POWER AND WATER AUTHORITY
WATER RESOURCES DIVISION

WATER RESOURCES SURVEY OF THE
WESTERN VICTORIA RIVER DISTRICT

SPIRIT HILLS STATION

REPORT 32/1995D
S. J. Tickell and L. R. Rajaratnam
Darwin
June 1995

WATER RESOURCES SURVEY OF SPIRIT HILLS STATION NORTHERN TERRITORY

List of Abbreviations

List of Conversions

SUMMARY

1. INTRODUCTION

2. WATER SUPPLY DEVELOPMENT

3. GROUNDWATER

3.1 Areas with yields 0 to 0.5 L/s (brown zone).
3.2 Areas with yields 0.5 to 5.0 L/s (blue zone).
3.3 Areas with yields more than 5 L/s (yellow zone).

4. SURFACE WATER

4.1 Surface Water Storage Types
4.2 Selection of Sites for Excavated tanks
4.3 Design and Construction of Excavated tanks
4.4 Waterholes and Springs
4.5 Piping of Surface Water
4.6 Supply of Stock Water from Tanks

5.RECOMMENDATIONS

6.ACKNOWLEDGMENTS

APPENDICES

Appendix 1: Station bores
Appendix 2: Chemical analyses of groundwaters
Appendix 3: Water quality requirements for stock and domestic water
Appendix 4: Pumping test results
Appendix 5: Surface water storages on Spirit Hills
Appendix 6: Site investigations
Appendix 7: Construction details of excavated tanks, turkey nests and modified waterholes
Appendix 8: Glossary

TABLES

1. Climatic data for Spirit Hills station

FIGURES

1. Locality diagram
2. Landform map of Spirit Hills station
3. Typical offstream excavated tank
4. Typical drainage-line excavated tank
5. Sketch showing improved size of grazing area due to piping away from a reliable bore or tank
6. Test hole plan for an excavated tank

MAPS

1. Water Resources Development Map of Spirit Hills Station, including side maps showing Groundwater and Surfacewater Resources

LIST OF ABBREVIATIONS

km	-	kilometre
L/s	-	litres per second
m	-	metre
m^3	-	cubic metre
mg/L	-	milligrams per litre
ML	-	megalitre (one million litres)
mm	-	millimetre
μS/cm	-	microsiemens per centimetre
pH	-	acidity and alkalinity index
TDS	-	total dissolved solids

LIST OF CONVERSIONS

1 mm (millimetre)	=	.04 inches (4 points)
1 m (metre)	=	3.3 feet
1 km (kilometre)	=	0.6 miles
1 L (litre)	=	0.22 gallons
1 ML (megalitre)	=	220,000 gallons
1 L/s (litre per second)	=	800 gallons per hour

SUMMARY

The accompanying Water Resources Development Map can be used as a guide to determine the type of water supply most appropriate to specific areas of the station. On the black soil plains (the main grazing area) the best options for future water supply developments are considered to be either bores or excavated tanks, sited to capture wet season sheet floods. In areas of the plains underlain by shale groundwater supplies are not available.
The reliability of existing waterholes can be improved in some cases by deepening where appropriate. All existing and planned surface water storages including excavated tanks, waterholes and springs should be fenced and stock watering infrastructure provided.

The distribution of watering points on Spirit Hills could be improved in order to spread grazing pressure more evenly. Some sections of the station, especially those in southwestern areas and those between Kneebone Yard and Brown Duck Waterhole could benefit from additional watering points.

1. INTRODUCTION

This project was initiated by the Victoria River District Conservation Association (VRDCA) and it's aim is to provide station managers with up to date information on water resources , so that they can make more informed decisions about water and land management. It is funded by the Northern Territory Government and the National Landcare Program with a contribution by the VRDCA. A total of 20 properties will be studied between July 1993 and June 1998.

Spirit Hill station covers an area of 2498 square kilometres and is located on the Western Australian border adjacent to the Keep River and extending east to the Victoria River. It is bordered to the north by Legune station, to the east by Bullo River station and to the south by Newry station and the Keep River National Park. Road access is only possible through Western Australia via Kununurra (figure 1).

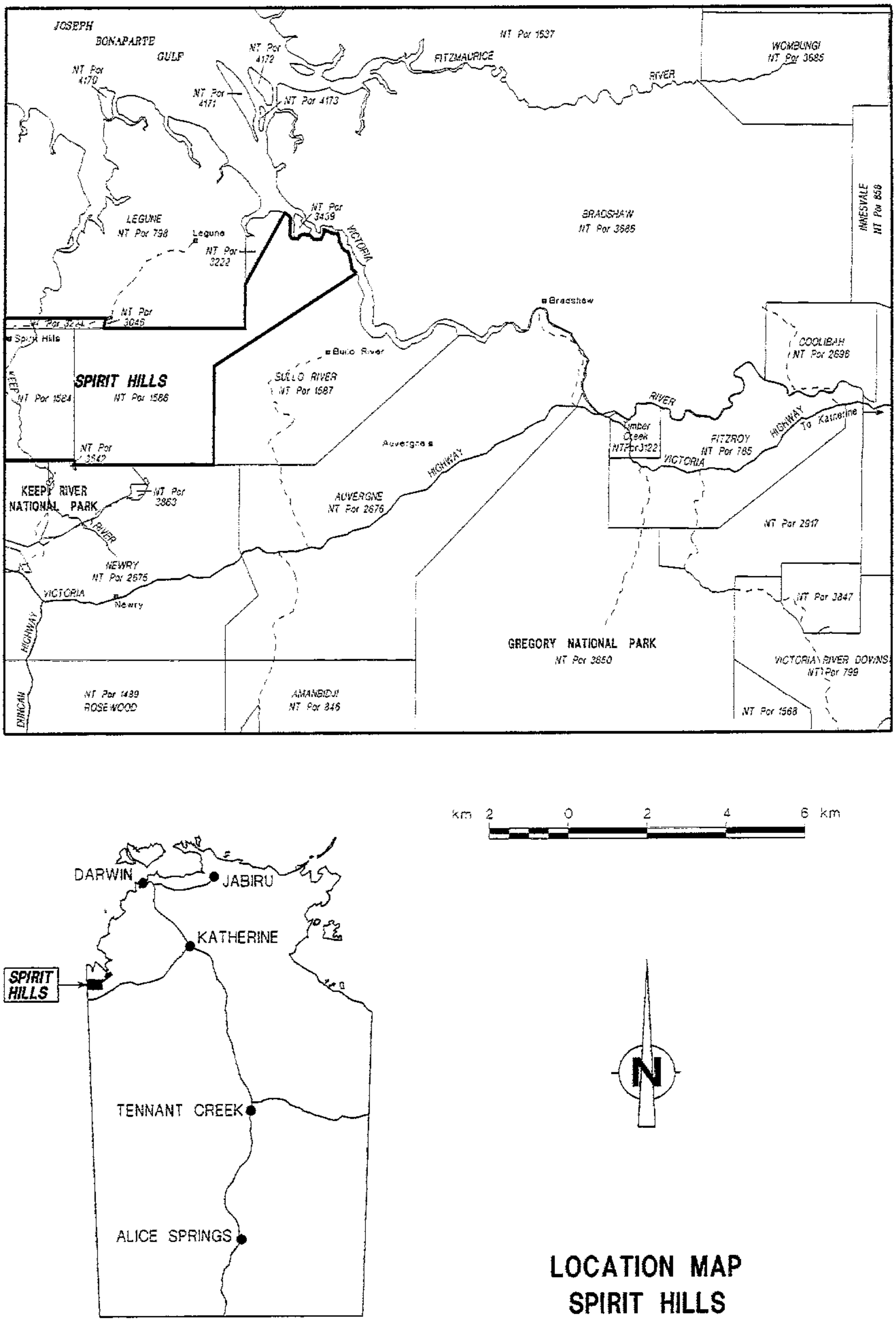
The availability of stock water is the major influence on stock management since virtually all of the annual rainfall, which averages 857mm, occurs in the short hot monsoonal wet season between December and March (Table 1). For the remainder of the year temperatures are warm and very little rainfall is experienced. During the Wet, when the Keep River and Sandy Creek flow, low lying areas are inundated by water. Recharge to groundwater aquifers occurs at this time. During the Dry evaporation rates of between 5 mm and 9 mm (average about 7 mm) per day (2.6 m per year) ensure that water levels in creeks, waterholes, and shallow bores decline rapidly. Air temperatures are high throughout the year. The mean monthly maxima range from about 30.1 in July to 38.7 degrees in November. The corresponding mean monthly minima are 14.4 to 24.7 degrees.

Current stock management is based on water availability. At present the station carries about 4,500 head of cattle. During the Wet and the early Dry, surfacewater is extensively used, but as the Dry progresses, these sources become depleted and more reliance is placed on groundwater. Six bores are used, normally in conjunction with metal tanks which act as temporary storages. Some surface water storages do not last until the end of the Dry. Milligans Lagoon however is successfully exploited throughout the year. There are no artificially built surface water storages such as excavated tanks or gully dams on the station.

