AUGUSTA - LEEUWIN SPRING

ENVIRONMENTAL IMPACT STUDY

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Prepared for: Water Authority of Western Australia

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SUMMARY

In December 1993 E M Mattiske and Associates and Ninox Wildlife Consulting were commissioned by the Water Authority of Western Australia (WAWA) to undertake botanical studies associated with the flora and fauna of the Leeuwin Spring at Augusta, and to investigate options for management of the spring and the surrounding environment. The Leeuwin Spring is located on Cape Leeuwin near the town of Augusta, approximately 370 km south of Perth. Cape Leeuwin lies within the Warren Sub-region within the Darling Botanical District (South-West Forest Region) of the South-Western Botanical Province (Diels, 1906; Gardner, 1942; Beard, 1981). The South-Western Botanical Province is characterized by an abnormally high proportion of endemic species (Beard, 1981).

Water supply for the town of Augusta has been drawn solely from the Leeuwin Spring since 1963. The yield from the Leeuwin spring has declined from an original output of 4,500 kilolitres per day (kL/d) to an estimated 1,400 kL/d. With the recent construction of the soak the yield has increased to 1,750 kL/d. Appleyard (1989) suggests that the main reason for the yield declining is due to the fact that the rainfall intensity in the region has dropped significantly, and that this has resulted in falling groundwater levels. Appleyard (1989) also notes that water levels in caves increase only if monthly rainfall exceeds about 300 mm. Monthly totals of this magnitude have been uncommon in recent years (Figure A1).

The Water Authority is currently reviewing the future management options for the Leeuwin Spring with the Department of Conservation of Land Management (CALM), the WA Museum and the National Parks and Nature Conservation Authority (NPNCA). One of these options is to abandon the Leeuwin Spring source to enable the water reserve to be vested with the NPNCA as part of the Leeuwin National Park. As a result the Water Authority have made a commitment to carry out a study to assess the impact of continued pumping from the Leeuwin Spring on the surrounding flora and fauna, particularly a rare species of snail, *Austroassiminea letha*, present in the area. If this study and/or an ongoing monitoring programme highlight any significant impacts of pumping then the Water Authority may have to abandon the Leeuwin Spring as a water source, or use it solely as a standby source.

Flora and Vegetation

The specific objectives of the botanical studies within the Cape Leeuwin area were:

- to establish a monitoring programme (transect and quadrat work; with selected controls if possible in nearby areas with similar vegetation) on the flora and vegetation (including spatial and temporal changes in community structure and composition). Data to include percentage foliage cover, heights and plant condition for all plant species in the quadrats.

- to assess the growth requirements of the native flora and vegetation.

- to prepare a data entry format suitable for future comparative studies.

- to review historical aerial photographs to assess the past changes near the project area in plant communities and condition.

- to prepare a vegetation map of the Leeuwin Spring area.

- to make recommendations regarding the preservation of the integrity of the historic waterwheel and the effect of continued abstraction on vegetation.

- to prepare a report summarizing the results and management issues for the flora and vegetation in the area.

Six vegetation transects were established and monitored at the Leeuwin Spring and surrounding area in January 1994. All were situated in areas fed by the spring, with the exception of Transect 5 which was designed as a control transect. The transects were located to maximize coverage of different plant communities within the area fed by the spring.

A total of 54 vascular plant species belonging to 28 families were recorded along the transects in the Cape Leeuwin area in January 1994 and on a second visit in May 1994. Of these, 13 were introduced (weed) species. A total of eight plant communities were located and mapped in the Leeuwin Spring area.

The dominant families recorded were Poaceae (7 species) and Cyperaceae (7 species).

No flora species Declared Rare, pursuant to subsection (2) of section 23F of the Wildlife Conservation Act 1950, were located inside or adjacent to the WAWA reserve containing the Leeuwin Spring. No species listed a Priority flora in the Declared Rare and Priority Flora List for Western Australia (CALM, 1992) were located at the time of monitoring.

The historical aerial photographs reflected a change in dominant species in some sections of the swamp, with changes in the *Typha* and *Baumea* communities.

Recommendations are given on the effects of continued abstraction at Leeuwin Spring on the vegetation, the continued use of chlorinated water to maintain the integrity of the wooden portion of the flume and comments on the preservation of the historic waterwheel.

Austroassiminea letha

The results of this baseline study show that live, aestivating and dead snails can be successfully located and counted during the peak water demand period in mid-summer at Leeuwin Spring. This data can be used as a benchmark for future studies at the same time of year, using the same techniques, although it is recommended that studies also be undertaken during seasons other than summer as well.

Earlier sampling of the snail by the Western Australian Museum suggested that it avoided the central portions of the swamp, especially where there was flowing water, or sandy parts of the swamp base where vegetation detritus was absent. The current study has shown that *Austroassiminea letha* is generally spread throughout the swamp near Leeuwin Spring, but has a preference for splash zones, denser vegetation and locations where calcareous deposits have formed around sedges.

Although very few snails, live or dead, were found in the main body of the swamp, some were found for the first time since the Museum surveys. It is therefore possible that the snail has increased its local distribution throughout the Leeuwin Spring site and that this may be related to the progressive drying out which has occurred over the years. Whether the proposed reduction in the rate of abstraction will result in a contraction of this apparent increase in local distribution is as yet unknown, and can only be established through long-term monitoring.

Two new sites where the snail occurs where located, one during the main study and another during a short site visit. The first of these is "The Spring", about two kilometres north-east of Leeuwin Spring and the second is a seepage area at Quarry Bay some 500 metres north-east of the historic waterwheel.

Recommendations are given on the effects of continued abstraction at Leeuwin Spring on the rare snail, the use of chlorinated water to maintain the integrity of the wooden portion of the flume and comments on the preservation of the historic waterwheel.

PART A

INTRODUCTION AND BACKGROUND TO THE STUDY

A1.0 INTRODUCTION AND BACKGROUND

For ease of reference, the following report is divided into four sections:

- Part A, the current section, is a general introduction to the study area which explores the historical and contemporary environment. The rationale for the study is also discussed;

- Part B describes the current flora and vegetation of the area and assesses, by means of aerial photography, any changes which may have occurred since abstraction from the spring commenced in 1963;

- Part C describes the current status of the rare snail *Austroassiminea letha* in the study area;

- Part D lists the conclusions and recommendations for both aspects of the study and provides an integrated monitoring programme based on the results of the recent survey commissioned by the Water Authority of Western Australia (WAWA).

A1.1 The Study Area

The Leeuwin Spring is located on Cape Leeuwin near the town of Augusta, approximately 370 kilometres south of Perth. The spring is situated within a Water Authority of Western Australia (WAWA) Reserve within the Leeuwin National Park.

Water was originally drawn from the outflow of a swamp below the spring, fed to a wooden waterwheel by means of a wooden flume. Abandonment of the lighthouse as a working unit and its transformation to a tourist attraction resulted in several problems. The calcium carbonate rich outflow from the flume and, presumably, lack of maintenance caused a calcareous accretion to form on the waterwheel, resulting in a structure apparently consisting of limestone rather than wood. Over time, the original wooden flume supplying the waterwheel deteriorated. Water flow ceased and the limestone deposit on the waterwheel started to dehydrate and exfoliate. This was halted by reconstructing the wooden section of the flume near the waterwheel and adding a fibreglass section near the swamp outflow. After discharge from the swamp effectively ceased (see below), this wooden section was irrigated during the dry summer months by a sprinkler system to maintain its integrity and to allow water to flow over the waterwheel and preserve it's limestone coating. In 1986 the rare snail *Austroassiminea letha* was recorded at several points near the flume and on the periphery of the adjacent swamp.

