/80 and 104 thousand cubic metres annually thereafter (pers. com. Tennant Creek Area Manager).

The summation of these additional demands is of the same order as that estimated by Verhoeven and Knott (1979).

The summation of predicted town demand, abattoir demand and hobby farm demand is plotted on Figure 12, and listed in Table 5. Examination of Figure 12 highlights a number of difficulties associated with demand prediction:

(i) Demand projections are invariably wrong as they cannot readily identify large climatic variations (such as those in the mid 1970's which reduced water demand), sociological changes (the 'green thumb revolution' resulting in higher demand for garden watering) or economic changes (establishment of a high water use industry such as an abattoir).

(ii) Demand projections are almost invariably low, as evidence by the projections of both Rose (1973) and Verhoeven and Russell (1980). The projection by Rose departs from actual extraction after 1978/79 as he did not allow for the establishment of an abattoir. That the projection of Verhoeven and Russell is lower than actual extraction after so short a period is cause for concern. For example in 1980/81 the major water use industry (abattoir) used only 150 thousand cubic metres instead of the 280 thousand cubic
metres projected. Yet total actual demand exceeded projected by 200 thousand cubic metres. The higher than predicted demand is attributed to increased usage by the Town Council and various Government Departments in a beautification program, below average rainfalls for 1979/80 and 1980/81, and increased usage by mining companies (pers. comm. Regional Engineer Water, Tennant Creek).

(iii) Demand projections, such as that of Rose, assume a steady state condition at some time in the future. However such a steady state is not discernable from actual extraction figures.

While in the short term demand exceeds that predicted by Verhoeven and Russell (1980), it is hypothesised that the introduction of management measures including water conservation (discussed in Chapter 6) will hold demand to that predicted.

Peak daily demand was predicted using the relationship:

$$ \text{Peak daily demand} = F \times St \times \text{Average daily demand} \hspace{1cm} (3) $$

where $F$ = Factor relating average daily demand in year 'n' to peak daily demand in year 'n'. The relationship, plotted in Figure 13, gave a value for $F$ of 2.3.

$St$ = Mechanical standby factor of 1.3 for bore or pump failure, and is equivalent to one third the average daily demand.

From the above, peak daily demand is three times the average daily demand. Predicted peak daily demand values to 1999 are listed in Table 5.

5.2 Development of Existing Water Sources

The existing water sources for Tennant Creek town water supply are all groundwater; borefields in the Cabbage Gum, Kelly Well and Kelly Well West areas. The annual safe yield of 1170 thousand cubic metres calculated by Verhoeven and Knott in 1979 is not altered. The safe yield is composed of groundwater inflow at Cabbage Gum and Kelly Well, and surface recharge. The annual demand already exceeds this safe yield (see Figure 12).

As the Kelly Well - Kelly Well West aquifers have the relatively high storage to annual underflow ratio of approximately 65, a percentage of this storage can be safely dewatered to meet short term and medium term demand before augmenting the source. A storage depletion value of 25% is adopted, on the basis of the following:

(i) This value allows for errors in the estimated storage and safe yield, with 75 per cent of the storage as reserve.

(ii) Extraction will be of better quality water in the centre of the aquifer; it is unlikely that poorer quality water at the aquifer margins will be pumped.

Verhoeven and Russell (1980) developed a simplified water balance model of the existing borefield at Kelly Well and Kelly Well West to assess the inter-relationship of recharge, storage and yield. This model is reported in Appendix 2. Predicted aquifer behaviour is plotted in Figure 15, and shows that with continually increasing extraction storage is depleted. Using the demand values developed in Section 5.1, the model predicts that the aquifer attains 25% storage depletion over a range of years depending on the amount of annual
precipitation (and hence recharge). This level of depletion will occur between 1986/87 and 1990/91 with the expected occurrence in 1988/89. Based on available information, after 1988/89 another water source will be required to augment the existing sources. However the results of a current recharge investigation and of improved management measures (discussed in Chapter 6) may delay this date further.