The station can be classed into three broad landform types; rugged hills and ranges, laterite plains and low hills, and alluvial plains (figure 2). No pastoral development is carried out in the ranges due to the rugged terrain.

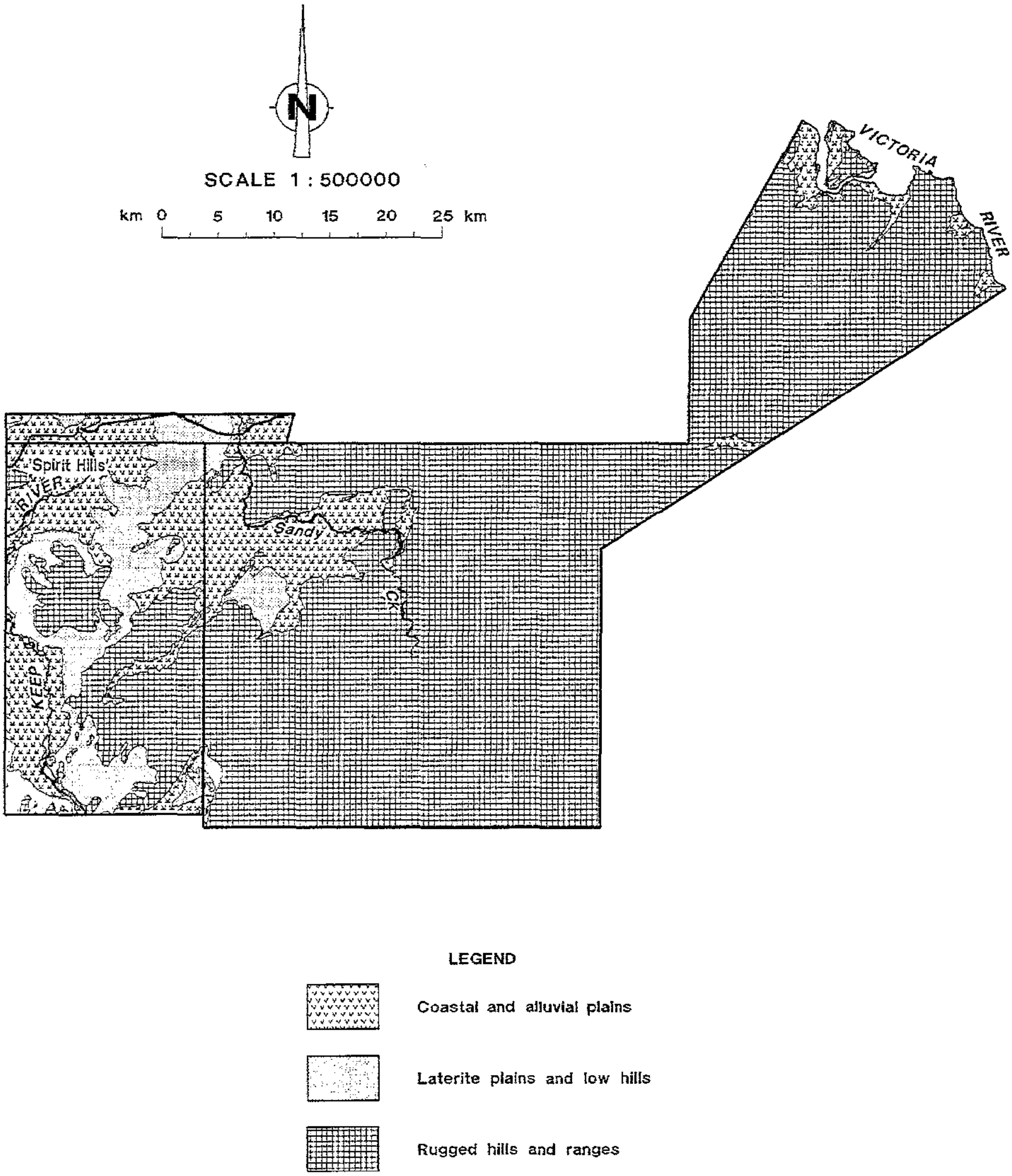
The ranges cover the eastern two thirds of the station where they rise abruptly out of the plains to a maximum elevation of approximately 380 metres above sea level. They are steep and rocky, supporting low open woodland and sparse grassland. Numerous short streams dissect the ranges, with many deep valleys, gorges and waterholes. Soils are thin and stony.

The laterite plains and low hills flank the Keep River plains . They are mainly formed on flat lying strata of soft sandstone. A laterite (ironstone) cap is developed but minor stream erosion has partially removed it, resulting in undulating topography in many areas. The plain lies at elevations of between 20 and 40 metres above sea level ,with isolated hills rising 40 metres or more above the plain. The area supports woodland vegetation. Drainage on the laterite plain is often poorly developed, probably due to the permeable nature of the soils and the underlying sandstone. Deep sandy soils predominate with minor clayey lateritic profiles present in places.



LOCATION MAP
SPIRIT HILLS

Fig. 1



LANDFORM MAP OF SPIRITS HILLS STATION

Figure 2

The alluvial plains flank the Keep River and the Sandy Creek. Apart from a few isolated low hills such as the one behind the homestead, they are flat and featureless, varying in elevation from 15 metres in the north to 36 metres above sea level in the south. The plains are covered in grasslands with patches of low woodland and shrubland. Soils on the Keep River plain are black cracking clays while on the Sandy Creek they also include sandier types. Drainage on the plains is relatively poor , much of it being subject to sheet flooding during the wet season. The Keep River is deeply incised into the plains , particularly in it's lower reaches. The tidal limit of the river is located immediately downstream of the station.

TABLE 1

CLIMATIC AVERAGES - SPIRIT HILLS STATION

	RAINFALL (mm)	RAIN DAYS	DAILY MINIMUM TEMPERATURE (°C)	DAILY MAXIMUM TEMPERATURE (°C)
JANUARY	239	13	24.8	36.1
FEBRUARY	188	12	24.6	34.8
MARCH	136	9	23.7	34.9
APRIL ·	23	2	20.7	35.1
MAY	8	1	18.5	32.8
JUNE	4	0	15.6	30.4
JULY	3	0	14.4	30.1
AUGUST	0	0	16.5	33.3
SEPTEMBER	2	0	19.9	36.1
OCTOBER	18	3	23	38.2
NOVEMBER	96	6	24.7	38.7
DECEMBER	140	9	25	37.8
TOTAL	857	55		

NOTE: *: Temperatures noted are from Kimberly Research Station, Kununurra.

2. WATER SUPPLY DEVELOPMENT

An attempt has been made to classify the station according to the type of water resource developments considered most appropriate for particular areas. The results are shown on the accompanying **Water Resources Development Map** of Spirit Hills station. The map was made by combining information on existing developments (waterholes, bores etc.) with information on groundwater occurrence, topography and soil types. Local conditions, such as soil types can vary considerably, so the map should not be taken as a definitive guide to cover every situation. Rather it is a broad scale map which is intended to give an overall picture of possible development options. Detailed on-ground investigations are recommended when considering specific developments.

For an explanation of the colours on the map refer to the legend entitled "Water Resources Development Options". The various "preferred options" listed there fall into four types:

- -areas which are unsuitable for artificial water supplies such as surface water storages or bores (options 1 and 2).
- -areas in which surface water storages are the best option (options 3 and 4).
- -areas in which groundwater is the best option (option 5).
- -areas in which surfacewater and groundwater may both be viable options (options 6 and 7).

Some of the main features of the map are:

- -the areas used most for grazing, the black soil plains, are generally suitable for the development of either groundwater or surfacewater supplies. Areas of the plains underlain by shale are unlikely to yield sufficient quantities of groundwater.
- -large areas of the station are unsuitable for water supply developments due to rugged terrain.

3. GROUNDWATER

Groundwater conditions across the station have been assessed using geological information, satellite images, aerial photos and information from existing boreholes. The results are presented as the "Groundwater Resources Map", one of the two small side maps on the accompanying map of Spirit Hill station.

Technical information on water bores is shown in Appendix 1. More detailed information on individual bores is held on the Water Resources Division's files and is available on request. Chemical analyses of groundwaters and recommended limits for common uses are listed in Appendix 2 and 3, while the results of the pump testing program are presented in Appendix 4 .

Stock water is presently obtained from six bores on Spirit Hill. Only a three bores drilled on the station RN 7865, 29657 and 29661 have been unsuccessful due to insufficient supply.

