Water
AUTHORITY

Extensions to Exmouth Water Supply Borefield

Consultative Environmental Review

Report No. WP 225
June 1995

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WATER RESOURCES DIRECTORATE
Water Resources Planning Branch

Extensions to Exmouth Water Supply Borefield

Consultative Environmental Review

Muir Environmental

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INVITATION

The Environmental Protection Authority invites people to make a submission on this proposal.

This Consultative Environmental Review is for Proposed Extensions to the Exmouth Town Water Supply Borefield. The document has been prepared in accordance with Section 46 of the Environmental Protection Act 1986, and is available for public review for a period of four weeks from 2 August 1995 to 30 August 1995.

Comments from government agencies and from the public will assist the EPA to prepare an assessment report in which it will make recommendations to government.

Why Write a Submission?

A submission is a way to provide information, express your opinion and put forward your suggested course of action - including any alternative approach. It is useful if you indicate any suggestions you have to improve the proposal.

All submissions reviewed by the EPA will be acknowledged. Submissions will be treated as public documents unless specifically marked confidential, and may be quoted in full or in part in any report.

Why Not Join a Group?

If you prefer not to write your own comments, it may be worthwhile joining with a group or groups interested in making a submission on similar issues. Joint submissions may reduce the workload for an individual or group, as well as increase the pool of ideas and information. If you join a small group (up to 10 people) please indicate all the names of the participants. If your group is larger, please indicate how many people your submission represents.

Developing a Submission

You may agree or disagree with, or comment on, the general issues discussed in the review or the specific proposals. It helps if you give reasons for your conclusions, supported by relevant data. You may make an important contribution by suggesting ways to make the proposal more environmentally acceptable.

When making comments on specific proposals in the review document:

- clearly state your point of view;
- indicate the source of your information or argument if this is applicable;
- suggest recommendations, safeguards or alternatives.

Points to Keep in Mind

By keeping the following points in mind, you will make it easier for your submission to be analysed:

- attempt to list points so that issues raised are clear. A summary of your submission is helpful;
- refer each point to the appropriate section, chapter or recommendations;
- if you discuss different sections, keep them distinct and separate, so there is no confusion as to which section you are considering;
- attach any factual information you wish to provide and give details of the source. Make sure your information is accurate.

Submissions will be treated as public documents unless confidentiality is requested.

REMEMBER TO INCLUDE

YOUR NAME
ADDRESS
DATE

THE CLOSING DATE FOR SUBMISSION IS 30 AUGUST 1995.

SUBMISSIONS SHOULD BE ADDRESSED TO:
The Chairman
Environmental Protection Authority
Department of Environmental Protection
Westralia Square, 141 St George's Terrace
PERTH WA 6000
Attention: Juliet Cole

EXECUTIVE SUMMARY

Introduction

The town of Exmouth is located approximately 1,260 km north of Perth on the east side of North West Cape. A borefield was established in 1963 to supply the town with water. Since the mid-1970s successful fishing and tourism industries have grown around Exmouth and water demands have increased. The town has also become a regional recreation centre for the rapidly developing Pilbara region. With continued development of the Town, and especially with an influx of overseas visitors, it is necessary to ensure that water supply remains adequate and at a high standard of quality. This responsibility falls to the Water Authority of Western Australia. The aim of the Exmouth Borefield Expansion Project is to achieve an adequate supply of good quality water to meet the needs of the town.

The existing borefield would be extended to a minor extent to the west (equipping existing bores) and to a greater extent to the south. Eleven new bores would be constructed, all to the south. Existing but unequipped bores, and new bores, would be equipped with new pumps. The bores would be connected to the current pipe network by means of 150 mm and smaller polyethylene pipes laid on the ground surface. Power supplies would be required to run the pumps at the new and upgraded bores. This would be supplied by overhead powerline, as for the present bores.

The proposal to undertake the work was presented to the Department of Environmental Protection/Environmental Protection Authority (DEP/EPA) in January 1995. DEP/EPA considered that a Consultative Environmental Review (CER) would be required. This document has been prepared according to guidelines provided by DEP/EPA and incorporates input from public comment before and during preparation of this CER. When this public review period is over, DEP/EPA will undertake an assessment of the Project taking into account the public comments. DEP/EPA will then, make recommendations to the Minister for the Environment regarding the acceptability or otherwise of the Project.

The Minister will publish the DEP/EPA report and set conditions under which the Project must proceed. If those conditions are acceptable to the Water Authority the Authority will then commence construction of the new bores.

The Project

The people of Exmouth have been aware of the present Project in concept since 1973, when the Water Authority commenced discussions regarding the long-term growth of Exmouth and likely future water supply requirements. Sites for possible construction of future bores were selected at that time. Discussions with government agencies and the Shire of Exmouth were held regarding borefield extension to the south.

The fresh groundwater occurs in unconfined aquifers. The volume of fresh water under Cape Range is estimated to be about 200 million cubic metres per kilometre length of the range. However, recharge to the shallower aquifers is dependant on the low (about 280 mm per year) and unreliable local rainfall. The "safe yield" of aquifers flowing to the east coast of the peninsula has been estimated to be about 100,000 cubic metres per year from each kilometre length of the range.

A layer of fresh to brackish (400-600 mg/l TDS) water overlies much more saline water beneath Cape Range. Currently the southern bores, which yield lower salinity water are accessed first, then, with progressively increasing demand, the more northerly bores. Pumping causes a local "cone of depression" of the water table surface, centred on the bore. Salinity records for bores used for groundwater abstraction show changes of salinity, with the greatest increases in salinity believed to be a result of "upconing" of the underlying saline water as a result of inappropriate bore construction and excessive pumping rates at those particular locations.

To remain within the estimated safe yield of the aquifer, the only way to increase total yield is to extend the borefield to the south. New bores in the southern extension would be pumped at low rates to minimise salt water upconing. The rugged topography makes it difficult to obtain access for drilling equipment and bore maintenance to some sites which may be otherwise attractive, such as within Cape Range itself.

Bores would be constructed by a contractor using standard drilling and casing methods. Pipelines would be polyethylene as these are safe and durable. Burial of pipes is impractical as almost the entire route from the bores to the collector main is rock. The cost and environmental impact of covering pipes with soil far outweighs the risks and cost associated with leaving the pipes uncovered, so they would just be laid on the surface.

A collector main would approximately follow the route of the powerline from Exmouth to Learmonth. It is mostly on low-lying sand and clay country, and can be buried. In rocky areas where the collector main would cross minor creeks, it would simply be laid on the surface and replaced if damaged by flooding. At Mowbowra Creek it would either be buried, with concrete anchors to hold it down during floods, or would pass over the creek in a raised cradle.

Power supply to the bores would be via spur lines from the existing Water Authority-owned electrical network which services the existing bores. This is an 11 kV/22 kV line. The poles would be steel, with standard or greater spacing.

There are no alternatives for pipeline routes. The landscape is highly dissected and the only feasible access is along the ridge crests. Generally pipeline and access road routes follow existing 4-wheel drive tracks which are already disturbed. The collector main would follow the Exmouth to Learmonth powerline as this route is already disturbed.

Bore pumps and valves in the new sites would be fitted with telemetrically-controlled systems which can be operated and controlled from the Water Authority office in Exmouth. There would, however, be regular visual checking of all bores and pipelines.

The existing water treatment plants would continue to operate. Water reticulation within Exmouth would remain unchanged except for normal maintenance and the provision of extended services as demanded by regional growth.

Pipeline construction would be undertaken by Water Authority staff, or private contractors overseen by Water Authority staff. It would be a condition of contract that fuels, oil, etc., are kept in secure containers, that spillage is prevented and, in the event of accident, cleaned up and removed off site, not buried. Daily or more frequent inspections of the field operations would be carried out by Water Authority staff. Failure by contractors to meet specified conditions would result in loss of contract, with the cost of remediation being transferred to the contractor but the work undertaken by the Water Authority.

Management of the extension to the borefield would require the same number of Water Authority staff as at present. There would be no change to Water Authority operational infrastructure except where telemetry would reduce staff workload.

The Environment

Vegetation over the route and bore sites is primarily spinifex (*Triodia* sp) with scattered shrubs of *Melaleuca cardiophylla, Acacia bivenosa* and *A. pyrifolia*. Clearing of vegetation would be minimal as access roads already exist. The significant plant *Brachychiton obtusilobus* was recorded both in the present borefield and at several locations on all legs in the proposed borefield. It is believed it would not be adversely affected by the Project.

The only significant terrestrial fauna which may be affected is the Pebble-mound Mouse. Nests of this species appear to be moderately common and fairly widespread in the borefield, although only one old nest has been located near the route. A detailed search for places where the proposed works might come into contact with nests has been carried out and only one old nest was found. The pipe route will be moved to avoid this nest.

In contrast to the surface fauna, the subterranean fauna is exceptional as below-ground habitats have been buffered from the major surface changes associated with the onset of an arid climate. The humid caves of the peninsula contain species that represent what is essentially a rainforest fauna as well as species that are specially adapted to living underground. The cave fauna of the region is of high national estate and scientific significance, and of great conservation value, being endemic to the Cape Range Formation and highly separated from related fauna which, for the most part, are recorded only in the Canary Islands and the Caribbean region.

Comparison of pumped and unpumped Water Authority bores shows significant differences in the fauna sampled. Extension of the borefield would reduce this impact in the existing borefield by spreading the total required drawdown over a larger area.

A substantial number of individuals in the cave aquatic fauna are killed directly by borefield pumping in the old borefield as this had wide slots in the bore casings which allowed animals to be sucked into the bores. This includes individuals of two species listed under Schedule 1 of the Wildlife Conservation Act 1950. The proportion of the total population this represents is unknown and, in the absence of better data, the impact of this loss on the population structure cannot be estimated. In the southern borefield this is less of a problem because the modern PVC bore casings have narrow slots which exclude the majority of species of cave animals from being drawn into the bores.

As well as the direct loss of animals, a further concern is the loss of food sources to predators in the ecosystem, plus the loss of nutrients which occur naturally in groundwater flow. Nonetheless, even with so many unknowns, it is clear that the proposed extension of the borefield would reduce the long-term adverse impact on the stygofauna habitat in the north by spreading the total impact over a larger area.

No Aboriginal Heritage significance has been identified. It is difficult to assess the potential significance of any finds which may be made during pipeline construction work. Any sites which are discovered, particularly if they present a potentially stratified and dateable deposit, would be of extremely high significance for future research. Such sites, if they were to be located, could present an impediment to development of the borefield in their immediate vicinity.

Conclusion

If the population of Exmouth continues to increase as expected, eventually the southern borefield as well would be unable to cope with demand and water quality may decline. At that time alternative methods of supply may be inevitable. Also at that time the community may be willing to bear the much increased cost of the supply as a substantial increase in water rates would be necessary.

It is concluded that the Project would have minimal adverse impacts on surface flora or fauna, or on the people of Exmouth. By contrast, advantages to the community would be considerable, allowing it to continue to grow and to further promote tourism in the region.

The most important adverse impact would be on subterranean fauna. Every effort must be made to minimise disturbance to caves and their catchments. The proposed borefield extension would result in reduction in drawdown in the existing borefield. It is expected this would allow some restoration of the freshwater lens in the latter area. Restoration of the lens may allow regeneration of the cave ecosystem. Offset against this is the necessity to increase the zone of influence by extending the borefield. However, it is felt that with the better aquifer management which would be facilitated by the extension, it would be possible to meet the requirements of stygofauna as well as community expectations.

PROPONENT'S COMMITMENTS

All work involved in the Extensions to the Exmouth Borefield will be undertaken by the Water Authority of Western Australia. The details of the work and timing are complex and are described in the text of this Consultative Environmental Review. The work would be carried to Water Authority standards in consultation with the Department of Environmental Protection.

1. The sites or routes (to 50 m downslope) of all surface constructions (roads, drilling pads, pipelines, buildings) will be inspected by a competent speleologist and/or hyrdologist prior to construction to ensure that there would be no alteration to water flow or other factors which may influence the biological integrity of the underlying cave systems. If necessary, the route or methods will be changed to minimise any direct or downstream effects of the constructions. Pipelines will be laid on the surface and not buried or covered with soil.

2. Caves, even holes too small for people to enter, that are found by the Water Authority or contractors will be reported to the relevant speleological group[1] prior to construction and its advice sought as to the appropriate course of action.

3. Salinity concentration profiles will be determined quarterly by electrical conductivity measurements in bores designed for the purpose.

4. Monthly measurement of rest water levels will be taken in all production and observation bores, including bores not yet equipped, plus all decommissioned bores that are in a suitable condition. The equipment used for this purpose will be upgraded.

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[1] Mr R.D. Brooks, telephone: (099) 491 274; address: Post Office Box 710, Exmouth, WA 6707, or the WA Speleological Group in Perth (telephone Mr R. Webb (09) 333 4444).

5. A series of monitoring bores will be installed adjacent to selected production bores within the borefield to observe changes in the salinity profile. One piezometer will penetrate through to the saltwater wedge. All piezometers will be of sufficient diameter to permit sampling of the stygofauna.

6. Stygofauna monitoring bores will initially be sampled twice yearly. It is likely that the sampling rate could be halved after several years by which time adequate background data will be available.

7. As it is not possible to set meaningful threshold values for changes in the stygofauna it is proposed that the apparent loss of any stygofauna species in 33% (one in three) of monitoring bores within the area of impact of the proposed borefield extension is a rational performance criterion to set. If such an impact was found a more detailed monitoring of that section of the borefield would be initiated, in consultation with the DEP/EPA and CALM to determine the generality of the findings.

8. If it becomes apparent that adverse impacts on the fauna exceed the established criterion discussed above, the associated bore will be shut down from production pending detailed examination of the data and its implications.

9. The above stygofauna impact performance criterion will be reviewed annually as new data become available. Results of the review will be reported to and discussed with DEP/EPA and CALM and the agreed new criteria applied for the following year.

10. All production bores from which pumps have been temporarily withdrawn for maintenance will be sampled for stygofauna and salinity profiles.

11. All new bores will be sampled for stygofauna and salinity profiles prior to pumps being set in place.

12. Dedicated stygofauna monitoring bores penetrating to different depths (including into the saltwater wedge) will be established downstream of the proposed borefield extension (inland of Murat Road), and will be of sufficient size to enable hydrological and fauna sampling. These will be established and monitored three times before each new segment of the borefield starts to operate. One such bore series will be established for each two legs of the established and extended borefield.

13. All bores decommissioned in the northern borefield will have the pump and rising column withdrawn, and be capped and locked. The casing will be left in place. This will permit monitoring of the aquifer and the stygofauna downstream of bores to assess its impact, and to monitor the recovery of the aquifer. They will be monitored twice yearly for stygofauna.

14. Stygofauna sampling will be performed by Water Authority staff after suitable training, and the specimens sent to Perth for examination.

15. All borefield monitoring data will be collated, analysed and reported to DEP/EPA, CALM and other relevant regulating authorities once every year, beginning in the January following approval of this Project. The data will also be made available to the public.

16. If monitoring records show a change in salinity which may render the water unacceptable for drinking or nearing the established thresholds where it may affect stygofauna, the rate of pumping from that bore will be reduced.

17. Where there is evidence of inland movement of the salt water interface beyond that which can be expected to result from variable rainfall, the total production of water from the group of bores in the area will be reduced.

18. If the above responses to adverse water quality do not overcome the problem the Water Authority would abandon the groundwater production from bores in the particular area.

19. During burial of the collector main, if strong winds cause excessive dust blow for the trenching crew then operations will stop until the wind had subsided.

20. The soils along the collector main will be replaced after pipe burial. No formal rehabilitation will be undertaken but the pipe route will be regularly monitored and, if necessary, active rehabilitation will be undertaken.

21. If it is decided to bury the collector main where it crosses Mowbowra Creek every effort will be taken to minimise environmental damage, the disturbed areas will be armoured to prevent erosion, and the area will be monitored and, if necessary, repaired after every storm event.

22. In the event of any material believed to be of Aboriginal origin being found during construction, work will cease on that particular site and a professional opinion sought on the significance of the find.

23. The Water Authority will finalise a detailed stygofauna monitoring program in consultation with DEP/EPA, CALM and the WA Museum.

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PROPOSED EXTENSIONS TO EXMOUTH BOREFIELD

1.0 INTRODUCTION

1.1 BACKGROUND

The town of Exmouth is located approximately 1,260 km north of Perth on the east side of North West Cape (Figure 1). Exmouth was principally established in the early 1960s to service a joint United States Navy (USN) and Royal Australian Navy (RAN) Communications Base, later to become known as the Harold E Holt Naval Communications Base.

A water supply was established in 1963 using a borefield constructed in a designated Water Reserve which was declared in 1962 and extended in 1966. This borefield produced an average of 895 million litres per year during the period from 1987 to 1992. Since the mid-1970s successful fishing and tourism industries have grown around Exmouth and water demands have increased. The town has become a regional recreation centre for the rapidly developing Pilbara region, and following the establishment, in 1983, of Ningaloo Marine Park. With the withdrawal of USN personnel from the Harold E Holt Naval Communications Base in early 1993, future growth of Exmouth will largely be dependent on tourism. With continued development of the Town, and especially with an influx of overseas visitors, it is necessary to ensure that water supply remains adequate and at a high standard. This responsibility falls to the Water Authority of Western Australia (Water Authority).

1.2 OBJECTIVES AND TIMING OF THE PROJECT

The Water Authority sets a very high standard for the quality and reliability of its water supplies. Thus, the aim of the Exmouth Borefield Expansion Project is to continue to meet existing supply standards (Section 2.3.2) and achieve:

- no less than 13 m head of water pressure at all times;
- water salinity of less than 1,000 ppm Total Dissolved Salts (TDS);
- security of water supply by means of :
    - multiple source points;
    - multiple collector mains and transfer systems;
    - multiple storage tanks;
    - multiple supply mains from storage to distribution;
    - multiple water treatment points; and
    - introduction of telemetric monitoring of borefield and equipment performance to ensure rapid responses to any system failure which might occur.

Under these proposed conditions, the only potential for loss of water supplies to the town is through power failure. Power failures occur on a frequency of about once a month and rarely exceed 15 minutes. Backup water storage would prevent power failures from stopping supply.

The Water Authority's aim is to have obtained all necessary environmental and other approvals by the end of October 1995, and to have the extended borefield constructed and in operation by August 1996.

1.3 PROJECT OUTLINE

The Project is discussed in detail in Section 3.0 but the following briefly describes the main components.

1.3.1 Borefield

The existing borefield would be extended to a minor extent to the west (equipping existing bores) and to a greater extent to the south (Figure 1). Eleven new production bores would be constructed, all to the south. There will also be two Stygofauna Monitoring Bores and four clusters of Salinity Profile Monitoring Bores.

1.3.2 Pumps and Pipelines

Existing but unequipped production bores, and new production bores, would be equipped with new pumps. These bores would be connected to the current pipe network by means of 150 mm and smaller polyethylene pipes laid on the ground surface.

1.3.3 Treatment Plants

The existing treatment plants would remain unchanged.

1.3.4 Infrastructure

Power supplies would be required to run the pumps at the new and upgraded bores. This would be supplied by overhead powerline, as for the present bores. Water storage is currently located on two high points at elevations of 48.1 m and 56.8 m Above Sea Level (ASL) to the west of the town. Water is gravity fed from the tanks to the town reticulated water supply. The tanks and pipes in this section would remain unchanged.

1.4 THE PROPONENT

The Proponent for the Exmouth Borefield Extension Project is :

Water Authority of Western Australia
629 Newcastle Street
LEEDERVILLE WA 6007
Telephone: 420 2420
Facsimile: 420 3174
Contact: Mr Peter Goodall, Supervising Engineer, County Source Planning.

The Water Authority office at Exmouth is located at:

Lot 3, Nimitz Street,
EXMOUTH WA 6707
Telephone: (099) 491 021
Facsimile: (099) 491 763
Contact: Ms Kathy Ryan, Operations Supervisor, Exmouth.

1.5 STATUTORY REQUIREMENTS AND APPROVALS

Legislation relevant to the proposed Project is :

Water Authority Act 1984;
Environmental Protection Act 1986;
Conservation and Land Management Act 1984;
Soil and Land Conservation Act 1945;
Construction Safety Act 1972;
Bushfires Act 1954;
Rights in Water and Irrigation Act 1914;

Country Water Supplies Act 1947;
Occupational Health, Safety and Welfare Act 1984;
Aboriginal Heritage Act 1972;
Health Act 1911;
Wildlife Conservation Act 1950; and
Agriculture and Related Resources Protection Act 1976.

The Project is required to comply with all the above legislation. In that respect this document fulfils the role of a Consultative Environmental Review (CER) under the Environmental Protection Act 1986.

1.6 THE CER PROCESS

The procedure which would be followed in this Project is set out diagrammatically in Figure 2. The proposal to undertake the work was presented to the Department of Environmental Protection/Environmental Protection Authority (DEP/EPA) that administers the Environmental Protection Act 1986 in January 1995. DEP/EPA then considered the Proposal and decided that an Environmental Impact Assessment would be required. The Level of Assessment was set at Consultative Environmental Review (CER). A copy of the DEP/EPA Guidelines for the Project are presented in Appendix A. A primary environmental issue identified in the guidelines relates to the potential for impact on cave fauna.

This document has been prepared according to guidelines provided by DEP/EPA and incorporates public comment as indicated below. DEP/EPA reviewed the draft document and considered it to be suitable for public release. When this public review period is over, DEP/EPA will undertake an assessment of the Project, taking into account public comments. DEP/EPA will then make recommendations to the Minister for the Environment regarding the acceptability or otherwise of the Project.

The Minister will publish the DEP/EPA report and set conditions under which the Project must proceed. If those conditions are acceptable to the Water Authority the Authority will then commence construction of the new bores.

1.7 PUBLIC PARTICIPATION

The people of Exmouth have been aware of the present Project in concept since 1973, when the Water Authority commenced discussions regarding the long-term growth of Exmouth and likely future water supply requirements. Sites for possible construction of future production bores were selected at that time. Then, in the mid-1970s to early 1980s Leg 4 (Figure 3) was expanded and Leg 5 added incrementally, with almost yearly construction activity. In the mid-1980s the boreholes for Leg 6 (Figure 4) were added. At that time the strategy of continuing the borefield southwards changed somewhat, as it then appeared prudent to extend the borefield to the west, rather than cross Mowbowra Creek which was an expensive option. Discussions were held with the Shire of Exmouth and other interested groups regarding the impacts and cost of that approach.

In 1990-91, exploration drilling to the west confirmed good prospects. Therefore, the borefield was continued to the west as the Water Authority was still trying to contain costs by not crossing Mowbowra Creek. However, the very high cost of extending further westward (because of the very rugged terrain) was almost the same as, or more than, the cost of extending south.

Up to that time the northern end of the borefield had been over-abstracted, as evidenced by increasing salinities in that part of the field. As indicated, water quality and availability to the west was better, but to extend the borefield to the west would exacerbate the over-abstraction. It was decided the best solution would be to abandon parts of the existing borefield in the north. Water would come from bores to the west while extending the borefield to the south.

In this way the over-abstraction would be eliminated and the quality of water delivered to the Authority's customers would be improved.

In addition, it had become apparent through discussions with the Western Australian Museum that the interception of groundwater throughflow was significant and may be affecting the aquatic cave fauna. This impact was being exacerbated by the over-abstraction but would be significantly reduced by the proposed changes.

Thus discussions with government agencies and the Shire of Exmouth recommenced in earnest regarding borefield extension to the south. When it became clear that the Project would probably be carried through, the Water Authority spoke again to the Shire of Exmouth, Department of Conservation and Land Management (CALM), and the Australian Defence Industry (Royal Australian Navy) regarding options and impacts. In addition, local real estate agents, the Principal of the Exmouth High School, hotel/motel managers and Kailis Fisheries (which draw from private bores) were contacted to determine their likely long-term needs for water.

When the Project was officially commenced by means of a Proposal Application lodged with DEP/EPA, a CER level of assessment was set. This was primarily to give the public further opportunity to comment on the Project. Advertisements advising the public of the proposed Project were published monthly in the "Exmouth Times", and once in "The West Australian" and Carnarvon newspapers.

A study team was set up (Appendix B) to prepare the CER. During preparation of the CER document further discussions have been held with the Water Authority in Exmouth, the Shire of Exmouth, CALM, RAN, Gascoyne Development Commission, and Aboriginal interests.

Discussions were not required with Main Roads as the pipeline does not cross any roads, or with pastoralists, as none operate in the area. Discussions were held with Western Power regarding supply of electricity although all power lines to the borefield are owned and operated by the Water Authority.

After preparation of the Draft CER document it was informally reviewed by Water Authority staff in Perth and Exmouth, the Shire of Exmouth, and DEP/EPA. Only after the document was considered fully accurate was it approved by DEP/EPA for public release.

After a period of public review any comments received will be collated, and any changes required to the borefield construction and management programme incorporated. The revised programme, together with any additional commitments by the Water Authority, would then be re-submitted to DEP/EPA with a request for issue of Works Approvals.

2.0 NEED FOR THE PROJECT

2.1 CURRENT WATER SUPPLY REQUIREMENTS

Since commencement of data collection in 1972 there has been a steady and continuous rise in number of water services in Exmouth (Figure 5). The rate of increase in consumption increased sharply in the late 1980s when tourism began in earnest. It then fell in 1992 when USN personnel left the communications base, and is still falling as the community adjusts to the reduced permanent population and the Water Authority water-efficiency programme takes effect (Section 2.4.6).

The major users of water related to tourism are the Potshot Motel, Norcape Lodge and Caravan Park, Murat Caravan Park, and Leroy Caravan Park.

Annual consumption of water by the town is in the order of 760 million litres per year, with peak daily consumption in the order of 4,000 kL.

2.2 LIKELY FUTURE DEMANDS FOR WATER

The growth rate for Exmouth, as predicted by Government agencies, is 2.5% per annum. Some agencies believe this to be conservative due to an expected increase in tourism. This level of growth can be accommodated within current town development subdivision areas and incorporation of vacated USN properties. Based on available data, the predicted demand in the year 2004 will be 986 million litres per year with a peak daily demand of 5,090 kL (Water Authority, August 1994a, b).

2.3 CURRENT WATER SUPPLY SCHEME

2.3.1 General Layout

The layout of the current water supply scheme is shown on Figure 3. Water supply is sourced from a borefield immediately to the west and south of the town. There are currently 42 low-yielding bores which draw water from a thin lens of fresh and slightly brackish water overlying saline water. The existing bores produce water of salinities ranging from 500 mg/litre to 1,700 mg/litre. Water from the bores is pumped into reinforced concrete storage tanks or directly into the town reticulation, dependent on demand. The bores are manually operated by the Water Authority, according to levels in the town storage tanks.

2.3.2 System Supply Standards

The Water Authority is mandated by Government to provide unrestricted supply of water (in 90% of years) to its rate payers at a quality which meets National Health and Medical Research Council (NHMRC) Guidelines. It is acknowledged that, whereas the NHMRC Guidelines allow for salinities up to 1,000 mg/L Total Dissolved Salts (TDS), this is generally unacceptable to the Australian public and the preferred target is 500 mg/L TDS. This target would be difficult, if not impossible, to achieve at Exmouth, so the Water Authority has set a salinity target of 800 mg/L for the Exmouth Town water Scheme.