Total projected daily demand to 1998/99 is listed in Table 5. The average and peak demands on the Kelly Well and Kelly Well West borefields are obtained by subtracting the recommended annual and daily extraction rates for Cabbage Gum borefield from the total demand values.

The projected demands on the Kelly Well and Kelly Well West borefields, as well as the capacity of bores to supply those demands, are listed in Table 6. As peak demand often extends for a number of days and the borefields are used as large reservoirs, the number and capacity of production bores must be such as to meet peak demand including standby. However the capacity of the collector and rising mains need only be for peak demand.

Much of the upgrading of the existing sources at Kelly Well and Kelly Well West has been carried out. Prior to 1980 six production bores P1, P2, P4, P5, P6, and P7 provided a maximum 6048 m\(^3\) d\(^{-1}\) (70 Ls\(^{-1}\)). During 1980 bores P8 and P9 were test pumped and equipped to provide an additional 2160 m\(^3\) d\(^{-1}\) (25 Ls\(^{-1}\)) standby capacity as shown in Table 6. In 1980/81 six additional production bores were drilled, constructed and tested, the results being reported by Verhoeven (1981). These bores were sited to intersect the greatest possible thickness of sediments overlying granite basement. Aquifers were intersected in both the siltstone and sandstone members of the Point Wakefield Beds, confirming the findings of the 1979/80 field investigation. These latest production bores were sited to enlarge considerably the aquifer volume from which water is pumped (see Figure 2). The output of these bores is 7258 m\(^3\) d\(^{-1}\) (84 Ls\(^{-1}\)).

In the latter half of 1984 four older, shallow production bores in the Kelly Well area will need to be replaced with deeper, higher yielding bores. The total output of the Kelly Well and Kelly Well West borefields will thereafter need to be 17000 m\(^3\) d\(^{-1}\) or approximately 197 Ls\(^{-1}\) to meet the expected peak demand including standby in 1988/89 (see Table 6).

5.3 Development of Future Additional Water Sources

Based on available information and current projections for water demand, a supplementary water source will be required in 1989/90. This source was identified by Verhoeven and Knott (1979) as being groundwater from the Tennant Creek West area.

The area of this proposed borefield is outlined on Figure 16; it differs somewhat from the area outlined by Verhoeven and Knott in 1979. The majority of production bores should be sited to intersect the deepest sequence of aquifers within the Point Wakefield Beds siltstone and sandstone, that is in the down faulted area trending north-north-west. A smaller number of production bores should be sited on the more shallow margins to make full use of available storage and underflow. These production bores will need to be drilled with mud (to prevent hole collapse), logged with geophysical tools (to help identify the major water bearing zones), lined with stainless steel screens having small aperture size, and gravel packed.
Each production bore should be capable of yielding between ten and twenty litres per second, with pump settings of between thirty and forty metres. The spacing between production bores cannot yet be defined; this can only be established once long term pumping has commenced. However, based on experience of similar aquifers in the existing borefields, an initial spacing of one kilometre should be considered.

The water from this potential borefield has a chemical quality marginally suitable to unsuitable for human consumption, specifically with high nitrate and fluoride concentrations. However treatment will not be required if this water is blended with that from the existing borefields.

There is insufficient information to establish the safe yield of this potential borefield. The value of underflow (1200 m$^3$d$^{-1}$) is considered a lower bound estimate. As with the question of spacing, safe yield can only be assessed once the behaviour of the aquifer under stress has been monitored; that is after long term pumping has commenced. Continued water level monitoring and computer simulation (discussed in Chapter 6) should provide a better estimate of safe yield before the borefield is established.

Beyond Tennant Creek West, additional potential sources include:

(i) Possible groundwater beneath the floodout of the Edinburgh Creeks systems centred 45km south of Tennant Creek.