Rock type is the main factor which determines groundwater availability and the three yield zones shown on the map (0 to 0.5, 0.5 to 5 and more than 5 Litres per second) reflect different rock formations. Groundwater is stored in and moves through minute spaces in rocks caused by fractures (cracks), the spaces between sand grains or spaces where minerals have been dissolved away. If economically viable quantities of water can be extracted, the water bearing horizon is termed an aquifer. The zones of groundwater yield are meant to give an indication of the most likely yield which could be expected. Natural variations in the properties of rocks means that variation also occurs in groundwater yields. For example in a zone mapped as 0.5 to 5.0 L/s a certain percentage of bores may obtain higher yields and some may obtain lower yields. At a specific site, yield is often highly dependent on the number of water bearing fractures intersected. There are generally too few existing bores to determine the likely yields with statistical certainty. Rather they are based on a combination of geological knowledge and known yields.

Brackish water occurs under the Keep River plains but it's salinity is generally within acceptable limits for use by stock. The salt water is thought to originate from inflows of seawater along former tidal sections of the rivers and possibly from salts dissolved out of a particular shale formation. Fresh groundwater beneath the plains is restricted to places where the river passes directly over aquifers with no intervening impermeable material. The black clay soils are very tight and allow relatively little water to seep down.
Each of the three yield zones on the groundwater map are now described:

3.1 Areas with yields 0 to 0.5 L/sec (brown zone).

This zone includes the hills and range country in the southeast part of the station. The rocks are mainly hard sandstones and siltstones. Although no drilling has been done over the main part of this zone, results obtained on neighbouring Legune suggest that yields are likely to be low and that the success rate will be low. The narrow area of this zone located between the blue and yellow zones on the groundwater map comprises a shale formation Two bores RN5661 and RN7411 obtain water from this shale but others have failed to obtain an adequate supply. .Aquifers are formed locally, usually at depths shallower than 50 metres where the rocks are sufficiently fractured. Prospects for successful bores can be improved by siting bores along major fractures identified on aerial photographs or satellite images. Valleys cutting into the hills may also indicate the presence of water bearing fracture zones.

3.2 Areas with yields 0.5 to 5.0 L/s (blue zone).

Two areas have been mapped in this zone, a large area of ranges in the southeastern part of the station and a narrow strip running north northeast along the front of the ranges. The first area is rugged and inaccessible and no drilling has taken place there. On the basis of boreholes drilled in similar sandstone formations on Bullo River station to the east, the area has been mapped as having moderate yielding aquifers with good prospects for successful drilling. The sandstones in this area are separated from low yielding sandstones and siltstones to the northwest by the Victoria River Fault, a major geological fault which runs northeast to southwest. It forms a long narrow valley bounded by steep sandstone walls on both sides ,locally known as the "Great Walls of China".
The other area where moderate yields can be obtained flanks the northwestern side of the ranges and is underlain by sandstone and limestone. Information from these aquifers has come from two investigation bores, RN29667 and 29668 and several mineral exploration bores. Aquifers are

likely to be within 50 metres of the surface but may be deeper in some areas and will be locally developed dependant on the presence of fractures. In the case of limestone, aquifers may be more widespread due to the presence of solution cavities. Sinkholes in this area indicates that the limestone is cavernous and so may locally have potential for yields above 5 L/s.

If bores tapping the limestone aquifer are to be used to supply water for human consumption it would be advisable to have the water analysed for heavy metals, particularly lead. Unacceptable lead levels have been found in groundwater from similar rock formations at Sorby Hills, just west of the station.

3.3 Areas with yields more than 5 L/s (yellow zone).

The main aquifer in this zone is in an extensive sandstone. It is exposed in the bed of the Keep River at the Spirit Hills road crossing, where it can be seen to be soft and porous. Another aquifer is present beneath the Keep River plains, consisting of loose sand and gravel beds which are deposits of former courses of the Ord and Keep Rivers. The former Ord River flowed eastwards into the Northern Territory between the homestead and Border Creek where it was joined by the former Keep River. It then flowed north into Spirit Hills station where it is found just east of the present day river. These sands and gravels overlie the main sandstone aquifer.

Quantities sufficient for stock supplies should be available throughout this zone. The groundwater is brackish but generally suitable for cattle. One exception is the bore RN29656 with a salinity of 19100mg/L total dissolved solids. Water quality is generally better in the slightly higher sandy country which flanks the southeastern margins of the Keep River plain.
A problem sometimes encountered in constructing bores in the sandstone is that it is fairly soft and prone to disintegrate around the bore following extended periods of pumping. If slots in the casing are cut too wide, fine sand can enter the bore damaging the pump and eventually blocking the bore. The finest possible slots are recommended to avoid this. An extra length of slotted casing can be added to compensate for the reduced intake area. Although the sandstone is soft it is generally stable enough to be drilled with the air/rotary technique. The river sands and gravels below the Keep River plains however are completely unconsolidated and it would be advisable to use drilling mud instead of compressed air to keep the hole open.

4. SURFACEWATER

Surface water flow in the creeks, rivers, and the floodplains is largely confined to the wet season. However replenishment of some waterholes during the Dry are due to spring flows. An effective annual evaporation rate of about 2.6 metres is responsible for the subsequent rapid loss of stored water from waterholes. During the average Wet, flow of the Keep River, and minor streams are often accompanied by sheet flow over much of the low lying inland plains country. After the Wet, all drainages above the tidal influence deplete to form unconnected waterholes, the majority of which are dry by about October. Surface water studies have been directed at designing structures to conserve enough of the wet season flow to provide reliable stock supplies for the duration of the Dry. In a paddock holding 400 head the requirement is to hold 7.3 megalitres (million litres) of water for stock supply (50 litres/day/head) after allowance is made for evaporation losses.

For it's stock water supply from surface water, Spirit Hills Station is largely dependent on natural waterholes. Less than 40% of the stations stock water demand is supplied from surface water.

The region has been divided into five zones showing suitability for surface water development for stock watering. They are based on soil type , topography and runoff characteristics. The results are presented as the **Surface Water Resources Map**, one of the two small side maps accompanying the Water Resources Development Map of Spirit Hills.

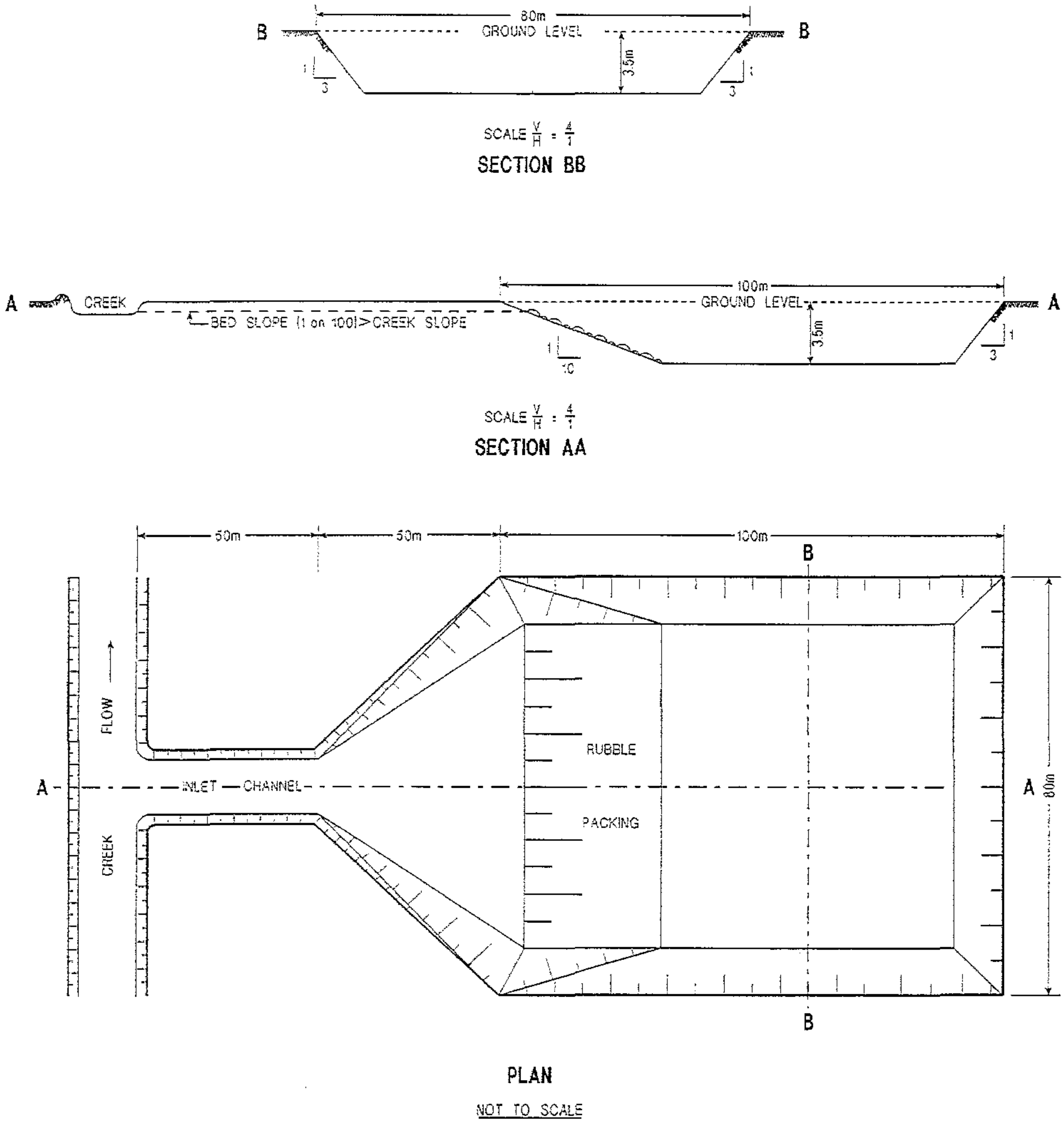
4.1 Surface Water Storage Types

Three types of excavated tanks are suitable for the flat and gently undulating plains, onstream tanks, offstream tanks, and drainage-line tanks, the latter being the preferred option. On Spirit Hills the depth of excavated tanks should be 3.5 to 4 metres, depending on subsoil types. As the depth of the tank increases beyond three metres, it's reliability increases. Details of the station's key surface water storages and an assessment of their capabilities are given in Appendix 5.