2.3.3 Bores

Many of the existing bores are 20-30 years old and were originally installed with steel casings and slotted steel screens. Inspections of bore condition have proven difficult, but it is felt that most are near to failure and some have already failed. This has resulted in overdraw from some remaining bores, i.e. draw in excess of the aquifer performance criteria of 100 million litres per kilometre throughflow limit (refer Section 4.1.5).

The current borefield layout has the potential to intercept about 7.5 km length of the throughflow area and should, therefore, be able to access about 750 million litres per year according to accepted aquifer performance criteria. However, water quality deteriorates towards the north and east of the borefield, so this quantity cannot be achieved without deterioration of water quality to in excess of 1,000 mg/litre TDS.

The northern end of the borefield produces water of very poor quality. Thus, if only the remainder of the borefield is used, there would be a throughflow front access of about 650 million litres per year. As current annual demand is about 800 million litres per year either some portion of the aquifer must be overdrawn, the borefield extended, or demand reduced. The Water Authority has a water efficiency programme under way in Exmouth but reductions in use are unlikely to be sufficient to remove the need for additional bores.

2.3.4 Pumps and Collector Mains

Existing electric pumps are of several types and have been installed over many years. Hence they are not standardised. This is currently being remedied progressively as the need for pump renewal arises.

Due to extremely hard surface soil conditions, the collector system from the pumps is above ground. Smaller diameter pipes were originally installed in unlined galvanised iron pipes with screw joints. These are in poor condition and are gradually being replaced with polyethylene pipes laid on the surface or covered with gravel. Large pipes are either cement-lined mild steel above ground or asbestos-cement below ground.

2.3.5 Storage

Water from the 20 northern-most bores discharges into two 2,250 (kL) reinforced concrete storage tanks (the northern tanks). Water from the remaining bores discharges into a single 2,250 kL reinforced concrete storage tank (southern tank) or directly into the town reticulation, dependent on demand. Water can be transferred between the northern and southern tanks via a 150 mm main. Under the current mode of operation this line is generally shut with a valve. It would be necessary to upgrade water transfer management after extension of the borefield.

The northern tank is at a lower elevation than the southern tank which dominates supply except during periods of high demand. To prevent the southern tank emptying, flow from the southern tank is throttled by two gate valves on the southern inlet to the town. Flow rate is set at about 30-50 kL per hour.

The current volume of water storage is sufficient to meet requirements in the foreseeable future.

2.3.6 Water Treatment

Water is chlorinated and fluoridated at two sites on the northern and southern inlets to the town reticulation system. Water treatment is provided by flow-paced dosing equipment. Both dosing facilities are fairly new, well maintained and in good condition. Currently fluoridation is carried out by the addition of powder, but this may be replaced with a florosilic acid plant some time in the future.

2.3.7 Town Reticulation

Town reticulation is mainly buried asbestos-cement pipe in good condition. The current system covers all areas which are likely to be developed in the next ten years, including the proposed marina. The current reticulation system is expected to meet foreseeable demands, although this is conditional on the continued use of the dual storage and outlet mains currently employed. Any move to a single outlet would result in substandard pressures throughout a large portion of the town.

2.3.8 Power Supplies

Power to the borefield is supplied via overhead cables. The Western Power station at Exmouth supplies 11 kV at the northern end of the borefield. There are then three 11 kV/440 V transformers and a 440 V distribution system to the northern borefield, and an 11 kV/22 kV step-up transformer located in the centre of the borefield which also supplies the southern bores, each of which has its own 22 kV/440 V transformer. The electrical switch system, etc. is in good condition and only requires normal maintenance, but the overhead wires may need to be replaced soon. The switch mechanism, overhead power lines and poles are the property of the Water Authority and are maintained by it, not Western Power.

Western Power can easily meet the electricity requirements of the additional bores from its Exmouth operations.

2.4 EXAMINATION OF OPTIONS

Some proposed options for improving water supply are discussed below. Comments and costs (where they have been calculated) are derived primarily from Halpern Glick Maunsell (1992) and updated in Water Authority (July 1994).

2.4.1 Continue Current Supply Programme

The existing population of Exmouth, and the trend towards increasing numbers of visitors for tourism, requires a continued water supply of acceptable quality. The prevention of any further expansion of Exmouth because of water supply constraints is a socially and politically unacceptable option. It is not anticipated that the Water Use Efficiency Programme can reduce consumption to levels that would make this a viable option.

If growth in demand in Exmouth is as expected, and the borefield is not expanded or supplemented, the resulting over-abstraction will cause an inland migration of the salt water interface and accelerated thinning of the fresh water layer of the aquifer. This would result in loss of habitat to stygofauna, with, presumably, corresponding impacts on stygofauna populations. It would also result in deterioration of water quality delivered to Exmouth and deterioration of private bores. Both these impacts are considered to be unacceptable.

The cost to the Water Authority of the present supply is \$1.69/kL (1992-1993 data) and the cost to the consumer \$1.03/kL. This represents a loss of about 30% to the Water Authority but is in accord with the mandate of the Authority to supply good quality water. It should be noted that most other options <u>reduce</u> the level of service which is against the Authority's mandate.

2.4.2 Dual Use Supply

This would comprise a small potable supply of good quality (or desalinated) water and a large volume brackish supply for other domestic uses. Sub-options are:

- separate reticulation of untreated brackish water produced by allowing over-pumping of some bores. This is not considered to be responsible management of the aquifer and would cause severe impacts on aquatic cave fauna. The cost of dual reticulation would also be excessive, in the order of $8M of capital investment; or
- as borefield water is already very close to the required potability standards it is not necessary, and is too expensive, to desalinate the water.

The environmental impacts of this option will be associated with laying pipes in every street in Exmouth and the resulting social disruption.

2.4.3 Bottled Water Plus Brackish

The very high cost and long-term unacceptability of such a scheme would not be appropriate to an expanding tourist industry. A water treatment plant, bottling plant, and bottle disposal service would be required. Such a supply would cost the Water Authority in the order of $5/kL of water supplied. In addition, the reduction in service would result in consumer demands for reductions in water rates. The resultant operating loss to the Water Authority, and the final cost to the consumer (i.e. reduced rates more than offset by much higher cost of purchase of bottled water) would be unacceptable.

The environmental impact of this option would primarily be associated with disposal of used bottles and with the resultant increase in salinity in the borefield which would impact on stygofauna habitat.

2.4.4 Expansion of Borefield with Desalination

The brackish water from the borefield, and some new bores, could be mixed with desalinated water to bring the salinity down to within an acceptable range. Possible sources of desalinated brackish water are:

- purchase of excess desalinated water from Harold E Holt Naval Communications Base. The Naval Base draws water from a borefield 1 km west of the Base and 3 km north of the Exmouth town water supply borefield. The water is desalinated to supply the needs of the Base. The system was originally designed to supply 1,000 people but now only supplies 200, all of whom live in the town. Options of incorporating the Naval Base and its water supply into the town water scheme are being explored with the Navy. However, such options would have short-term benefits and would not result in any significant long-term benefits in reducing the current source problems. The Naval Base borefield cannot be expanded because of salinity constraints. The existing desalination plant could supply 400 kL/day at a cost of $2.10/kL.

  The main environmental impact of connecting the Navy Base supply with the town supply is associated with a pipeline buried along the road reserve. With this option, the Navy Base borefield would be used much more heavily, with corresponding impacts on the groundwater at the northern end of the Cape, and which may also be stygofauna habitat. The Navy Base desalination plant would be used more which would result in increased volumes of hypersaline blow-down water. Disposal of the blow-down water would also have environmental impact; and

- a number of wells at the northern end of the Exmouth borefield could be re-routed to a small desalination plant. This would exacerbate the current over-abstraction problems and have a much greater effect on the stygofauna. Such a plant could produce up to 500 kL/day at a cost of about $2.40-$3.08/kL. Desalination will produce hypersaline blow-down water and disposal of this will also have an environmental impact by locally increasing salinity at the discharge point.

2.4.5 Seawater Desalination

Seawater from wells along the coast could be desalinated. An initial plant supplying 500 kL/day could supply water at a cost of about $3.26/kL. Seawater desalination would produce hypersaline blow-down water. Disposal of blow-down water will result in an environmental impact by locally increasing salinity at the discharge point.

2.4.6 Water Conservation Measures

There has been a reduced peak demand since the USN left and the trend has been to a reduction in peak consumption. This trend has already begun to reverse as USN buildings are sold and have become re-occupied, and as tourism increases. Some costs could be reduced (but these are not significant) by not refurbishing certain components of the system and gradually taking them out of service. Ultimately, however, further expansion of the borefield will be necessary, or a ceiling must be put on development at Exmouth. The Water Authority has attempted to reduce water use within the town by implementation of a water efficiency education programme. The average domestic use in Exmouth is not considered to be excessive, so savings in this area can, at best, be minimised.

The largest five or six users of water have been identified and approached by the Authority. Their operations will be examined in detail to try and identify water efficiency measures. Examples might be landscaping with low water-demanding plants, automatic night reticulation systems, and expanded use of treated sewage effluent for watering public open space. The Water Authority would enter into a cost-sharing partnership arrangement to help the users reduce their demand on the public supply.

It is estimated that the savings to water users would be approximately $20,000 and net savings to the Water Authority an additional $20,000.

Following the high volume water users conservation programme, it is proposed that a conservation programme be targeted at domestic users. It is estimated that such a programme could save as much as 69,000 kL/year. This would translate to an annual saving of $33,000.

2.4.7 Expansion of Borefield without Desalination (Preferred Option)

In order to meet the demand for an increased quantity of water at a reasonable cost to the community, more bores must be constructed. However, as each bore only has a capacity in the order of 100-150 kL/day, the number of bores required can be expected to increase. Thus other options, as discussed above, must be long-term considerations.

There are two options within the proposal to extend the borefield:

- **Option 1**: utilise the existing high yielding bores to the west of the existing borefield to meet peak demands, with further development to the south to meet annual demand; or
- **Option 2**: develop bores to the south to meet both peak and annual demands. This option would only be implemented if the existing high yielding bores to

the west of the current field do not hold up under pumping. This is currently under investigation.

These options are compared in Table 1 and illustrated in Figures 4 and 6.

TABLE 1

COMPARISON OF WATER SUPPLY SOURCE ALTERNATIVES

SOURCE ALTERNATIVES	MAJOR FEATURES AND IMPACTS	CAPITAL COST $ M	COST PER kL ($/kL)	ANNUAL YIELD (kL/YR)
Expansion of borefield without desalination (Option 1)	◆ Equip existing western bores ◆ Equip existing bores to the south ◆ Develop new production bores to the south ◆ Decommission some bores ◆ Replace some pipes ◆ Retain current tanks and connection ◆ Retain treatment plants and inputs to town	5.08	3.23	986,000
Expansion of borefield without desalination (Option 2)	◆ Equip existing production bores to the south ◆ Develop new production bores to the south ◆ Decommission some bores ◆ Replace some pipes ◆ Retain current tanks and connection ◆ Retain treatment plants and inputs to town	6.31	4.00	986,000
Continue current supply programme	◆ Decommission some bores ◆ Replace some pipes ◆ Retain current tanks and connections ◆ Retain treatment plants and inputs to town ◆ Requires over abstraction of aquifer ◆ Will cause inland migration of salt interface ◆ Will result in loss of stygofauna habitat ◆ Will produce unacceptable water quality	0	1.69	986,000

TABLE 1 (continued)

SOURCE ALTERNATIVES	MAJOR FEATURES AND IMPACTS	CAPITAL COST $ M	COST PER kL ($/kL)	ANNUAL YIELD (kL/YR)
Dual use supply	◆ Equip existing production bores to the west ◆ Equip existing bores to the south ◆ Develop new bores to the south ◆ Replace some pipes ◆ Retain current tanks and connection ◆ Reduce treatment plants ◆ Retain inputs to town ◆ Construct secondary reticulation system	8	5.10	986,000
Bottled water plus brackish	◆ Equip existing production bores to the west ◆ Equip existing bores to the south ◆ Develop new bores to the south ◆ Decommission some bores ◆ Replace some pipes ◆ Retain current tanks and connection ◆ Abandon treatment plants ◆ Retain inputs to town ◆ Construct water purifying and bottling plant ◆ Establish bottled water distribution system	4.0	3.00	986,000
Expansion of borefield with desalination	◆ Decommission some bores ◆ Replace some pipes ◆ Retain current tanks and connections ◆ Retain treatment plants and inputs to town ◆ Construct new brackish water desalination plant ◆ Requires over abstraction of aquifer ◆ Will cause inland migration of salt interface ◆ Will result in loss of stygofauna habitat ◆ Will produce unacceptable water quality	10.3	5.00	986,000
Seawater Desalination	◆ Construct seawater bores ◆ Construct desalination plant	9.1	7.00	986,000
Water Conservation Measures	◆ Large users conservation of irrigation water ◆ Domestic users conservation programme	0.1	Annual savings $73,000	63,000

Clearly an important factor in decision-making must be the cost to the State and the local community. Perth metropolitan area ratepayers heavily subsidise the cost of water to remote communities, including Exmouth. The additional $1.23 M capital outlay and $0.68 M in future expenditure for Option 2 cannot be justified just to reduce abstraction rates of certain bores in some areas at Exmouth. Further, Option 1 requires the least development of the borefield to meet projected demands whilst complying with the current understanding of resource abstraction constraints. Option 2 still remains available for future examination as long-term viability of Option 1 is still under consideration.

3.0 DESCRIPTION OF THE PROPOSED PROJECT

3.1 DEFINITION OF THE RESOURCE

3.1.1 Location and Quantity

Groundwater occurs in confined and unconfined aquifers in the geologically young calcareous sediments which make up the Cape Range and coastal plain. These sediments are believed to extend to a depth of 600 m near Exmouth and overlie much older (Palaeozoic and Mesozoic) sediments. A hydrological cross section is presented in Figure 7.

The volume of fresh water under Cape Range is estimated to be about 200 million cubic metres per kilometre length of the range. However, recharge to the shallower aquifers is dependent on the low (about 280 mm per year) and unreliable local rainfall. The "safe yield" of aquifers flowing to the east coast of the peninsula has been estimated to be about 100 million litres per year from each kilometre length of the range (Section 4.1.5).

Maximum allowable annual abstraction rate for each kilometre of resource, and target abstraction rates, are set out in Table 2.

TABLE 2

MAXIMUM ALLOWABLE ABSTRACTION, AND EXISTING AND TARGET ABSTRACTION RATE FOR EACH LEG OF THE PROPOSED BOREFIELD

BOREFIELD LEG (Figure 4)	MAXIMUM ALLOWABLE ABSTRACTION RATE (ML/YR)	1992-1993 ABSTRACTION RATE (ML/YR)	PROPOSED ABSTRACTION RATE (ML/YR)
1	100	168	90
2	135	136	90
3	85	14	80
4	175	150	175
5	135	194	135
6	160	0	150
7	125	0	125
8	180	0	180
TOTALS	**1,095 (630 in Legs 1-5)**	**662 (Legs 1-5)**	**1,025 (All Legs)**

It can be seen that Legs 1 and 5 were being over-abstracted in 1992-93, and that Legs 3 and 4 have some water available, but not enough to support Exmouth in the long term.

3.1.2 Water Quality

Groundwater in the Exmouth area is very hard (high in calcium) and the sodium concentration is close to the World Health Organisation Guidelines for Drinking Water Quality. However, total salinity is the chemical parameter of greatest concern (Halpern Glick Maunsell, 1992).

A layer of fresh to brackish (400-600 mg/l TDS) water overlies much more saline water in the Tulki and Mandu Limestones. There is a wedge of saline water in these strata which extends inland for about 5 km from the coast in the Exmouth area. Further to the west (towards the centre of the Range) the thickness of the layer of fresh groundwater is up to 150 m, but access for drilling is extremely difficult and costly because of the rugged landscape.

Currently the southern, better quality bores are pumped first, then, with progressively increasing demand, the more saline northerly bores. This practice would be continued, providing the abstraction limits are not exceeded. Prior to construction of the full borefield, however, some overdraw may be inevitable so as to avoid use of the more saline northern water.

Water quality in most of the southern bores is in the order of 600-1,000 mg/l TDS. In the north it ranges from about 700-1,600 mg/l TDS.

There are no records of groundwater levels beneath Cape Range before installation of the Naval Communications Base and Exmouth Town Water Supply borefields, or backyard bores for domestic irrigation in Exmouth. Water Authority records provide evidence of changes in both water level and salinity within the existing Exmouth borefield. Over the period 1981 to 1991 water levels declined in most bores. This was attributed to long-term below average rainfall. The above-average rainfall in 1992-93 resulted in a rise in water level in most bores.

Half of the apparent long-term changes in water levels (original measurement compared with June 1993 measurement) are in the range -0.97 m to -0.11 m, with (less reliable) extreme values of -2.66 to +0.96 m. Apparent increases of water level in some bores are considered to be incorrect. They are attributed to the relatively crude method of measurement of water levels in the production bores.

Pumping causes a local "cone of depression" of the water table surface, centred on the bore. The combination of low pumping rates and high aquifer conductivity results in relatively small drawdown around production bores in the Exmouth Borefield. Measurements of water levels taken between one and eight hours after pumping show that the residual drawdown is generally less than 1 m and very rarely 2 m.

Salinity records for bores used for groundwater abstraction also show changes of salinity relative to original measurement. Half the changes are in the range +12% to +50% with (less reliable) extremes of -9.6% to +233%.

The greatest increases in salinity are believed to be a result of "upconing" of the underlying saline water as a result of inappropriate bore construction and excessive pumping rates at those particular locations. These changes do not present a realistic picture of changes of salinity over the borefield as a whole.

3.2 BORE CONSTRUCTION

3.2.1 Options for Sites of Bores

The Water Authority has examined two options for development of the borefield (Table 1). The option chosen is for redevelopment of the western extension of the existing borefield in the north and further extension to the south.

A primary factor in selecting sites for new production bores was the salinity of the groundwater and the thickness of the fresh/brackish water layer overlying the more saline water. Many of the existing production bores are hydraulically capable of being pumped at greater rates, but records show that this results in the production of higher salinity water due to up-coning of saline water from beneath the fresh water layer. A maximum desirable salinity of 800 mg/l has been adopted. This limit provides a margin for any possible increase of salinity with increase in future demand. Existing bores producing water with a salinity of more than 1000 mg/l would be closed off and abandoned.

Another factor in selecting bore sites is the safe yield of the aquifer flow from Cape Range towards the east coast of the peninsula. This is estimated at 100 million litres per year for each kilometre length of the Range. Test production bores to the west of the existing borefield show lower salinity water. Because of the greater depth (or possible absence) of the salt water interface in this area higher pumping rates may be acceptable. This would be determined by controled controlled test pumping and modelling methods. Other bores which produce water of marginal quality from close to town would be abandoned to maintain total draw in this area to within the safe yield of the aquifer.

Thus, to remain within the estimated safe yield of the aquifer, the only way to increase total yield is to extend the borefield to the south. New production bores in the southern extension would be tested by salinity profiling and controlled test pumping to establish sustainable pumping rates. Low pumping rates will probably be required to minimise salt water up-coning. The rugged topography makes it difficult to obtain access for drilling equipment and bore maintenance to some sites which may be otherwise attractive, such as within Cape Range itself.

3.2.2 Construction Method

Bores would be constructed by a contractor using standard drilling and casing methods. All new production bores will have narrow slots to exclude the majority of stygofauna.

3.3 PIPELINE INSTALLATION

3.3.1 Options for Construction and Routing Pipelines

Polyethylene pipes would be used as these are safe and durable. It must be borne in mind that the water is near-potable to potable quality and so there would be no salt-kill from leaking or burst pipes.

Burial of pipes is impractical as almost the entire route from the bores to the collector main is rock. It is believed the pipes should not be covered with soil. Advantages and disadvantages of covering the pipes are set out in Table 3: significant environmental considerations are shown in italics.

In addition, the cost of covering the pipes far outweighs the risks and cost associated with leaving the pipes uncovered, and cannot be justified.

The collector main would be made of UPVC and would approximately follow the route of the powerline from Exmouth to Learmonth. It is mostly on low-lying sand and clay country and can easily be buried. In rocky areas where the collector main would cross minor creeks it would simply be laid on the surface and replaced if damaged by flooding. At Mowbowra Creek it would either be buried, with concrete anchors to hold it down during floods, or would pass over the creek in a raised cradle.

3.3.2 Drainage Control along Pipe Routes

It is recommended that pipes from the bores to the collector main not be covered with soil. Thus, the pipes will not create a barrier to overland rainfall flow and there should be almost no change to the surface hydrology. Where the pipes cross drainage lines (there are very few such locations), they would be laid on the surface and would not inhibit or redirect surface runoff.

The collector main on the coastal plain would be mostly buried, and the channel created would be back-filled in such a way as to allow for settling and to ensure that runoff does not become re-routed along the trench alignment. Where the collector main crosses Mowbowra Creek it would either be buried and anchored down with concrete, or suspended about 3 m above the creek in a steel cradle supported on each bank by concrete stanchions. Suspension of the pipe would have least environmental impact and this is the favoured option.

TABLE 3

ADVANTAGES AND DISADVANTAGES OF COVERING OR NOT COVERING THE PIPELINES WITH SOIL
(significant environmental considerations shown in italics)

PIPE TREATMENT	ADVANTAGES	DISADVANTAGES
Not covered	1. *Minimal disturbance to the environment along the pipe route (very little clearing of pipe route required).* 2. Small fauna can pass easily under the pipe. 3. Medium and large fauna can pass easily over the pipe. 4. *No gravel or sand required as cover material. This reduces the need to create or enlarge borrow pits (about 5,000 m^3 of material required).* 5. No cost or environmental impact of transport of cover material. 6. *No need or cost to rehabilitate borrow pits.* 7. Easy inspection of pipe for minor leaks or damage. 8. *Minor or no diversion of surface water flows which may affect cave hydrology.* If required, the pipe can be placed on small concrete feet near caves.	1. Excessive movement of the pipe due to thermal expansion and contraction. This increases the likelihood of pipe damage and consequent failure. 2. Potential for vandalism of the exposed pipe increased. 3. Risk of damage by fire increased. 4. Ultra-violet radiation causing degradation of plastic (minor & long-term). 5. Pipe visible and therefore obtrusive (however, area not used by public). 6. Pipe will move with expansion and contraction and pumping pressures, causing rubbing of the soil surface and clearing of small areas. 7. The water temperature in the pipe is raised due to heating by the sun.
Covered	1. Reduction in movement of the pipe due to thermal expansion and contraction. However, a substantial covering would be required to achieve sufficient reduction. 2. Reduced vandalism of the pipe. 3. Less risk of damage by fire but only if covering substantial. 4. Reduced damage to pipe by ultra-violet radiation. 5. Small fauna can pass over the pipe by negotiating the mound of earth. 6. Medium and large fauna can pass easily over the pipe. 7. Reduced visual impact, but note that the area is not used by the public.	1. *Much greater disturbance to the environment along the pipe route (perhaps to 10 m wide as machinery laying the soil cover would need to access the pipe laterally).* 2. *Gravel pit or removal of beach sand required to supply covering material. Estimated cover material required ca 5,000 m^3: this would create or enlarge a second area of impact.* 3. *If a suitable supply of gravel cannot be found, an alternative covering material would be beach sand. This amount of sand removed from a beach-front area could exacerbate local erosion.* 4. *Salt from beach sand could be detrimental to the environment in the borefield.* 5. High cost of transport of cover material. 6. Difficult to inspect pipe for minor leaks or damage. 7. *Diversion of surface water flows which may affect cave hydrology.*

Access roads to the pumps would have minimal windrows as most of the area is covered with rock and there is only a thin veneer of soil. There would, therefore, be very few earth bunds which might redirect flow.

3.3.3 Vegetation Removal

Vegetation over the route and bore sites is primarily spinifex (*Triodia* sp) as described in Section 4.2.2. There are also scattered shrubs of *Melaleuca cardiophylla, Acacia bivenosa* and *Acacia pyrifolia* shrubs. Some were pushed aside when the access tracks were constructed for exploration. There will be no need to clear any additional vegetation unless it is required that the pipeline be covered with soil. In the latter case about another 10 m clearance width would be damaged along the 18 km of pipe routes, totalling about 18 ha of clearing.

Clearing of vegetation along the collector main route will be minimal as an access road already exists to service the Exmouth to Learmonth power line. Vegetation here is *Acacia bivenosa* and *Acacia pyrifolia* over spinifex with scattered eucalypts, mainly *Eucalyptus dichromophloia* or *E. prominens*.

3.3.4 Topsoil Removal

There is virtually no topsoil over much of the area in the borefield. Where it does exist it rarely exceeds more than a few centimetres. As it is anticipated that the pipe would not be buried there would be no need to remove and replace topsoil.

Topsoil along the collector main is minimal. However, once the trench has been dug, the pipe laid and the trench refilled, the temporarily removed topsoil would be pushed back over the surface.

3.4 BOREFIELD INFRASTRUCTURE

3.4.1 Power Supply Type

Power supply to the bores would be via spur lines from the existing Water Authority-owned electrical network which services the existing bores. This is an 11 kV/22 kV line (Section 2.3.7). The poles are steel, with standard or greater spacing. New lines would have the same structure and configuration.

Diesel-powered generators are sometimes used in the early testing of bores when electric power to the site is unavailable. In these circumstances only small amounts of fuel are kept on site and the tanks are steel and kept within a plastic lined and bunded pit. However, diesel is not an operational option because of the excessive cost and risk of accidental groundwater contamination.

3.4.2 Route Options

There are no acceptable alternatives for pipeline routes. The landscape is highly dissected and the only feasible access is along the ridge crests. Any activity on slopes would lead to erosion of the already skeletal soil, and in the gully floors there would be a greater risk of washing out or damage to the pipe. Generally, pipeline and access road routes follow existing four-wheel drive tracks which are already disturbed.

The collector main would follow the Exmouth to Learmonth powerline as this route is already disturbed.

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The collector main would follow the Exmouth to Learmonth powerline as this route is already disturbed.

3.4.3 Telemetry System

Bore pumps and valves in the new sites would be fitted with telemetrically-controlled systems which can be operated and controlled from the Water Authority office in Exmouth. There would, however, be regular visual checking of all bores and pipelines.

The use of the telemetric system has been checked with the Naval Communications Base and has been cleared for operation.

3.5 WATER TREATMENT AND DISTRIBUTION

The existing water treatment plants will continue to operate. They will not need to be upgraded. Water reticulation within Exmouth will remain unchanged except for normal maintenance and the provision of extended services as demanded by regional growth.

3.6 CONSTRUCTION REQUIREMENTS

3.6.1 Workforce and Workforce Accommodation

Construction would be undertaken by Water Authority staff, or private contractors overseen by Water Authority staff. Probably four people would be on the contracting team. Pump installation would also be undertaken by contractors, probably three people. Pipe laying would be by contract with three people.