(ii) Surface water storage on Gibson, Hayward and Attack Creeks, 50km to 70km north of Tennant Creek.
CHAPTER 6  FURTHER INVESTIGATION AND MANAGEMENT

6.1 Further Investigation

Much of the investigation work recommended by Verhoeven and Knott (1979) has been carried out, and is reported in this document. The infiltration and recharge study in the existing borefields forms a separate Water Division project; Project 11 entitled KELLY WELL INFILTRATION STUDY. At the time of writing, the field investigation had been carried out and assessment commenced. The report on that study is due for completion in mid 1982.

These studies complete the surface water and groundwater investigations for the existing borefields, and for the proposed borefield at Tennant Creek West. The results of these investigations provide input into the next important stage, that of management of the resource.

6.2 Resource Management

Management of the water resources takes two forms; direct management of daily extraction from the borefields, and broader management measures including the Control of Waters Act, monitoring, aquifer simulation and water conservation.

6.2.1 Extraction from existing borefields

Management of extraction, which has been detailed by Verhoeven (1981), is summarised:

(i) Pumping from the three low yielding Cabbage Gum production bores (CG2, CG9 and CG10) should be continued. The combined maximum recommended yield is 6 Ls⁻¹ continuously.

(ii) The Kelly Well - Kelly Well West Production Bore 1, 2, 4, 5, 6, 7, 10, 11, 12, 13, 14 and 15 should be pumped in rotation to distribute extraction throughout the aquifer. The combined yield of these bores is 154 Ls⁻¹.

(iii) Production bores 8 and 9 should be maintained for mechanical standby. They should not normally be pumped because of their proximity to other bores.

(iv) Production Bore 3 has been decommissioned.

The daily management should be carried out under the supervision of the Regional Engineer Water, Tennant Creek, who is also responsible for other aspects of water supply.

6.2.2 Control of Waters Act

As Tennant Creek obtains its present and proposed additional water supplies from groundwater sources, it is important that the development of the aquifers be controlled to protect consumers. One important management tool is provided under the Control of Waters Act; the protection of groundwater resources with a declared Water Control District.

In the Tennant Creek environs two water control districts are current, protecting groundwater resources in different parts of the Wiso Basin (see Figure 17):
(i) Kelly Water Control District covering the area of the Cabbage Gum, Kelly Well and Kelly Well West borefields.

(ii) Warrego Water Control District covering the area from which Peko Mines N.L. obtain their bore water supply, approximately 30km west of Warrego Mine. This water control district was declared to protect the aquifer and to give Peko some assurance that their large investment in the water supply was protected.

In both water control districts it has been necessary to prohibit, except in accordance with a permit, the sinking or construction or use of a well or bore. This allows the Minister to control the construction of further bores within the area and the rate of extraction from bores.

With increasing town water demand, the next borefield will be established at Tennant Creek West, with possible future borefields in smaller basins underlying the floodouts of Edinburgh Creek and Gilbert Creek. These areas lie outside the management control of existing water control districts.

There is a recognised need to extend the area of protection provided by the water control districts.

(i) The growing interest in the use of water for horticulture. While such interest should not be discouraged management is necessary to ensure that the future security of the town water supply is not threatened. Such management is also in the interests of any horticultural development itself, in that a situation where the resources from any given area are depleted must be avoided.

(ii) Because aquifers in all the above discussed areas are at relatively shallow depth, the groundwater resources are at a potential risk of pollution, particularly if industrial development or mineral exploration were to take place over the area of the proposed borefields.

It has been strongly recommended that the water control districts be expanded to cover the area outlined in Figure 17 (Verhoeven 1980a). The western half of this proposed water control district would cover that part of the Wiso Basin from which water is extracted for the Warrego borefield, and the proposed Tennant Creek West borefield. The eastern half would cover the existing borefields and a number of other small groundwater basins which may be utilised as future borefields.

To carry out this recommendation it is necessary to simultaneously:

(i) abolish the existing Kelly Water Control District and Warrego Water Control District; and,

(ii) declare the Tennant Creek Water Control District, to cover the areas of existing and future borefields.