Since 1963 Leeuwin Spring has provided a major proportion of the water supply to Augusta through the services of WAWA. Water from the spring is contained by a small weir, pumped into a service tank and gravity fed to the town. The yield from the Leeuwin spring has declined from an original output of 4,500 kilolitres per day (kL/d) to an estimated 1,400 kL/d. With the recent construction of the soak the yield has increased to 1,750 kL/d. Appleyard (1989) suggests that the main reason for the yield declining is due to the fact that the rainfall intensity in the region has dropped significantly, and that this has resulted in falling groundwater levels. Appleyard (1989) also notes that water levels in caves increase only if monthly rainfall exceeds about 300 mm. Monthly totals of this magnitude have been uncommon in recent years (Figure A1).

As a result, there has been pressure on WAWA to abandon the Leeuwin Spring site and develop an alternative source. This would enable the water reserve to be-vested with the National Parks and Nature Conservation Authority, consequently protecting the spring and its biota. Primary considerations are the rare snail *Austroassiminea letha*, its known habitat, the historic waterwheel and its reconstructed flume. The following report mainly deals with the first two aspects.

The Water Resources Planning Branch of WAWA carried out a recent study to assess the future capacity of the Leeuwin Spring source to meet future demand. The subsequent report recommended that a new groundwater source should be developed along Fisher Road, near Molloy Island. It was also recommended that the Leeuwin Spring be used to augment the new source. The new source is scheduled to be operational by November 1994 and will enable the abstraction rate (both peak week and annual) from the Leeuwin Spring to be reduced substantially. However, WAWA acknowledges that the quantity of water that can be safely pumped from the spring without significantly impacting the local environment is unknown, and this would need to be trialed once the new source is operational. With the current abstraction rates, for about two months in summer, almost all of the water from the spring is used to supply Augusta and very little, if any, flows into the adjacent swamp. The concern raised by the W.A. Museum, for example, is that the local environment is becoming increasingly more arid and endangering the rare snail *Austroassiminea letha* and its habitat.

As a consequence, WAWA commissioned a study to assess the current status of the snail *Austroassiminea letha* and its environment in an attempt to assess the effects of continued pumping from the spring. If this study and/or an ongoing monitoring programme highlight any significant impacts of pumping then the Water Authority may have to abandon the Leeuwin Spring as a water source, or use it solely as a standby source.

A1.2 Climate

The Cape Leeuwin/Augusta area lies within the Moderate Mediterranean bioclimatic zone as defined by Bagnouls and Gaussen (1957). This zone is characterized by warm summers and cool, wet winters. On average, only 3 to 4 months per year are dry. This results in an average annual rainfall of approximately 1090 mm per year, making the area the wettest in the state of Western Australia. Most rainfall is recorded between April and October.

Figure 1 shows the total annual rainfall for Cape Leeuwin over the past 30 years supplied by the Bureau of Meteorology. This illustrates the unusually low total rainfall recorded in 1993.

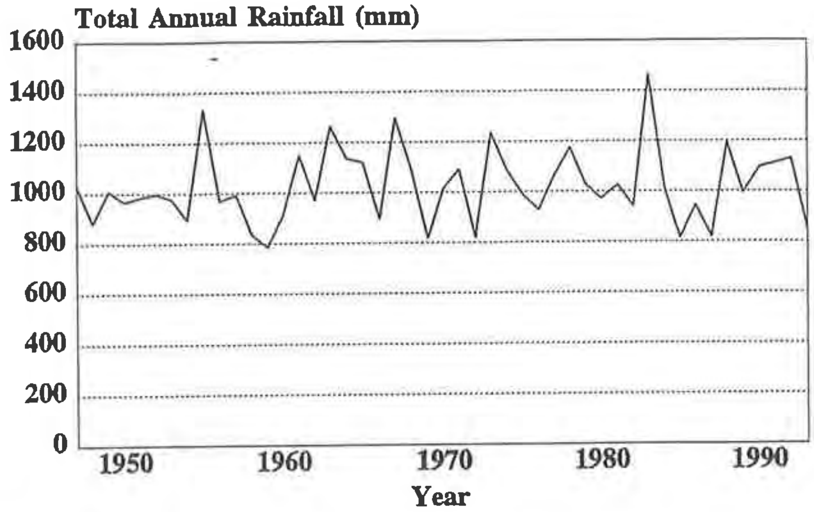

Figure A1: Total Annual Rainfall for Cape Leeuwin, 1950 - 1993

Mean monthly minimum temperatures range from 11 degrees Celsius in the winter to 17.3 degrees Celsius in the summer, and mean monthly maximum temperatures range from 16.5 degrees Celsius in the winter to 23.5 degrees Celsius in the summer. Winds are consistent all year blowing south-west and west throughout the winter and varying between south and south-east during the summer (Lewis Environmental Consultants, 1990).

A1.3 Geology and Soils

Augusta is included in the Leeuwin-Naturaliste Ridge Geological Region as defined by Clarke (1926).

This ridge is a north-south trending horst of Precambrian granite and granulite forming hills rising to 200 m. The majority of this outcrop is obscured by dune sand and calcarenite on the western, seaward side. The coast has a rugged retrograding shoreline with small sandy bays between promontories of granite and limestone. Soils on the seaward side of the outcrop where the Leeuwin Spring is located are calcareous sands (Beard, 1981).

A1.4 Flora and Vegetation

Cape Leeuwin lies in the Warren Sub-region within the Darling Botanical District (South-West Forest Region) of the South-Western Botanical Province (Diels, 1906; Gardner, 1942; Beard, 1981). The South-Western Botanical Province is characterized by an abnormally high proportion of endemic species (Beard, 1981).

The vegetation survey by Beard (1981), at a scale of 1:1,000,000 for the Swan region, provides a major summary of the extent of the different plant communities in the Augusta area. In this and his later studies, Beard highlighted the importance of underlying geology, landforms, soils and climate in determining the distribution of plant communities.

The Cape Leeuwin area includes three vegetation types as defined by Beard (1980).

- **Thicket** - consists of a dense, closed, single layered community of relatively simple floristic composition. Dominant species *Casuarina* spp., *Acacia* spp. and *Melaleuca* spp. Character species *Acacia decipiens*.

- **Peppermint Low Woodland** - a scrub to low forest on recent sands of the southwestern coasts. Structure is influenced by fire, soil quality and exposure to wind. Understorey contains a range of large and small shrubs, reeds and herbaceous perennials. Character species *Agonis flexuosa*.

- **Tall Forest** - an open tall tree layer over a wet sclerophyll to sclerophyll understorey. Character species *Eucalyptus diversicolor* (Karri).

The general objectives of the study were to:

- carry out a study of the spring and its surrounding environment to establish the parameters which need to be measured;
- quantify these to determine a benchmark from which to compare future data once the groundwater source near Molloy Island is operational;
- develop a monitoring programme to assess changes to the status of the rare snail and the flora and vegetation at the spring and surrounding area once abstraction is reduced at Leeuwin Spring.
- make recommendations regarding the preservation of the historic waterwheel, the effect of the use of chlorinated water on the wooden part of the flume on surrounding vegetation and snail populations and the continued abstraction of water from the spring.

One of the major problems with a study such as this is that there is little systematic data available on the status of the snail and its environment prior to the commencement of abstraction from the spring. The current study therefore describes the Leeuwin Spring environment after some 30 years of abstraction, assesses the present status of the flora and vegetation of the area and explores the interaction between this and the rare snail *Austroassiminea letha*. Aerial photography has been used to delineate gross changes in vegetation, but there is very little site-specific information on *Austroassiminea letha* micro-habitat over this 30 year period. Judgements on the original status of the snail can only be made by inference from literature since 1982.

PART B

FLORA AND VEGETATION

B1.0 INTRODUCTION

E M Mattiske and Associates were commissioned by the Water Authority of Western Australia to undertake botanical studies associated with the flora and vegetation near the Leeuwin Spring at Augusta and to investigate options for management of the spring and the surrounding environment.