The contractors would arrange all accommodation in Exmouth. It would probably be hotel/ motel accommodation with meal facilities, etc., organised through the hotel.

3.6.2 Transportation, Power Supplies and Fuels

Transport to and from site would be by contractors' truck. Power supply for drilling equipment and on-site operations would be by means of diesel engines and a small generator. It would be a condition of contract that fuels, oil, etc., are kept in secure containers, that spillage is prevented and, in the event of accident, cleaned up and removed off site, not buried. Refuelling of heavy vehicles would be required on site but oil changes would be carried out off-site in Exmouth. Any spilled fuel or spent oil would be removed from site, not disposed of onto the ground or in a hole.

Daily or more frequent inspections of the field operations would be carried out by Water Authority staff. Failure by contractors to meet specified conditions would result in loss of contract, with the cost of remediation being transferred to the contractor but the work undertaken by the Water Authority.

3.6.3 Water Supply for Workforce, Communications and Waste Disposal

Water would be carried to site daily by each person on the contractor's team. Communications between construction sites and the Water Authority at Exmouth would be by two-way radio (mobile telephones do not operate in the area). Sewage disposal would be by chemical toilet supplied by the contractor. Emptying of the tank would only be carried out at a Shire-approved disposal site.

3.7 OPERATIONAL REQUIREMENTS

Management of the extension to the borefield would require the same number of Water Authority staff as at present. There would be no change to Water Authority operational infrastructure except where the use of telemetry would reduce staff workload.

4.0 DESCRIPTION OF THE ENVIRONMENT

4.1 BIOPHYSICAL ENVIRONMENT

4.1.1 Climate

The main climatic feature relevant to the Project is rainfall recharge to the aquifers. The long-term average rainfall is about 260 mm, however, rainfall at Exmouth for the period 1985 to 1991 was significantly below average while the 1992 and 1993 rainfall totals were above average.

In order to evaluate long-term trends in rainfall which may affect the borefield, the total annual rainfalls for four weather stations on or near the Cape Range peninsula were compared (Figure 8). It is seen that total annual rainfalls are erratic. This is because they are mostly related to irregular cyclonic events. However, they also show very similar trends at all sites.

Thus, having ascertained that the recorded annual rainfall at each of the stations is similar, it was then possible to use the long-term data available at Exmouth Gulf Station and Ningaloo Station to examine these trends. Exmouth Gulf Station has 79 years of records and Ningaloo has 95 years. Results are presented in Figure 9. There is a suggestion of a decrease in total annual rainfall during the early 1900s but it then appears to stabilise. It is uncertain if the perceived decline in the early data is real or chance because of irregular cyclonic events. If the graph is reliable, there is currently slightly less than average variation in annual falls, but there is no trend in overall rainfall. Predictability of falls in the foreseeable future should be similar to the present.

The only other climatic factor which may affect the Project is strong winds causing dust blow. The coastal plain is very flat and occasionally experiences strong winds which could be an issue when trenching is being carried out for the collector main. Although there are no residences anywhere in the area, if strong winds cause excessive dust blow for the trenching crew then operations would stop until the wind had subsided.

4.1.2 Geology

The area is located within the Carnarvon Basin (Hocking *et al.*, 1987). The peninsula is formed of Tertiary Age calcareous sediments, with minor Quaternary deposits near the coast. The area of the borefields consists of a conformable sequence of three calcareous sediments which dip to the east from the axis of the Cape Range. The upper formation is the Trealla Limestone: this formation is from 0-20 m thick near Exmouth and contains most of the accessible sink holes and other karst features such as caves, pipes and solution cavities. Beneath this is the Tulki Limestone some 80 m thick, and beneath that again the Mandu Limestone. The deeper sediments are generally less cavernous. Water is drawn from both the Trealla and Tulki Formations. Layers of marl (a clay-like calcareous sediment) occur in the Mandu Limestone and may act as barriers to water flow. The Mandu Limestone also contains fresh water inland but mainly salt water near the coast. A geological and hydrological cross-section of the area was presented in Figure 7.

4.1.3 Topography and Geomorphology

North West Cape (also known as Cape Range peninsula) is a peninsula measuring 96 km in length from north to south and 21 km from east to west. Exmouth town and the coastal plain between Cape Range and Exmouth Gulf (Figure 1) rises up to about 20 m Above Sea Level (ASL).

From the coastal plain Cape Range rises steeply to about 300 m ASL. Ordinarily, with such a steep rise in topography, there would be a steep hydraulic gradient towards the coast.

However, the limestones are extremely permeable and so the groundwater gradient is poorly developed.

4.1.4 Soils

Soils of the borefield area are skeletal, pink, alkaline clays derived from breakdown of the underlying limestone. They are rarely more than a few centimetres deep.

Valley floors are almost entirely pebbles as bands of conglomerate within the limestone erode away and release the rounded, water-washed stones they contain.

Soils along the collector main route are mostly over a metre deep and are pink, alkaline clays mixed with sands of marine origin. These soils are saline and have a high pebble content derived from the conglomerates.

4.1.5 Groundwater Hydrology

Groundwater occurs in confined and unconfined (water table) aquifers within the limestones which make up the peninsula. Geological folding of the rocks which form Cape Range has resulted in jointing and fracturing. There appear to be major sets of joints in the rocks, running north and east, and north-east and north-west. These joints and joint intersections are suitable sites for the construction of production bores (Martin, 1990). Bore yields ranging from negligible to 460 kL/day have been reported from pumping tests of bores into the Tulki and Mandu limestones.

Unconfined water table aquifers in the Cape Range area are recharged both directly by rainfall, and indirectly through the beds of ephemeral streams which carry storm runoff from the Range. During the 1980s three major rainfalls (in excess of 200 mm of rain in a month) were recorded at Exmouth. There were changes in water level with rainfall, although there was no clear rapid-response correlation.

Rainfall recharge maintains a layer of fresh groundwater in the limestones. Due to lower density, the fresh water "floats" on top of the saline water, with a zone of mixing occurring between the two. This freshwater layer varies from negligible thickness at the coast to at least 20 m well inland. Forth (1972) estimated recharge for the area west of the borefield to be 25 mm/year or about 10% of average rainfall. This estimate has been supported by subsequent monitoring.

Water levels in the existing borefield are rarely more than 1 m Above Height Datum (AHD), regardless of the pumping regime. Martin (1990) reports water levels in seven new bores (not used for groundwater production), about 7 km to the west of the existing borefield, as ranging from 0.84 m to 7.51 m AHD. Because of increasing ground elevation the depth to water in these bores ranges up to 109 m below ground level.

An accurate map of the regional water table has not been produced because of the lack of monitoring bores and the coarseness of water level measurements. According to Forth (1972) the gradient of the water table was about 1.7×10^{-4} in the borefield as it existed in the early 1970s. This gradually increased to the west to about 3.2×10^{-4} near the Range. The flatter water table gradient near the coast is attributed to karst features below the water table permitting easy passage of water through the limestone.

Forth *(ibid.)* considered the transmissivity of the aquifer to be about 2,720 m^3/day and concluded that throughflow in the aquifer was about 460 m^3/day/kilometre of length of the Range.

The karst features are developed primarily below the water table within about 5 km of the coast and above the water table to the west of the existing borefield.

4.1.6 Groundwater and Cave Systems

The general hydrogeological model for oceanic islands can be applied to the groundwater of Cape Range peninsula (Allen, 1993). In this model, a fresh water lens overlies salt water. In essence, a wedge of salt water lies under the fresh water contained in the limestone. The greater the transmissivity of the limestone and the more arid the area (or the greater the withdrawal of water for human use) the greater the distance inland the wedge penetrates. In the Exmouth area the fresh water-salt water transition is at about 5 km from the coast (Martin, 1990), which is exceptionally far inland.

Where the layer of fresh groundwater overlies seawater, there is a broad zone of diffusion 10-20 m thick which partly results from tidal changes (O'Driscoll, 1963; Forth, 1972, 1973; Martin, 1990). This zone of diffusion has been considered to be 10-20 m thick, but it is clearly much thicker than that even 3 km from the sea. This diffusion zone is the major habitat of the aquatic fauna which occur in the caves (refer Section 4.2.6).

In caves as far as 1.5 km from the coast, a flow of water under tidal influence is seen. In the Exmouth area, the inland limit to the saltwater interface appears to be controlled by the presence below the water table of solution cavities and channels (Martin, 1990), and in the Water Authority borefield, highly transmissive karst features allow the groundwater levels to be influenced by tides up to at least 3.5 km from the coast (Forth, 1973).

Inland from the borefield, transmissivity of the rock decreases, with the hydraulic gradient increasing 40-fold from the borefield westwards to where the Mandu Limestone occurs (data from Martin, 1990). This gradient, together with the distribution of stygofauna in both production and non-production bores, suggests that a substrate transmissivity represented by a gradient of 6.8×10^{-3} is unsuitable for stygofauna (Humphreys, 1994).

4.1.7 Surface Hydrology

There are several surface watercourses in the area of the borefield, but these rarely flow except after extremely heavy rainfalls. The drainage system consists of a complex network of small valleys which probably follow fractures in the limestones. These valleys are quite deep for their width as the limestone readily erodes. Mowbowra Creek is the only substantial water-course and flood debris has been observed up to 2 m above the valley floor. It has not been known to flow for several years.

The terrestrial cave fauna are supported mainly by plant-derived detritus being washed into caves after exceptional rain and supplemented by downward seepage, root growth, carcasses etc. (Humphreys, 1991). As such, any structure or activity changing the natural drainage lines or the primary productivity of the area will impinge on cave fauna. In consequence, surface development and subsequent management of the borefield will be designed to cause minimal disturbance to both natural surface flow and the primary productivity of the area.

4.2 BIOLOGICAL ENVIRONMENT

4.2.1 General

Species richness of flora and fauna on the Cape Range peninsula is exceptionally high for the region because of the geomorphologic diversity of the area. High ranges, deep gorges, caves, undulating limestone hills, deep and shallow valleys, outwash plains, residual inland dunes and coastal dunes are all represented on the peninsula.

The surface biota is, nonetheless, unexceptional, being essentially an arid zone biota with little endemism. Almost all of the plants and certainly all but a few of the surface (as opposed to cave-dwelling) fauna are common and widespread throughout the Pilbara and Gascoyne regions.

4.2.2 Vegetation and Flora

Vegetation of the borefield area was described by Beard (1975) as being dominated by eucalypts and acacias. Inspection of the area proved this to be the case along the drainage lines but not on the hills. The dominant species over almost the entire area was *Melaleuca cardiophylla*, although *Acacia* species were prominent in some locations. A vegetation description which would be typical of almost the entire borefield is as follows:

Stratum 1

Melaleuca cardiophylla shrubs from 5 to 50% cover depending on soil depth and amount of runoff. In some locations *Acacia bivenosa* and *A. pyrifolia* may become locally abundant, but they are rarely dominant. Other widespread but not particularly common species are *A. tetragonophylla, A. xylocarpa, Cassia pruinosa* and *Grevillea variifolia.*

Stratum 2

Stratum 2 is dominated by *Triodia pungens* at all sites with canopy cover varying from 10 to 90%. There are small numbers of shrubs of *Brachysema macrocarpum, Indigofera monophylla* and *Solanum lasiophyllum* present.

In the drainage lines, where the soils are a little deeper and a little more runoff is available, the vegetation is almost entirely as follows:

Stratum 1

Eucalyptus dichromophloia, E. oleosa and *Eucalyptus ?prominens* 3-4 m tall, together with scattered trees of *Ficus platypoda* in clumps on rocky outcrops, and sometimes large *Acacia bivenosa* and *A. pyrifolia* shrubs/trees.

Stratum 2

Mainly *Acacia bivenosa* and *A. pyrifolia* to 2 m tall together with scattered *A. tetragonophylla, A. xylocarpa, Alyogyne cuneiformis, Brachychiton australe, Corchorus parviflorus, Exocarpus sparteus, Gossypium robinsonii* and *Grevillea* sp.

Stratum 3

Triodia pungens hummock grass with small clumps of *Themeda australis*, plus scattered shrubs of *Senna artemesioides, Dodonaea* sp, *Eremophila leucophylla, E. longifolia, Indigophora monophylla, Hibbertia spicata* and *Solanum lasiophyllum.*

These types of vegetation structure and species composition were observed along every leg of the borefield in both the existing field and throughout the proposed extension. Inspection of aerial photographs suggests the assemblage is very similar over the entire area of low, undulating limestone hills which form the eastern border of Cape Range.

4.2.3 Rare or Significant Flora

Although no Gazetted Rare (refer Appendix C) plant species are recorded from the Exmouth and Cape Range area, a number of scarcer and endemic species are known (Keighery and Gibson, 1993). These are listed in Table 4.

TABLE 4

SIGNIFICANT FLORA RECORDED FROM THE CAPE RANGE AREA

SPECIES	CONSERV. CODE	KNOWN DISTRIBUTION	FLOWERING PERIOD AND COMMENTS
Abutilon sp Cape Range	2	Cape Range, Yardie Creek, Learmonth	Jul-Oct. Red sand over limestone.
Abutilon sp. Quobba	2	Quobba, Cape Range, Manilya	Jul-Oct.
Acacia alexandri	3	Cape Range, Exmouth	Jun-Sep. Shallow soil over limestone, especially along gullies.
Acacia didyma	3	Dirk Hartog Island, Tamala Station, East Wallabi Island	May-Oct. Included because Tamala Station and the islands are of similar geology and soils although they are some distance from Cape Range.
Acacia startii	3	Cape Range, Rough Range, Manilya River	Jul-Aug. Coastal sand and limestone.
Acanthocarpus rupestris	Endemic	Cape Range	On limestone.
Acanthocarpus sp (Trudgen 6654)	Endemic	Cape Range western side	Red sand over limestone.
Brachychiton obtusilobus	4	Cape Range	Aug-Sep.
Corchorus elachocarpus Cape Range	2	Exmouth, Ningaloo Station	May-Sep.
Daviesia sp Cape Range	2	Cape Range south end	Sep-Oct. Red sand dunes and sand over limestone.
Eremophila glabra Dirk Hartog	2	Dirk Hartog Island, Coral Bay, Dorre Island	Sep-Dec.
Eremophila occidens	2	Cape Range	No data
Eremophila youngii ssp *lepidota*	4	South of Cape Range, Roy Hill, North of Mt. Vernon, Paraburdoo	Mar, Jun.
Eucalyptus "ultima"	Endemic	Cape Range	On skeletal soils over limestone.
Grevillea calcicola	Endemic	Western side and in gullies	On limestone and sand over limestone.
Grevillea variifolia	Endemic	Cape Range and Rough Range	On limestone or shallow sand over limestone.
Ipomoea yardiensis	Endemic	Cape Range western side	On limestone.
Lechenaultia aff. *lutescens*	Endemic	Cape Range western coastal plain well to south	Red dunes over limestone after fire.

TABLE 4 (continued)

SPECIES	CONSERV. CODE	KNOWN DISTRIBUTION	FLOWERING PERIOD AND COMMENTS
Livistona alfredi	4	Millstream, Cave Creek, Cape Range	Nov-Dec.
Melaleuca huegelii ssp *pristicensis*	2	Shark Bay, Dirk Hartog Island, Tamala	Sep-Oct.
Microtis media ssp *quadrata*	3	Albany to Augusta	Dec-Jan.
Stackhousia umbellata	Endemic	Cape Range mainly on western side	On terraces but not calcarenities.
Verticordia serotina	2	Cape Range	Sep. Red sand over limestone.
Zygophyllum sp Karratha	3	Karratha, Coral Bay	No data

NOTE: Conserv. Code means Conservation Code as defined by the Department of Conservation and Land Management (CALM) (refer Appendix C).

These plants were specifically searched for in the field. The only one recorded was *Brachychiton obtusilobus* which was recorded both in the present borefield and at several locations on all legs in the proposed borefield. It is believed it would not be adversely affected by the Project because it:

- is common and widespread, including to the west beyond borefield limits;
- appears to prefer upper and mid-slopes of the valleys whereas the pipes and access tracks, by nature of the topography, must follow the ridge crests;
- mostly grows in cracks in indurated limestone where it normally receives very little moisture. Thus, minor changes in surface runoff, if any did occur, would be unlikely to affect it; and
- is widespread and appears to be unaffected in the existing borefield which has been in operation for many years.

No *B. obtusilobus* specimen was observed within 3-4 m of the access tracks and so it is highly unlikely that any would be damaged by pipe laying. However, covering of the pipe with beach sand, as has been suggested, is not recommended because this species may be sensitive to salt which could leach from the sand and wash onto the roots of nearby plants. The additional disturbance caused by covering the pipe with sand or gravel could also damage some of the trees.

4.2.4 Terrestrial Fauna

As indicated above, the surface-dwelling fauna of the area is mostly widespread and common. Searches were made for scats, tracks, burrows or other signs of fauna, and direct observations were made. Nothing was found to suggest the presence of any animals other than those already recorded in the literature.

Kendrick (1993) indicates that there are 30 mammals, 84 reptiles, five amphibians and about 200 birds known from the Cape Range peninsula either as living species or from fossils. With the exception of the Black-footed Rock-wallaby (*Petrogale lateralis*) all the living mammals are common elsewhere in the arid and semi-arid North-west. Most of the bats are northern species, but two southern species have also been recorded.

The reptiles and birds are also widespread and common, again mostly with affinities to the north although some southern species are represented. Only two species, the skink lizard *Lerista allochira* and the Grey Shrike-thrush (*Colluricincla harmonica rufiventris*) show specific and sub-specific endemism within the peninsula.

A habitat evaluation was carried out at several locations for a number of key environmental features which are known to be related to certain groups of fauna or to specific fauna requirements. These are set out in Table 5.

TABLE 5

HABITAT FEATURES KNOWN TO BE OF SIGNIFICANCE TO SOME FAUNA AND OCCURRING IN THE EXISTING AND PROPOSED BOREFIELD AREAS

FEATURE	ABUNDANCE
Abundance of hollow tree limbs:	absent.
Abundance of hollow fallen limbs:	absent.
Abundance and depth of leaf litter:	mostly absent.
Soil depth and texture suitability for burrowing:	moderate suitability but rarely deep enough.
Presence and cover of spinifex:	abundant.
Presence and cover of bunch grasses:	absent.
Time since fire:	long unburned.
Presence of deep cracks in the soil:	absent.
Presence of surface saline lakes:	absent.
Presence of exposed fresh water:	absent.
Presence of seeps and soaks:	absent.
Drainage and creek lines with denser vegetation which might form corridors for movement:	abundant but all terminate in shallow valleys.
Presence of dunes of gypsum or sand:	absent.
Presence of caves and significant rock overhangs:	reported from area. One was examined. Appear to be not common.
Boulder strewn cliffs or large piles of rocks:	mostly absent.
Exfoliated sheets of rock:	absent.
Observed abundance of bird nests:	none seen.
Abundance of reptile and mammal diggings or burrows:	a few small reptile or insect burrows observed.
Evidence of rabbits, foxes, cats or dogs:	none seen.
Abundance of faeces:	euro abundant, few emu.
Other:	several old mounds and one possibly active mound of Pebble-mound Mouse (*Pseudomys chapmani*). Evidence of Lesser Sticknest-rat (*Leporillus apicalis*) found in rock overhang.

It can be seen that there are no outstanding habitat features in the area. The Pebble-mound Mouse and the Lesser Sticknest-rat are discussed below.

4.2.5 Rare or Significant Fauna

Black-footed Rock-wallaby (*Petrogale lateralis*)

The Black-footed Rock-wallaby is listed in Schedule 1 of the Wildlife Conservation (Specially Protected Fauna) Notice 1994. This list is of fauna which are Rare or likely to become extinct. It was once widespread in Western Australia but is now restricted to isolated populations scattered through the State. The Cape Range population is secure but has been recorded only in the gorges on the western side of Cape Range National Park. There are no similar suitable habitats in the borefield area.

Pebble-mound Mouse (*Pseudomys chapmani*)

The Pebble-mound Mouse was not listed for the area by Kendrick (1993). However, many of what appear to be old pebble mounds were observed in the area, including one which appeared to be active (near Leg 8 of the proposed borefield). The Pebble-mound Mouse is listed in Schedule 1 of the Wildlife Conservation (Specially Protected Fauna) Notice 1994. This list is of fauna which are Rare or likely to become extinct. The Pebble-mound Mouse was once widespread in Western Australia but is now restricted to isolated populations scattered through the State. The nests in the borefield area appear to be moderately common and fairly widespread. Several were noted well away from areas of impact and two were observed where old access tracks had damaged nests. A detailed search for places where the proposed works might come into contact with nests has been carried out and there is only one location where the pipe access track may impinge on an old and probably unused nest. The pipe route has been altered to avoid the nest.

It must be assumed that the animals are present: construction work will avoid damaging nests or coming too close to them.

Lesser Sticknest-rat *(Leporillus apicalis)*

The Lesser Sticknest-rat is listed in Schedule 2 of the Wildlife Conservation (Specially Protected Fauna) Notice 1994. This list is of fauna which are believed to be extinct although it was once widespread in Western Australia. Caves with remains of sticknests have been recorded at several locations in the Range and remains of a nest was found during the present survey. There is no evidence of occupation of the nests for many years.

Grey Shrike-thrush (*Colluricincla harmonica rufiventris*)

This species is not listed as Rare or endangered, and is very widespread. However, the Cape Range population is isolated geographically from both Pilbara and southern interior populations and the individuals are smaller (Kendrick, 1993).

Some other species e.g. the Spinifex Pigeon (*Petrophassa plumifera*) of the Cape Range are also morphologically distinct, but have not been given sub-specific status. Spinifex Pigeon was recorded in the Project area during this Study, but it is considered unlikely to be affected by the Project.

Peregrine Falcon (*Falco peregrinus*)

Peregrine Falcon is listed in Schedule 4 of the Wildlife Conservation (Specially Protected Fauna) Notice 1994. This list is of fauna which are not Rare or likely to become extinct, but are protected for other values. The species ranges widely over most of Australia and indeed the world. It is generally uncommon, probably declining in settled regions, but is still well established in remote areas. It is "sedentary, nomadic, or part-migratory", and its habitat includes coastal or inland cliffs and gorges, timbered watercourses, swamps, plains and open woodland (Pizzey, 1991). Peregrine Falcon has been recorded in the region. It may use the Cape Range area although there is no evidence that the area has any particular significance for the species. The Project is unlikely to affect this species.

Lerista allochira

Lerista allochira, a skink lizard, is the only true endemic vertebrate of the Cape Range peninsula (Kendrick, 1993). It appears to be restricted to the dissected limestone country of Cape Range itself, although theoretically, it could occur in the borefield area. It is believed that, if it is present, it would not be affected by the Project because of the very large areas of this type of habitat and the very small total area of Project impacts. Also, the decision not to cover the pipelines would ensure that the animals could move freely beneath the pipes.

Pseudophryne douglasi

Pseudophryne douglasi is a frog which appears to occupy restricted areas across the southern Pilbara and Ashburton. While the other frog species in the area all breed following summer rains, *Pseudophryne douglasi* appears to be a winter breeder. It occurs only in permanent wetlands in deep gorges or canyons. It is known from Shothole Canyon about 10 km to the south-west of the borefield. The species is mainly of significance because it is poorly known. There are no permanent wetlands in the borefield area.

4.2.6 Subterranean Fauna

Aquatic Fauna (Stygobites)

In contrast to the surface fauna, the subterranean fauna is exceptional as below ground habitats have been buffered from the major surface changes associated with the onset of an arid climate. They have been primarily studied by Humphreys and a paper on their significance and relationships to the borefield is attached (Appendix D).

Aquatic cave fauna are known to exist at least as far south as near Kailis' fish processing plant on the eastern coast of the Peninsula, to Billy Well in the centre of the Range, and Yardie Creek on the west coast (Figure 10). Species composition on the east and west coasts is different. Several species also occur on Barrow Island, although the latter is less rich and the species composition is again different. The humid caves of the peninsula contain species that represent what is essentially a rainforest fauna as well as species that are specially adapted to living underground.

Fauna which spend their entire life cycle in caves are known as troglobites (or stygobites if they are aquatic). The invertebrate (insects, shrimps, etc.) fauna are usually pale and eyeless, with enhanced antennae and long limbs. Two species of fish (a blind cave eel, *Ophisternon candidum*, and a Gudgeon, *Milyeringa veritas*) are also present. These are the only vertebrate troglobites known in Australasia. Two atyid shrimps (*Sygiocaris stylifera* and *S. lancifera*) in the subterranean coastal fauna of the Cape Range peninsula have been included in Schedule 1 of the Wildlife Conservation Act 1950. Schedule 1 includes species which are Rare or likely to become extinct.

Many of the troglobites from the Cape Range peninsula have a very advanced degree of troglobitic adaptation: scientists specialising in a particular group often comment that they are the most troglobitic forms they have ever encountered. This is sometimes taken to indicate that the species has long been isolated in caves and certainly the Cape Range fauna is ancient (Adams and Humphreys, 1993; Humphreys, 1993b).

The cave fauna of the region is of high national estate and scientific significance, and of great conservation value, being endemic to the Cape Range Formation and highly separated from related fauna which, for the most part, occur only in the Canary Islands and the Caribbean region. The fauna comprises a relict community derived from the ancient Tethys Sea (Humphreys, 1993a, 1993b; Knott, 1993) that separated the continents of Gondwana and Laurasia, and which persisted from the Triassic until the late Eocene (200-40 million years before present; Smith and Briden, 1977). The fauna may well have been separated from its relatives with the break-up of the ancient landmass and then dispersed by sea-floor spreading. There is no doubt that the fauna is very ancient.

Terrestrial Fauna (Troglobites)

The closest affinities of the Cape Range terrestrial troglobitic fauna lie with the ground-litter fauna of closed-canopy moist forests, both temperate and tropical, that are today typically found on the eastern seaboard of Australia. The fauna is considered to be a relic, isolated from similar species by the onset of an arid climate in the late Miocene or early Pliocene. It contains some very ancient elements with clear eastern Gondwana affinities (papers in Humphreys, 1993a).

The troglobite fauna is entirely comprised of endemic taxa, often at the generic level (plus one family), to the Cape Range Formation and as such it makes a significant contribution to biodiversity in Australia.

Troglobitic animals are found extensively in Cape Range proper, where they occur in a number of discreet zones, being more highly speciated in the north of the Range and becoming progressively less isolated towards the south. A related, but discreet, fauna is found on the coastal plain: this has some species in common with Barrow Island. Two species of terrestrial fauna, a micro-whip scorpion (*Schizomus vinei*, now renamed *Draculoides vinei*) and a cockroach (*Nocticola flabella*), in the subterranean fauna of Cape Range have been included in Schedule 1 of the Wildlife Conservation Act 1950.