The objective is to protect both the resource (in respect of water quality and quantity) and the consumers. It is not intended that any existing consumers would have their operations curtailed; bona fide consumers should be allowed to continue as at present, with the main interest being directed towards proposed new developments.
6.2.3 Monitoring

An important component of management is monitoring; to provide information on recharge events, to provide feedback on the effects of pumping, and to provide data as input to the aquifer simulation (see Section 6.2.4). Monitoring has been conducted since pumping commenced and these notes serve to update elements of the monitoring network.

(1) Groundwater extraction

Water Division staff of the Tennant Creek Area Office record daily extraction for each production bore and pumping figures for the Cabbage Gum pumping station. This data is sent to the Water Management Engineer of Water Division, Alice Springs for assessment.

(2) Water quality

Production bores are sampled regularly for water chemistry and bacteriological analyses. The work is carried out by Water Division staff based in Tennant Creek.

(3) Hydrographic data

Streamflow in the main channel of Kelly Creek (upstream of the borefields) has since been recorded at gauging station G.S. 029 012 since July 1974. The station is maintained by Hydrographic staff of Water Division based in Alice Springs. Daily rainfall data for Tennant Creek is available from the Bureau of Meteorology.

(4) Groundwater levels

Bore water levels are monitored at intervals of six weeks by Water Management staff of Water Division Alice Springs. Both locations are plotted on Figure 18.

Bores in the Cabbage Gum area in the monitoring program include RN 5239, RN 5248, RN 5253, RN 5278, RN 5279 and RN 5287.

Bores in the Kelly Well and Kelly Well West areas in the monitoring program include RN 5338, RN 6355, RN 6360, RN 10161, RN 10165, RN 10167, RN 10564, RN 10761, RN 10763, RN 12144, RN 12145, RN 12147, RN 12598, RN 12599, RN 12600 and RN 12611. Bores RN 10167 and RN 10564 are equipped with continuous water level recorders. Bore RN 10761 is also equipped with a recorder, but it is recommended that this recorder be moved to a new bore to be drilled one kilometre to the south-east in the major aquifers.

Bores in the Tennant Creek West area in the monitoring program include: RN 1408, RN 10926, RN 10927, RN 10928, RN 11559, RN 11597, RN 11598, RN 11599, RN 11600, RN 11601, RN 11602, RN 11603, RN 11606, RN 11607, RN 11608, RN 11609, RN 11626, RN 11637, RN 11638, RN 11639, RN 11640, RN 11641, RN 11683, RN 11688, RN 11689, RN 11691, RN 11744, RN 12128, RN 12129, RN 12130, RN 12132, RN 12134, RN 12137, RN 12138, RN 12139, RN 12142, RN 12143. In addition the water level on the lake should be measured and reduced to A.H.D. Bore RN 11626 should be equipped with a continuous water level recorder to monitor recharge events within the floodout.

6.2.4 Aquifer simulation

During the course of this study a number of problems associated with describing and predicting aquifer behaviour have been identified. These problems have
arisen as a result of the constraint to use simplified models; one-dimensional, lumped, arithmetic models have been used to assess recharge, safe yield and storage in the various borefields. Before the water resources can be effectively managed the following need to be resolved:

(i) Prediction of long term drawdown trends due to groundwater extraction from the borefields for a variety of water demand and recharge patterns. To date only the effect on storage has been examined.

(ii) Safe yield of the existing borefields, including components of underflow, recharge and storage. To date only underflow and recharge have been included.

(iii) Assessment of the above for the proposed Tennant Creek West borefield.

Aquifer modelling is complicated by varying recharge, non steady state groundwater extraction, and the vast amount of information available; geological data, aquifer characteristics, groundwater extraction records since the commencement of pumping, regularly recorded water levels, water chemistry data, rainfall and stream flow records. Aquifers in the Cambrian siltstone and sandstone can be approximated by a semi-confined aquifer with leakage from overlying Cainozoic sediments. This system can best be modelled numerically using a digital computer. A number of suitable aquifer simulation programs are available and one of these, by Prickett and Lonnquist (1971), is held by Water Division. It is recommended that aquifer simulation be conducted.