The majority of the existing waterholes are shallow, similar to excavated onstream tanks but with bunds on either sides, made from the excavated material. From the top of the bund these waterholes are about 2 to 2.5 m deep, but with a maximum depth of only 1.5 to 2.0 metres below the cease to flow level. The existing design has resulted in rill erosion of the bund and silting of the tanks . This is further aggravated by cattle watering direct from the waterhole.

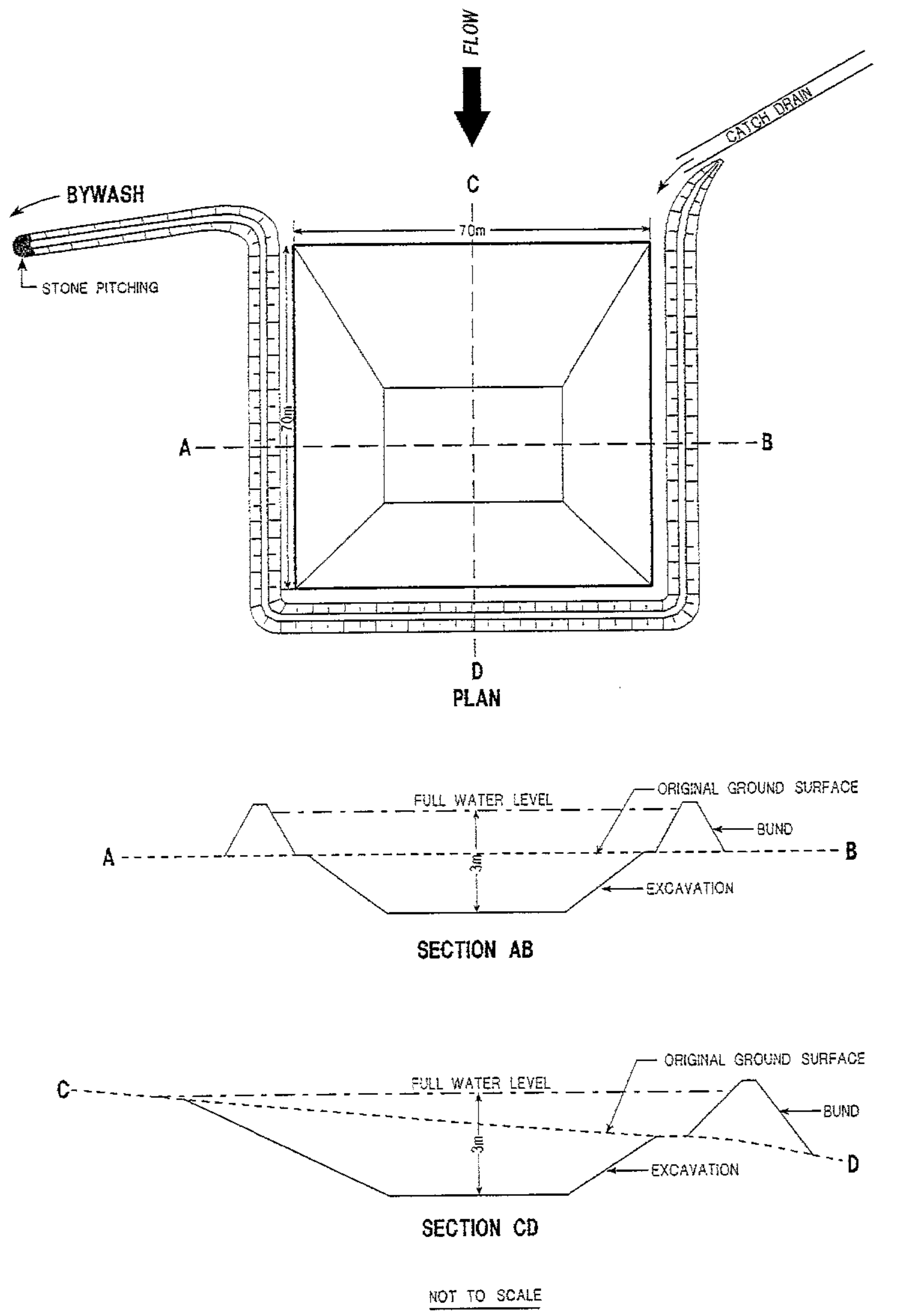
Regular maintenance is required before the next Wet to correct damage due to these problems. The current waterhole size does not give sufficient storage capacity for cattle requirements, due mainly to evaporation losses and to a lesser extent leakage.

The onstream excavated tank requires a high standard of design and construction and is prone to erosion or silting because of its location in a fast flowing main stream channel. The offstream design (Figure 3) reduces these problems by using a man-made channel to divert water from a natural stream to the tank. This is an improvement on the onstream design, but has excessive excavation costs since to take advantage of short lived stream flows, the tank level must be below that of the natural stream bed.
The drainage-line tank (Figure 4) is an excavated tank constructed in flat to moderately sloping areas where there are no clearly defined creek systems. The tank itself is of the same design as the offstream one, but without an inlet channel. It is excavated in a drainage area which does not have a defined creek system and water may be directed towards it using catch drains or wing walls. Sheet flow on the plains, with its low silt load, may be harvested in this manner. This design is most suitable for Spirit Hills and has been used successfully on Auvergne and Bradshaw Stations in the same situation.



TYPICAL OFF CREEK EXCAVATED TANK

Fig. 3



TYPICAL DRAINAGE-LINE EXCAVATED TANK

Fig 4

Another type of dam, the gully dam is suited to gently undulating country and consists of an embankment built across a drainage line. Bakers Dam, built last year in Legune Station is an example of gully dam. It should be noted that structural failures are high amongst gully dams, as they require a high standard of design, construction and management. Construction of these dams in much of the hilly country on Spirit Hills may not be possible due to the thin permeable soils and permeable sandstone bedrock. Areas where soils are clayey may be locally suitable for gully dams. The minimum average depth of the dam should be 4 metres in order to compensate for the high evaporation. All excess runoff has to be taken through a by-wash or spill. Constructing a gully dam at an appropriate location in the region would involve high costs in coping with the foundation condition and flood flows. It is recommended to consult a Civil Engineer before planning to construct these dams on rock foundation. Embankments more than 3 metres high need licensing from the Water Resources Division.

4.2 Selection of Sites for Excavated Tanks

The selection of a site for an excavated tank is determined by the availability of runoff and the water holding capacity of the ground. A drainage-line tank is best located on flat or gently sloping ground. Excavation will be minimised where the tank site has some slope, say about 1%, to allow bunds constructed from excavated material to add to the storage volume of the tank. On areas mapped as flat alluvial plains on the **Surface Water Resources Map** cracking clays extend to a depth of up to 4 metres in some areas and are suitable for excavated tanks. Areas mapped as gently sloping alluvial plains may also be suitable, however places with sandier soils should be avoided. Drainage-line tanks may be feasible in areas immediately adjacent to the hilly country if clayey soils with sufficient depth are present. Areas suitable for consideration are also summarised on the **Water Resources Development Map**. Following selection of a general area, more detailed investigation is required (Appendix 6) and may require the input of a geotechnical consultant. For drainage-line storages a minimum catchment area of 0.5 km^2 is required. Other types of excavated tanks require a minimum catchment area of 1.5 km^2.

Cracking clay soils are suitable for holding water. Remedial work such as installing a clay liner, or reselection of the site will be necessary where dispersive or sandy soils, or high permeability zones are encountered.

4.3 Design and Construction of Excavated Tanks

Design dimensions for the excavated tank are determined by the stock numbers to be watered for a whole year (stock numbers will be higher if the tank is utilised for only part of the year). This in turn is dependent on the carrying capacity of the paddock, usually varying between 150 and 500 head (ie. a requirement of between 2.7 and 9.2 megalitres per year when based on 50 litres per head per day).