B2.0 OBJECTIVES

The specific objectives of the botanical studies within the Cape Leeuwin area were:

- to establish a monitoring programme (transect and quadrat work; with selected controls if possible in nearby areas with similar vegetation) on the flora and vegetation (including spatial and temporal changes in community structure and composition). Data to include percentage foliage cover, heights and plant condition for all plant species in the quadrats.
- to assess the growth requirements of the native flora and vegetation.
- to prepare a data entry format suitable for future comparative studies.
- to review historical aerial photographs to assess the past changes near the project area in plant communities and condition.
- to prepare a vegetation map of the Leeuwin Spring area.
- to make recommendations regarding the preservation of the integrity of the historic waterwheel and the effect of continued abstraction on vegetation.
- to prepare a report summarizing the results and management issues for the flora and vegetation in the area.

B3.0 METHODOLOGY

B3.1 Flora

Detailed recordings of vascular plant species were carried out on the transects established within the Cape Leeuwin area in January 1994. The site was again visited in May 1994 to enable a vegetation map to be produced.

All plant specimens which were collected during the field programme were dried and fumigated in accordance with the requirements of the Western Australian State Herbarium, and then sorted in readiness for identification.

Plant specimens were identified by the use of local and regional flora keys and by comparison with the named specimens held at the Western Australian State

Herbarium. Plant taxonomists who are considered to be an authority on a particular plant group were consulted, when necessary. The conservation status of all recorded flora was also checked against the current lists published in the Governmental Gazette and available from the Department of Conservation and Land Management (1992) and Hopper et. al. (1990).

B3.2 Vegetation Transects

Six understorey transects were established and monitored at and nearby the Leeuwin Spring in January 1994. The location of these is shown in Figure B1.

Each transect was located to maximize coverage of different plant communities within the area fed by the Leeuwin Spring. Transect 5 was established as a Control Transect. The transect layout was based on the pattern established by Havel (1968) and Heddle (1980). The quadrats were positioned at 5 m intervals along the northern or western side of the transects. With the exception of Transects 2 and 5 the corner of each quadrat was pegged to assist in future relocation.

At each quadrat the following measurements were taken for each plant species present:

- Total foliage cover alive and dead. This included plants both rooted in the quadrat and those rooted outside but overhanging the quadrat.

- Average height of each species recorded in the quadrat.

Notes were also made at each quadrat regarding water depths to allow quantitative comparisons after pumping from the Leeuwin Spring is reduced or stopped.

B3.3 Review of Historical Photographs of the Leeuwin Spring

Aerial photographs were obtained from the Central Map Agency for 1963, 1980 and 1993. These were examined for visible changes in plant communities over this period.

B3.4 Photographic Records of Transects

Photographs were taken of each understorey transect. These are presented in Appendix B3 for reference. All photographs will provide a basis for future monitoring of changes.

B3.5 Vegetation Mapping

The vegetation adjacent to the Leeuwin Spring was mapped at a scale of 1:5000 during a site visit in May 1994. This mapping was undertaken on foot and by vehicle.

B3.6 Data Analysis

All field data was entered within Quattro-Pro software. All data was entered for each quadrat.

B4.0 RESULTS AND DISCUSSION

B4.1 Review of the Conservation Status of the Flora

No flora species Declared Rare, pursuant to subsection (2) of section 23F of the Wildlife Conservation Act 1950, were located inside or adjacent to the WAWA reserve containing the Leeuwin Spring. No species listed as Priority flora in the Declared Rare and Priority Flora List for Western Australia (CALM, 1992) were located at the time of monitoring.

A Declared Rare species *Kennedia macrophylla* has been previously recorded in the area but was not located during this study.

B4.2 Flora

A total of 54 vascular plant species belonging to 28 families were recorded along the transects in the Cape Leeuwin area in January and May 1994. Of these, 13 were introduced (weed) species.

The number of weed species recorded during the survey is relatively high when compared to the total number of species recorded. This is due to disturbance at the Leeuwin Spring caused by construction of the weir and pumphouse. Weeds were also present on the transects at "The Spring" and near the flume due to use of these areas by tourists.

The dominant families recorded were Poaceae (7 species) and Cyperaceae (7 species). The Poaceae species recorded were predominantly introduced species, while the high number of Cyperaceae species recorded reflects the swampy nature of the study area.

B4.3 Vegetation Transects

Six understorey transects were established and monitored at and nearby the Leeuwin Spring in January 1994. Details of these are outlined below.

Transect 1: Established inside the Water Authority Reserve containing the Leeuwin Spring. Runs at a bearing of 70° starting at the 21st post from the entry gate along the western fence. Transect length 40 m (7 quadrats).
Starting point: **S** 34° 22' 00"
E 115° 08' 21"

Transect 2: Established along the outside of the southern fence of the Water Authority Reserve. Runs parallel to the fence at a bearing of 138°

with the first quadrat positioned one fence post east of corner. Quadrats positioned at every second post. Transect length 9 quadrats.

Transect 3: Established near the waterwheel and flume in the Leeuwin National Park. Runs at a bearing of 45° from the northern end of the flume. Transect length 50 m (10 quadrats).
Starting point: **S** 34° 22' 11"
E 115° 08' 06"

Transect 4: Established near the southern-most intersection of Leeuwin Road and Skippy Rock Road. Runs at a bearing of 180° on the southern side of Skippy Rock Road. Transect length 30 m (5 quadrats).
Starting point: **S** 34° 22' 06"
E 115° 08' 34"

Transect 5: Established at "The Spring" on the northern section of Skippy Rock Road. Runs on a bearing of 3° across the spring outflow. Transect length 25 m (5 quadrats).
Starting point: **S** 34° 21' 04"
E 115° 09' 14"

Transect 6: Established on the western side of Leeuwin Road, south of the intersection of Leeuwin Road and Skippy Rock Road. Runs on a bearing of 0° from a point approximately 20 m from road edge. Transect length 50 m (10 quadrats).
Starting point: **S** 34° 22' 07"
E 115° 08' 19"

Further descriptions of transects are available in Part C.

Appendices B1 and B2 give the details of vegetation along the transects monitored. The majority of the understorey species were healthy at the time of monitoring in January 1994. Tables B1 to B6 below show summaries of each transect.

Transect 1 recorded the highest species diversity with a total of 24 species recorded. A high number of these were weed species, due to disturbance caused by construction of the weir and pumphouse at the spring. Transect 3 displayed the lowest species diversity with only 9 species recorded. These differences in species diversity are due to the variety of water depths and habitats through which each transect passes.

Dominant species varied on each transect, again due to water depths and site conditions. Transect 1 was dominated by *Muehlenbeckia adpressa*, a non-aquatic species. This reflects the narrow wet area through which this transect passes. This species was again common on Transect 2 although aquatic species such as *Schoenoplectus validus* and *Lepidosperma gladiatum* were dominant. *Schoenoplectus validus* occurs on the coastal plain in natural wetlands, winter wet depressions and estuaries and is tolerant of some salinity. This species tolerates some variation in water levels but thrives best at a constant shallow water level (Chambers et.al., 1992). Although this species is intolerant of much seasonal variation it can adapt equally well to deep water or waterlogged conditions so is unlikely to be adversely affected by changing water levels after pumping from the spring is reduced.

Transects 3 and 4 were also dominated by aquatic sedge species particularly *Baumea juncea* and *Baumea articulata*. *Baumea juncea* was the most widespread of these two species as it has a greater tolerance of drier conditions and can occur when water levels are up to 0.3 m below ground. Some specimens have been recorded in drier conditions than this (Froend et al., 1993). This species is likely to have been present prior to pumping but in lower densities as it prefers drier conditions although seasonal flooding is tolerated (Chambers et. al., 1992). *Baumea articulata* is an ecologically important sedge as it is the dominant species in many natural wetlands throughout the coastal area. This species has fairly strict growth requirements as it's roots must be moist for a large part of the year. This species was noted to be restricted to areas near the spring where water was present at or near the surface. It is therefore possible that *Baumea articulata* was dominant in more areas prior to pumping but has disappeared as water levels have decreased although this species has also been recorded in dry areas (Froend et al., 1993).