Modelling can be conducted using one of at least two alternatives:

(i) A rainfall-recharge model and one groundwater model including the existing borefields and the proposed Tennant Creek West borefields; or,

(ii) A rainfall-recharge model and four groundwater models, one for each of the Kelly Well, Kelly Well West, Cabbage Gum and Tennant Creek West borefields. Groundwater outflow from the Cabbage Gum and Kelly Well borefields would comprise the inflow to the Kelly Well West borefield.

The second alternative is favoured as it is more economical with computer storage and allows for separate calibration and verification of each component.

The objectives of the simulation are categorised into three divisions: descriptive, predictive and prescriptive.

(i) Descriptive - establish, calibrate and verify the models from pre-pumping to the present.
- describe or interpolate aquifer characteristics in areas where drilling has not been conducted.
- describe recharge mechanisms and calculate annual recharge volumes.
- conduct sensitivity analyses to determine the simplest model(s) which will adequately describe the systems.

(ii) Predictive - generate various recharge and pumping sequences to predict a range of drawdown trends to 2001.
- evaluate safe yield based on the above.

(iii) Prescriptive- prescribe where replacement bores are to be sited in the Kelly Well borefield in 1984.
- prescribe when pumping from the proposed Tennant Creek West borefield should be commenced to satisfy hydrological constraints for various cases of recharge and pumping.

The models, once completed, should be retained so that new situations can be readily modelled should they arise. Dynamic management requires further verification and modelling as time progresses and input variables change.

6.2.5 Water conservation

Over the past decade total annual water consumption has more than trebled, to a figure of 1.58 million cubic metres in 1980/81 (see Figure 12). Peak daily volumes have also dramatically increased (6369 cubic metres during 1980/81) placing a stain on the ability of the supply system to meet demand. The demand growth rate of approximately 12 per cent per annum is high, being composed of both increasing per capita consumption and population growth. If the high demand growth rate can be moderated to half that being experienced then considerable cost savings, both capital and operating, can be made.

While population growth is difficult to control, measures can be introduced as part of a management program to moderate per capita consumption. It is recommended that a local water conservation committee be established with the Tennant Creek Area Manager as chairman. The committee would need to:

(i) Recognise the need for water conservation as a component of water resources management, and recognise the importance of local participation.

(ii) Identify losses in the water supply system and act to contain the losses.

(iii) Identify areas of wastage by consumers.

(iv) Examine all mechanisms available to moderate consumption, including both enforced and voluntary.

Consumption moderating mechanisms have been reported on by Verhoeven (1980b) and are outlined below. Consumption restraint can be enforced by methods such as the imposition of general restrictions, specific restrictions (such as garden watering only during the cooler evening hours), or the inclusion of flow restrictors in household pipes leading from the meter. The committee would need to assess the acceptability of these measures.

Voluntary measures include the application of:

(i) Direct pricing mechanism. Economic theory and empirical studies such as those conducted in Perth suggest that pay-as-you-use marginal cost marketing systems for water may be effective in moderating consumption. However the direct pricing mechanism is not available to the Department in the short term, in the light of current political commitments.
(ii) Incentives. The effectiveness of incentives is now being studied both interstate and overseas.

(iii) Non price mechanisms. As probably half of the water demand is used on lawns and gardens, a social question needs to be answered. A decision to encourage water saving provokes questions about the value of gardens, the assessment of that value, and the comparison with alternative recreational resources. Discussion at the 1975 Perth Hydrology Symposium concluded that if water saving procedures are to be encouraged by non price mechanisms then the campaign should be aimed at selective areas. Publicity programs should concentrate on changing specific attitudes towards water consuming behaviour rather than emphasising general water issues. Such a campaign would require the services of a professional marketing consultant.