4.2.7 <u>Significance of the Cave Fauna</u>

The Cape Range peninsula has been reported by Humphreys as having high species density and exceptional endemism in its subterranean animals (papers in Humphreys, 1993a; and Appendix D). Of the described specialist underground fauna known from the world's tropics, Humphreys states about 6.5% are known only from the Cape Range area (Humphreys, 1993a). There is, however, little data available from other areas in Western Australia. Humphreys reports that the significance of the Cape Range area is further enhanced because in the composition of the fauna are indications of local changes in sea and land levels, climatic change, and of past connections with other parts of Australia and eastern Gondwanaland. The fauna contains the only evidence of the past existence of closed forest, both temperate and tropical, in the region since the Miocene when the Cape Range limestones were laid down.

The significance of the Cape Range area is further enhanced by its relative isolation and by the inclusion of many higher order taxa (genera, families) found nowhere else in the world, and by the close affinity of some aquatic taxa with other subterranean species on either side of the North Atlantic.

Humphreys says the stygofauna is, at present, as severely constrained in its distribution as at any time during the last 240 thousand years. This means that the current genetic fragmentation of the populations (Humphreys and Adams, 1991; Adams and Humphreys, 1993; Humphreys, 1994) is being exacerbated by small geographical range and low population size. Hence, the stygofauna must be considered vulnerable.

4.3 SOCIO-ECONOMIC ENVIRONMENT

4.3.1 Profile

Exmouth townsite is geographically isolated from other towns in the region, and was originally created as a support town to the USN and RAN communications base. It is rapidly becoming an important tourist destination, largely because of the attractions of the Cape Range National Park, Ningaloo Marine Park, "big-game fishing", and a desire for a "wilderness experience".

The town has an area zoned for future residential use that is at least as big as that currently under housing (Exmouth Structure Plan, 1989).

Several major projects have been proposed for the area including:

- a large marina just south of Norcape Lodge;
- a palm nursery;
- a lime manufacturing plant;
- limestone quarries;
- a number of tourist developments; and
- possible bases for the oil industry.

4.3.2 Community Structure and Expectations

At 31 July 1991 the population at Exmouth was 3,820 persons (Australian Bureau of Statistics data). This figure would include tourists who were resident at the time of the census. When USN personnel left the Communications Base, the population dropped by about 450 people. Nonetheless, it is believed (Shire of Exmouth personnel, pers. comm.) that numbers of people are now growing rapidly as USN houses are purchased and occupied by newcomers.

Because of the low salinity water supplied historically (although it is accepted that the water may not be of equivalent quality to the Perth metropolitan area), it is unacceptable to the community to accept a higher salinity (lower quality) of water in the future. Concerns are being raised regarding increasing salinity, and there is general objection to an increase in water rates, despite the fact that the cost of water in Exmouth is currently being subsidised by about 30%.

These factors, together with the increase in tourism with its accompanied requirement for good quality and adequate water supplies, requires that the Water Authority endeavour to meet the community expectations. Alternative methods of meeting this expectation were discussed in Section 2.4. While the impact of borefield extension and pumping on stygofauna is recognised, if the community requirements are to be met without considerable increases in cost, the only feasible option is to extend the borefield.

4.3.3 Ethnography and Archaeology

McDonald, Hales and Associates was commissioned to conduct Aboriginal Heritage research in relation to the proposed extensions to the existing Exmouth borefield.

Investigation of all documentary sources available, particularly the register of Aboriginal Sites maintained by the Aboriginal Affairs Department, Heritage and Culture Branch, revealed the existence of four previously recorded sites in the vicinity of the proposed borefield (PO7004; PO7005; PO7006; PO7007). Only one of these, PO7005, is located within the area proposed for development.

Site PO7005 is reported to lie *ca* 2 km south-west of the Exmouth townsite. The site is the location of discovery of a portion of a human femur (confirmed as such by medical authorities, possibly in Exmouth) located in a gully running inland from the coast. The current whereabouts of this material is unknown.

Since the site was reported in 1992 by a member of the public, no attempts have been made to locate any additional skeletal material which may still remain in the gully. No consultation with local Aboriginal groups has yet been undertaken, consequently the contemporary significance of this find is unknown. On the basis of McDonald Hales' experience with other exposures of skeletal material, it is likely that this site will be attributed a high level of significance when consultation is undertaken. It is likely, however, that the bone was transported by water from further up the creek.

Any burial in the area would be, by necessity, either in a cave or in a creek bed, as all the rest is rock. Thus, it is highly likely that a burial in a creek bed could be washed out by flooding with the actual grave a considerable distance from the site where the bone was found.

The reported sites do not appear to have been verified prior to inclusion in the register, despite the potential sensitivity of the skeletal material in one of them. As a result, it is difficult to judge whether additional material is likely to be located within areas subject to potential impact. If all known sites in this area are considered uncritically, then there exists a potential for other places of Aboriginal Heritage importance to be discovered on land within the proposed borefield extension.

On the basis of more extensive archaeological research previously conducted on the western margin of the Exmouth Peninsula, and focused largely in Cape Range National Park, it would appear that the entire peninsula has a very high site discovery potential (see particularly Morse and Kee, 1985; Morse and Fry, 1989; Turner, 1985). Along the coastal strip within the National Park, a total of 57 Aboriginal sites have been located and recorded in detail. These sites, which mainly consist of archaeological material, occur at a density of approximately one per kilometre and exhibit a degree of association with potential water sources such as ephemeral creeks which run through deep gullies into the sea. Since similar features occur on the eastern margin of the peninsula (but well inland), it is considered likely that Aboriginal sites, apart from those already noted, would be located there also. Not withstanding this, the borefield routes have been examined in the field by an archaeologist and no artefacts have been found.

The possibility of finding artefacts is supported by unconfirmed reports by other researchers working in this area, and that archaeological material is present in a number of caves located in the karstic landscape to the south of Exmouth (Dr W. Humphreys, pers comm.). During the course of field survey these finds were assessed and recorded where appropriate.

In the absence of systematically collected data from the few sites already known to be in the vicinity of the Exmouth borefield, it is difficult to assess the potential significance of any additional finds which may be made during pipeline construction work. However, this region represents one of the few parts of the Western Australian coastline which has remained virtually unchanged despite fluctuations in sea level, and archaeological material dating to the earliest periods of Aboriginal occupation of Australia has been preserved as a result (Morse, 1988). Consequently, any sites which are discovered, particularly if they present a potentially stratified and dateable deposit, will be of extremely high significance for future research. Such sites, if they were to be located, could present an impediment to development of the borefield in their immediate vicinity.

4.3.4 European Heritage Values

There is no evidence that the Project area has any particular European Heritage value, and no structures or other indications of possible historic interest were found.

5.0 IMPACTS AND MANAGEMENT OF THE PROJECT

5.1 SOIL AND LANDFORMS

5.1.1 Impacts

The main impact along the pipeline routes is the construction of an access track to allow drilling equipment, etc., to gain access to bore locations without staking tyres. This consists of skimming the vegetation and very shallow soil from the routes. In most cases there is so little vegetation and soil that no windrow is created. In some areas the track is created by simply driving over the vegetation.

On the main connector pipeline, the pipe would be buried along the edge of the existing access track for the powerline. Minimal additional clearing would be required. Where the pipe crosses Mowbowra Creek it may be buried or suspended in a raised cradle. If burial is chosen, the pipe would be placed in a trench, anchored down with concrete then covered with river material. The sides of the Creek may be armoured with rock to prevent erosion.

5.1.2 Management

Almost no management would be required on the pipe routes. Erosion is unlikely as most of the surface is rock. Any small areas of windrow would be flattened to ensure that they do not direct water runoff. With time, vegetation along the edges of the tracks would grow back in, as the rootstocks of plants, which occupy cracks in the limestone, would remain intact. The collector main route and crossing at Mowbowra Creek would be inspected regularly, and any damage repaired.

5.2 BIOLOGICAL ISSUES

5.2.1 Vegetation Impacts and Management

The only impacts on vegetation are those discussed above in relation to soils. No special management would be required.

5.2.2 Terrestrial Fauna Impacts and Management

The main issue with terrestrial fauna is the presence of Pebble-mound Mouse. The pipeline routes have been examined and where necessary altered to avoid any possible Pebble-mound Mouse mounds. Experience in several locations in the Pilbara and central goldfields has indicated that the mounds remain active very close to tracks, providing the track does not actually go over them (B. Muir, pers. obs.).

5.2.3 Stygofauna - Impacts and Management

5.2.3.1 Impact of Changes to Existing Hydrology

Over-abstraction of groundwater has resulted in increased salinity in the existing borefield as throughflow is insufficient to support extraction rates (Halpern Glick Maunsell, 1992). It is known that some cave fauna are quite tolerant to considerable ranges in salinity, as might be expected in an environment with tidal influences and saline water beneath the zone of mixing. For example, the Gudgeon has been recorded in salinities from 250-26,500 mg/L TDS, the eel in 1,000-5,000 mg/L TDS, and the atydid shrimps from 370-20,000 mg/L TDS (Humphreys, 1994; and pers. comm.). There is no evidence to suggest that increases in salinity as a result of water abstraction have caused the loss of any species. There is however, also no evidence to suggest that changes in salinity have had no effect on population distributions, species abundance ratio or some other factor.

There may, however, be more subtle changes to the stygofauna. For example, the biological energy source for the stygofauna is unknown, although a mixture of organic carbon (from both downward infiltration and groundwater flow) and chemical processes are likely to be important. While the effect of pumping cannot be predicted in the absence of information on the energy sources for the ecosystem, the dynamics of water flow will have important consequences on the energy source.

The safe yield of the borefield is estimated to be 60% of the estimated throughflow, or 100 ML/yr per kilometre length of the Range (Water Authority, 1994a). Actual production peaked at about 158 ML/yr/km (1990/91) or about 95% of the estimated throughflow. Rates of abstraction have now declined: nonetheless, such high rates of groundwater interception would affect stygofauna that depend on particulate carbon in the groundwater flow. In addition, it would affect the horizontal and vertical location of the zone of water mixing (within which much of the stygofauna lives), thinning it and moving it upwards and inland.

Not only will there be a proportional loss of biological energy in the system, the resulting reduced population sizes may lead to a disruption of the food balance within the ecosystem and a shortening of the food chain. Hence, the distribution and abundance of the populations may be affected, as well as structure of the community.

There is also a direct relationship between salinity and sulphate concentration of the waters. Hence, if the ecosystem is driven by chemical energy systems, changes in the mixing interface and its location may be important.

Inadequate knowledge of the system prevents accurate prediction of the effects of changes to the water flow. Detailed research needs to be undertaken to establish the energy basis of the system. A number of dedicated monitoring bores needs to be established, to enable the sampling of water and fauna throughout the zone of mixing and in the salt water wedge that underlies the brackish water.

Protection of stygofauna

The regional significance and composition of the fauna has been discussed in the previous sections. Of that fauna, a number of taxa are known specifically from within the borefield area and its proposed extension, or are known to occur downstream of the borefield so that direct impact may occur through interception of the groundwater or by contamination.

There is evidence that water abstraction itself causes reduction of water quality. Water colour, sulphate and nitrate change over time. Each of these parameters was greater in those bores that had been long in production than in those bores never equipped for pumping. The relevance of this to the stygofauna is unknown.

The water quality occupied by the stygofauna appears to be quite varied. Water quality profile data are unavailable for any parameters within the present borefield. In particular, none are available on the dissolved oxygen levels in the water profiles, *in situ* pH or redox potential. The importance of the latter relates to the reducing environment likely to be encountered both in sediments (hydrogen sulphide commonly occurs in superficial sediments), and in the water body below temperature and salt boundaries. In the latter areas oxygen levels may be as low as 0.1 mg/L, and concentrations of hydrogen sulphide may occur.

To assess changes in the use of the water profile by the stygofauna, and to monitor the performance of the borefield, comprehensive profile data on the biological and physico-chemical environment need to be gathered regularly from dedicated monitoring wells that penetrate to below the saltwater interface.

5.2.3.2 Implications of Changes in Groundwater Level and Quality for Stygofauna

Community Structure

Comparison of pumped and unpumped Water Authority bores shows significant differences in the fauna sampled (Appendix D). In essence, there is a considerable excess of *Stygiocaris* in production bores (observed/expected = 80/56) and too few in those never used for water supply (6/30), whereas there was a large excess of *Halosbaena tulki* in bores never used (44/22) and a deficit in production bores (21/43).

The tentative conclusion is that the pumping of water from the production bores changes the community structure in the groundwater from one numerically dominated by *H. tulki* to one dominated by *Stygiocaris* sp. The reasons for this change are unclear.

Direct mortality

Humphreys (1994) showed that, based on existing mortality data from the operational borefield, the proposed expansion of the borefield could result in direct mortality of between 200,000 and 500,000 individual animals per year. These figures are very approximate and further data need to be collected. The mortality results from pumping the animals out with the water. Most of the animals are less than a few millimetres in size and all are removed in the Water Authority filtering system before the water enters the supply network. Loss of animals in this way has the added effect of removing potential food for predators.

The current projected water extraction rate is 1,029 ML/yr (Option 1 - discussed in Section 2.4.7) or 1,021 ML/yr (Option 2) which would pump in the order of 100,000 and 300,000 individuals per year, but the two options would have different impacts on the fauna. Direct mortality would be about 11% less under Option 1 than under Option 2 as this proportion of the water would be drawn from the unpopulated part of the water resource. Over-abstraction in parts of the borefield, as is happening at present, would cease.

Under Option 1 the downstream effects would occur over 25% less of the coastal plain because of a difference in the borefield length (about 10.3 versus 13.8 km).

Humphreys (*ibid.*) concluded that a substantial number of individuals in the stygofauna would be killed directly by borefield pumping. This includes individuals of a species listed under Schedule 1 of the Wildlife Conservation Act 1950. However, the proportion of the total population this represents is unknown and, in the absence of better data, the impact of this loss on the population structure cannot be estimated. However, stygofauna generally comprise long-lived species with low reproductive rate and high investment in young, so that the replacement rate is low. Certainly this is the case for *H. tulki* and *Stygiocaris* spp which have about 7 and 8 young per brood respectively.

Of more concern is the loss of biological energy to the ecosystem as represented by the loss of individuals, added to the already substantial loss of energy resulting from the interception of nutrients in groundwater flow. Nonetheless, even with so many unknowns, it is clear that Option 1 is favoured over Option 2 in that it will minimise the impact of the borefield expansion on the stygofauna.

Species Composition of the Fauna

Not all taxa known from close proximity to the Exmouth borefield have been recorded from the borefield itself. This is considered simply to be an artefact of collecting; the collecting methods necessarily used in the borefield being unsuitable for some species (e.g. *Ophisternon candidum*).

The fauna species differences between pumped and unpumped production bores is considered not to be significant. *Milyeringa veritas,* for example, was collected only once by the sampling method employed, even at sites where it was known to be common, and thus its presence is unlikely to be recorded.

Stygofauna recovered from production bores in the Exmouth borefield, and that recovered from bores never used, indicate that the active borefield probably contains all species of stygofauna known from the north-east coast of the peninsula and the species composition of the fauna probably has not been changed by borefield pumping.

Conclusion with Respect to Stygofauna

The borefield development must be considered in the context of the region and as one stage of the incremental impact of developments on the fauna. There are a number of large projects proposed for the region (refer Section 4.3.1). These developments impinge on the stygofauna of the coastal plain so that the area can no longer be considered as a potential refuge for them.

Altogether, 20 km of the eastern coastal plain of the Cape Range peninsula, including all downstream areas from the borefield, must now be considered to be potentially developed. This development encompasses a considerable proportion of known stygofauna sites on the east coast, the area of the greatest known diversity. While to date there has been relatively little human-caused contamination of the groundwater in the Exmouth area (Humphreys, 1994), that will change as key areas are subdivided and contaminant loads increase.

5.2.3.3 Acceptance Criteria

The stygofauna in the borefield area is accessible only indirectly through deep bores. There are no robust quantitative, or even qualitative, data on the density, age-structure or species composition of the population of stygofauna throughout it's range. The best available data are those from the current Water Authority borefield which offers the main access to monitor these parameters. Consequently, it is not possible to set meaningful threshold values for these parameters beyond which remedial action should be taken. Indeed, the definite presence of stygofauna in most of the proposed borefield can only be ascertained following bore construction.

The stygofauna characteristic of the Cape Range peninsula has a much wider distribution than just the proposed borefield extension (Figure 10). However, genetic variation and even species level differences are known to occur in some taxa within this range. In view of the lack of data, it is proposed that the apparent loss of any stygofauna species in 33% (one in three) of monitoring bores within the area of impact of the proposed borefield extension is a rational performance criterion to set. It would indicate that the range of the species may have been reduced by some unknown amount, but over less than 10% of its range. If such an impact was found a more detailed monitoring of that section of the borefield would be initiated, in consultation with DEP/EPA, to determine the generality of the findings.

It should be noted that the base-level information required to establish firm acceptance criteria can only be gathered through continual long-term monitoring. That monitoring, in turn, is possible only through specially designed monitoring bores of the type proposed.

5.3 WATER QUANTITY AND QUALITY

5.3.1 Short and Long-term Impacts on the Water Table

As pumping lowers the water table, it results in thinning of the freshwater lens. In the past, water was pumped from the existing borefield at rates which were high relative to the estimated natural flow in the aquifer. Although pumping rates in the existing borefield have been lowered, it must be expected that the layer of fresher water, and perhaps the mixing layer, is now thinner than it was before pumping began. It is uncertain whether the thickness of the fresher layer will now increase or continue to decrease. Proposed pumping for the southern extension of the borefield will result in the thinning of the freshwater lens in that area, but the reduction in pumping at the north may help to offset some of this impact if the freshwater lens is partly restored.

5.3.2 Implications for Long-term Water Quality

If the population of Exmouth continues to increase as expected, eventually the southern borefield as well will be unable to cope with demand and water quality may decline. At that time alternative methods of supply such as discussed in Section 2.4 may be inevitable. At that time the much increased cost of the supply could not be carried by the wider community, and a substantial increase in water rates will be necessary.

5.4 AIR QUALITY

5.4.1 Bushfire Prevention

It would be a condition of contract that drillers, pipe-laying teams, etc., would not light fires and would take reasonable steps to prevent accidental ignition of the bushland. This is to prevent smoke affecting Learmonth or Exmouth and to protect the habitat.

5.4.2 Dust and Noise Control

Dust would not be created except during excavation of the trench for the collector main. Work on the trench and covering would stop if there is excessive dust blow towards Exmouth (Learmonth is too far distant to be affected). There would be some noise from construction machinery but there are no residences anywhere in the vicinity. All pumps are down-hole design and are electric. They generate very little or no noise at the surface.

5.5 REHABILITATION OF DISTURBED AREAS

No rehabilitation will be required in the borefield as the pipes will be laid on the surface, and there is no clearing except for the access track and bore drilling. These areas will require continued access as long as the borefield is operating. The vegetation on the track margins will grow back as rootstocks remain intact, and, after bore construction only a light vehicle will require access for maintenance and monitoring.

The soils along the collector main will be replaced after pipe burial. It is expected that spinifex will regrow over the trench with time. No formal rehabilitation will be undertaken but the pipe route will be regularly monitored and, if necessary, active rehabilitation will be undertaken.

5.6 AESTHETICS

The pipelines and production bores are all within a closed water reserve where there is, at least in theory, no public access. The pipes and bores are not visible from the Learmonth to Exmouth Road.

5.7 SOCIO-ECONOMIC ISSUES

5.7.1 Local Landholders

There are no freehold lands or pastoral leases in the area.

5.7.2 Ethnography and Archaeology

Since neither the current status of PO7005 (refer Section 4.3.3) (in terms of exact location or whether additional material is present) nor ethnographic significance is known, it is difficult to derive detailed management guidelines for PO7005. However, given the potential high significance of the skeletal material, avoiding this area completely is the most prudent course of action.

As the bone (refer Section 4.3.3) was found in a creek bed, and it is very likely any additional material would also be in a creek bed or cave, it is suggested the proposed borefield expansion would not have any impact. The pipelines, by necessity, must follow ridge crests.

During the field research programme, these issues have been addressed. More detailed management guidelines are being developed and will be in place before construction commences.

5.7.3 European Heritage

No features of European Heritage value have been recorded from the area and none were observed during field work.

6.0 MONITORING PROGRAMMES

6.1 GROUNDWATER MONITORING AND RESPONSES

6.1.1 Accuracy of Measurement

Instruments used by the Water Authority to measure water levels in bores have potential errors of from 0.1-0.5 m.

Inaccuracy of monitoring is exacerbated because water levels are measured in production bores, and unless the bore is turned off for sufficient time, the water level will be lower than under equilibrium conditions. There is a requirement for dedicated monitoring bores appropriately positioned throughout, and downstream of the borefield.

6.1.2 Interpretation of Data

The behaviour of the borefield appears to be inconsistent between bores and over time and is not open to simple interpretation. Proper quality control analyses should be implemented and applied so that statistically significant departures are detected when they occur, and to avoid subjectivity. The nature, reliability, resolution, interpretation and control of procedures monitoring the performance of the aquifer(s) need to be substantially enhanced.

6.1.3 Drawdown

The existing groundwater monitoring programme would be expanded to include the borefield extensions. Abandoned production bores will be re-cased with 80 mm slotted PVC and used to monitor groundwater levels and salinity profiles. Frequency of monitoring of these re-cased bores would be reduced to quarterly or bi-annually when regular aquifer behaviour patterns are established. This may also occur if there are nearby bores still being monitored regularly.

A record would be kept of the amount of water pumped out of each production bore every month.

When existing production bores are replaced, the old bore will be re-cased with 50 mm or 80 mm PVC and used for monitoring water levels by using an electric probe tape measure. Rest water levels will be measured by waiting for the appropriate time after the pump is switched off.

Every month the salinity of a sample of water pumped from each production bore will be determined by measurement of electrical conductivity (EC), and every six months a sample from each bore will be analysed in a laboratory to determine concentrations of all major ions, pH, EC and TDS.

The monitoring results will be assembled into an annual report. Copies of this report will be made available to DEP/EPA and all other regulating authorities, and will be made available for public inspection in Exmouth.

6.1.4 Demand

Monitoring of demand will continue on a daily basis to:

- confirm the apparent fall in demand associated with USN withdrawal;
- identify peak demand rates to confirm the bore refurbishment programme; and
- identify annual demand for capital investment implementation.

6.1.5 Response to Monitoring

If monitoring records show a change in salinity which may render the water from the bores unacceptable for drinking, or nearing the threshold (Section 6.2) where it may affect stygofauna, then:

- the first stage of management will be to reduce the rate of pumping from the bore;
- where there is evidence of inland movement of the salt water interface beyond that which can be expected to result from variable rainfall, the second stage of management will be to reduce the total production of water from the group of bores in the area; and
- the third stage of management would be to abandon groundwater production from bores in a particular area. To maintain total production for the borefield, the third stage will also necessitate further extensions to the borefield or the implementation of alternative means of providing potable water.

6.2 STYGOFAUNA MONITORING

To monitor the stygofauna, Humphreys (1994) recommended that bores independent of production bores should be used for sampling, that salinity profiles be collected, and that samples be taken more frequently. These recommendations closely match those required for the purpose of monitoring the behaviour of the aquifer (Water Authority, 1994a), and above.

Humphreys (1994 - this report) recommends that:

- monthly measurement of rest water levels be undertaken in all appropriate production and Salinity Profile Monitoring Bores, including bores not yet equipped, and all decommissioned bores that are in a suitable condition. Where decommissioned bores become unsuitable for monitoring because of deterioration they will cease to be used for this purpose;
- a series of monitoring bores should be installed, adjacent to selected production bores within the borefield, to observe changes in the salinity profile beneath the bores. This will assist in identifying the extent of, and potential for, upconing before a problem occurs. One piezometer should penetrate through to the saltwater wedge. All piezometers should be of sufficient diameter (at least 65 mm, preferably > 100 mm, diameter), and with suitable slots and screens in the casing, to permit sampling of the stygofauna. These should initially be sampled for stygofauna twice yearly. It is likely that the sampling rate could be halved after several years, by which time adequate background data should be available;
- dedicated salinity profile monitoring bores penetrating to different depths (including into the saltwater wedge where it is present) should be established downstream of the proposed borefield extension (inland of Murat Road). They should be of sufficient size to enable hydrological and fauna sampling.

These should be established and monitored three times before each new segment of the borefield starts to operate;

- all bores decommissioned in the northern borefield should have the pump and rising column withdrawn, and be capped and locked. Casings will be left in place. This will permit monitoring of the aquifer and the stygofauna downstream of Option 1 to assess its impact and to monitor the recovery of the aquifer. They should be monitored bi-annually for stygofauna; and
- it is not possible to set meaningful threshold values for changes in the stygofauna and beyond which remedial action should be taken. In view of the lack of data, it is proposed that the apparent loss of any stygofauna species in 33% of monitoring bores within the area of impact of the proposed borefield extension is a rational performance criterion to set. It would indicate that the range of the species may have been reduced by some unknown amount, but over less than 10% of its range. If such an impact was found a more detailed monitoring of that section of the borefield would be initiated, in consultation with the DEP/EPA, to determine the generality of the findings.

All these recommendations have been incorporated into the management of the borefield extensions and are reflected in the Commitments.

6.3 MONITORING OF REHABILITATION

Although there will be no formal rehabilitation, the collector pipe trench will be periodically inspected to ensure the vegetation is regrowing naturally. In the event that erosion is occurring, or regrowth of spinifex is unsatisfactory, the Water Authority will repair the damage, undertake artificial restoration or seek specialist advice, depending on the nature of the problem.

7.0 CONCLUSIONS

It is concluded that the Project would have minimal adverse impacts on surface flora or fauna, or on the people of Exmouth. By contrast, advantages to the community would be considerable, allowing it to continue to grow and to further promote tourism in the region.

The most important adverse impact would be on subterranean fauna. Significant cave fauna occur within the borefield area or immediately downstream, some taxa being known only from single caves. The terrestrial cave fauna is dependent on the influx of water to the cave for humidity and food resources, and consequently interruption to the surface flow of water to caves may impact on the fauna of a particular cave. Every effort must be made to minimise disturbance to caves and their catchments.

The proposed borefield extension would result in reduction in drawdown in the existing borefield. It is hoped this would allow some restoration of the freshwater lens in the latter area. Restoration of the lens may allow regeneration of the cave ecosystem and hence assist recovery of stygofauna populations. Offset against this is the necessity to increase the zone of influence by extending the borefield. However, it is felt that with the better aquifer management which would be facilitated by the extension, it would be possible to meet the requirements of stygofauna as well as community expectations.

8.0 PROPONENT'S COMMITMENTS

All work involved in the Extensions to the Exmouth Borefield will be undertaken by the Water Authority of Western Australia. The details of the work and timing are complex and are described in the text of this Consultative Environmental Review. The work would be carried to Water Authority standards in consultation with the Department of Environmental Protection.

1. The sites or routes (to 50 m downslope) of all surface constructions (roads, drilling pads, pipelines, buildings) will be inspected by a competent speleologist and/or hyrdologist prior to construction to ensure that there would be no alteration to water flow or other factors which may influence the biological integrity of the underlying cave systems. If necessary, the route or methods will be changed to minimise any direct or downstream effects of the constructions. Pipelines will be laid on the surface and not buried or covered with soil.