Transect 5 was dominated by weed species due to disturbance through tourist activity. Transect 6 was dominated by aquatic sedge species including *Schoenoplectus validus* and a species that is not native to Western Australia, *Typha orientalis*. This species of *Typha* was dominant throughout a large part of the wetland surrounding the Leeuwin Spring and was also present at "The Spring" (Transect 5). It is known as an aggressive colonizer of disturbed sites (Chambers et.al., 1992) and as a result is present in many wetlands in rural and urban areas. It is found on a variety of substrates and can tolerate a wide range of water levels. The dominance of this species in the study area is most likely due to the combination of a number of factors:

- clearing and other disturbance during the construction of the pumphouse and weir producing areas into which this species could spread.

- severe disturbance to the area during a major fire in Augusta in recent years.

- reduced water levels are likely to have resulted in the dying out of other aquatic rush and sedge species. This disturbance may also have promoted the colonization of the area by *Typha orientalis*.

Once this species establishes it spreads rapidly, out-competing many other established species and is difficult to control or remove. Therefore, increasing the water levels by reducing pumping is unlikely to restore the diversity of the areas where this species is present to pre-extraction levels.

Table B1: Summary of Vegetation Recorded on Transect 1.

	Species	Ave. % Cover Alive	Ave. % Cover Dead	Ave. Height (cm)
	Acacia littorea	0.57	0.00	120.0
	Asteraceae sp.	0.00	0.36	10.0
*	*Avena fatua*	0.00	0.57	200.0
*	*Bromus diandrus*	0.00	0.14	150.0
	Cassytha racemosa	1.14	0.29	0.0
*	*Cynodon dactylon*	4.29	0.74	50.0
	Gahnia trifida	9.00	0.29	150.0
	Hardenbergia comptoniana	1.71	0.00	0.0
	Isolepis nodosa	0.71	0.14	150.0
*	*Lagurus ovatus*	0.00	0.03	30.0
	Lepidosperma gladiatum	0.71	0.00	250.0
*?	*Lolium sp.*	0.86	0.14	100.0
	Muehlenbeckia adpressa	14.64	3.71	121.7
	Olearia muelleri	7.14	0.00	140.0
	Phebalium anceps	5.71	0.29	140.0
	Pimelea ferruginea	2.86	0.00	100.0
*	*Plantago lanceolata*	0.03	0.00	40.0
	Pteridium esculentum	8.00	3.36	132.0
	Rhagodia baccata	0.57	0.00	106.7
	Samolus repens	0.14	0.00	100.0
	Schoenoplectus validus	4.36	0.86	250.0
	Senecio ramosissimus	0.01	0.00	80.0
	Sollya heterophylla	0.29	0.00	100.0
*	*Typha orientalis*	5.57	3.57	240.0

Table B2: Summary of Vegetation Recorded on Transect 2.

	Species	Ave. % Cover Alive	Ave. % Cover Dead	Ave. Height (cm)
	Agrostis sp.	3.25	0.5	97.5
	Cassytha racemosa	1.09	0.1	0
*	*Cynodon dactylon*	0.10	0.00	40.0
	Gahnia trifida	1.02	0.00	86.7
	Isolepis nodosa	0.90	0.20	110.0
	Juncus kraussii ssp. australiensis	2.10	0.00	90.0
	Lepidosperma gladiatum	8.25	1.60	210.0
*?	*Lolium sp.*	1.40	0.50	96.7
	Muehlenbeckia adpressa	13.15	2.62	141.0
	Olearia muelleri	6.00	2.00	250.0
	Phebalium anceps	2.25	0.20	126.0
	Pteridium esculentum	2.80	1.22	120.0
	Rhagodia baccata	3.50	0.10	180.0
	Samolus repens	0.17	0.00	40.0
	Schoenoplectus validus	15.00	10.00	236.7
*	*Solanum nigrum*	0.50	0.00	140.0
	Sphaerolobium macranthum	0.20	0.05	70.0
*	*Typha orientalis*	3.50	0.60	250.0

Table B3: Summary of Vegetation Recorded on Transect 3.

	Species	Ave. % Cover Alive	Ave. % Cover Dead	Ave. Height (cm)
	Baumea juncea	3	0.5	74.1
	Centella asiatica	2.6	0.1	27.5
	Chorizandra sp.	27.00	56.00	121.0
	Epilobium billardierianum ssp. billardierianum	1.00	0.60	50.0
	Lobelia alata	0.02	2.00	0.0
*	*Mentha spicata*	0.20	0.00	30.0
	Olearia muelleri	0.65	0.00	105.0
	Samolus repens	2.02	0.20	35.0
	Senecio ramosissimus	1.22	0.10	86.7

Table B4: Summary of Vegetation Recorded on Transect 4.

	Species	Ave. % Cover Alive	Ave. % Cover Dead	Ave. Height (cm)
	Agrostis sp.	1.67	0.17	80.0
	Baumea articulata	12.50	8.92	225.0
	Baumea juncea	40.08	8.33	100.0
	Centella asiatica	0.33	0.00	30.0
*	*Foeniculum vulgare*	0.17	0.00	80.0
	Isolepis nodosa	6.67	1.67	90.0
	Lepidosperma gladiatum	2.50	0.33	310.0
	Muehlenbeckia adpressa	4.83	1.00	96.7
	Pteridium esculentum	2.50	0.83	110.0
	Rhagodia baccata	0.33	0.17	90.0
	Schoenoplectus validus	0.67	0.33	90.0

Table B5: Summary of Vegetation Recorded on Transect 5.

	Species	Ave. % Cover Alive	Ave. % Cover Dead		Ave. Height (cm)
	Eucalyptus diversicolor	0.20	0.00		100.0
*	*Foeniculum vulgare*	6.00	0.00		126.7
	Gahnia trifida	4.00	0.00		110.0
	Hydrocotyle plebeja	28.00	0.00		25.0
	Lepidosperma gladiatum	6.00	0.00		230.0
*?	*Lolium sp.*	2.20	0.20		77.5
	Muehlenbeckia adpressa	7.80	0.00		71.3
	Paraserianthes lophantha	1.00	0.00		210.0
	Pteridium esculentum	0.60	0.00		100.0
*	*Rorippa nasturtium-aquaticum*	12.40	0.00		43.3
*	*Typha orientalis*	2.60	0.00		260.0

Table B6: Summary of Vegetation Recorded on Transect 6.

	Species	Ave. % Cover Alive	Ave. % Cover Dead		Ave. Height (cm)
	Agrostis sp.	0.10	0.70		145.0
	Cassytha racemosa	4.60	0.00		0.0
	Chorizandra sp.	4.40	0.50		122.5
	Epilobium billardierianum ssp. billardierianum	1.10	0.00		51.7
*	*Holcus lanatus*	0.03	0.00		100.0
	Isolepis nodosa	16.30	0.60		152.0
	Lepidosperma ?effusum	0.91	0.10		125.0
	Muehlenbeckia adpressa	12.00	0.70		123.3
	Phebalium anceps	0.60	0.00		140.0
	Schoenoplectus validus	25.15	1.50		161.1
*	*Solanum nigrum*	0.02	0.00		20.0
*	*Typha orientalis*	19.82	3.00		281.7

It should be noted that as these transect results are a set of base line data, no comparisons or conclusions (apart from observations from the aerial photography) regarding any changes in vegetation diversity and cover, as a result of pumping from the spring, can be drawn from them at this time. Also, no comparisons can be made between the control transect (Transect 5) and the other transects until pumping at the Leeuwin Spring is reduced.

In addition, it should be noted that the Blister Bush (*Phebalium anceps*) occurs on several of the transects and therefore it is recommended that all personnel visiting the site should wear appropriate clothing as this plant can cause severe blistering of the skin.

B4.4 Vegetation Mapping

A total of eight plant communities were described and mapped in the area adjacent to the Leeuwin Spring. These are outlined below with boundaries shown in Figure B1.

Woodland

1. Dense Low Woodland of *Melaleuca lanceolata* ssp. *occidentalis* over sparse low mixed shrubs and grasses on granite and brown sandy-loam.

Shrubland

2. Dense shrubland of *Agonis flexuosa* over *Muehlenbeckia adpressa*, *Spyridium globulosum*, *Templetonia retusa* and mixed shrubs over sparse *Lepidosperma gladiatum* on grey sand.