Should the committee make the decision to embark on a water conservation campaign, then feedback on the degree of success and reinforcement by annual repetition will be important on-going elements of this management option.
CHAPTER 7 REFERENCES

BINCHE, I.R. (1966)

BRAYBROOK, D.J. (1980)

DEPARTMENT OF HEALTH, NATIONAL HEALTH AND MEDICAL RESEARCH COUNCIL, AND AUSTRALIAN WATER RESOURCES COUNCIL (1980)
Desirable quality for Drinking Water in Australia.

EGGINGTON, H.F. (1965)

JOLLY, P.B. (1979)
Minute from Engineer Water Management to Senior Engineer Water Investigations, Water Division Alice Springs Internal File.

Project 91. Tennant Creek West Groundwater Geological Report Northern Territory of Australia, Department of Transport and Works, Water Division File Report, Alice Springs September 1980 (unpub.)

PRICKETT, T.A. & LONNQUIST, C.G. (1971)

ROSE, H.J. (1973)

VERHOEVEN, T.J. & KNOTT, G.G. (1979)

Northern Territory of Australia, Department of Transport and Works, Water Division, Alice Springs. (unpub.)

VERHOEVEN, T.J. (1980a)

Minute from Senior Engineer Water Investigations to Projects Officer Policy and Legislation. Water Division Alice Springs Internal File.

VERHOEVEN, T.J. (1980b)

Minute from Senior Engineer Water Investigations to Director Water Division. Water Division Alice Springs Internal File.

VERHOEVEN, T.J. (1981)

Northern Territory of Australia Department of Transport and Works Water Division Technical Report (unpub.)
APPENDIX 1 TABLES
LIST OF GEOLOGICAL SYMBOLS USED: TABLES 1, 2 AND 3

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<th>Symbol</th>
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Additional demand met from supplementary source.
APPENDIX 2 KELLY WELL - KELLY WELL WEST ANNUAL WATER BALANCE
APPENDIX 2 KELLY WELL - KELLY WELL WEST ANNUAL WATER BALANCE

Verhoeven and Russell (1980) developed a simplified water balance model of the existing bore fields at Kelly Well and Kelly Well West to assess the inter-relationship of recharge, storage and yield.

The water balance can be expressed volumetrically as:

\[ P_n - EX_n + (Ig - Og)_n + SR_n - ET_n = V_n - V_{n-1} \]  \hspace{1cm} \text{(A1)}

where \( P_n \): precipitation infiltrating directly on the borefield in year \( n \) (considered negligible as much of it is subsequently evaporated).

\( EX_n \): extraction (pumping) from the borefield in year \( n \).

\( (Ig-Og)_n \): difference between groundwater inflow and outflow in year \( n \).

To date this difference has been observed to be negligible. Assume that for storage depletion of less than 25% inflow equals outflow.

\( SR_n \): surface water recharge in year \( n \) from Kelly Creek, Edinburgh Creek and their floodouts. It is function of precipitation in year \( n \) and in previous years, that is

\[ SR_n = f(P_n, P_{n-1}, \ldots) \]  \hspace{1cm} \text{(A2)}

\( ET_n \): evapotranspiration in year \( n \), considered negligible as the aquifer is relatively deep and there are few deep rooted trees.

\( V_n - V_{n-1} \): volume of groundwater in storage at the end of year \( n \) less the volume of groundwater in storage at the end of the previous year. It is the change in volume of groundwater storage in year \( n \), and can be expressed as:

\[ V_n - V_{n-1} = \Delta V_n \]  \hspace{1cm} \text{(A3)}

Equation (A1) then simplifies to

\[ SR_n - EX_n = V_n - V_{n-1} \]  \hspace{1cm} \text{(A4)}

Substituting equations (A2) and (A3) in equation (A4), and rearranging results in:

\[ f(P_n, P_{n-1}, \ldots) - EX_n - \Delta V_n = 0 \]  \hspace{1cm} \text{(A5)}

A number of annual rainfall - recharge relationships were examined to evaluate the form of the function in the first term of equation (A5). While the establishment of a detailed rainfall - recharge model falls within the objectives of Water Division Investigations Project 11 (Kelly Well Infiltration Study), a more realistic model than the simple linear relationship used by Verhoeven and Knott (1979) was required.