The larger the catchment, the more runoff that can be expected to be captured by a tank. As for drainage-line tanks, catchment sizes between 0.5 km^2 and 2 km^2 should supply between 150 and 600 head respectively, with 90% reliability (ie. for 9 years out of 10), using the proposed drainage-line storage design. An offstream tank with a catchment size range of between 1.5 and 4 km^2 should supply between 450 and 800 head of cattle, with 90% reliability, depending on the tank size.

The basic design for a typical drainage-line tank is shown in Figure 4 and dimensions of 70 x 70 x 3 metres are recommended for stock numbers up to 230. Dimensions of 100 x 80 x 3.5 metres are required for stock numbers up to 650, depending on the area of the catchment. A minimum tank depth of 3 to 4 metres is required to allow for an annual 2.6 metres water loss due to evaporation. The basic design for a typical offstream tank is shown in Figure 3 and dimensions of 100 x 80 x 3.5 metres are required for stock numbers up to approximately 625. The design of excavated tanks are covered in more detail in the internal Water Resources Division Report No 20/1995D, entitled " Surface Water Storage Potential - Spirit Hills Station".

Construction is covered in more detail in Appendix 7. The proposed design is relatively simple. Excavated spoil can be dumped to waste or used to build a bund on three sides of the tank. A bund and wing walls will increase the storage capacity of an drainage-line tank where there is a moderate slope on the natural ground surface . Excavated volumes are large for the proposed design dimensions (approximately 10,000 m^3 for the smaller tank, and 16,000 m^3 for the large) so construction costs will be high. Cost will also be influenced by ground conditions.

4.4 Waterholes and Springs

Natural waterholes are present during the Dry, in depressions in stream and riverbeds. Some of the waterholes , such as Milligan Lagoon never dry. The available capacity of the waterholes could be increased by excavation of the base (Appendix 7), but only where site investigation proves that this will not result in leakage. A shale base could be excavated without fear of leakage, however the region is underlain largely by sandstone which is not water tight. Waterholes in the hilly country may be deepened, provided the excavation is confined to cracking clay soils. The storage capacity of a well confined waterhole with high banks could be increased by construction of a bund at its downstream end.

There are some springs on hill slopes and in river valleys. None of them have been exploited for stock watering. Piping water from springs to areas where groundwater or surface water are not available may be an option in some situations. If a spring is found to have more than 2 litres per second flow at the end of dry, it should be more than sufficient to supply a turkey nest designed to store three days supply of stock water for 500 head of cattle.

4.5 Piping of Surface Water

Piping surface water from a source to supply point could be utilised as an alternative low cost water supply option where possible. Pumping direct to turkey nests is the preferred option because of the smaller volumes of water lost to evaporation. Fifty millimetre polythene pipe, buried where possible, can be used to pipe water up to four kilometres in flat country. The distance can be increased by using larger diameter pipes and higher capacity pumps. It is desirable to bury polythene pipes to protect them from physical damage (eg. grass fires or accidental ploughing) and because their strength is reduced if subjected to elevated daytime temperatures. Burial, to protect from fire, stock trampling, etc., is easy where surficial materials allow excavation using a tilted grader blade, but is not possible in areas of exposed rock.

4.6 Supply of Stock Water from Tanks

Turkey nests are required as a balancing reservoir between the tank and stock watering troughs. Dimensions for turkey nests providing three days water for various stocking rates are given in Appendix 7.

The basic equipment to transfer water from an excavated storage tank to a turkey nest is a pump, with a choice of three energy sources, diesel, wind or solar. The initial cost of a windmill or solar powered pump is high but running costs are low. The low cost and availability of a relatively cheap diesel motor and centrifugal pump makes diesel the preferred option even though running costs are high. The advantages are mobility and ease of maintenance.

5. RECOMMENDATIONS

1. The water resources development map should be used to determine the type of water supply most appropriate to a specific area on the Station. In areas where alternative options are available economics will normally determine the final development type selected.
2. Either bores or excavated tanks located away from clearly defined drainages, and sited to harvest sheet flow are considered the best option for new sources of stock water for most of the plains area.
3. The provision of reliable water supplies with a maximum grazing radius of six kilometres throughout the good pasture of the plains should be a priority, in order to reduce over-grazing and soil erosion.
4. Advice should be sought from geotechnical engineering consultants when considering the construction of larger and deeper excavated tanks, or from groundwater consultants or the Water Resources Division for detailed bore siting information.

Specific recommendations are considered under three headings: distribution, groundwater, and surface water.

5.1 Water Supply Distribution

In many parts of the V.R.D. over-grazing has resulted in a reduction of ground cover and in places, in soil erosion. Another unwanted result is degradation of pasture quality by allowing unbeneficial species and weeds to become dominant. Apart from the number of cattle present, the distribution of watering points is a major factor affecting grazing pressure. A rule of thumb commonly adopted for planning the location of watering points is that they should be located so that cattle can graze the whole paddock without having to walk more than six kilometres for water. Where possible, tanks or bores should be located to give a maximum spacing of twelve kilometres between watering points. Otherwise the water can be piped to turkey nests or directly to troughs in appropriate locations. The piping of water away from supplies sited in the corners of paddocks may decrease the grazing pressure by keeping the cattle spread over a greater area. (Figure 5).

Spirit Hills has a patchy distribution of watering points and there is considerable scope for creating more at appropriate sites. As the station has potential for high yielding bores, piping to multiple watering points is a good option. Large waterholes, such as Milligans Lagoon are also suitable sources.

5.2 Groundwater

Reliable groundwater supplies are available beneath much of the Keep River plains and adjacent lateritic plains. Some of the groundwater in these areas are brackish but are still usable for stock watering. Areas underlain by shale are unlikely to yield sufficient quantities for stock supplies. The alluvial plains of the Sandy Creek are also unlikely to be prospective for groundwater, however this area is untested.

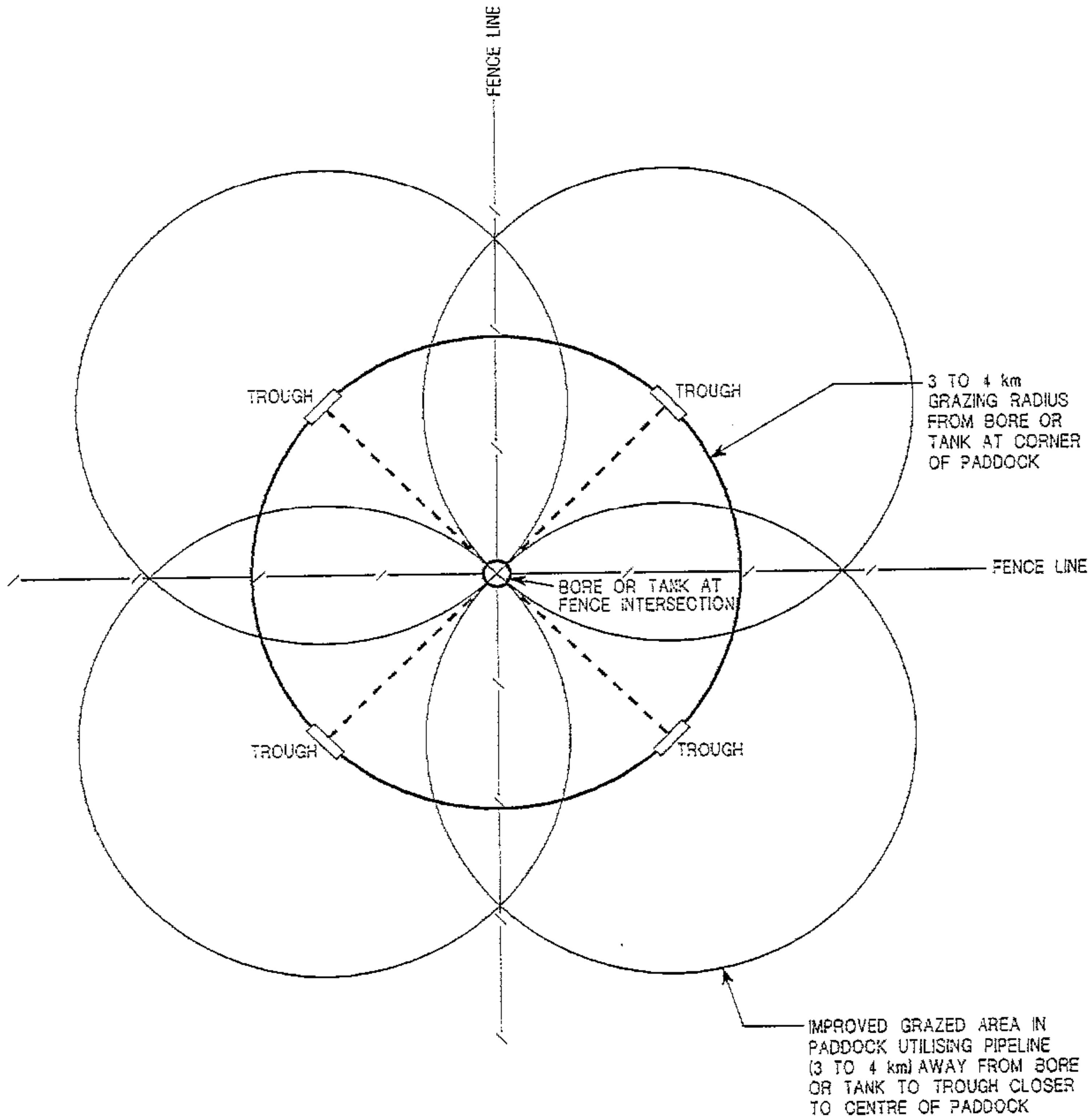
In the northwestern part of the station there is considerable potential for high yielding bores (more than 5 L/sec.). In that situation multiple watering points could be easily sourced from a single bore.