3. Dense low shrubland of *Spyridium globulosum*, *Templetonia retusa* and mixed shrubs over sparse *Lepidosperma gladiatum* on grey sand.

4. Dense low shrubland of *Phebalium anceps*, *Boronia alata*, *Olearia axillaris* and *Leucopogon parviflorus* on brown sandy-loam.

Heath

5. Dense low coastal heath of *Olearia axillaris* and *Calocephalus brownii* over mid-dense *Lepidosperma gladiatum*, *Carpobrotus ?virescens* and **Tetragonia decumbens* on white sand.

Sedgeland

6. Seasonally inundated tall sedgeland of *Baumea articulata* over mid-dense *Baumea juncea* and *Schoenoplectus validus* on black sandy-loam.

7. Seasonally inundated tall sedgeland of mid-dense *Typha orientalis* over dense *Schoenoplectus validus*, *Muehlenbeckia adpressa* and *Lepidosperma gladiatum* on black sandy-loam.

8. Seasonally inundated low sedgeland of *Chorizandra* sp. and *Baumea juncea* on brown sandy-loam.

B4.5 Review of Historical Photographs of the Leeuwin Spring

Aerials photographs from 1963, 1980 and 1993 (Scale 1:25,000) were reviewed for changes in the swamp vegetation downslope from the Leeuwin Spring (Appendix B4).

The findings indicated a shift in dominant plant species within the swamp communities, and in particular an increase in the *Typha* and *Baumea* communities both downslope of the Spring and near Skippy Rock Road. The observations support the earlier references cited on the invasion of sedges.

PART C

THE RARE SNAIL

Austroassiminea letha

C1.0 INTRODUCTION

This section of the study was structured to gather baseline data on the rare snail, *Austroassiminea letha*, known from six localities along a narrow coastal strip between Margaret River and Cape Leeuwin. The southernmost point where the snail has been found, Leeuwin Spring, is assessed in this report.

C2.0 OBJECTIVES

The specific objectives of this part of the study were:

- to evaluate the current status of the snail at Leeuwin Spring
- to use this baseline data to prepare a monitoring programme to identify and quantify the environmental parameters influencing its presence.

Pumping of water from the spring, in addition to a natural diminution of recharge (Appleyard, 1989), has markedly reduced outflow to the swamp where the rare snail occurs. The Curator of Aquatic Invertebrates at the W.A. Museum, S. Slack-Smith, considers that this combination of circumstances has placed the continuing survival of the current swamp environment at risk and, as a direct result, its population of *Austroassiminea letha*. However, WAWA is in the process of commissioning a new groundwater source near Molloy Island and, as a consequence, the amount of water drawn from the spring will be markedly reduced. How this will affect the snail after approximately 30 years of abstraction and, presumably, its adaptation to a modified environment is unknown. The following part of this report discusses the current status of *Austroassiminea letha* at Leeuwin Spring.

C3.0 METHODOLOGY

C3.1 Background Research

The State reference collection of *Austroassiminea letha* at the Western Australian Museum (WAM) was inspected, and several snail shells were provided to enable field identification to be confirmed on site. Initial discussions regarding recognition, distribution and habitat requirements of *Austroassiminea letha* took place on January 13, 1994 between the two principals of Ninox Wildlife Consulting and the Curator of Aquatic Invertebrates at the W.A. Museum. Subsequent to this familiarisation period, the field survey was undertaken between January 16 -18 (inclusive).

This small snail was first described as a new genus and species in 1982, with the type locality nominated as Cosy Corner, Hamelin Bay, near Augusta, Western Australia, ca. 34° 15' 05" S, 115° 01' 00" E (Solem et. al., 1982). The micro-habitat where the snail was found at this locality is described by the authors of the paper as:

"......tussocks of grass on granite cliffs near coast wet by seepage from limestone-granitic rock contact above."

At the time of description in 1982, the live snail was known from only three localities: Turner Brook, belōw Deepdene Cliffs; Cosy Corner and Ellen Brook. It was found at two sites on Ellen Brook, effectively giving four localities. Since then, the snail has been discovered in two additional locations, Leeuwin Spring and Gnoocardup, consequently widening its known distribution. These populations are isolated from one another and the total area of distribution of the snail was estimated at about 0.25 hectares (Slack-Smith, 1989). *Austroassiminea letha* was recognised as an unusual, if not unique, freshwater representative of a family of snails which generally inhabit the interface between marine or brackish water and the adjacent land (Slack-Smith, 1989). It is a prosobranch gastropod and therefore has an operculum to close the aperture of the shell during periods of unfavourable conditions and, although related to aquatic species, it still needs to keep its mantle cavity moist for gas exchange with the air. Its body surface also needs to remain moist to prevent water loss and the combination of these factors results in the snail being critically dependent on the continuance of a narrowly defined and poorly represented environment typified by locations such as Leeuwin Spring. Fossil records show that its distribution was wider in the recent geological past.

Solem et. al. (1982) describe the shell of this snail as variable in shape, from squat ovate-conic to elongate-conic with the spire angle generally uniform. Males are often smaller and squatter than females. Shell height ranges from 3.45 - 5.39 mm (mean 4.50 mm).

C3.2 Field Logistics

The field survey team consisted of three consultants and a volunteer. A planning reconnaissance of the Leeuwin Spring and its adjacent swamp was undertaken on the afternoon of January 16 and site discussions were held between the survey team, Mr Henderson of WAWA and R Neal of the Department of Conservation and Land Management (CALM) early on the morning of January 17. Sampling commenced soon after and continued at Leeuwin Spring and the adjacent swamp until late afternoon. On the following day, sampling continued at Leeuwin Spring and, once completed, other surrounding locations were assessed for *Austroassiminea letha*. These consisted of establishing a site at "The Spring" just north of Skippy Rock Road and a brief, opportunistic visit to Redman Brook on Leeuwin Road. No site was established in the latter area.

A brief site visit was undertaken to Quarry Bay on May 28th 1994 to establish whether the snail was present in this location also. No transects were established.

C3.3 Conditions During the Survey

At the time of the survey in mid-January 1994, very little water was passing over the weir at the WAWA pumping station on the spring. However, there was a continuous, shallow pool of water in the outflow drain leading to the main swamp. The limestone rocks around the spring showed a conspicuous deposit of copper sulphate used to control algae and, at the point where the outflow drain met the swamp, a patch of introduced watercress (*Rorippa nasturtium-aquaticum*) had apparently been treated with a herbicide. The dense *Typha orientalis* dominated section of the swamp commencing just within and just beyond the southern boundary of the WAWA enclosure held water, but this was only obvious as surface inundation in one or two areas, or when the spongy peat base of the swamp was compressed by footprints. The central, southern section of the swamp, also dominated by patches of *Typha orientalis*, was substantially drier, while the main body of the swamp, dominated by *Baumea juncea* had no surface water. The soil surface in most of this latter section was dry to barely damp, although moisture levels tended to increase slightly at about 5 centimetres depth or within depressions.

The fibreglass portion of the flume at the extreme western limits of the *Baumea juncea* dominated section of the swamp was totally dry, while the wooden section leading to the waterwheel was very wet, with windblown spray from the CALM sprinkler system extending well beyond the flume into the vegetation on the southern side. A small, isolated swampy patch dominated by *Typha orientalis* at the junction of Leeuwin Road and Skippy Rock Road had relatively damp to wet soil, and "The Spring", some two kilometres north-east of the study area had flowing water.

C3.4 Field Sampling

Table C1 provides a brief description of the sites which were sampled during the study. Expanded descriptions of the flora and vegetation are available in Part B.

Table C1: Description of the Sites Sampled for Snails at Leeuwin Spring and Surrounding Areas in January 1994.