Rainfall - recharge relationships examined include:

- linear - linear
- log - linear
- log - log (annual rainfall)
- log - log (two year moving average rainfall)
- log - log (three year moving average rainfall)
The simplest relationship having a reasonable straight line fit was the log-log (two year moving average rainfall). This relationship has physical justification, as examination of rainfall and bore water levels shows that recharge is influenced by antecedent rainfall. When fitted to 10 years of data (1968/69 to 1977/78) by least squares regression the relationship is defined by.

\[
\log (SR_n) = 3.04 \left( \log \left( \frac{P_n + P_{n-1}}{2} \right) \right) - 5.18 \quad \ldots \ldots \ldots \ldots (A6)
\]

Rearranging equation (A6) and substituting into equation (A5) gives the final water balance equation:

\[
10 \left( 3.04 \left( \log \left( \frac{P_n + P_{n-1}}{2} \right) \right) - 5.18 \right) - EX_n - \Delta V_n = 0 \quad \ldots \ldots \ldots \ldots (A7)
\]

where each term or function has units of thousand cubic metres (megalitres) and precipitation P is in millimetres.

**Historic and modelled aquifer behaviour** for the 10 years (to 1977/78) used to calibrate the model and following two years used to verify the model are plotted in Figure 14. The model adequately represents the aquifer system in the following instances:

(i) small annual changes in volume are modelled well.

(ii) the direction of volume change is anticipated by the model.

Large volume changes are poorly modelled, the difference between historic and modelled volumes is as much as 8%. Such differences can be expected for large changes in variables while such a simplified model is used. Improved aquifer simulation can only be obtained by using a more complex model and computer simulation techniques.

The model was used to predict storage behaviour for the twenty years from 1979/80 to 1998/99. Estimation of total demand is outlined in Section 5.1. It is assumed that the annual underflow of 183 thousand cubic metres in the Cabbage Gum borefield will be fully utilised. The predicted annual extractions from the Kelly Well-Kelly Well West borefields (EX in equation (A7)) are thus given by total demand (Table 5) minus 183 thousand cubic metres.

From the 106 years of recorded rainfall a number of twenty year sequences were selected for use in the predictive stage of the model. Rainfall sequences included:

(i) Twenty years of the lower ten percentile rainfall value (210mm).

(ii) The period 1960 to 1979 which includes a period of drought followed by years with the highest rainfall on record.

(iii) Twenty years of the mean rainfall value (370mm).

(iv) The period 1921 to 1940.

(v) The period 1881 to 1900.
Predicted aquifer behaviour is plotted on Figure 15. With continually increasing extraction storage is gradually depleted. However, as no allowance has been made for reduced demand in years of high rainfall or for increased recharge by artificial means, the model results are conservative. As expected the aquifer reaches a certain level of depletion over a range of years depending on the rainfall (and hence recharge) sequence. For example Figure 15 shows that ten percent storage depletion will occur between 1982/83 and 1984/85, and twenty five percent storage depletion will occur between 1986/87 and 1990/91.
APPENDIX 3 FIGURES
LEGEND
- Bore drilled prior to 1979-80 investigation
- Production bores drilled in 1980-1981 with Production Number.
- Other production bores with Production Number.

SCOPE OF 1979-1980 INVESTIGATION

HORIZONTAL DATUM: AUSTRALIAN MAP GRID

FIG. 2
C. Cainozoic sand and clay

Cmp4. Point Wakefield Beds — upper siltstone

Cmp2. white sandstone

Cmp1. lower siltstone

Emh. Hooker Creek Formation — dolomitic sandstone

Emm. Montjinni Limestone — dolomite

P. Red sandstone unit

Pg. Lower Proterozoic Granite

A. Archaean schist

Basement profile extrapolated from geophysical data.