5.3 Surface Water

Drainage-line and offstream type excavated tanks are recommended for areas with black clay soils. Selection of sites depends on the presence of suitable sub-soils. Gully dams may be locally suitable in undulating country but site investigations and proper design and construction methods are essential. Deepening or enlarging the surface area of existing surface water storages should be subject to satisfactory sub-soil investigations. Site investigations are an essential prerequisite for any construction work. All existing and planned surface water storages (excavated tanks, waterholes, springs etc.) should be fenced and stock watering infrastructure such as troughs, windmills, turkey nests or on-ground fabricated tanks should be provided.

6. ACKNOWLEDGMENTS

The authors would like to thank Rob Kelly of Spirit Hills Station for his hospitality and assistance during the study. The guidance of Mr Peter Jolly, and Mr. Fred Barlow throughout the survey has been much appreciated, as has the efforts of the drafting and GIS staff, Lynton Fritz and Jeff Fong, who produced the maps and figures for the report. Thanks also to Technical Assistants Roger Farrow and Rob Roos who carried out the GPS surveys and to the drilling and pump testing crews. The staff of the Pastoral Branch of the Department of Lands and Housing also provided much assistance in the form of pastoral maps, inspection reports and general advice.



SKETCH SHOWING IMPROVED SIZE OF GRAZING AREA DUE TO PIPING AWAY FROM RELIABLE BORE OR TANK

Fig. 5

APPENDIX 1

STATION BORES

The following table is a list of bores drilled on the station together with selected details about their location, construction and groundwater intersections. More detailed information on many bores is available on request from the Water Resources Division in Darwin. Some of the headings on the table are explained below:

-BORE RN A registered number assigned to each bore by the Water Resources Division.

-EASTING The east-west coordinates of the bore in metres. It refers to the grid lines on the map.

-NORTHING The north-south coordinates of the bore in metres. It refers to the grid lines on the map.

-DEPTH The total depth of the bore in metres below ground level.

-CASING The length of casing in the hole in metres and it's internal diameter in millimetres .

-DEPTH STRUCK The depth in metres below ground level at which the main water bearing zone was encountered.

-AIRLIFT YIELD The amount of water obtained in litres per second by airlifting, usually during drilling of the hole.

-SWL Standing water level, the depth below ground level that water rises to in the bore.

-SLOTS The depths in metres below ground level between which the bore casing is slotted.

APPENDIX 2

CHEMICAL ANALYSES OF GROUNDWATERS

The following table lists chemical analyses performed on groundwaters on Spirit Hills. See Appendix 3 for an explanation of the main factors which limit water use for stock and domestic consumption.

APPENDIX 1 STATION BORES SPIRIT HILLS

BORE RN	STATUS	EASTING	NORTHING	LOCAL NAME	COMPLETION DATE	Depth(m)	Casing depth(m)xdiam(m)	Depth struck(m)	Airlift yield(L/S)	SWL(m)	Slots(m)
2592	Equipped	507591	8285895	SPIRIT HILLS BORE	11/16/60	915.3	7.3x1067	305	1	flowing	
5661	Equipped	506313	8290861	WEABERS BORE	7/10/66	32.6	32.6x	27	1.8	16.8	23.5-32.6
5662	Equipped	506149	8295850	KEEP BORE	10/19/66	24.4	24.4x152	13	2	11.6	18.3-24.4
7410	Equipped	513428	8296694	KNEEBONE BORE	11/18/70	62.5	62.5x152	26	1.1	15.2	50.362.5
7411	Equipped	502174	8292864	HOMESTEAD BORE	11/19/70	44.2	44.2x152	43	6.3	18.3	38.1-44.2
7412	Capped?	505417	8292168		11/19/70	30.5	30.5x127	26	0.1	18.3	
7413	Abandoned	500700	8295100		11/20/70	30.5	30.5x127	dry			
7414	Capped?	500700	8291300		11/20/70	30.5	30.5x127	21	0.1	18.3	
7415	Capped?	503600	8295000		11/21/70	30.5	29x127	31	0.1	18.3	
7863	Capped?	510300	8297200		12/6/72	27.4	22.9x152	23	1.3	12.2	
7864	Capped?	508500	8292000		6/14/72	30.5	24.4x152	25	0.1	20.1	
7865	Abandoned	504100	8288400		6/14/72	30.5	30.5x152	dry			
9024	Abandoned	519000	8290000	AQUITANE EXPLORATION NO.1		0					
9025	Abandoned	519200	8293400	AQUITANE EXPLORATION NO.SH1		0					
29654	Observation bore	509590	8297668		10/17/94	22					
29655	Abandoned	505752	8294949		10/17/94	22					
29656	Observation bore	504705	8293243		10/18/94	36.8	29x104				25-29
29657	Abandoned	506502	8289659		10/18/94	36.8					
29658	Abandoned	502076	8293765		10/19/94	12.8					
29659	Observation bore	503056	8295817		10/24/94	39.7	33x156	33	6	14.1	32.6-33
29660	Observation bore	499907	8295097								
29661	Abandoned	499897	8290673					24			
29662	Observation bore	500458	8287919		10/26/94	21.2	18x156	9	0.5		15-18
29663	Abandoned	509590	8297668		10/27/94	21.7	19x104			12.8	15-19
29664	Abandoned	511179	8297835		10/27/94	23					
29667	Capped	500404	8280097		11/14/94	78.4	12.6x207	18	5.5		
29668	Capped	513650	8288680		11/16/94	102.4	4x207	94	2.5	44.1	
29947	Equipped	502028	8265776	SWEETWATER BORE			?x140				

APPENDIX 2 CHEMICAL ANALYSES OF GROUNDWATERS SPIRIT HILL STATION

BORE RN	BORE NAME	DATE	CONDUCTIVITY	T.D.S.	pH	SODIUM	POTASSIUM	CALCIUM	MAGNESIUM	CHLORIDE	SULPHATE	BICARBONATE	NITRATE	FLUORIDE	IRON	SILICA	ALKALINITY	HARDNESS
			uS/Cm	mg/L		mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L
2592	SPIRIT HILL 1	27/11/64	3442	2688	7.2			208		955	90	190					312	1370
2592		9/7/70	620	420	7.7	34	20	55	25	14	93	305		0.7	<0.1		250	238
2592		6/8/73	640	440	7.5	33	18	62	26	15	69	309		0.7	<0.1		253	242
2592		12/8/94	631	389	7.3	31	21	66	24	13	81	309	1	0.4	<0.1	25	253	264
5661	WEABERS BORE	15/11/70	4770	3730	7.0	500	18	326	234	989	1150	405		1.3	<0.1		332	1774
5661		11/8/73	4850	3550	7.4	496	14	305	217	936	1041	389		1.3	5.6		319	1653
5661		12/8/94	4570	3300	7.5	486	15	286	190	780	1090	333	<1	0.2	2.1	37	273	1500
5662	KEEP BORE	2/6/69	390	250	7.2	48	1	16	11	36	19	151		0.3	<0.1		123	84
5662		3/8/76	600	380	6.7	75	2	24	19	72	42	196		0.2	<0.1		161	138
5662		12/8/94	2690	1660	7.7	307	5	128	95	590	268	370	<1	0.2	0.2	56	303	711
5662		14/10/94	2790	1670	7.7	332	5	128	95	620	279	387	<1	0.2	6.2	50	317	711
7296		1/10/70	530		8.0					8		234					192	128
7411	HOMESTEAD BORE	19/11/70	650		7.5	21	12	56	25	55		254			7.2		208	243
7411		17/2/71	450	260	7.8	6	9	56	22	10	16	283		0.2	0.4		232	230
7411		6/8/73	840	540	7.3	21	10	96	35	67	148	250		0.4	0.5		205	384
7411		20/2/81	2460	1390	7.4	153	14	148	80	326	380	287		0.3	1.9		235	698
7411		12/8/94	2410	1560	7.3	206	14	201	83	440	426	316	<1	0.2	2.8	27	259	844
7412		19/11/70	salty															
7414		20/11/70	190	140	6.3	17	19	8	7	33		54		0.2			44	49
9024		14/8/76	1350	880	7.0	105	14	98	70	93	224	536		0.5	0.6		440	532
9025		9/8/73	810	540	7.2	10	8	92	54	15	62	496		0.2	<0.1		407	451
9025		9/8/73	1070	660	7.2	37	10	88	75	82	7	604		0.3	<0.1		495	525
9025		3/8/76	460	250	7.3	60	8	12	18	32	15	232		0.2			190	104
9025		14/8/76	1350	880	7.0	105	14	98	70	93	224	536		0.5	0.6		440	532
29656		18/10/94	24400	19100	7.3	4870	15	705	853	6700	5820	480	2	0.1		48	394	5270
29659		24/10/94	4100	2570	7.8	547	12	164	126	970	450	416	<1	0.2	1.1	47	341	928
29660		25/10/94	2840	1700	7.8	469	14	68	66	570	255	559	1	0.8		68	458	442
29661		25/10/94	496	289	6.8	81	8	14	10	22	59	210	<1	1.1		15	172	76
29662		26/10/94	120	167	5.9	16	4	3	5	14	22	14	<1	0.3		24	11	28
29667		12/11/94	280	170	7.3	21	9	23	10	28	18	115	<1	0.1		24	94	99
29668		16/11/94	1200	759	7.2	83	28	97	52	93	323	263	1	0.3		12	216	456
29947	SWEETWATER BORE	11/8/94	502	299	7.7	12	7	59	28	18	25	282	<1	0.2	3.1	24	231	263