TRANSECT	LOCATION
ST1	Limestone rocks, shoreline and grassed area surrounding the pool behind the weir at Leeuwin Spring itself.
ST2	Shoreline and wet portions of the outflow drain from the weir prior to its junction with the northern edge of the swamp (north-south transect).
ST3	Extreme northern edge of the swamp just within the fenced WAWA enclosure (east-west transect).
ST4	Northern portion of the swamp just south of the fenced WAWA enclosure (east-west transect).
ST5	Extreme western limits of the swamp close to the eastern end of the flume (approximately east-west transect).
ST6	Isolated swampy area east of the main swamp. Situated on the junction of Skippy Rock Road and Leeuwin Road (north-south transect).
ST7	"The Spring". Situated approximately 2 kilometres north-east of Leeuwin Spring (north-south transect).
ST8	Wooden portion of the flume close to the waterwheel.
ST9	Fibreglass portion of the flume east of the waterwheel.
ST10	Southern portion of the swamp directly opposite the WAWA enclosure (north-south transect).

Ten 25 metre transects were established and sampled during this study (Table C1); six of these were set parallel to the six vegetation transects described in Part B, and shown in Figure B1. The remaining four were arranged to cover highly modified or disturbed sites with little or no native vegetation. These were: the Leeuwin Spring weir and it's rocky surrounds (ST1); the outflow drain below the weir (ST2); the wooden portion of the flume and it's rocky stanchions (ST8); the fibreglass portion of the flume (ST9). In setting out these transects, the primary objective was to sample as many habitats and moisture gradients as possible. Five sampling sites, 5 metres apart, were positioned along each snail sampling transect, giving a total of 50 sampling stations.

The height and density of the swamp vegetation precluded the use of any form of measured quadrat as originally planned, but to enable current and future comparisons to be made, the time spent at each station was standardised to 20 minutes. During this time, several samples of soil and debris were collected by hand within 1 metre of a marked point and methodically examined for snails. Notes were taken on soil moisture based on five subjective categories: wet; very damp; damp; slightly damp; dry. Brief site descriptions are given in Table C1, with greater detail provided in Part B, Flora and Vegetation.

Initial field identifications of *Austroassiminea letha* were confirmed by comparing each specimen with the Museum sample until field proficiency was reached. The number of *Austroassiminea letha* in each sample was counted and entered on a field data sheet. As with most data sheets designed prior to a field survey of a species which has not been previously monitored, flaws and omissions were encountered. These were overcome by placing comprehensive field notations on the sheet. A modified field data sheet suitable for monitoring is shown in Appendix C1.

Numbers of live and dead snails were noted, as was an estimate of age (Table C2). Solem et. al., (1982) describe adults as having thickening of the basal lip and a beginning of irregular, gerontic growth visible behind the palatal lip. As a definitive statement on the age class of individuals would have necessitated a microscopic analysis of specimens in a laboratory, it was considered that this level of assessment was not warranted for the baseline study, particularly as attempts to keep the snail alive in captivity have been unsuccessful (S. Slack-Smith, personal communication). The identification of juvenile and adult age classes was therefore estimated on the relative size of individuals.

Assessing whether snails were live, aestivating or recently dead was extremely difficult to establish, although snails that had been dead for some time were very obvious due to surface decalcification of the shell. Live, active snails were also obvious and were observed on the wet, wooden section of the flume leading to the waterwheel. However, at Transect 9 on the dry, plastic section of the flume, two snails that appeared to be dead proved to be alive when dissected. The shells of these two snails were translucent, with a dark area confined to the last two spirals at the tip of the shell. This dark area was wrongly assumed to be the dried carcase of a recently dead individual. It is likely therefore that there is an error factor in the dead/alive category of the results, particularly for the sites which were sampled first. This is unlikely to be more than approximately 10%.

C4.0 RESULTS AND DISCUSSION

The results of the hand searches for *Austroassiminea letha* in 10 transects in various locations are shown in Table C2. A total of 111 live snails (75 adults , 36 juveniles) and 109 dead snails (48 adult, 61 juvenile) was recorded during sampling.

Table C2: Results of Sampling for Snails at Leeuwin Spring and Surrounding Locations in January 1994.

Transect	Station	Soil Moisture	Adult		Juvenile	
			Live	Dead	Live	Dead
ST1	A	Very Damp	0	0	0	0
	B	Very Damp	0	0	0	0
	C	Very Damp	0	0	0	0
	D	Very Damp	0	0	0	0
	E	Very Damp	0	0	0	0
		Total	0	0	0	0
ST2	A	Very Damp	0	0	0	0
	B	Very Damp	0	0	0	0
	C	Very Damp	0	0	0	0
	D	Very Damp	0	0	0	0
	E	Very Damp	0	0	0	0
		Total	0	0	0	0
ST3	A	Damp	0	0	0	0
	B	Damp	0	0	0	0
	C	Very Damp	2	0	2	1
	D	Very Damp	0	5	0	0
	E	Dry	0	0	0	0
		Total	2	5	2	1
ST4	A	Very damp	0	0	0	0
	B	Slightly damp	1	2	0	0
	C	Very Damp	1	3	0	0
	D	Damp	1	0	10	0
	E	Slightly damp	12	2	2	0
		Total	15	7	12	0

Table C2: Results of Sampling for Snails at Leeuwin Spring and Surrounding Locations in January 1994 (Continued).

Transect	Station	Soil Moisture	Adult		Juvenile	
			Live	Dead	Live	Dead
ST5	A	Dry	3	1	15	0
	B	Dry	5	2	1	0
	C	Dry	1	5	0	0
	D	Slightly Damp	1	3	0	4
	E	Slightly Damp	2	4	0	0
		Total	12	15	16	4
ST6	A	Damp	3	0	0	0
	B	Wet	1	0	4	0
	C	Damp	0	0	0	0
	D	Damp	0	0	0	0
	E	Damp	0	0	0	0
		Total	4	0	4	0
ST7	A	Dry	0	0	0	0
	B	Wet	0	0	0	1
	C	Damp	0	4	0	2
	D	Damp	0	0	0	0
	E	Damp	0	1	0	0
		Total	0	5	0	3
ST8	A	Wet	5	0	2	0
	B	Wet	15	1	0	0
	C	Wet	4	2	0	0
	D	Wet	7	0	0	0
	E	Dry	0	0	0	8
		Total	31	3	2	8
ST9	A	Dry	4	2	0	0
	B	Dry	0	12	0	0
	C	Dry	4	2	0	0
	D	Dry	2	25	0	0
	E	Dry	0	8	0	0
		Total	10	49	0	0

Table C2: Results of Sampling for Snails at Leeuwin Spring and Surrounding Locations in January 1994 (Continued).

Transect	Station	Soil Moisture	Adult		Juvenile	
			Live	Dead	Live	Dead
ST10	A	Damp	0	0	0	0
	B	Damp	0	0	0	0
	C	Damp	0	6	0	0
	D	Damp	0	3	0	0
	E	Damp	1	0	0	0
		Total	1	9	0	0

Data from Table C2 has been summarised in Figure C1 which shows the numbers of live and dead snails in each transect. The influence of moisture gradients on snail numbers is discussed later.