2. Caves, even holes too small for people to enter, that are found by the Water Authority or contractors will be reported to the relevant speleological group[1] prior to construction and its advice sought as to the appropriate course of action.

3. Salinity concentration profiles will be determined quarterly by electrical conductivity measurements in bores designed for the purpose.

4. Monthly measurement of rest water levels will be taken in all production and observation bores, including bores not yet equipped, plus all decommissioned bores that are in a suitable condition. The equipment used for this purpose will be upgraded.

5. A series of monitoring bores will be installed adjacent to selected production bores within the borefield to observe changes in the salinity profile. One piezometer will

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[1] Mr R.D. Brooks, telephone: (099) 491 274; address: Post Office Box 710, Exmouth, WA 6707, or the WA Speleological Group in Perth (telephone Mr R. Webb (09) 333 4444).

penetrate through to the saltwater wedge. All piezometers will be of sufficient diameter to permit sampling of the stygofauna.

6. Stygofauna monitoring bores will initially be sampled twice yearly. It is likely that the sampling rate could be halved after several years by which time adequate background data will be available.
7. As it is not possible to set meaningful threshold values for changes in the stygofauna it is proposed that the apparent loss of any stygofauna species in 33% (one in three) of monitoring bores within the area of impact of the proposed borefield extension is a rational performance criterion to set. If such an impact was found a more detailed monitoring of that section of the borefield would be initiated, in consultation with the DEP/EPA and CALM to determine the generality of the findings.
8. If it becomes apparent that adverse impacts on the fauna exceed the established criterion discussed above, the associated bore will be shut down from production pending detailed examination of the data and its implications.
9. The above stygofauna impact performance criterion will be reviewed annually as new data become available. Results of the review will be reported to and discussed with DEP/EPA and CALM and the agreed new criteria applied for the following year.
10. All production bores from which pumps have been temporarily withdrawn for maintenance will be sampled for stygofauna and salinity profiles.
11. All new bores will be sampled for stygofauna and salinity profiles prior to pumps being set in place.

12. Dedicated stygofauna monitoring bores penetrating to different depths (including into the saltwater wedge) will be established downstream of the proposed borefield extension (inland of Murat Road), and will be of sufficient size to enable hydrological and fauna sampling. These will be established and monitored three times before each new segment of the borefield starts to operate. One such bore series will be established for each two legs of the established and extended borefield.

13. All bores decommissioned in the northern borefield will have the pump and rising column withdrawn, and be capped and locked. The casing will be left in place. This will permit monitoring of the aquifer and the stygofauna downstream of bores to assess its impact, and to monitor the recovery of the aquifer. They will be monitored twice yearly for stygofauna.

14. Stygofauna sampling will be performed by Water Authority staff after suitable training, and the specimens sent to Perth for examination.

15. All borefield monitoring data will be collated, analysed and reported to DEP/EPA, CALM and other relevant regulating authorities once every year, beginning in the January following approval of this Project. The data will also be made available to the public.

16. If monitoring records show a change in salinity which may render the water unacceptable for drinking or nearing the established thresholds where it may affect stygofauna, the rate of pumping from that bore will be reduced.

17. Where there is evidence of inland movement of the salt water interface beyond that which can be expected to result from variable rainfall, the total production of water from the group of bores in the area will be reduced.

18. If the above responses to adverse water quality do not overcome the problem the Water Authority would abandon the groundwater production from bores in the particular area.

19. During burial of the collector main, if strong winds cause excessive dust blow for the trenching crew then operations will stop until the wind had subsided.

20. The soils along the collector main will be replaced after pipe burial. No formal rehabilitation will be undertaken but the pipe route will be regularly monitored and, if necessary, active rehabilitation will be undertaken.

21. If it is decided to bury the collector main where it crosses Mowbowra Creek every effort will be taken to minimise environmental damage, the disturbed areas will be armoured to prevent erosion, and the area will be monitored and, if necessary, repaired after every storm event.

22. In the event of any material believed to be of Aboriginal origin being found during construction, work will cease on that particular site and a professional opinion sought on the significance of the find.

23. The Water Authority will finalise a detailed stygofauna monitoring program in consultation with DEP/EPA, CALM and the WA Museum.

9.0 REFERENCES

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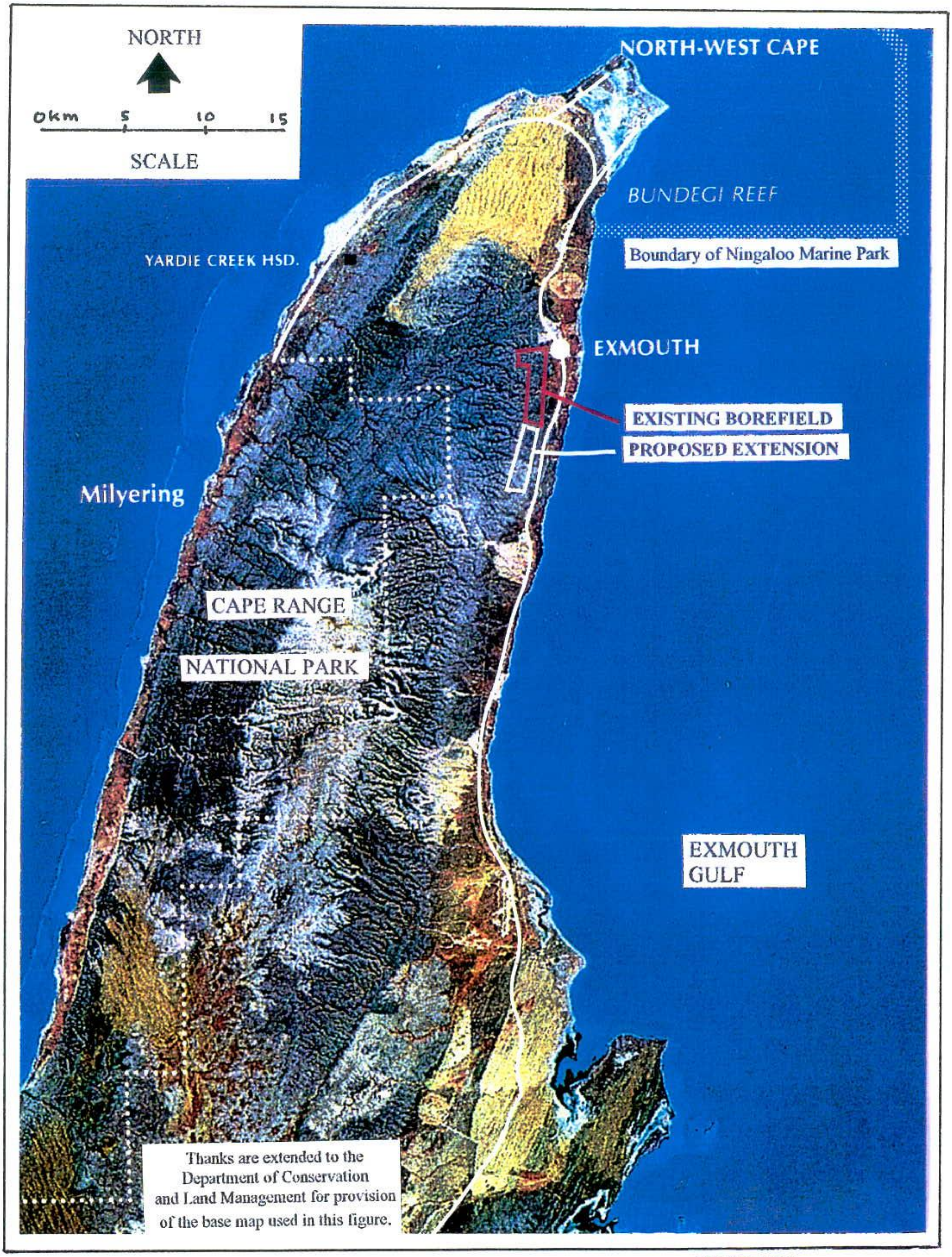
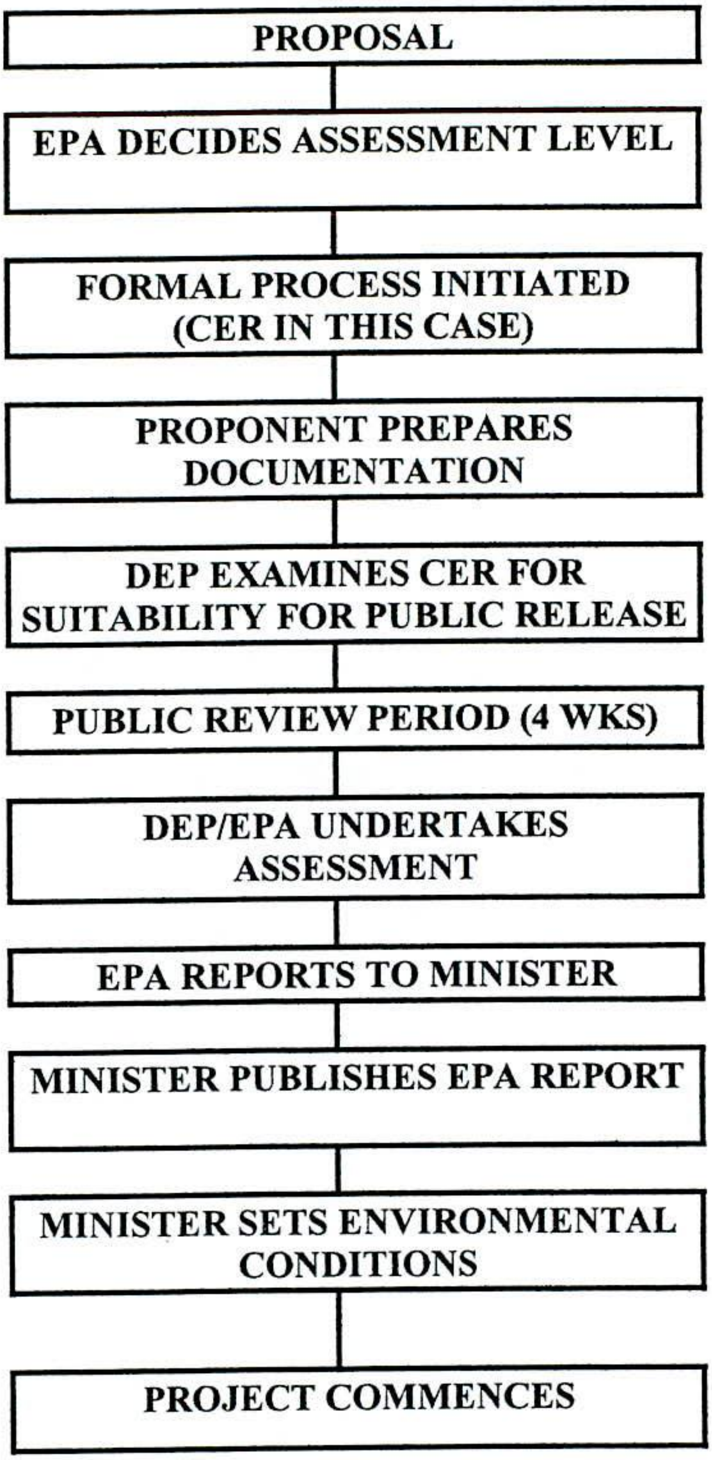
FIGURES



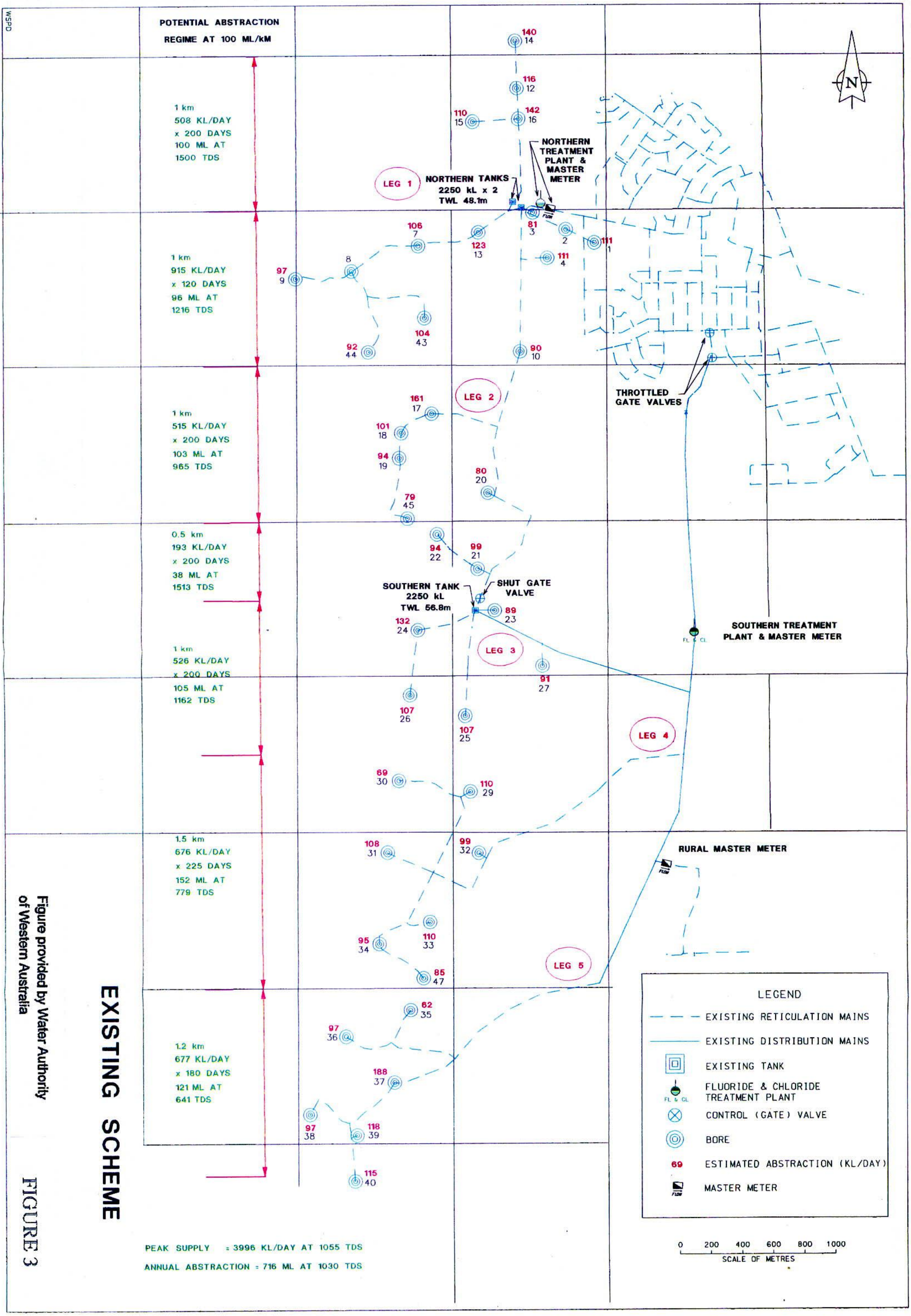
Thanks are extended to the Department of Conservation and Land Management for provision of the base map used in this figure.

FIGURE 1
PROJECT LOCATION



DEP = Department of Environmental Protection
EPA = Environmental Protection Authority