APPENDIX 3

WATER QUALITY REQUIREMENTS FOR STOCK AND DOMESTIC WATER

1. WATER QUALITY STANDARDS FOR STOCK USE

SUBSTANCE	GUIDELINE VALUE
pH range	5.5 - 9.0
Total dissolved solids	8000 mg/L
Sodium chloride	Not more than 75% when total dissolved solids near limit.
Sulphate	2000 mg/L
Nitrate	400 mg/L
Fluoride	5.0 mg/L
Magnesium	300 mg/L

The composition of mineral supplements to stock feed must be considered when stock waters are near to the guideline limits, especially for fluoride and sulphate. Further information is available from the Chief Veterinary Officer, Northern Territory Department of Primary Industry and Fisheries.

2. WATER QUALITY STANDARDS FOR DOMESTIC USE (NATIONAL HEALTH AND MEDICAL RESEARCH COUNCIL, AND AUSTRALIAN WATER RESOURCES COUNCIL CRITERIA)

Analyses of water intended for human consumption should lie within the guidelines listed below. Discussion relating to the quality of domestic water should be addressed to the Northern Territory Department of Health and Community Services.

SUBSTANCE	GUIDELINE VALUE
pH range	6.5 - 8.5
Total dissolved solids	1000 mg/L
Chloride	400 mg/L
Sulphate	400 mg/L
Nitrate	45 mg/L
Fluoride	0.5 - 1.7 mg/L
Hardness (as Calcium Carbonate)	500 mg/L
Sodium	300 mg/L

APPENDIX 4

PUMPING TEST RESULTS

Only one bore on Spirit Hills has been pump tested. The results are summarised in the following table. More detailed information is available from the Water Resources Division in Darwin.

RN	PUMP RATE (L/s)	PUMP SETTING (m)	BORE DIAMETER (mm)	SWL (m)
29659	2	20	152	14.1

RN -Registered number of the bore

PUMP RATE -The recommended pump rate in litres per second

PUMP SETTING -The recommended depth below ground level at which the pump intake should be set

BORE DIAMETER -The minimum internal bore diameter in millimetres

SWL -The standing water level in the bore, in metres below ground level, measured immediately prior to the test

APPENDIX 5

SURFACE WATER STORAGES ON SPIRIT HILLS

1. ALBERT WATERHOLE:
This is part of a creek channel which channels flood waters from the Keep River. Cattle drink directly from the waterhole and at the time of inspection, the side slopes were so clayey and boggy that several dead cows were seen bogged in the mud. The waterhole can be deepened, subject to sub soil investigation. At present it can supply 200 head of cattle throughout the year with 90% reliability. It is recommended that the waterhole be fenced and a turkey nest be built to regulate the supply.

2. MILLIGANS LAGOON:
This occurs on the same flood channel as Albert Lagoon. It is long and deep enough to cater for 750 head of cattle with 90% reliability. In an average wet year it can supply 900 head of cattle with 90% reliability. The lagoon is fenced, and this reduces siltation. The turkey nest has enough capacity to supply water to 700 head over 15 days.

3. DUNCAN WATERHOLE:
This waterhole also captures sheetflow and holds water until late dry. It can supply 125 head of cattle throughout the year, and during an average wet year it can supply 150 head of cattle. Though this is situated in an area with cracking clay soils, sub soil investigation is required before expanding and deepening the waterhole. It is also recommended that it be fenced and a Turkey Nest be built.

4. BROWN DUCK WATERHOLE:
This located in the catchment of the Sandy Creek. It can supply 100 head of cattle with 90% reliability. The storage capacity is small and it is shallow. All the necessary investigations should be done before any deepening is carried out.

5. ROCKY HILL LAGOON:
This is located on a small drainage which is a tributary of Sandy Creek. It can supply 100 head of cattle throughout the year with 90% reliability. Situated on the northern floodplain of Sandy Creek this lagoon is not accessible until after the flows in the Sandy Creek recede. It is recommended that a Turkey Nest be built on the other side of the creek and that water be piped across.

APPENDIX 6

SITE INVESTIGATIONS

Having determined a catchment capable of supplying stock quality water for the required stock numbers, site investigations must be undertaken to confirm that the proposed tank site is suitable. The site investigation guidelines presented here are based on a very useful booklet entitled "Design and Construction of Small Earth Dams" (Nelson, 1985, Inkarta Press, Melbourne). The key investigation method is to auger a series of investigation holes. In an excavated tank situation this helps to:

- determine the extent of impermeable soils and the presence of any layers which are likely to have leakage problems
- show if there is any impermeable and soft rock present, such as rippable shale
- ascertain whether shallow groundwater is present, and if so, is it suitable for stock
- provide information on the soils to ensure the tank sides will be stable

If an onstream tank is proposed then spillway conditions will also require investigation. If it is too sandy it will erode and wash away or if it is in rock, excavation could be very expensive.

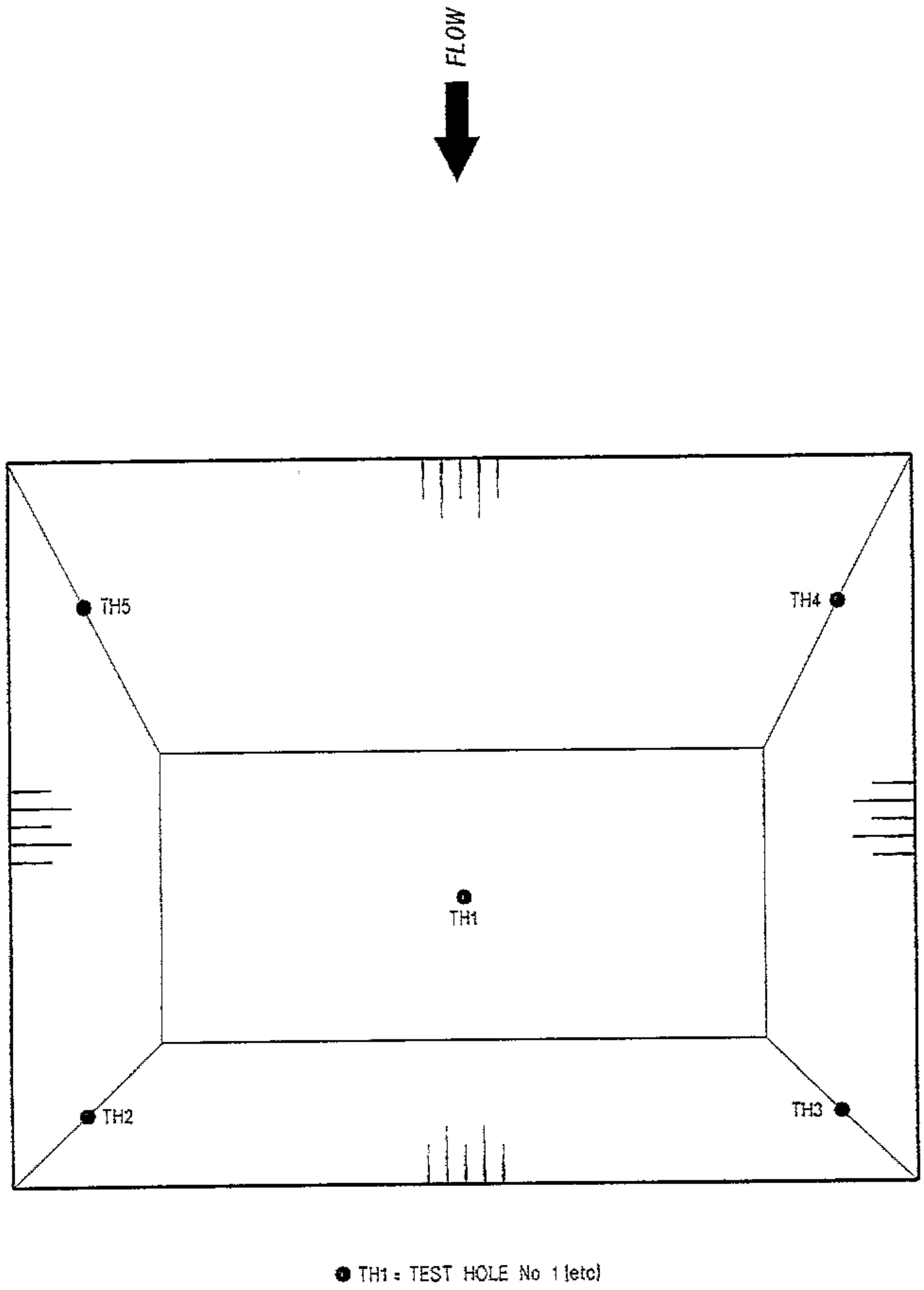
A hand operated 100 mm earth auger capable of drilling to between 5 and 6 metres is the basic tool for the subsurface investigations. Auger holes are sunk in soil to one metre deeper than the tank design depth, with minimum 500 gram samples taken wherever there is a change in soil. A plan of the soil changes down each hole should be kept to compare variations from hole to hole. Excavated tanks require a minimum five test holes, one in the centre and the other 4 positioned at the mid point of each corner slope of the proposed tank (Figure 6). For the modification of an existing waterhole, auger holes are sunk at 50 metres apart along the centre of the bed, and 100 metres apart along the edges of the bed.
The site for proposed excavation must fulfil three main conditions :