Horizontal Scale: 1:100 000
Vertical Scale: 1:2 000
Vertical Exaggeration: 50:1
Vertical Datum: A.H.D.

TENNANT CREEK WEST
REVISED GEOLOGICAL CROSS SECTION
LINE 1

FIG. 3
Basement profile extrapolated from geophysical data.

C  Cainozoic sand and clay

Emp₂  Point Wakefield Beds — upper siltstone
Emp₁  — white sandstone
Emp₀  — lower siltstone

Pg  Lower Proterozoic granite

Horizontal Scale: 1:100,000
Vertical Scale: 1:2,000
Vertical Exaggeration: 50:1
Vertical Datum: A.H.D.
C... Cenozoic sand and gravel
\Ep4 Point Wakefield Beds - upper siltstone
\Ep3 Point Wakefield Beds - white sandstone
\Ep2 Point Wakefield Beds - lower siltstone
\Pg Lower Proterozoic granite
A Archaean schist
C  Cainozoic sand and gravel

empl Point Wakefield Beds  upper siltstone
empl white sandstone
empl lower siltstone

Pg  Lower Proterozoic granite

A  Archaean schist

Basement profile extrapolated from geophysical data.

Horizontal Scale: 1:100 000
Vertical Scale: 1:2 000
Vertical Exaggeration: 50:1
Vertical Datum: A.H.D.
NW

R.L.(m) 300

SE

R.L.(m) 300

C Cainozoic sand and clay

omp Point Wakefield Beds — lower siltstone

hm Hooker Creek Formation — dolomite siltstone

mm Montejinni Limestone — dolomite

Red sandstone unit

P Lower Proterozoic granite

Basement profile extrapolated from geophysical data.

Horizontal Scale: 1:100,000
Vertical Scale: 1:2,000
Vertical Exaggeration: 50:1
Vertical Datum: A.H.D.
LEGEND

Pw  Warramunga Group sediments
Pg  Granite - gneisses
A  Schists
F  Major fracture zone

Contour interval 10m from RL 260m to RL 310m
20m below RL 260m
Contours reduced to A.H.O.

REVISED BEDROCK CONTOURS AND TYPE

FIG. 9
FIG. 11

TENNANT CREEK
MONTHLY RAINFALLS
IN THE PRESENT
BOREFIELDS
1968-1981

PERIOD OF RAINFALL RECORD AT TENNANT CREEK POST OFFICE (015007)

BoRE WATER LEVELS
IN THE PRESENT
BOREFIELDS
1968-1981
TENANT CREEK WATER SUPPLY.
ANNUAL EXTRACTION, PROJECTED WATER DEMAND AND SAFE YIELD

FIG. 12
Points plotted using Peak Daily = 0.20 x Total Peak weekly (due to incomplete records.)

Peak = 2.3 x Average (from graph)
Including 33% standby.
Then Peak requirement = 3.0 x Average.

FIG. 13
HISTORIC AND MODELLED AQUIFER STORAGE VOLUMES IN THE KELLY WELL AND KELLY WEST BOREFIELDS

DEPARTMENT OF TRANSPORT AND WORKS
WATER DIVISION

FIG. 14

END OF WATER YEAR
NB  Prepared using a 2 year moving average model of rainfall-recharge relation. (refer to Appendix 2)

FIG. 15

PROJECTED PERCENTAGE STORAGE DEPLETION IN KELLY WELL AND KELLY WELL WEST BOREFIELDS

NUMER OF YEARS


PERCENTAGE STORAGE DEPLETION
Greater concentration of production bores on this area. Contains the deeper sequence of aquifers.

Lesser concentration of production bores in this area, to fully utilise aquifer storage.

AREA OF PROPOSED BOREFIELD
TENNANT CREEK WEST

FIG. 16
LEGEND

- 10906 Observation bore and RN
- 10926 Observation bore with continuous water level recorder.

BORES IN MONITORING NETWORK

FIG. 18