FIGURE 2
THE ENVIRONMENTAL IMPACT ASSESSMENT PROCESS



EXISTING SCHEME

Figure provided by Water Authority of Western Australia

FIGURE 3

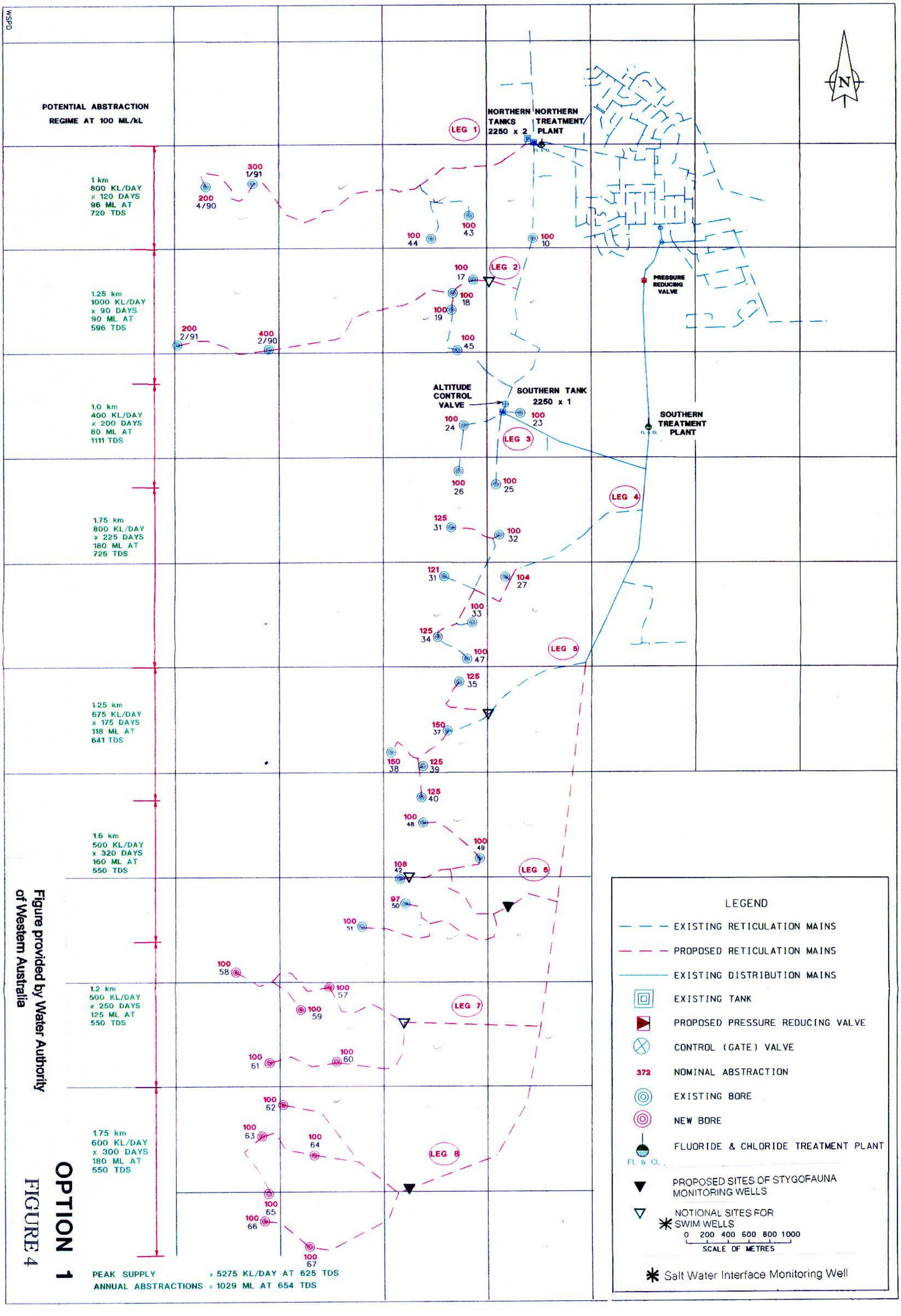


Figure provided by Water Authority of Western Australia

OPTION 1

FIGURE 4

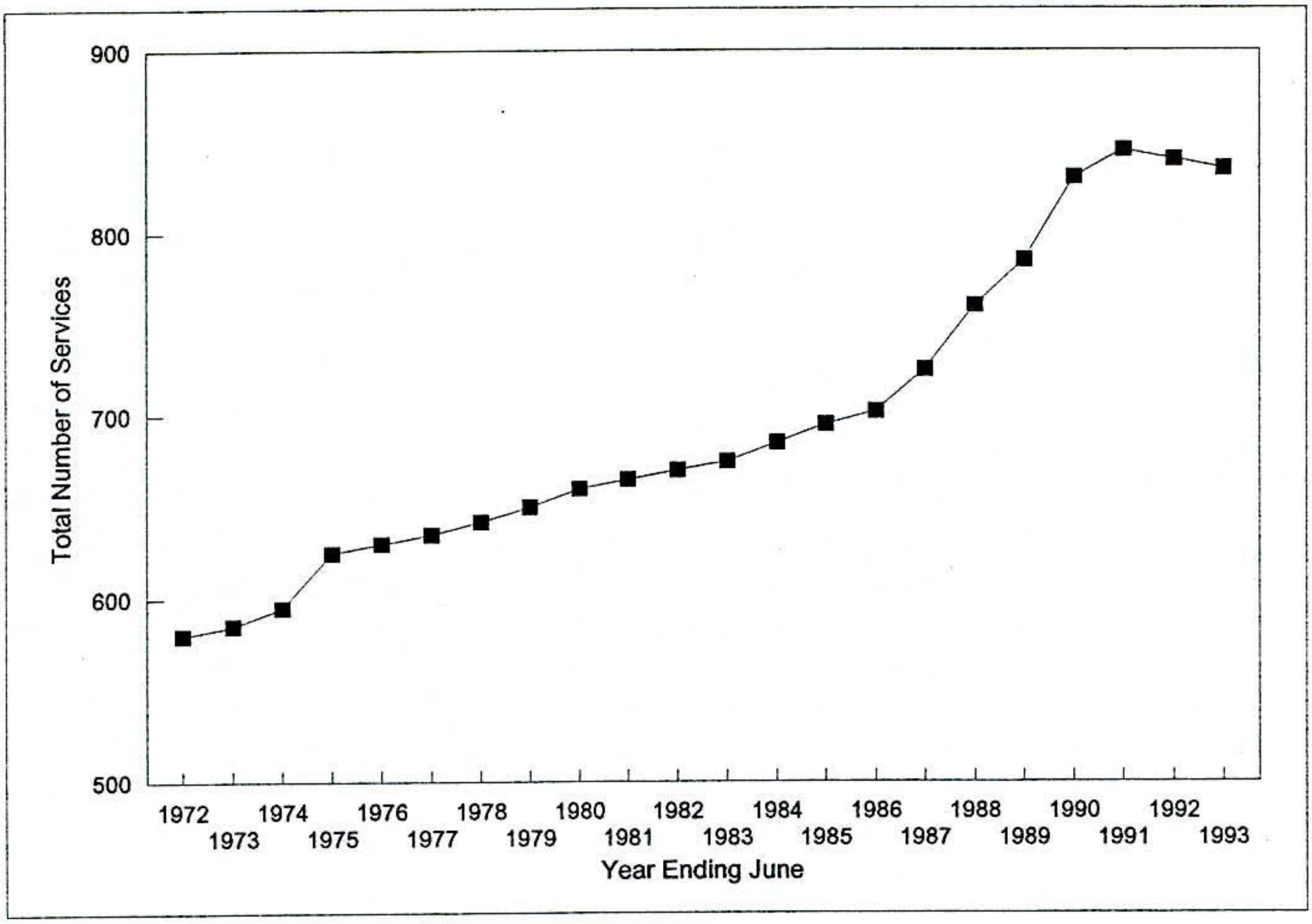


FIGURE 5
NUMBERS OF WATER SERVICES
IN EXMOUTH

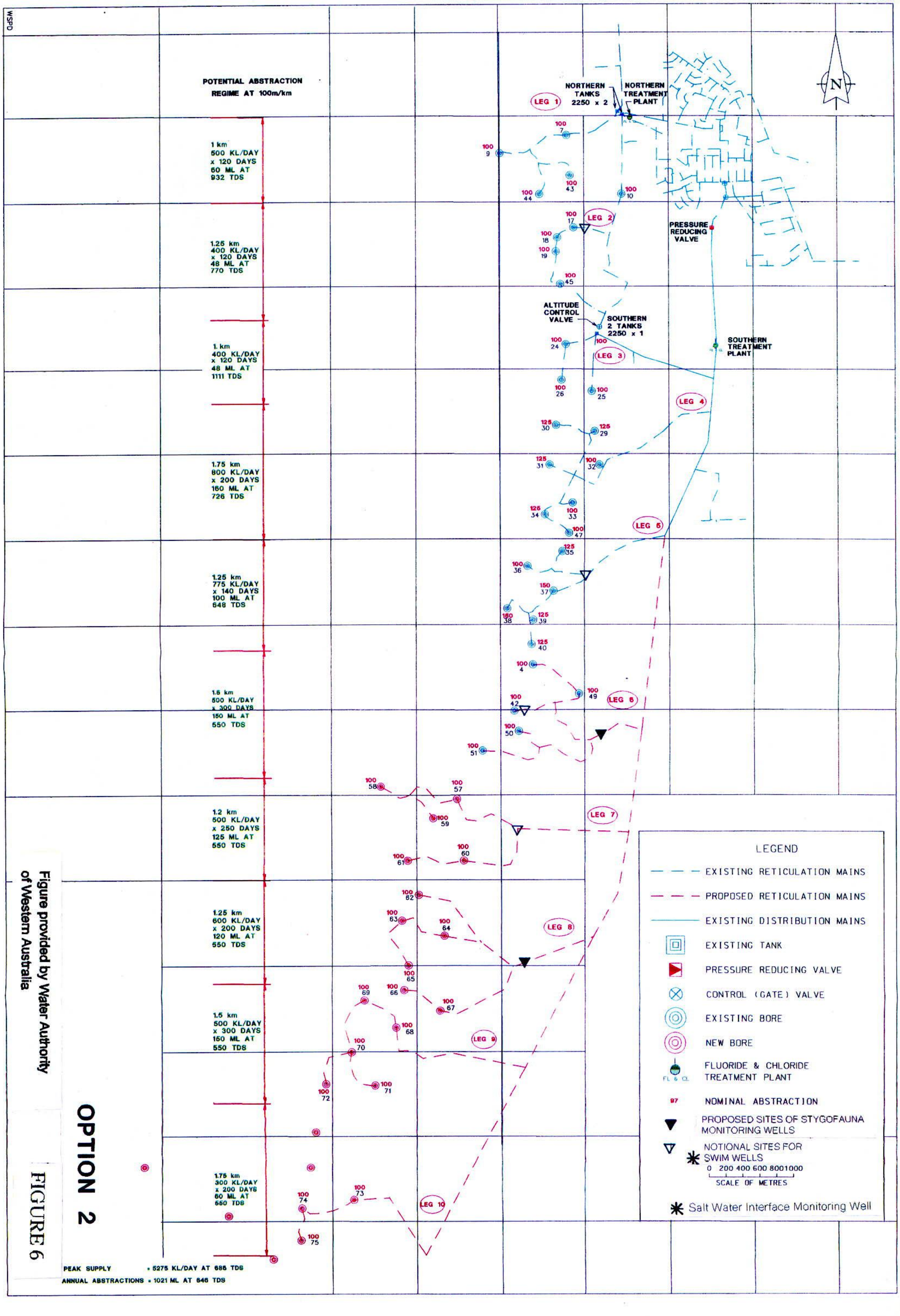


Figure provided by Water Authority of Western Australia

OPTION 2

FIGURE 6

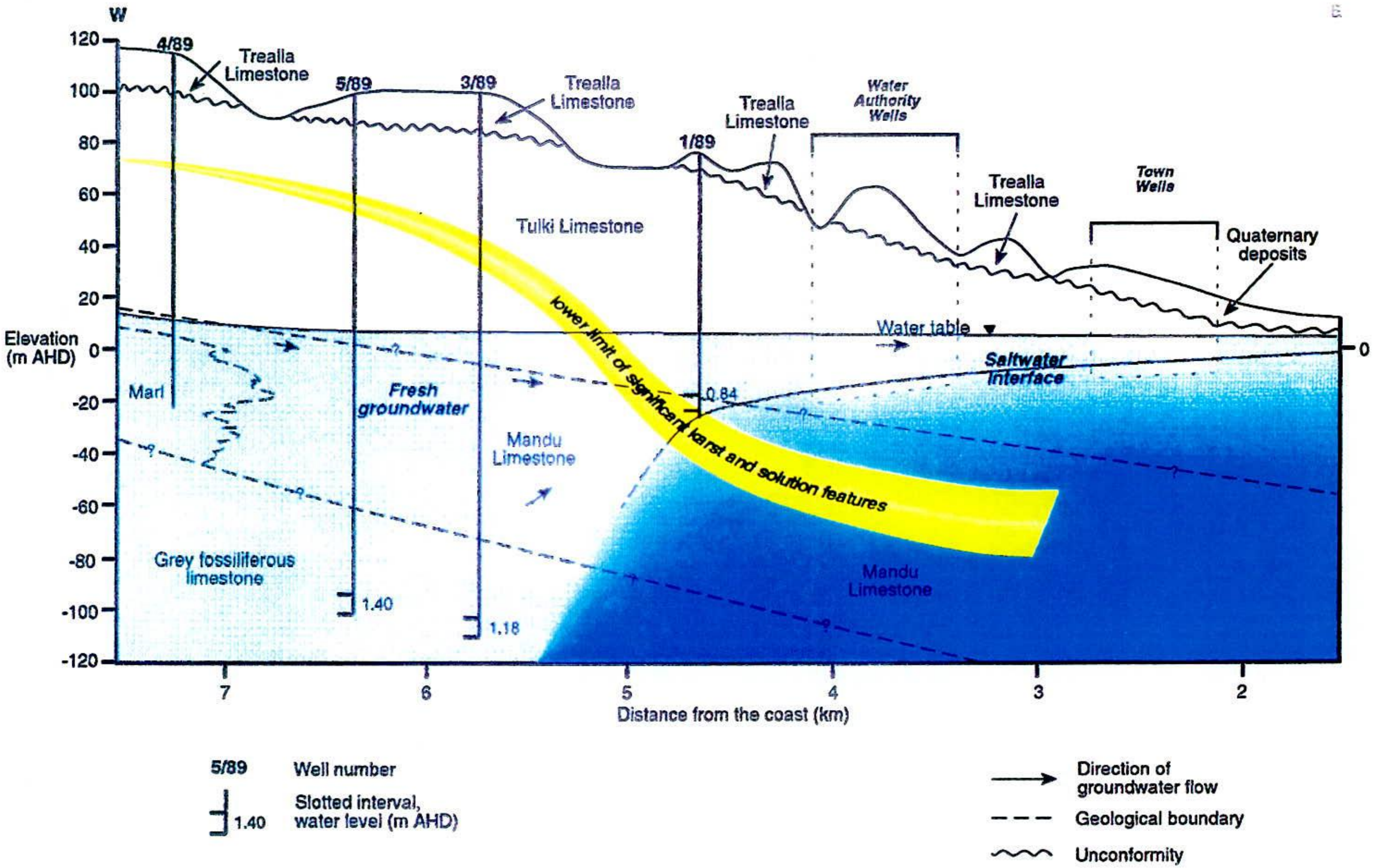


Figure provided by Water Authority of Western Australia

Hydrogeological Cross Section of the Exmouth Groundwater Area

FIGURE 7

Information obtained from GSWA reports

Graphics compiled by IMS Groundwater Consulting

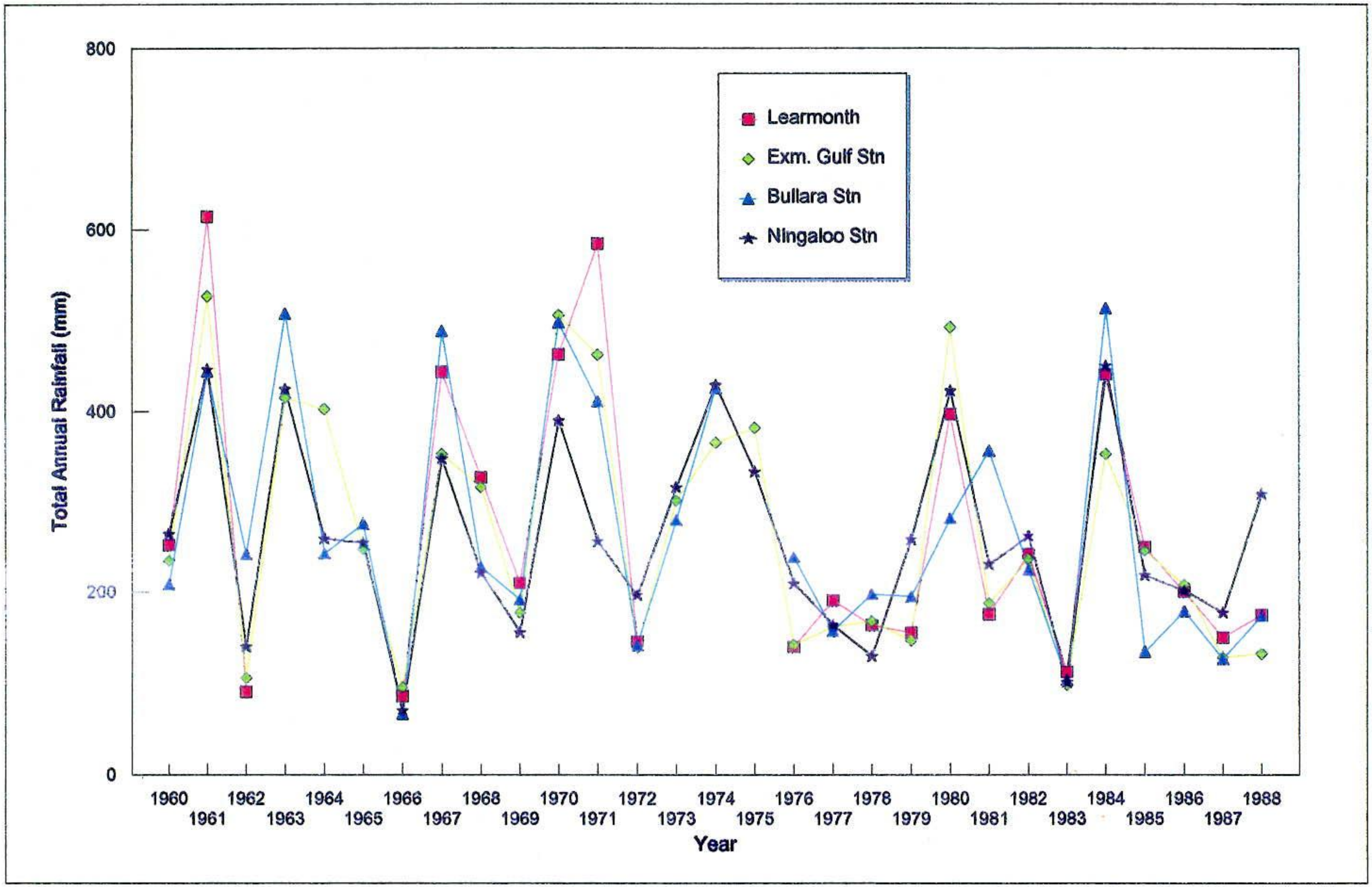


FIGURE 8
RAINFALL 1960 - 1988 AT FOUR
STATIONS WITH COMPARABLE DATA

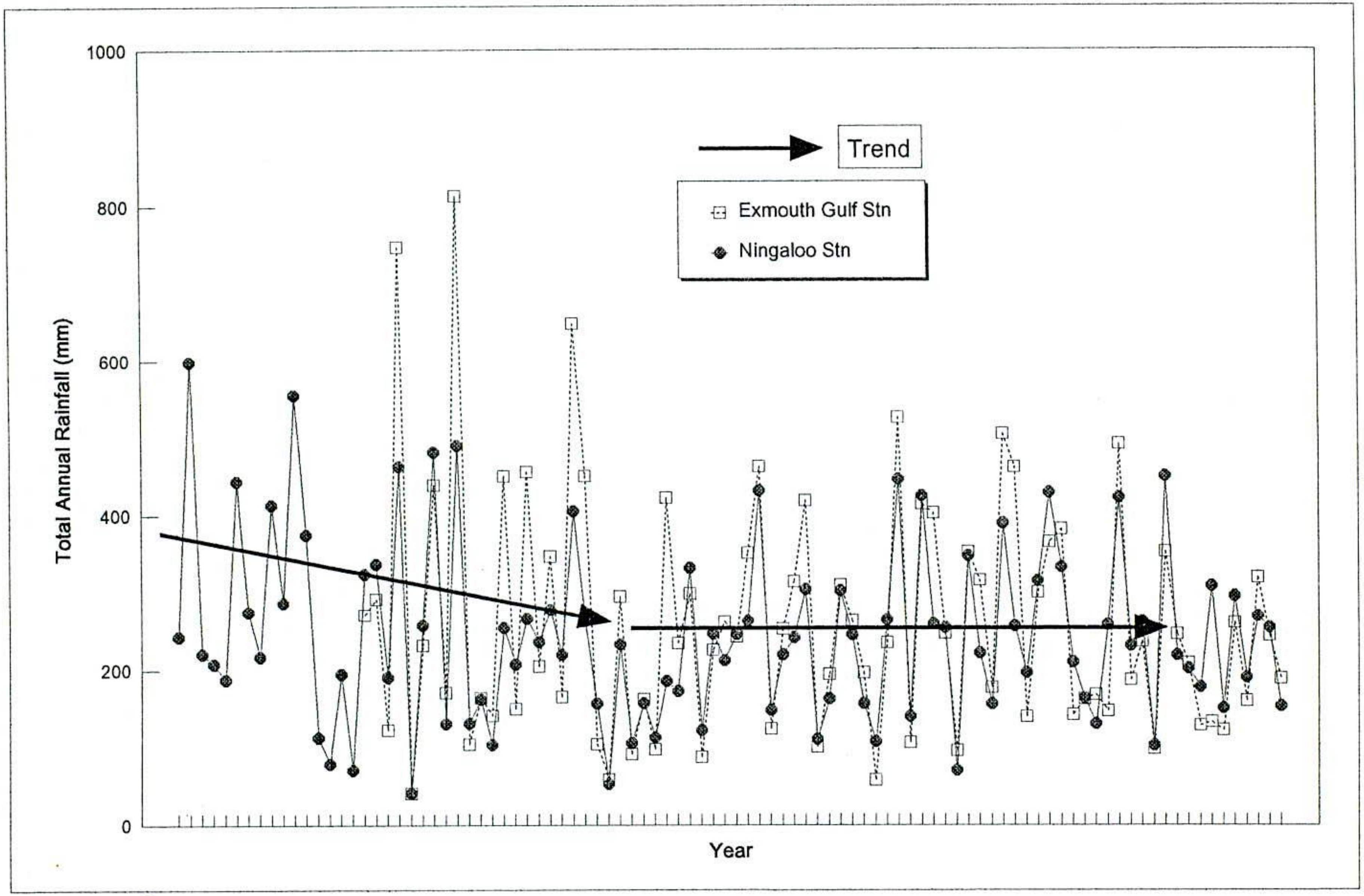


FIGURE 9
LONG-TERM ANNUAL RAINFALLS AT
EXMOUTH GULF AND NINGALOO STATIONS

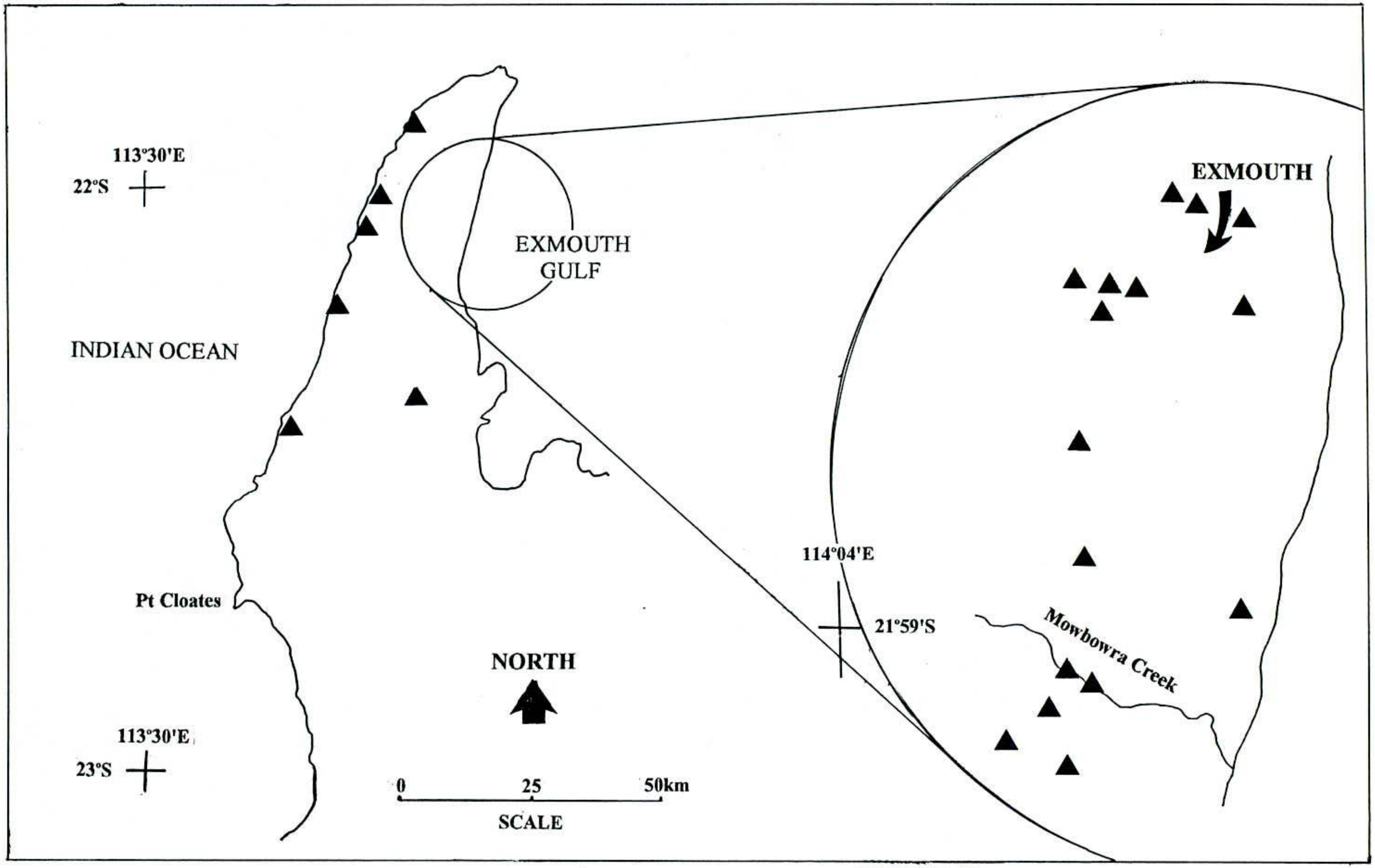
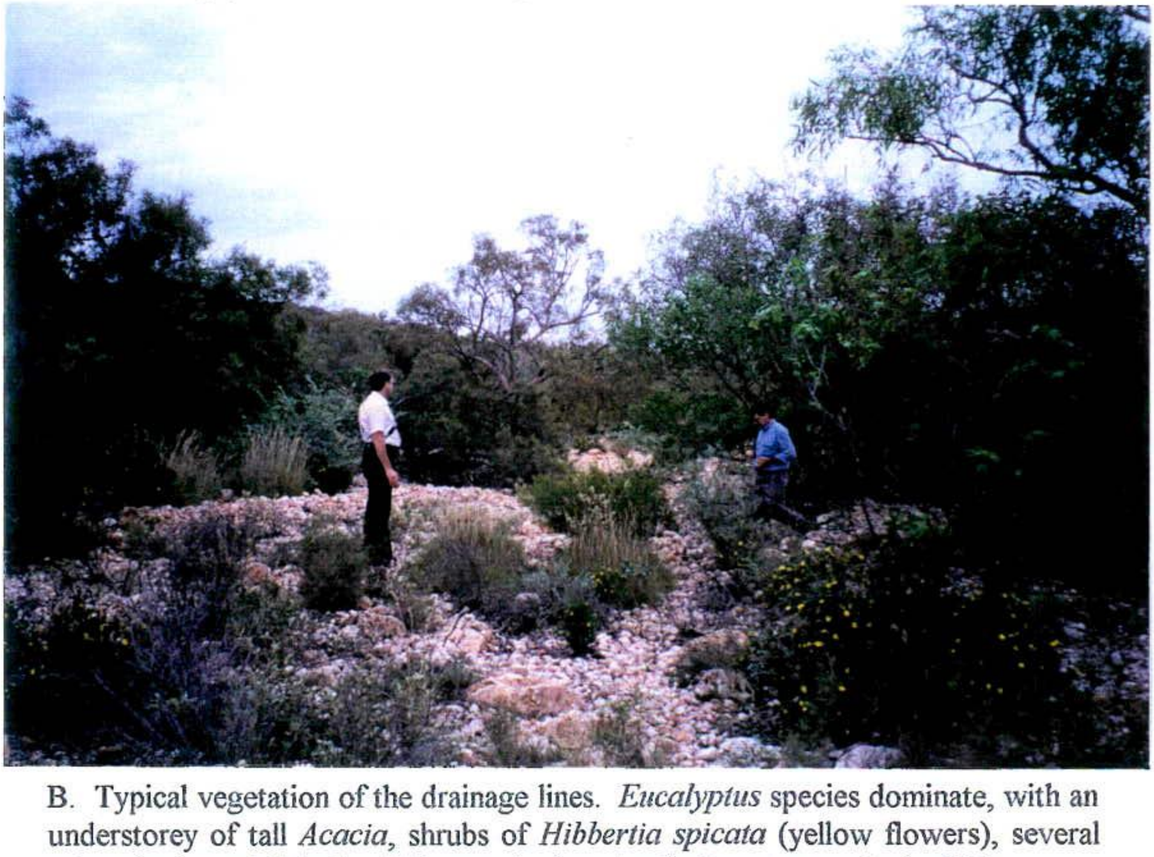


FIGURE 10
KNOWN LOCATIONS OF
STYGOFAUNA ON CAPE RANGE PENINSULA

PLATES

A. Vegetation typical of the ridge crests in areas where the upper storey of shrubs is sparse. Scattered *Acacia bivenosa*, *Acacia pyrifolia* or *Melaleuca cardiophylla* are present over spinifex. Ground is bare limestone or may have a thin cover of soil and many pebbles. For denser vegetation refer Plate 2A.



B. Typical vegetation of the drainage lines. *Eucalyptus* species dominate, with an understorey of tall *Acacia*, shrubs of *Hibbertia spicata* (yellow flowers), several other shrubs and *Triodia*. Substrate is almost entirely water-washed pebbles.

PLATE 1

A. A Water Authority bore in the existing borefield. The proposed bores are of the same construction. After completion of work the vegetation is permitted to regrow. Vegetation here is a little denser than in Plate 1A, with a more prominent overstorey of *Melaleuca cardiophylla*. A power line support is visible on the right.

B. A typical newly-constructed access road. The width is required for equipment access during construction. Once installed the vegetation grows back on the sides until the track is only a car width. The polypipe has been laid on the surface and is identical to that proposed for the extensions.

PLATE 2

APPENDICES

APPENDIX A

DEPARTMENT OF ENVIRONMENTAL PROTECTION GUIDELINES FOR THE CER

Department of Environmental Protection

Managing Director
Water Authority of Western Australia
629 Newcastle Street
LEEDERVILE WA 6007

Your Ref
Our Ref 195/94
Enquiries Juliet Cole

ATTENTION: MR PETER GOODALL

EXPANSION OF WELLFIELD, EXMOUTH (921)

Further to the discussion between Mr Peter Goodall of the Water Authority and Ms Juliet Cole of the Department of Environmental Protection on 25 January 1995, regarding the above proposal, please find enclosed the final guidelines for preparation of the proponent's document.

Should you need any further information please contact Juliet Cole on 222 7080 in the first instance.

for: Colin Murray
A/ DIRECTOR
EVALUATION DIVISION

25 January 1995

enc

LFINALGUIDELINES250195jcol

Westralia Square, 141 St George's Terrace, Perth, Western Australia 6000 Telephone (09) 222 7000 Facsimile (09) 322 1598

EXPANSION OF WELLFIELD, EXMOUTH

CONSULTATIVE ENVIRONMENTAL REVIEW GUIDELINES

Overview

All environmental reviews have the objective of protecting the environment, and environmental impact assessment is deliberately a public process in order to obtain broad ranging advice. The review requires the proponent to describe the proposal, receiving environment, potential environmental impacts and the management of the issues arising from the environmental impacts, so that the environment is protected to an acceptable level.

Throughout the assessment process it is the objective of the Department of Environmental Protection (DEP) to assist the proponent to improve the proposal such that the environment is protected in the best manner possible. The DEP would co-ordinate relevant government agencies and the public in providing advice about environmental matters during the assessment of the Consultative Environmental Review (CER) for this proposal.

Contents of the CER

The contents of a CER should be concise and accurate and be able to:

- communicate clearly with the public (including government agencies), so that EPA can obtain informed public comment to assist in providing advice to government;
- describe the proposal adequately, so that the Minister for the Environment can consider approval of a well-defined project; and
- provide the basis of the proponent's environmental management programme, which shows that the environmental issues resulting from the proposal can be acceptably managed.

The language used in the body of the CER should be kept simple and concise, considering the audience includes non-technical people, and any extensive, technical detail should either be referenced or appended to the CER. Remember that the CER would form the legal basis of the Minister for the Environment's approval of the proposal and, hence, should include a description of all the main and ancillary components of the proposal, including options if necessary.

The environmental management programme for the proposal should be developed in conjunction with the engineering and economic programmes of the proposal. Hence, the CER should be designed to be immediately useful at the start of the proposal, and the DEP recommends that the basis of an environmental management and audit programme be developed as a concluding part of the CER.

The fundamental contents of the CER should include:

- introduction of the proponent, the project and location (in relation to the Cape Range National Park and proposed addition to the park);
- the decision making authorities and involved agencies;
- a description of the components of the proposal and identification of the potential environmental impacts;
- description of the receiving environment which may be impacted;

- discussion of the key environmental issues, including an assessment of the significance as related to identified objectives or standards which may apply;
- discussion of the management of the potential environmental issues, including commitments to undertake appropriate action when necessary, and
- a summary of the proposed environmental management programme, including the key commitments, monitoring work and the auditing of the programme.

For this proposal, the environmental review document should focus on protecting the unique and highly specialised underground aquatic and terrestrial fauna population, collectively known as "stygofauna", in the Cape Range peninsula region.

Key issues

The key issues can be determined from a consideration, called scoping, of the potential impacts from the various components of the proposal on a receiving environment, including people. The CER should focus on the key issues for the proposal, and it is recommended that these be agreed in consultation with the DEP and relevant public and government agencies. With respect to this proposal, specific reference to discussions with officers of the WAWA and Western Australian Museum should be included. A description of the project component and the receiving environment should be directly included with, or referenced to, the discussion of the issue. The technical basis for measuring the impact and any objectives or standards for assessing and managing the issue should be provided.

For this proposal, the key issues include:

- protection of stygofauna (primarily troglobitic fauna) including:
  - the effect of borefield pumping on the stygofauna, and
  - potential consequences of the changes to existing hydrology for the fauna;
- impact on the groundwater system (including status of the water table);
- pipeline alignments and details of any other infrastructure associated with the proposed extension to the wellfield (eg access tracks), and
- alternatives to expanding the wellfield.

Additional key issues may be raised during the preparation of the CER, and on-going consultation with the DEP and relevant agencies is recommended. Minor issues which can be readily managed as part of normal operations for similar projects may be briefly described. Information used to reach conclusions should be properly referenced, including personal communications. Assessments of the significance of an impact should be soundly based on referenced data rather than unsubstantiated opinions, and the assessment should lead to a discussion of the management of the issue.

Public consultation

A description should be provided of the public participation and consultation activities undertaken by the proponent in preparing the CER. It should describe the activities undertaken, the dates, the groups/individuals involved and the objectives of the activities. Cross reference should be made with the description of environmental management of the issues which should clearly indicate how community concerns have been addressed. Those concerns which are dealt with outside the EPA process can be noted and referenced.

Environmental management commitments

The method of implementation of the proposal and all commitments made by the proponent in the CER would become legally enforceable under the environmental conditions of the Minister for the Environment's approval. Specific commitments to protect the environment, typically related to the key issues, should be separately listed, numbered and take the form of:

(a) **WHO** will do the work;

(b) **WHAT** the work is;

(c) **WHEN** the work will be carried out; and

(d) **TO WHOSE REQUIREMENTS** the work will be carried out.

These key commitments show that the proponent is committed to actionable and auditable management of the environmental issues.

APPENDIX B

CONSULTATIVE ENVIRONMENTAL REVIEW PROJECT TEAM

APPENDIX B

CONSULTATIVE ENVIRONMENTAL REVIEW PROJECT TEAM

ORGANISATION	PERSONNEL	PROJECT ROLE
Water Authority of Western Australia	Chris Dolley Peter Goodall	Project Managers and public consultation.
Muir Environmental	Barry Muir Jennifer Muir	CER co-ordinators, natural environment descriptions, European heritage, preparation of documentation.
Dr W. (Bill) Humphreys operating through auspices of Western Australian Museum	Bill Humphreys	All aspects of stygofauna protection and management.
A. J. Peck and Associates Pty Ltd together Peter Clifton and Associates	Adrian Peck Peter Clifton	All issues relating to hydrology and hydrogeology.
McDonald Hales and Associates	Angela Murphy	All issues relating to Aboriginal Heritage, including archaeology.

APPENDIX C

RARE AND SIGNIFICANT FLORA

APPENDIX C

RARE AND SIGNIFICANT FLORA

The term 'rare and significant flora', as used in this report, refers to species (or other taxa) that are:

- rare, geographically restricted or apparently rare, or restricted because they are poorly collected or recorded;
- at the limits of their ranges, or in areas outside their normal ranges or habitats;
- particularly susceptible or vulnerable to environmental changes, especially ones caused by humans, either directly or indirectly;
- diminishing significantly in abundance or geographical range, due to clearing and other environmental changes associated with agriculture, mining, recreation, urbanisation and provision of services; or
- poorly represented in secure conservation reserves.

The term 'significant' is used because terms such as 'vulnerable', 'threatened', 'depleted', or 'endangered' have become highly emotive through popular usage.