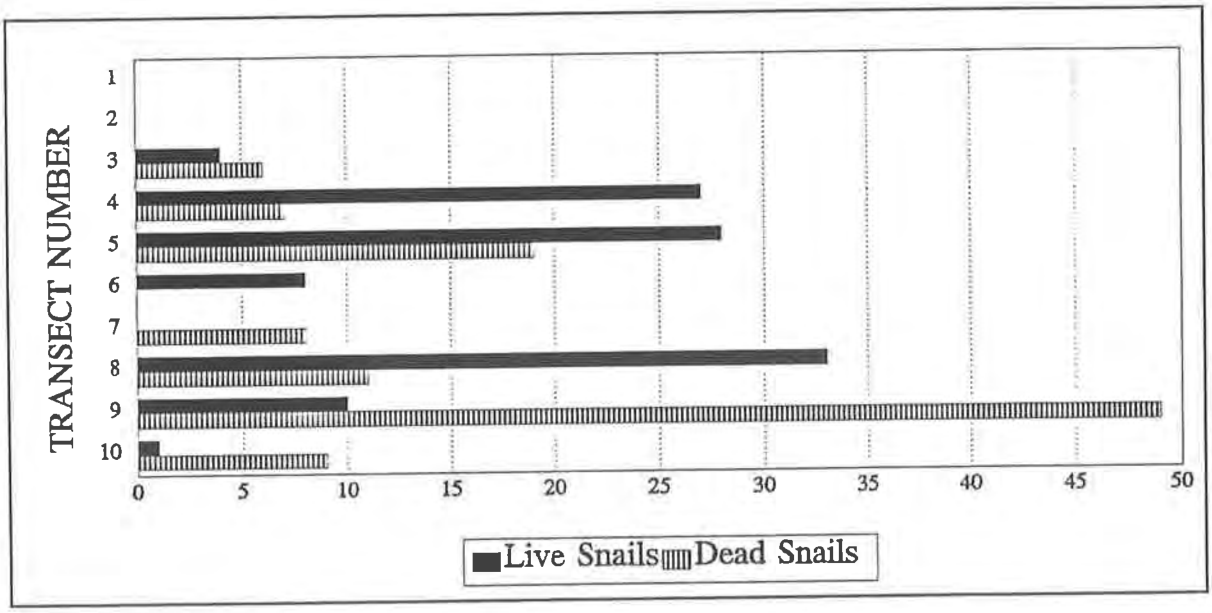

Figure C1: Numbers of Live and Dead Snails Found in Each Transect at Leeuwin Spring and Surrounding Locations in January 1994.

C4.1 Quarry Bay

During the short opportunistic visit to the Quarry Bay area one live and two dead snails were found in a seepage area.

C4.2 Transect Notes

Transects 1 and 2 were positioned around the small dam and outflow drain within the boundaries of the WAWA pumping station on the northern periphery of the swamp. No evidence of live snails of any species was recorded in the 10 stations in this area. However, large numbers of dead snails of another species were located. The water in the small dam is occasionally treated with copper sulphate to reduce algal growth and there is a high probability, as yet unconfirmed, that this has had an effect on snails. Some vegetation die-off, mainly watercress and grasses, was noted at the southern end of the outflow drain (Transect 2) and appears to be the result of herbicide treatment. This also may have had an effect on snails. However, searching of Transect 3 which was situated approximately 15 metres from Transect 2, also within the boundaries of the WAWA fenced enclosure, resulted in four live and six dead snails.

Live snails were most abundant in Transects 4, 5 and 8 (27, 28 and 33 individuals respectively). All of these sites differed markedly. Transect 4 was located immediately south of the WAWA enclosure, in extremely dense, mixed, swamp vegetation where the soil ranged from damp to very wet. Transect 5 was located in very dense, low *Baumea juncea* sedgeland, where the soil was mainly dry. At this latter location, most snails were found apparently aestivating within calcareous deposits that had formed around sedge stems. The sedges had subsequently rotted, leaving a complex network of hollow tubes which enabled snails to shelter in a protected environment. A sample of this type of micro-habitat has been collected for future reference. Four of the five sampling stations along Transect 8 were positioned along the wet, wooden section of the flume leading to the water-wheel. The number of live, adult snails varied considerably between sampling stations with a maximum of 15 to a minimum of four individuals. Eight dead snails were located on the dry, wooden flume at sampling point 8E; no live animals were encountered here. The controlling factor appeared to be windblown dispersal of water from the sprinkler system installed to protect the calcium carbonate deposits on the water-wheel. Most snails were located where water from the sprinkler system was maintaining high moisture levels in the adjacent vegetation, and a large proportion of these were very active and presumably feeding. The extremely dry, fibreglass section of the flume (Transect 9) revealed large numbers of dead adults (49) and 10 live adults. However, there was some difficulty determining the condition of snails at this transect (see Part C3.3). All were located on soil at the base of dense grasses adjacent to the flume.

Transect 6 was located at the northernmost section of swamp, at the junction of Skippy Rock Road and Leeuwin Road. Live snails were recorded on sampling stations 6A and 6B, and consisted of four adults and four juveniles. No dead snails were found.

Transect 7 was situated across the flowing stream at "The Spring", about two kilometres north-east of main study area. Eight dead snails were located on three of the five sampling stations peripheral to the stream itself. Of these, five were adult and three were juvenile. However, recently dead or aestivating snails were extremely difficult to distinguish, and there may be some doubt as to the condition of these individuals (see Part C3.3 for explanation). Detection of *Austroassiminea letha* at "The Spring" and later at Quarry Bay was an important aspect of the WAWA study. These are two new locations for the species, bringing the total of known localities to eight.

The western section of the swamp was sampled by Transect 10 where one live and nine dead snails were located. The soil at this section of swamp was damp but had little vegetation detritus on several sampling stations.

C4.3 Moisture Gradients

Figure C2 summarises the data from Table C2 and assesses the number of live and dead snails found in the five moisture gradients recognised in this study. These gradients varied along individual transects, and the diagram therefore deals with this aspect alone, rather than the specific transect where snails were found. Two major elements are immediately apparent in Figure C2:

- live snails were most common at the two extremes of moisture gradients, that is, wet habitats and dry habitats;

- dead snails were found much more frequently in dry habitats.

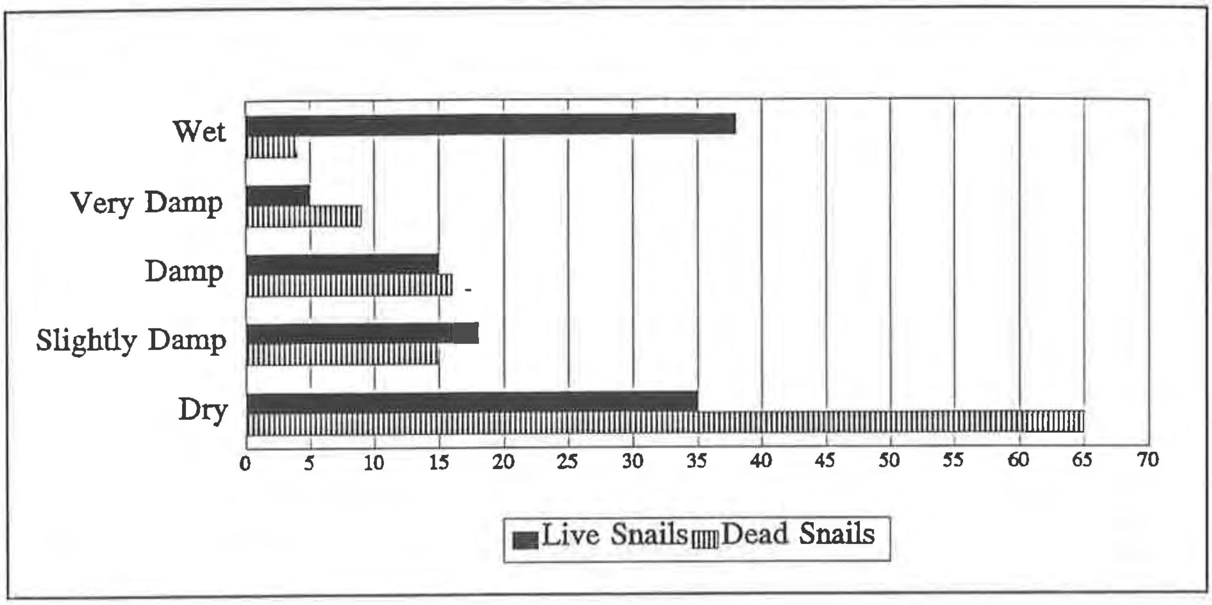

Figure C2: Diagram Showing the Number of Live and Dead Snails Recorded Across the Five Moisture Gradients Recognised in this Study.