- the loss by seepage must be relatively low
- the sides must be stable
- silting must not be excessive

1. Seepage Loss

In most areas of the plains country the watertable will be deeper than the proposed 4 to 4.5 metre tank depth. Hence leakage of stored water through the sides and base of the tank is possible. A simple permeability test can give an indication of potential leakage from the tank using the series of auger holes used for soil sampling. The following procedure is proposed but is only indicative:

1. Pre-soak each hole for at least 1 hour before starting the test by filling the hole to exactly 0.5 metres below ground level and maintaining it at this level by addition of water.
2. The test involves maintaining this water level (0.5 metres below ground level). The



TEST HOLE PLAN FOR
AN EXCAVATED TANK

Fig 6

/usr/foog/wrdrp.dgn

amount of water added to keep the water level is recorded. Continue the test for one day.

If the water added exceeds 30 litres per hour, then the site is too permeable for an excavated tank. If it is between 3 and 30 litres per hour then the area should be considered as doubtful and should only be accepted with professional advice. Rates less than 3 litres per hour indicate that leakage will not be a serious problem.

2. Tests on Soil Samples

Soils commonly consist of particles which may range in size from coarse gravels, through sands and silts, to very fine clays. Gravels and sands can be readily identified by appearance and feel and unless they are mixed with finer silts and clays will be prone to leakage. Clays and silts are indistinguishable when dry. While clay is one of the most useful soils in dam building, silt, when wet, is the most troublesome. It tends to be unstable in the presence of water, often collapsing when saturated.

Generally a favourable site investigation result will confirm the presence of non-dispersive clays that bind together any coarser particles to create a water holding material. Accurate classifications of soil types can be undertaken by sending at least 100 gram of sample to the Conservation Commission of the Northern Territory and these provide a very good indication of soil suitability. However simple field tests can give a good feel for the likely behaviour of the soils.

1. A simple test to differentiate clay from silt is to moisten the sample and feel it. Clay should be sticky. Pinch a sample between the thumb and forefinger; if it is clay it should be possible to form a flexible ribbon about 1.5 mm thick and at least 40 mm long.

2. If the presence of clay is established then the water holding potential of the soil can be tested using the "bottle test". The bottom of a 1.25 ml plastic drink bottle is cut off. The bottle is inverted and one-third filled with the soil to be tested. The bottle is filled with water. If no water seeps through the soil in 24 hours, it has good water-holding properties.

3. All clays should be tested for dispersion. Some clays break down in water to form a suspension of clay particles throughout the water. This is dispersion and has been the cause of many dam failures. To test for dispersion take 5 to 10 grams of air dried soil crumbs and drop them into 100 ml of distilled water in a cup. Allow it to stand for at least one hour without shaking. If the water appears cloudy then dispersion has occurred and special care will be needed if building tanks in these materials. The presence of deep erosion gullies suggests markedly dispersive soils and these sites should be avoided.

If site investigations show that there is likely to be problems with any of these factors then professional advice should be sought, and remedial measures may be possible. However it may be necessary to abandon the proposed site

APPENDIX 7

CONSTRUCTION DETAILS OF EXCAVATED TANKS, TURKEY NESTS AND MODIFIED WATERHOLES

Assuming preliminary investigations (Appendix 6) have shown the suitability of a site for a specific structure then construction can be begin. No matter how good the design, poor construction methods can lead to a less than perfect structure.

1. Excavated Tanks
The site is first cleared of vegetation and the planned tank laid out on the ground using marker pegs. Excavation is commonly carried out using scrapers or bulldozers. If the tank is in an area with some slope (say greater than 1 in 100) excavated material can be used to construct bunds around three sides of the excavation to increase it's storage capacity. The bund should have a minimum berm width of 5 metres (Figure 4). Topsoil with potential for leakage must be removed down to an impervious layer before the bund is built, and compaction should be undertaken using the available machinery. The ideal time to achieve optimum compaction is early in the Dry when soils are still slightly moist.

Three sides of the tank are excavated with a slope of 1 in 3, and flow enters the tank through the side with a mild slope, as low as of 1 in 10. The inflow side may be rubble packed to prevent erosion. Where the excavation is in rock, with little chance of erosion, the inlet batter may be increased to 1 in 4, to decrease the volume of material to be removed. The recommended slopes allow for machinery to enter the tank, excavate, turn and exit with ease.

For offstream excavated tanks catch drains can be constructed, eg. using a tilted grader blade, to direct an increased volume of sheet flow towards the tank.

2. Turkey Nests
The current design and construction techniques for turkey nests are adequate although special attention should be paid to:

- removal of leaky topsoil from the base before construction;

- the selection of a non - dispersive soil construction material (Appendix 6);

- compaction at optimum moisture content. This can be achieved if construction is undertaken early in the Dry while soil is still moist. Every 100 mm layer of loose soil should be compacted.

For three days water supply from a turkey nest the following dimensions are recommended:

NUMBER OF CATTLE	INNER DIAMETER AT BASE (metres)	INNER DIAMETER AT TOP (metres)	HEIGHT (metres)
200	6	13	1.1
500	8	16	1.5

These figures are based on sides with a 1 in 2.5 slope.

3. Modifying Waterholes

Modifying a waterhole usually means constructing a narrow excavated tank within the waterhole to increase its storage capacity. Site investigations are critical. If the subsoil is impermeable, non-dispersive, and there is no rock within two metres depth then excavation should be possible using a scraper. The presence of rock will usually require the use of rippers for excavation. The longitudinal batter could be 1 in 3 or less, while the cross sectional batter should not be more than 1 in 2.

APPENDIX 8

GLOSSARY

AQUIFER A body of rock that is sufficiently permeable to conduct groundwater and to yield economically significant quantities to bores and springs.

BATTER Slope expressed as a ratio of horizontal to vertical distance.

BERM Flat area between excavated area of tank and bund.

BORE Small diameter hole constructed with a drilling rig, and down which a pump is lowered to extract groundwater.

BUND Bank, constructed of compacted fill, used to contain water.

CEASE TO FLOW LEVEL The water level at a particular location along a creek at which the water ceases to flow.

DEMAND The volumetric flow rate required for stock watering, therefore the rate at which water would be supplied if available.

DRAINAGE -LINE TANK Excavated tank built in an area which does not have a defined creek.

GROUNDWATER Water contained in rock below the water table.

OFFSTREAM TANK Excavated tanks built near creeks, and connected to the creek by a channel to tap the creek flow.

ONSTREAM TANK Excavated tanks built across a well defined stream.

RELIABILITY The frequency at which a tank would be able to supply the annual stock water demand, eg. 90% reliability means that the tank should be able to supply annual stock demand for on average every nine years out of ten.

SPILLWAY A structure designed to overflow excess water out of a dam.

SPILL TAIL CHANNEL
A channel built downstream of the spillway to direct excess water back into the creek.

STANDING WATER LEVEL (SWL)
The level, below the ground surface, to which groundwater will rise in a bore or well.

STORAGE CAPACITY
The volume of water that can be stored in a tank up to its full supply level.

TOTAL DISSOLVED SOLIDS (TDS)
A measure of water salinity based on the quantity of solids left after evaporation of a litre of the sample.

WATERTABLE The surface resulting when the standing water levels in adjacent bores in the same aquifer are connected.