Some significant plant species are considered as 'Declared Rare Flora' (DRF). A list of Declared Rare Flora is published from time-to-time in the Government Gazette (hence the term 'Gazetted Rare Flora') by the Minister for Conservation and Land Management. Destruction, removal, or any other disturbance of Declared Rare Flora requires approval in writing from the Minister before any destructive operations commence. The Minister has the right to withhold permission to disturb the flora.

The status (importance) of significant species can change with time. In some cases, significant species are found in areas where they were not previously known to occur. In other cases, species are no longer found in areas where they were previously recorded.

The 'Priority' taxa, as defined by the Department of Conservation and Land Management (CALM), and their conservation codes are :

- Priority One (P1) - taxa known from one or a few (generally under five) populations, which are under threat and in urgent need of further survey work;
- Priority Two (P2) - taxa known from one or a few (generally under five) populations, at least some of which are not believed to be under immediate threat, but are in urgent need of further survey work;

- Priority Three (P3) - taxa known from several populations, at least some of which are believed to be not under immediate threat, and are in need of further survey work;
- Priority Four (P4) - taxa considered to have been adequately surveyed and which, whilst being rare, are not currently threatened by any identifiable factor;
- Priority Five (P5) - taxa which are presumed extinct and which have not been collected or reliably observed in the wild over the past 50 years.

These lists are modified and updated by CALM as relevant information and results of survey work become available. Priority One, Two and Three species are under consideration for declaration as rare flora, pending the outcome of further survey work.

SEARCHING FOR SIGNIFICANT SPECIES

Prior to field examination for rare or significant plant species, an interrogation of CALM's rare flora database is carried out. This search is for taxa associated with named localities in and near the Project Area. CALM's published Declared Rare and Priority Flora List for the relevant geographic region is also examined.

The Project botanist then becomes familiar with the significant taxa by reference to relevant literature (for example, Hopper *et al.* 1990) and examination of herbarium specimens held by research institutions. In particular the appearance, flowering time, preferred habitats and known distribution are noted. Whenever possible DRF, P1 and P2 taxa are photographed and the photographs used for reference in the field.

Discussions with CALM botanists and others who are familiar with the flora may also take place with respect to certain difficult taxa. This ensures that the ecology, distribution and appearance of the species is as well understood as possible.

During the field search likely habitats, as well as the actual plants, are searched for. Plants identified in the field as being DRF or Priority taxa are photographed and their locations and ecological relationships recorded. Specimens that do not destroy or badly damage the plants are carefully collected from suspected significant species. These are used for subsequent confirmation by use of taxonomic keys, and by reference to herbarium specimens or experts in the relevant taxonomic group. Botanical nomenclature used in this report follow Green (1985) and periodic updates.

There are limitations to the adequacy of any search for significant species. The principal limitations are:

- the period of time available in the field to undertake the work;

- the flowering times of the species being searched for. Thus, a search undertaken in summer or autumn is, in general, less likely to find significant plants than a search undertaken in spring. In spring a larger proportion of significant species is likely to be in flower or, in the case of ephemeral plants, in leaf. This seasonal variation in the adequacy of a search may be further affected by whether the spring or winter season has been 'early' or late', and if it has been exceptionally dry or wet;
- in an area which has been badly affected by drought, insect attack, or recent fire, it may be very difficult to locate suitable specimens to permit identification, even of the common species. Thus, searches in, for example, recently burned bushland, may be unreliable, and it may be necessary to rely on data from similar unburned habitats located elsewhere, or even to rely solely on available literature; and
- it must be recognised that finding a small inconspicuous plant, especially in dense vegetation, may be a matter of chance, even if the plant is well known. In these circumstances, the search for suitable habitat is of great importance, as it indicates the likelihood of the species' presence even if it is not recorded.

REFERENCES

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Hopper, S.D., van Leeuwen, S., Brown, A.P. and Patrick, S.J. (1990). Western Australia's Endangered Flora. Dept Conservation and Land Management.

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APPENDIX D

PAPER BY DR W. HUMPHREYS "SUBTERRANEAN FAUNA"

AN EXAMINATION OF THE LIKELY IMPACTS OF THE EXMOUTH BOREFIELD EXTENSION ON THE SUBTERRANEAN FAUNA

by W.F. Humphreys

CONTENTS

AN EXAMINATION OF THE LIKELY IMPACTS OF THE EXMOUTH BOREFIELD EXTENSION ON THE SUBTERRANEAN FAUNA

SUMMARY

The area of the proposed Exmouth borefield extension is inhabited by a terrestrial and aquatic subterranean fauna of international significance. The borefield is unlikely to impact on the fauna upstream (or upslope) of the project but the potential for impact within the borefield and downstream of the project is considerable.

The project is likely to result in substantial direct mortality of stygofauna (including protected species) and to impact outside the limits of the project area. However, inadequate data prevent projection of these impacts on the sustainability of the populations and the data cannot be gathered in the absence of dedicated monitoring bores. Two stygofauna species —*Haptolana pholeta* and a melitid isopod — are known on the peninsula only from the affected area.

A number of terrestrial troglobitic species — *Draculoides bramstokeri*, *Hyella* sp. nov., *Stygiochiropus* sp. nov. and an undescribed harvestman (Phalangodidae) and cixiid bug — are known on the peninsula only from the affected area. There is no evidence that stygal or troglobitic species will or will not be lost as a result of pumping activities.

The implementation of a broad programme of monitoring, using production bores and dedicated monitoring bores, both within and downstream of the project, needs to be implemented and rigorously followed. It is recommended that a standard monitoring programme is established and that a review of the status of the fauna should be undertaken if a species is apparently lost from more than 33% of the monitoring sites. If this proves to be the case then a review of the borefield operations should be referred back to the EPA.

Predetermined criteria should be established which will determine the next major review.

AN EXAMINATION OF THE LIKELY IMPACTS OF THE EXMOUTH BOREFIELD EXTENSION ON THE SUBTERRANEAN FAUNA

Introduction

The species density of the surface fauna and flora on the Cape Range peninsula is high for the region owing to the geomorphological and edaphic diversity of the area. The surface biota is, nonetheless, unexceptional, being essentially an arid zone biota with little endemism (papers in Humphreys 1993a). By contrast the subterranean fauna is exceptional as the below ground habitats have been buffered from the major surface changes associated with the onset of aridity.

The humid caves contain species that represent what is essentially a rainforest fauna in this now arid area and comprises species that are specially adapted to living underground. All the cave fauna is endemic and there is an exceptional degree of generic endemism, as well as an endemic (?sub-) family of animals. Within both the terrestrial and aquatic fauna speciation has occurred associated with local geomorphology and speciation continues as indicated by the many genetically isolated populations (papers in Humphreys 1993a).

The groundwater contains many relict taxa otherwise known from congeneric species in the North Atlantic and which represents a very ancient fauna associated with the Tethys Sea. The area contains the only representatives known in the southern hemisphere of entire classes, orders, families and genera of animals.

Subterranean fauna occur with varying degrees of dependence on underground life. Those totally dependent on subterranean existence — they spend their entire life cycle in caves — are known as troglobites (or stygobites if they are aquatic species). They are usually pale, eyeless, with enhanced non-optic sense organs (exceptionally long antennae, limbs etc.) and lack the ability to control water loss. Many of the troglobites from the Cape Range peninsula have a very advanced degree of troglobitic adaptation such that specialists in a particular group often comment that they are the most troglobitic forms that they have ever encountered. This is sometimes taken to indicate that the species have long been isolated in caves — certainly the Cape Range fauna is ancient (Adams & Humphreys 1993); Humphreys 1993b).

Occurrence/existence

The Cape Range peninsula contains a diverse fauna of troglobitic animals — obligatory inhabitants of the subterranean realm. The fauna has mostly been discovered recently and is sparsely documented. It comprises a number of distinct components.

Aquatic fauna

Obligatory inhabitants of underground waters, stygofauna, are found on the coastal plain (bar three species found in Cape Range).

The fauna contains classes, orders, genera and species not otherwise represented in Australia, nor indeed in the southern hemisphere, and as such it makes a significant contribution to biodiversity in Australia. The following taxa have been recorded (Table 1) and additional major taxa are likely to be discovered as has been successfully predicted with other taxa (Humphreys 1993b; Poore and Humphreys 1992; Wagner 1994).

Table 1: The composition of the stygofauna of the north west of Western Australia. About half of this fauna has been found since 1991. The fauna is found variously in caves in Cape Range itself [CR], on the coastal plain bordering Cape Range [cp], and on Barrow Island [BI].

Major taxon	Genus and species	Locality
Pisces: Eleotridae	*Milyeringa veritas* Whitley	cp
Pisces: Synbranchiformes	*Ophisternon candidum* (Mees)	cp
Decapoda: Atyidae	*Stygiocaris lancifera* Holthuis	cp
Decapoda: Atyidae	*Stygiocaris stylifera* Holthuis	cp, BI
Isopoda: Cirolanidae	*Haptolana pholeta* Bruce & Humphreys	cp, BI
Thermosbaenacea	*Halosbaena tulki* Poore & Humphreys	cp, BI
Amphipoda: Melitidae*	New genera, 6+ species	cp, CR, BI
Amphipoda: Bogidiellidae	?	BI
Ostracoda: Halocyprida	*Danielopolina* n. sp. Baltanas, Danielopol & Humphreys , in press	cp
Syncarida: Bathynellacea	*Atopobathynella* n. sp.	BI
Copepoda: Harpacticoida	?	cp, CR, BI
Copepoda: Cyclopoida	*Metacyclops* n. sp.	cp
	Microcyclops varicans G. O. Sars	cp, CR
	Apocyclops dengizicus (Lepechkine)	cp
	Halicyclops n.sp. Pesce, De Laurentiis & Humphreys, in press	cp
	Halicyclops spinifer Kiefer 1935	cp, CR
Remipedia: Nectiopoda	*Lasionectes* n. sp. Yager & Humphreys	cp
Turbellaria	?	cp, BI

* sensu Bousfield 1973

In addition to the undoubted stygofauna there are a number of other taxa which have been recovered from open water habitats that contain stygofaunal species but which are of uncertain stygal, or even taxonomic, affinity (Table 2).

Terrestrial fauna

The richness of the terrestrial troglobitic fauna of the Cape Range peninsula has been recognised only recently (1988 onwards). This fauna is rich, with at least 30 troglobitic species from many orders (in Humphreys 1993a, and Table 3). In addition there are many species not obviously troglomorphic but whose presence in this arid region is dependent on the subterranean habitat (Table 3).

Table 2. High level groupings of taxa collected in open water bodies and which may not comprise part of the stygofauna proper. However, note that a number of stygofaunal species are also known from the same habitats. The references denote the source of determinations other than the authors. [1]Status ambiguous (*cf.* Knott 1993; Slack-Smith 1993).

Taxon	Notes	Authority
Protista (sundry)	*Euplotes* sp.; *Paramecium* sp.	Knott 1993
Rotatoria		Humphreys 1994
Turbellaria		Humphreys 1994
Nematoda		Humphreys 1994
Polychaeta	Syllidae (two species)	G. Hartmann-Schrder, pers. comm.
Oligochaeta		Humphreys 1994
Mollusca	*Iravadia* (*Iravadia*) sp. ?*I. ornata*[1]	Slack-Smith 1993
Ostracoda		Humphreys 1994
Amphipoda: Aoridae	*Grandidierella* n. sp.	Myers & Lowry, pers. comm.
Acarina: Hydracharina	*Coaustraliobates* sp.	Harvey, pers. comm.
Odonata		Humphreys 1994
Hemiptera		Humphreys 1994
Diptera: Chironomidae	*Chironomus* (*Kiefferulus*) *intertinctus*	Knott 1993
Coleoptera		Humphreys 1994

The cave fauna of the southern section of Cape Range is much better known than that of the northern regions — knowledge of the fauna of the coastal plain, only recently found, is quite inadequately — it is distinct from the related fauna found in Cape Range (Table 3) and has several components in common with Barrow Island (Humphreys 1994).

Status

Aquatic fauna

The fauna is of high national estate and scientific significance, and of great conservation value, being endemic to the Cape Range Formation and highly disjunct from related fauna (which, for the most part, occur only in the Canary Islands and the Caribbean region, Table 4). The fauna comprises a relict community derived from the ancient Tethys Sea (Humphreys 1993a, 1993b; Knott 1993) that separated the continents of Gondwana and Laurasia and which persisted from the Triassic until the late Eocene (200-40 Ma; Smith and Briden 1977). It may well have been separated from its relatives with the break-up of Pangea and dispersed by seafloor spreading—in either case the fauna is very ancient.

Listed aquatic species

The two species of fish (*Ophisternon candidum* and *Milyeringa veritas*)—the only vertebrate troglobites known in Australasia—and two atyid shrimps (*Sygiocaris stylifera* and *S. lancifera*) in the subterranean coastal fauna of the Cape Range peninsula have been included in *Schedule One of the Wildlife Conservation Act 1950.*

Table 3. Some terrestrial troglobitic fauna known from Cape Range (CR), from the coastal plain of Cape Range peninsula (cp) or from Barrow Island (BI). Those marked ˙ exhibit extreme troglomorphies; the remainder are possibly restricted to cave environments.

	CHELICERATA		
Schizomida		˙*Draculoides vinei* (Harvey)	CR
		˙*Draculoides bramstokeri* Harvey & Humphreys	cp, BI
Pseudoscorpionida	Hyidae	˙*Hyella humphreysi* Harvey	CR
		˙*Hyella* sp. nov.	cp
	Chthoniidae	*Austrochthonius easti* Harvey	CR
	Cheiridiidae	?	CR
Opilionida	Phalangodidae	˙Gen?	cp
Araneae	Hahniidae	˙Gen?	cp
	Desidae	*Forsterina* sp.	?cp,CR
	Miturgidae	˙Gen .et sp. nov.	cp,CR
	Pholcidae	*Trichocyclus septentrionalus* Deeleman-Reinhold	
	˙Gallieniellidae		CR
	MYRIAPODA		
Diplopoda	Paradoxosomatidae	˙*Stygiochiropus communis* Humphreys & Shear	CR
		˙*Stygiochiropus isolatus* Humphreys & Shear	CR
		˙*Stygiochiropus sympatricus* Humphreys & Shear	CR
		˙*Stygiochiropus* sp. nov.	cp
	INSECTA		
Diplura	Japygidae	*Indjapyx* n. sp.1	CR
		Indjapyx n. sp.2	CR
		Gen. nov. & n. sp.1	CR
		Gen. nov. & n. sp.2	CR
	New family or sub-family		?cp,CR
Thysanura	Nicoletiidae: Atelurinae		CR
Coleoptera	Curculionidae: Brachycerinae (s. lat):		CR
	Polydrosinae	*Myllocerus* sp.	CR
Hemiptera	Meenoplidae	˙*Phaconeura proserpina* Hoch	cp
	Cixiidae	˙?gen.	CR
	CRUSTACEA		
Isopoda	Philosciidae		CR

Table 4: The affinities of genera from the stygofauna of north west of Western Australia. T= Tethyan distribution, G= Gondwanan distribution.

Taxon	Genus	Tethyan?	Affinities
Crustacea			
Syncarida: Bathynellacea	*Atopobathynella*	G	SE Australia, New Zealand, Chile
Thermosbaenacea	*Halosbaena*	T	West Indies, Columbia, Canary Is (Poore and Humphreys 1992)
Amphipoda: Melitidae	New gen. & sp.	T	Barnard & Williams, in press
Amphipoda: Melitidae	New gen. & spp.	T	Williams and Bradbury, pers. comm. 1995
Amphipoda: Bogidiellidae	?	Pangean	Bradbury, pers. comm. 1995
Isopoda: Cirolanidae	*Haptolana*	T	Cuba, Somalia (Bruce and Humphreys 1993)
Decapoda: Atyidae	*Stygiocaris*	T	Madagascar (Banarescu 1990)
Ostracoda: Halocyprida	*Danielopolina*	T	West Indies, Canary Is, Galapagos, Atlantic abyssal
Remipedia: Nectiopoda	*Lasionectes* sp. nov	T	Turks & Caicos I. West Indies.
Pisces			
Perciformes: Eleotridae	*Milyeringa*	?	?
Synbranchiformes	*Ophisternon*	?	Circum tropical (Mexican caves)

Terrestrial fauna

The affinities of the terrestrial troglobitic fauna lie with the litter fauna of closed moist forests, both temperate and tropical, that are today typically found on the eastern seaboard of Australia. The fauna is considered to be relictual, isolated from similar taxa by the onset of aridity in the late Miocene or early Pliocene and it contains some very ancient elements with clear eastern Gondwanan affinities (papers in Humphreys 1993a).

The troglobite fauna is entirely comprised of endemic taxa, often at the generic level (plus one family) and as such it makes a significant contribution to biodiversity in Australia.

Troglobitic animals are found extensively in Cape Range proper where they occur in a number of discreet zones, being more highly speciated in the north of the range and becoming progressively less isolated towards the south. A related but discreet fauna is found on the coastal plain which has some species in common with Barrow Island.

Listed terrestrial species

The two species of terrestrial fauna, a micro-whip scorpion (*Schizomus vinei* now *Draculoides vinei*) and a cockroach (*Nocticola flabella*) in the subterranean fauna of Cape Range have been included in *Schedule One of the Wildlife Conservation Act 1950.*

Overall significance of the fauna

The Cape Range peninsula has a high species density and exceptional endemism in its subterranean component (papers in Humphreys 1993a). Of the described specialist underground fauna known from the worlds tropics, *c.* 6.5% are known only from this area which comprises only 0.07% of Western Australia (Humphreys 1993a).

The significance is further enhanced:

- because in its composition are echoes of local eustatic events, climatic change, and of past connections with other parts of Australia, eastern Gondwana and even Pangea. The fauna contains the only evidence of closed forest, both temperate and tropical, since the Miocene when the Cape Range limestones were laid down.

- by a unique combination of subterranean terrestrial and aquatic communities and by the relatively pristine state of the area.

- by the inclusion of many higher order taxa (genera, families, orders and classes) found nowhere else in Australia, the southern hemisphere or the world, and by the close affinity of some aquatic taxa with other subterranean species found on both sides of the North Atlantic.

The stygofauna is currently as severely constrained in area as at any time during the last 240 ka. This means that the current genetic fragmentation of the populations (Humphreys and Adams 1991; Adams and Humphreys 1993; Humphreys 1994) is being exacerbated by small geographical range and low population size. Hence, the stygofauna must be considered relatively vulnerable from an palaeo-biogeographic perspective.

Existence of fauna under current and proposed conditions

Hydrogeological context

1. There is little information on the depth of the salt water interface, and the thickness of the overlying layer of fresher water in the Water Authority borefield at Exmouth, and none in the area between the borefield and the coast. Salinities have been recorded during drilling of a few holes (Martin 1992). At two sites to the west of the borefield, the thickness of the layer of water with salinities less than 4000 mg L^{-1} was about 25 and 27 m. Further west, there was a layer more than 100 m thick with salinity less than 600 mg L^{-1}. To the south of the borefield, the thickness of the layer with salinities less than 1600 mg L^{-1} was about 19 m.

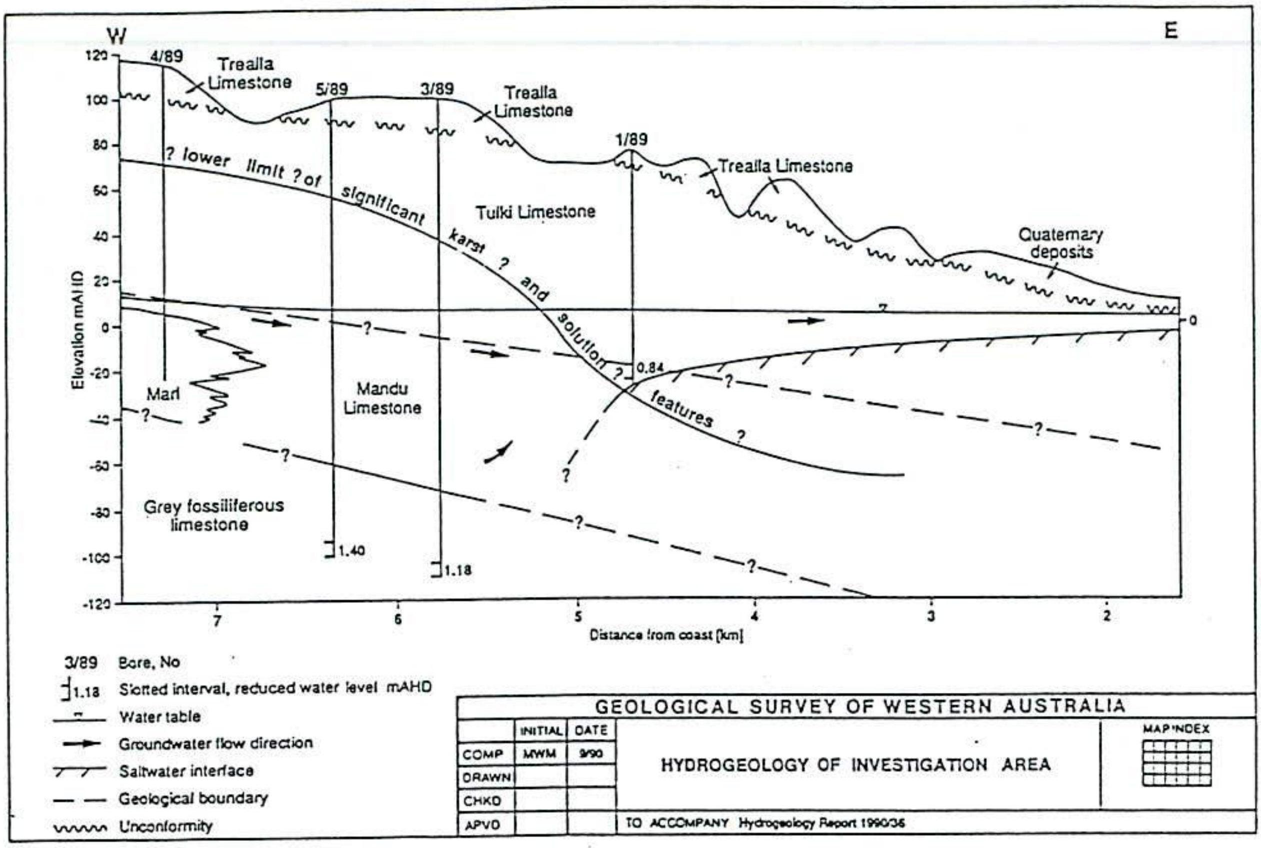
2. The thickness of a layer of fresher water overlying saline water in a coastal aquifer can be estimated using a theoretical relationship with water table height, a relationship which depends on the difference of density between the fresher and saline waters. When very low salinity water overlies sea water, the thickness of the fresh water is about 40-times the height of the water table above sea level. The ratio is greater when there is a smaller difference of salinity (Figure 1).

3. Water table data from the Water Authority borefield at Exmouth are of limited value, because all measurements are made by the air-line methods in bores which are used for groundwater production.

4. At Exmouth, the aquifer is very permeable near the coast and for 4-5 km inland (due to the presence, at least near the range, of cavernous Tulki Limestone) so that the water levels in this area are only slightly above sea level. Because of the low water table, there is expected to be a very shallow layer of fresher water in the aquifer. Further inland the water table is within the less permeable Mandu Limestone (at which point the Tulki Limestone is above the water table) resulting in a higher

water table and a thicker layer of fresh water. This general picture is consistent with the few observations of salinity at various depths in boreholes.

Figure 1: Hydrogeological section through the Water Authority borefield and the proposed westward extension (Option 1). From Martin (1990) with permission of the Director of the Geological Survey of Western Australia). Note the saltwater wedge pushing up the fresh water lens. A zone of mixing occurs at the saltwater interface.



5. As pumping lowers the water table, it results in a thinning of the layer of fresher water , and a rise in the saltwater interface, by about 40 times the distance the water table has been lowered. In the past, water was pumped from the Water Authority borefield at rates which are high relative to the estimated natural flow in the aquifer. Although pumping rates in the existing borefield have been lowered, it must be expected that the layer of fresher water at the top of the aquifer is now thinner than it was before pumping began. It is uncertain whether the thickness of the layer of fresher water in this area will now increase or continue to decrease. Proposed pumping from the southern extension of the borefield will result in a thinning of the layer of freshwater in that area.

6. An analysis of the trends in recorded salinity in the production bores up to 1991 was reported by Halpern Glick Maunsell (1992). There were small but significant increases of salinity over time in about 38% of the bores, most of them in the northern and eastern areas of the borefield. The increasing trend of salinity was

attributed to an inland and upward movement of the salt water interface within the aquifer. More recent data have not been subjected to the same analysis.

Habitats of subterranean fauna

The terrestrial cavernicolous fauna is predominantly found in caverns in Tulki Limestone. The aquatic cavernicolous fauna occurs in Tulki Limestone and in the more recent coastal limestones. The Tulki Limestone occurs over the Cape Range anticline where karst formation has occurred through a thickness of c. 100 m. Due to repeated vertical migration of the mixing zone during Quaternary glacio-eustatic changes we may expect that karstic development will be minimal in the coastal limestones but that caves should be well developed within the submerged dense crystalline Tulki Limestone to c.-100m. It is known to be cavernous to -34 m.

Under normal conditions much of the fresh water from the aquifer must escape through the seabed in the near-shore zone. The existence of submarine springs (*vruljas*) in karst terrains is well recognised and have been reported, but not confirmed, from both coasts of the Cape Range peninsula. This implies confined pipe flow at depth and their location probably reflects the position of springs during times of lower sea level.

Terrestrial fauna occurs in the airfilled caverns where the characteristic cave fauna is restricted to humid caves , mainly >90% relative humidity. Within Cape Range there are isolated perched water tables at an altitude of *c.* 190 m. These contain separate populations of an amphipod congeneric with that occurring in the coastal water table.

None of this fauna upstream of the borefield (including both surface and underground flows) is likely to be affected by the borefield.

Effect of pumping per se on community structure

The effects of pumping from the borefield can be derived from general principles but, unusually in this case, can also be considered from direct evidence. Comparison of pumped and unpumped Water Authority bores shows significant differences in the fauna sampled (Table 5) both overall ($\chi^2_4 = 80.40$, $P<0.0001$) and for the named species only ($\chi^2_2 = 62.39$, $P<0.0001$). In essence there was a considerable excess of *Stygiocaris* in production bores (observed/expected= 80/56) and too few in those never used (6/30), whereas there was a large excess of *H. tulki* in bores never used (44/22) and a deficit in production bores (21/43). This is possibly the result of the

Table 5: The number of individuals of various stygofaunal taxa collected by trapping and haul netting collected from Water Authority bores that have been long in production (N=3) compared with those never pumped (N=6). Sty = *Stygiocaris* sp.; *H.t.* = *Halosbaena tulki*; *H.p.* = *Haptolana pholeta*; Amp = melitid amphipod; Cop - copepods.

Treatment	Sty	*H.t.*	*H.p.*	Amp	Cop	Total
Never pumped	6	44	5	1	59	115
Production bore	80	21	4	2	30	137

additional water flow reducing the available flocculant substrate in which thermosbaenceans and other small stygofauna thrive. In the absence of experimental data the tentative conclusion is that the pumping of water from the bores changes the community structure in the groundwater from one numerically dominated by small *Halosbaena tulki* (c. 2 mm total length) to one dominated by *Stygiocaris* sp. (c. 6 mm).

Direct mortality

Humphreys (1994) showed that the proposed expansion of the borefield (to then 1852 ML a^{-1}) would result in an *absolute minimum* direct crustacean mortality in the order of between 200,000 and 500,000 individuals per year. These figures are appproximate and further data should be collected. The mortality will have the added effect of reducing the energy available in the ecosystem.

The current projected extraction is 1029 ML a-1 (Option 1) or 1021 ML a-1 (Option 2) (WAWA 1994b) which would pump in the order of 100,000 to 300,000 individuals per year but the two options would have different impacts on the fauna.

- Direct mortality would be c. 11 % less under Option 1 compared with Option 2 as this proportion of the water would be drawn from the afaunate part of the water resource.

- Under Option 1 the downstream effects would occur over 25% less of the coastal plain owing to a difference in the borefield length (c. 10.3 v's 13.8 km).

In conclusion, a substantial number of individuals in the stygofauna will be killed directly by borefield pumping and this includes a species listed under *Schedule One of the Wildlife Conservation Act 1950*. However, the proportion of the total population this represents is unknown and, in the absence of population dynamics data, the impact of this loss on the population structure and dynamics cannot be calculated. However, stygofauna generally comprises long-lived species with low reproductive output, high investment in young, often with direct development, so the replacement rate is low (Culver 1882). Certainly this is the case for *H. tulki* and *Stygiocaris* spp. which have c. 7 and 8 young respectively.

Of more concern is the loss of energy from the ecosystem resulting from the loss of individuals. This loss would be added to any loss of energy resulting from the interception of the groundwater flow. Nonetheless, even with so many unknowns, it is clear that Option 1 is favoured over Option 2 in that it will minimise the impact of the borefield expansion on the stygofauna.

The energy source for the stygofauna is unknown, although a mixture of organic carbon (from both downward infiltration and groundwater flow) and chemoautotrophy are likely to be important (Sarbu & Popa, 1992). While the effect on the stygofauna cannot be predicted in the absence of information on the energy sources for the ecosystem, the interception of between 60 and 95%of the estimated throughflow of 100 ML a^{-1} km^{-1} (WAWA 1994a) and the concomitant loss of organic carbon is liley to have important consequences for any downstream stygofauna that harvest particulate carbon in the groundwater flow — filterable organic carbon occurs with a mean concentration of 21.5±2.42 (n= 36) mg L^{-1} in groundwater on the Cape Range peninsula containing stygofauna. Such a loss of energy in the system could result in reduced population sizes and may disrupt the trophic balance within the ecosystem by shortening the food chain.

Composition of the fauna

Not all taxa known from close proximity to the Exmouth borefield have been recorded from the borefield itself. This is considered to be an artefact of collecting; the collecting methods necessarily used in the borefield being unsuitable for detection of some species (e.g. *Ophisternon candidum*).

The faunistic differences between the pumped and unpumped bores (Table 6) is considered not to be significant. *M. veritas* was collected only once by remote sampling methods (e.g. nets in boreholes), even at sites where it was known to be common, and thus its presence is unlikely to be recorded. The lack of copepods and ostracods is probably an artefact of the limited sampling that was not conducted specifically to derive this information.

In conclusion, the borefield probably contains all species of stygofauna known from the northeast coast of the peninsula and the species composition of the fauna probably has not been changed by borefield pumping.

Table 6: Stygofauna recovered from production bores in the Water Authority Exmouth bore field and that recovered from never used bores in Leg 6 of the proposed borefield extension immediately south of the current production field. My codes (e.g. BOA) equate to Water Authority data as follows—BOA (J/87 10/87; proposed production bore 51), BOB (I/87 9/87; ?), BOC (H/87 8/87; proposedproduction bore 50), BOD (proposed production bore 42), BOE (F/87 7/87; proposed production bore 48), BOF (G/87 6/87).

Taxon	Production bore No.	Bore never used My code
Turbellaria	44	-
Copepoda	44, 46	BOA, BOB, BOC, BOD, BOE, BOF
Ostracoda	44, 47	-
Melitid amphipod	10, 17, 46, 47	BOD
Haptolana pholeta	18, 44, 47	BOB
Halosbaena tulki	44, 46, 47	BOA, BOB, BOC, BOE, BOF
Stygiocaris sp.	10, 43, 44, 47, N1	BOA, BOC, BOE, BOF
Milyeringa veritas	44	-

Fauna likely to be affected by the borefield

The regional significance and composition of the fauna has been covered in the previous sections. Of that fauna, a number of taxa are known specifically from within the borefield area and its proposed extension, or are known to occur downstream of the borefield so that direct impact may occur through interception of the groundwater or by contamination (Table 7). The category 'likely to be present' in Table 5 is judged from overall knowledge of the fauna and the hydrogeology of the region. Those marked * are listed under *Schedule One of the Wildlife Conservation Act 1950.*

Water abstraction and water quality

There is evidence that water abstraction itself causes loss of water quality (in terms of water quality guidelines). Water quality was compared from bores in the Water Authority borefield that had or had not been in production. From a small number of comprehensive water analyses three parameters differed significantly in concentration; colour, SO_4 and NO_2. Each of these factors was greater in bores that had been in production than in those never in production (Table 8). These changes are unlikely to have a significant affect on the fauna as most of the fauna are known to occur in water with values of the three parameters substantially outside the range found in the borefield, whether or not in production (Table 9).

Water constituents and the fauna

The range of water characteristics in which each taxon has been found is given in Figure 2. It is clear from this figure that the water quality occupied by the stygofauna is quite varied — this is reinforced by the water quality data for each species (taxon) presented by Humphreys (1994).

Table 7: The occurrence of subterranean fauna in the immediate impact area of the borefield and the proposed extension. These species are known only from the Cape Range Formation. A= Known from the borefield area and its proposed expansion; B= Known from areas immediately downstream of the borefield area and its proposed expansion; C= Taxa likely to be present in areas impacted by the borefield and the proposed extension. ^{1} restricted to borefield area, Exmouth and Barrow I; ^{2} unique location; ^{3} not troglobitic.

		A	B	C
Aquatic	**Milyeringa veritas*	•	•	
	**Stygiocaris stylifera*	•	•	
	Haptolana pholeta^{1}	•	•	
	Halosbaena tulki	•	•	
	Amphipoda (Melitidae, new genus)	•	•	
	Turbellaria	•	•	
	Copepoda	•	•	
	**Ophisternon candidum*		•	
	Apocyclops dengizicus		•	
	Halicyclops spinifer		•	
	**Stygiocaris lancifera*			•
	Danielopolina sp. nov.			•
	Atopobathynella sp. nov.,			•
	Metacyclops sp. nov.			•
	Lasionectes sp. nov.			•
		A	B	C
Terrestrial	*Stygiochiropus isolatus*^{2}	•		
	Boreohesperus capensis Shear^{3}	•		
	Antichiropus humphreysi Shear^{2}	•		
	Stygiochiropus sp. nov.^{2}		•	
	Hyella sp. nov.^{2}		•	
	Ctenidae, gen. et sp. nov.^{2}		•	
	Draculoides sp. nov.^{2}		•	
	Phalangodidae (Opilionida) ?Gen.^{2}	•		
	Hahniidae (Araneae) ?Gen.^{2}		•	
	Phaconeura sp. nov.^{2}		•	
	Nocticola sp. nov.^{2}		•	
	Stygiochiropus sympatricus			•
	Stygiochiropus communis			•
	**Draculoides vinei*			•
	Phaconeura proserpina			•
	Indjapyx sp. nov. 1			•
	new family or sub-family^{2} (Diplura: Japygidae)			•
	Ctenidae, Gen. et sp. nov.^{2}			•
	**Nocticola flabella*			•

Table 8: Nitrite and sulphate concentration (log (x+1) mg L^{-1}) in and colour of water from Water Authority Exmouth bores that had been, or had never been, in production.

Parameter	df	Fs	P	Used			Unused		
				Mean	s	N	Mean	s	N
Colour	1,15	9.076	0.009	0.672	0.47	8	0.153	0.190	9
SO_4	1,15	5.538	0.033	1.878	0.75	8	1.231	0.323	9
NO_2	1,15	16.128	0.001	0.008	0.004	8	0.002	0.001	9

Table 9: Colour, and the sulphate, nitrite and total filterable solids (TFS) concentration (mg L^{-1}) of water from which various taxa have been found. The values are the mean (range) and n= number of samples used in the analysis. For comparison the untransformed mean values from Table 8 are given in the upper box.

Species or taxon	Colour	SO_4	NO_2	**TFS**
Used bores	3.7	74.5	0.02	0
Unused bores	2.3	16	0.005	0
Ophisternon candidum (n= 8).	15.9 (1-80)	176 (2-540)	0.84 (0-6.7)	3520 (710-7700)
Milyeringa veritas (n= 20).	4.7 (0-34)	579 (7-1950)	0.02 (0-0.19)	8168 (250-26500)
Stygiocaris spp. (n= 25).	3.6 (0-34)	178 (9-1500)	0.012 (0-0.069)	2859 (370-20000)
Halosbaena tulki (n= 19).	1.9 (0-8)	237 (14-1800)	0.01 (0-0.03)	2577 (610-7700)
Haptolana pholeta (n= 6).	2.3 (1-5)	82 (14-195)	0.01 (0.003-0.022)	1783 (660-3300)
Melitid amphipods , Cape Range (n= 3).	9.33 (1-23)	10 (7-14)	0.015 (0.008-0.026)	437 (390-500)
Melitid amphipods,coastal plain (n=19).	3.79 (0-20)	260.5 (2-1150)	0.057 (0.003-0.46)	3622 (660-11000)
Ostracoda (n= 7).	2.14 (0-6)	532 (9-1500)	0.03 (0-0.105)	1226 (110-3300)
Copepoda (n= 50).	4.76 (0-34)	334.3 (7-1800)	0.055 (0-0.98)	4574 (250-24000)
Harpacticoid copepods(n= 25).	6.04 (0-34)	466.5 (9-1800)	0.02 (0-0.185)	7073 (980-24000)
Calanoid copepods (n= 39).	3.8 (0-23)	280 (7-1800)	0.068 (0-0.98)	3820 (250-22000)

Nonetheless, there are serious deficiencies in the available data. Water column profile data are unavailable for any parameters within the present borefield. In particular, none are available on the dissolved oxygen levels in the water profiles, *in situ* pH or the redox potential. The importance of redox potential relates to the chemically reducing environment likely to be encountered both in sediments (H_2S commonly occurs in superficial sediments), and in the water body below the thermohalocline where oxygen levels may be as low as 0.1 mg L^{-1} and concentrations of H_2S occur. Hence, to assess changes in the use of the water column by the stygofauna and to monitor the performance of the borefield, comprehensive profile data on the biological and physicochemical environment need to be gathered regularly from dedicated monitoring wells that penetrate to below the saltwater interface.

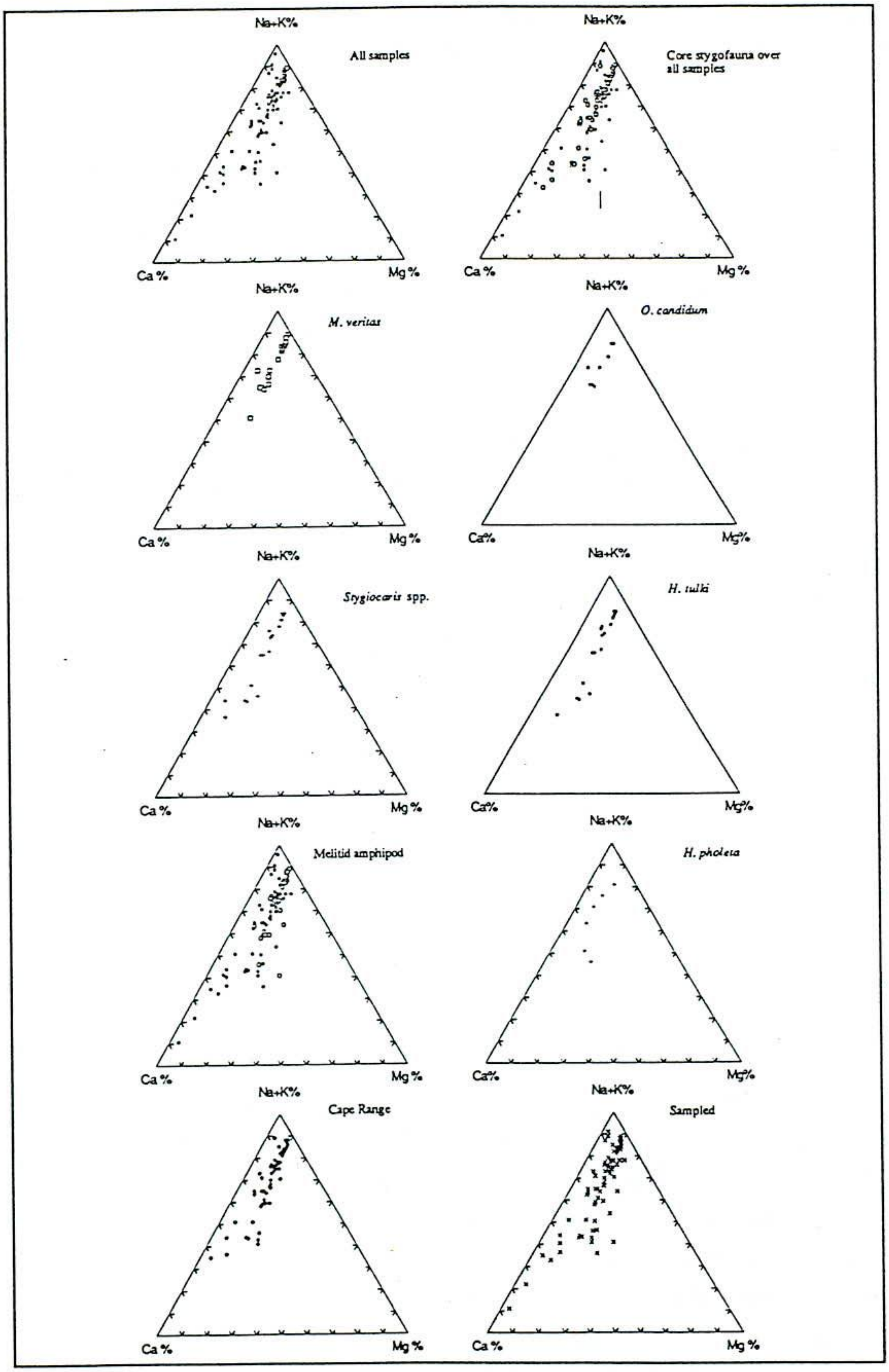
Fresh water/salt water transition in the Exmouth area

Despite repeated trapping and haul netting through considerable depths of water no stygofauna has been found to the west of the estimated location of the fresh water/salt water transition in the Exmouth area.

Hydrological and biological interpretation of this area is complicated by the apparent near-coincidence of several interrelated factors in the vicinity of the transition zone. These are:

- stygofauna is present to the east but not to the west of the transition zone;
- transmissivity of the limestone decreases abruptly;
- altitude of the water table increases sharply and hence the thickness of the freshwater lens;
- the lower limit of karst development in the Tulki Limestone rises above the water table;

Figure 2: Trilinear plots (Na+K, Ca and Mg) of groundwaters from the Cape Range peninsula including various subsets of the data, *viz.* all samples, core stygofauna (circles) overlying all samples (small squares), *Milyeringa veritas* sites, *Ophisternon candidum* sites, *Stygiocaris* spp. sites, *Halosbaena tulki* sites, melitid amphipod sites, *Haptolana pholeta* sites, sites on Cape Range peninsula *sensu stricto* and sites sampled for stygofauna (Humphreys 1994).



- base of the cavernous Tulki Limestone rises above sea level so that the water table is in the marly Mandu Limestone;
- mean salinity of water from which any taxon of stygofauna was collected from the coastal plain was mostly an order of magnitude greater than that found in the bores west of the saltwater interface. This suggests that the fauna may be excluded through physiological incapacity.

From these factors it is hypothesised that the fauna may be absent west of the interface either because it is unable physiologically to inhabit such fresh water or because the pore spaces are too small for the animals to pass through. However, Humphreys (1994) could not distinquish between the two hypotheses on the available evidence. Additional sampling of large volumes of water pumped from test bore 2/90 in December 1994 and March 1995 has yielded no stygofauna.

There is recent additional evidence to consider. A genus of amphipods of marine ancestry (Barnard and Williams, in press) occurs as separate congeneric species (W.D. Williams, pers. comm.). One inhabits the brackish waters of the coastal plain and the other inhabits the perched water tables in Cape Range proper. The latter occurs at altitudes of c. 200 m where the mean salinity is 456 mg L^{-1} (Humphreys 1994). It thus falls within the range of salinity recorded from the test bores west of the freshwater/ seawater transition. Hence, this genus, which occurs widely throughout the borefield, is clearly capable of evolving freshwater species. Thus, although sparse, the evidence suggests that it is a characteristic of the limestone matrix itself rather than the water quality that precludes stygofauna from the area to the west of the saltwater interface. The evidence suggests that the fauna is not one of 'a freshwater oasis beneath an arid land surface' (Knott 1993) but of a brackish-saltwater fauna of marine origin. The freshwater lens beneath Cape Range appears to be afaunate, not because the stygofauna cannot utilise fresh water but rather because it is inaccessible to them.

The salt water interface

Some members of the relictual Tethyan fauna are found only below the halocline of inland caves connected at depth to the sea. They occur on the Cape Range peninsula (C-28) and in the Northern Hemisphere, principally in the North Atlantic. Exploration wells that penetrate the saltwater interface are not accessible in the Exmouth area. However, given that cavernous karst is likely to be present on the east coast to a depth of c. 100 m below sea level then suitable habitat should be present. Certain taxa (e.g. thermosbaenaceans) have been successfully used on a global scale to predict the presence of Remipedia and *Danielopolina* (Poore and Humphreys 1992; Humphreys 1993b; Wagner 1994). Hence, the presence of

Halosbaena tulki in the Exmouth area indicates that these other taxa are also likely to occur.

The coastal habitat

The stygofaunal populations occur as a linear band on or near the coastal plain of the peninsula (Humphreys and Adams 1991, Adams and Humphreys 1993; Humphreys 1994). These populations are genetically fragmented (*ibid.*). Hence the potential zones of contact between these fragmented populations are important areas for the conservation of the fauna as they allow maintenance of gene flow between adjacent populations. Disruption of the linear community along the coast will isolate populations already severely constrained in distribution.

Hence borefield development should be considered in the context of the region and as one stage of the incremental impact of developments on the fauna. A number of large projects that will impinge on the fauna are in the planning stage. These include large scale subdivisions to the south of the Exmouth town site (DOLA, pers. comm. 28/2/95) encompassing most of the coastal plain to the east of Murat Road from Leg 7 through Leg 10 of Option 2 (WAWA 1994b), a palm nursery, lime kilns, limestone quarries, marina, a number of substantial tourist developments, bases for the oil industry etc. Not only will these developments impinge on the stygofauna on the coastal plain so that the area can no longer be considered as a potential refuge, but they will indirectly impinge through their substantial water requirements.

Altogether, 20 km of the east coastal plain, including all downstream areas from the borefield, must now be considered in the medium term to be heavily developed. This development encompasses almost all known stygofauna sites on the east coast, the area of the greatest known species diversity. While to date there has been relatively little anthropogenic contamination of the groundwater in the Exmouth area (Humphreys 1994), that will change rapidly as key areas are subdivided, contaminants loads increase and water extraction from the coastal plain is increased.

Proper quality control trend analyses (e.g. cusum analysis) should be implemented and applied to the periodic assessment of trend data so that statistically significant departures are detected as soon as possible.

The type, reliability, resolution, interpretation and control of procedures monitoring the performance of the aquifer(s) tapped by the Exmouth borefield need to be substantially enhanced. This is needed to determine the sustainability of the aquifer for water production and the effects of production on the stygofauna.

Terrestrial fauna

Significant terrestrial fauna occur within the borefield area or immediately downstream, some taxa being known from only single caves. The fauna is dependent on the influx of water to the cave for humidity and food resources and consequently interruption to the surface flow of water to caves may impact on the fauna of a particular cave . Every effort should be made to minimise disturbance to caves and their catchments and this is often simply a matter of minor rerouting of pipes.

The terrestrial cave fauna is supported mainly by photosynthetically-derived detritus being washed into caves after exceptional rain and supplemented by downward seepage, root growth, carcasses etc. (Humphreys 1991). Any structure changing the natural drainage lines or the primary productivity of the area may impinge on troglobite populations. In consequence, surface development and subsequent management of the borefield should be designed to cause minimal disturbance to both natural surface flow and primary productivity of the area.

Recommendations

General

- Best practice on the Cape Range peninsula (and other karst areas) should include an awareness of the constraints imposed by karst terrain for all Water Authority activities, and those of their consultants, based at the very least on Kiernan (1988).

Terrestrial fauna

- The sites or routes (to 50 m downslope) of all surface constructions (roads, drilling pads, pipelines, buildings) should be inspected by a competent speleologist and, if necessary, the route or methods changed to minimise any direct or downstream effects of the constructions. For example, pipelines and roads should preferably pass downstream of cave entrances; pipes laid on the karst surface are less likely to impede drainage if they are not covered by earth.

- Caves, even holes seemingly too small to enter, that are found by the Water Authority or its contactors' personnel should be reported to the relevant speleological group and their advice sought as to the appropriate course of action. In Exmouth this would currently mean contacting Mr R.D. Brooks, Phone 099 491 274, address P.O. Box 710, Exmouth, WA 6707) or the Western Australian Speleological Group in Perth (phone Mr R. Webb 09 333 4444). If the cave is likely to be adversely affected it should be examined by a competent biospeleologist and its significance assessed.

Aquatic fauna

The uncertainties involved in the understanding of both the hydrogeology and the stygofauna necessitate that more accurate base line data be collected and that monitoring be undertaken.

Monitoring

To monitor the stygofauna Humphreys (1994: 57) recommended that bores independent of production bores should be used for sampling, that salinity profiles be collected and that samples be taken more frequently, recommendations that closely match those required for the purpose of monitoring the behaviour of the aquifer (WAWA 1994a).

- Recommendation 3 (WAWA 1994a: 20) should be implemented *plus* the additions in square brackets — *monthly measurement of* rest *water levels in all production and observation bores including bores not yet equipped* [plus all decommssioned bores that are in a suitable condition].

- Recommendation 2 (WAWA 1994a: 20-21) should also be implemented with the additions in bold. *A series of monitoring bores should be installed adjacent to selected production bores within the well field to observe changes in the salinity profile beneath the bores. This will assist in identifying the extent of and potential for upconing before a problem occurs. ....* [one piezometer should penetrate through to the saltwater wedge — all piezometers should be of sufficient diameter (at least 65 mm, preferably >110 mm, diameter) to permit sampling of the stygofauna. These should be sampled for stygofauna twice yearly (at the same time that samples are taken for major ion analysis) together with all decommissioned bores that are in a suitable condition and bores yet to be equipped. It is likely that the sampling rate could be halved after several years by which time adequate background data should be available. Slotting in the bore casing should be of a type facilitating stygofaunal sampling].

- All production bores that are temporarily drawn of their equipment for maintenance should be sampled for stygofauna.

- All new bores should be sampled for stygofauna prior to being equipped

Downstream effects

Dedicated monitoring bores penetrating to different depths (including into the saltwater wedge) should be established downstream of the proposed borefield extension (inland of Murat road) and of sufficient size to enable hydrological and fauna sampling. These should be established and monitored thrice before each new segment of the borefield starts to operate. One such bore series should be established for each two legs of the established and extended borefield (i.e. five series under Option 2). *Slotting in the bore casing should be of a type facilitating stygofaunal sampling.*

- All bores decommissioned in the northern borefield should have the internal workings withdrawn and be capped and locked. This will permit monitoring of the aquifer and the stygofauna downstream of Option 1 to assess its impact and to monitor the recovery of the aquifer. They should be monitored biannually for stygofauna.

Recommendations summary

In general:

- Best practice should include karst awareness.

- The periodic assessment of borefield performance should include proper quality control trend analyses of the data (e.g. water level and salinity) so that statistically significant departures in the trend are detected when they occur.

For the terrestrial fauna:

- Inspect construction sites and routes (to 50 m downslope) for caves and act accordingly.

- Report caves to the relevant speleological group and have it assessed.

For the aquatic fauna:

- A monitoring program should be established for the stygofauna.

- Recommendation 3 (WAWA 1994a: 20) **plus** all decommissioned bores that are in a suitable condition.

- Recommendation 2 (WAWA 1994a: 20-21) **plus** one piezometer should penetrate through to the saltwater wedge, all piezometers of adequate diameter to sample stygofauna and the slotting in the bore casing should be of a type facilitating stygofaunal sampling.

- All monitoring bores to be sampled for stygofauna twice yearly.

- All production bores that are temporarily drawn of their equipment for maintenance should be sampled for stygofauna.

- All new bores should be sampled for stygofauna prior to being equipped

For downstream effects:
Dedicated monitoring bores (similar to Recommendation 2) to be established and subjected to hydrogeological and stygofauna monitoring biannually. Slotting in the bore casing should be of a type facilitating stygofaunal sampling.

- Decommissioned bores should be maintained in a condition suitable for stygofauna sampling.

Stygofauna monitoring procedure

Method

Fauna sampling from bores should comprise three traps suspended in the water column overnight. After the traps have been removed a net (250 µm mesh size) should be hauled through the entire water column. The contents of the net and traps should be concentrated and stored in separate numbered vials for each bore in 70% alcohol for transport to the analytical laboratory together with a completed data sheet. As well as routine sampling of monitoring and decommissioned bores, all production bores should be thus sampled whenever the workings are removed for maintenance. Operators conducting the sampling must be trained in the method.

The data sheet to include bore number, date, method of sampling, whether the bore is for observation, pre-production, production under maintenance, or decommissioned, and whether the bore is in, or downstream of, the borefield.

Criteria

Species useful for monitoring in the borefield are *Stygiocaris* sp., *Halosbaena tulki*, and *Haptolana pholeta*— other taxa may need to be added when deeper bores are available for sampling.

- The apparent loss of a common species from a given location should be flagged.

- The apparent loss of a species from >33% of monitoring sites within or downstream of the borefield should lead to a major review, involving the EPA, of the effects of the borefield on the stygofauna in the light of the more detailed and accurate environmental and baseline data that will by then be available.

Training

Sampling could be performed by Water Authority staff after suitable training and the specimens sent to Perth for examination. Personnel involved in taking stygofauna samples should be trained on site in the method of sampling and for concentrating and labelling the samples and data recording. The sampling procedure should be subject to quality control checks on occasion. If contract personnel were to conduct the sampling then frequent retraining of operators may be required.

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