Taking account of the two major elements listed above, there are three peaks in Figure C2: live snails in wet habitats; live snails in dry habitats; dead snails in dry habitats. Numbers of live snails in wet habitats, an environment which skews the above graph, were dominated by Transect 8 where 87% of all such observations were found on and near the section of the wooden flume where windblown spray from the sprinkler system kept the environment very wet. This habitat, although "artificial", aligns well with the tendency for active *Austroassiminea letha* to be found on seepage films and splash zones as documented by Slack-Smith (1982). If "natural habitats" alone are considered, the distribution of live snails from wet to dry environments forms an increasing gradient which closely follows a reduction in soil moisture levels.

The second peak, shown by the number of live snails in dry environments, is one of the more interesting aspects of the study. About 71% of all live snails in dry habitats came from Transect 5 which was located in a very dense, *Baumea juncea* sedgeland at the eastern limits of the flume. At this site the snails were mainly found within the calcareous deposits described earlier.

The last peak, dead snails in dry habitats, is again related to the flume. About 75% of all dead snails in dry habitats came from Transect 9, the dry fibreglass section of the flume. Whether these dead snails were stranded after radiating from Transect 8 or Transect 5 (Figure B1) during wet periods is unknown.

PART D

CONCLUSIONS AND

MONITORING RECOMMENDATIONS

D1.0 CONCLUSIONS

D1.1 Flora and Vegetation

The initial monitoring of vegetation transects in the study area found that dominant species varied on each transect, due to water depths and site conditions. Transect 1 was dominated by *Muehlenbeckia adpressa*, a non-aquatic species. This reflects the narrow wet area through which this transect passes. This species was again common on Transect 2 although aquatic species such as *Schoenoplectus validus* and *Lepidosperma gladiatum* were dominant due to the surface water present on this transect. Transects 3 and 4 were also dominated by aquatic sedge species while Transect 5 was dominated by weed species due to the presence of tourist activity. Transect 6 was dominated by aquatic sedge species.

It should be noted that as these results are a set of baseline data, no comparisons or conclusions (apart from observations from the aerial photography) regarding any changes in vegetation diversity and cover, as a result of pumping from the spring, can be drawn from them at this time. Also, no comparisons can be made between the control transect (Transect 5) and the other transects until pumping at the Leeuwin Spring is reduced.

It is already known that water levels in the area have dropped markedly since pumping commenced as water no longer flows along the flume and water-wheel. This is likely to have had an effect on vegetation although the lack of historical data makes it difficult to document this. Investigation of historical aerial photographs of the area do indicate a change in dominance of sedge and rush species in the area due partly to disturbance caused by decreasing water levels. This has promoted the colonization of the area by *Typha orientalis*, leading to increased vegetation density but lowered diversity. The reduction of pumping alone will not restore the previous diversity of the area as *Typha orientalis* is very difficult to control once established. A manual removal programme could be considered once pumping is reduced to increase vegetation diversity although the impact of this on the rare snail should be considered prior to any action.

Continued monitoring of the area may also reveal changes that have occurred in the past as any effects of increased water levels, due to reducing pumping from the Leeuwin Spring, are noted in the future.

D1.2 *Austroassiminea letha*

Based on the results of this baseline study, the following conclusions can be made about the habitat preferences and current status of the rare snail *Austroassiminea letha* at Leeuwin Spring:

- live, aestivating and dead snails can be successfully located and counted during the peak water demand period in mid-summer at Leeuwin Spring;

- while information from the survey can be used as a benchmark for monitoring studies at the same time of year using the same techniques, another seasonal data point is required. Summer is not the ideal time to sample moisture-dependent fauna, and it is possible that the number of snails recorded and their distribution could differ substantially in winter;

- earlier sampling of the snail suggested that it avoided the central portions of the swamp, especially where there was flowing water or sandy parts of the swamp base where vegetation detritus was absent. The current study has shown that *Austroassiminea letha* is distributed throughout the swamp near Leeuwin Spring, but has a preference for splash zones, denser vegetation and locations where calcareous deposits have formed around sedges;

- the snail has apparently increased its local distribution throughout the Leeuwin Spring area, a feature which may be related to the progressive drying out of the swamp through abstraction and rainfall changes;

- whether the proposed reduction in the rate of abstraction will result in a contraction of this apparent increase in local distribution is, as yet, unknown and can only be established through long-term monitoring.

D2.0 MONITORING RECOMMENDATIONS

The main aims of management of the Leeuwin Spring area should be to preserve the snail populations and vegetation diversity in the area, as well as protecting the historical significance of the water-wheel and flume. It is unknown whether an increase in water levels will achieve these aims and therefore a comprehensive monitoring programme is necessary to record the effects, if any, of a decrease in the volume of water pumped from the Leeuwin Spring.

D2.1 Flora and Vegetation

Changes in vegetation due to increasing/decreasing water levels generally take several years to become evident. As a result monitoring of the vegetation transects at the Leeuwin Spring does not need to be as frequent as may be required to adequately monitor the status of the rare snail. However, it is recommended that at some stage the two monitoring programmes coincide and that a general report covering both aspects of the study be written. This will allow trends affecting both the vegetation and snail communities to be noted, leading to better understanding of the overall effects of changing water levels.
Methodology: the techniques described in Part B4.0 will adequately fulfil the objectives of the study and it is therefore recommended that they are adopted. In summary, this would entail monitoring the six transects and 46 associated quadrats at the Leeuwin Spring and surrounding area.

Monitoring Frequency: as changes in plant community diversity and cover can occur over long periods of time, monitoring of the vegetation transects needs to be undertaken only at a maximum of yearly intervals with reassessment of frequency after two years.

Monitoring Timing: as the transects are being monitored to determine the effects of water levels it is important that monitoring always be undertaken during the same season each year. It is therefore recommended that the transects always be assessed in early January.

Long Term Assessment: the monitoring programme described above should be continued from January 1995 and up to five years after the new source near Molloy Island is commissioned.

Duration of Monitoring: based on the recent survey, two full days, including travelling, should be adequate to sample the six transects.

Personnel requirements: two field personnel who must be informed of the need to wear protective clothing.

Reporting: a comprehensive interim report should be prepared each year combining the results of both the annual vegetation transect monitoring and bi-annual snail transect survey (see below).

D2.2 *Austroassiminea letha*

Techniques to successfully sample *Austroassiminea letha* were developed during this study and could be used for long term monitoring of Leeuwin Spring. The objective is not to document the life history and biology of the species, but rather to focus on population fluctuations or alteration to local patterns of distribution brought about by modifications to water abstraction rates. Detailing the biology of the species would entail a completely different sampling regime and is, perhaps, more the responsibility of a body such as CALM who are already running several rare animal projects.

As a result of the WAWA study, we now know that there is an apparently thriving population of snails at Leeuwin Spring, generally distributed throughout and beyond the swamp. Given that the two primary objectives are to verify the continuing presence of the snail over the long term and detect impact, the following monitoring programme is recommended.

Methodology: the techniques described in Part C3.4 (Field Sampling) will adequately fulfil the objectives described above and it is therefore recommended that they are adopted. In summary, this would entail monitoring the ten transects and 50 associated sampling stations at Leeuwin Spring.

Annual Sampling Frequency: a full scale research project on the species would require at least four seasonal visits per year. However, to monitor snail numbers and assess changes to distribution patterns would require biannual surveys.

Survey Timing: the optimum periods to sample would be when the swamp is under the greatest and least stress, mid-summer and mid-winter respectively. Sampling during these extremes would tend to emphasis any potential changes and give advance warning on excessive impact.

Long Term Sampling: a mid-winter survey should be undertaken this year to obtain seasonal baseline data. The bi-annual programme described above should be continued from mid-winter 1994 and up to five years after the new source near Molloy Island is commissioned. Sampling frequency should be reassessed after two years.

Sampling Session Duration: judging by the recent survey, two days, including travelling, should be adequate to sample the ten transects.

Personnel requirements: two field personnel each survey.

Reporting: a brief summary of results should be lodged with WAWA after each survey and a more comprehensive interim report prepared each year.

It is also recommended that the addition of copper sulphate to the water be reduced if possible as the presence of this appears to be adversely affecting the snail population in the vicinity of the weir.

D3.0 OTHER RECOMMENDATIONS

Continued Abstraction: One of the goals of this study was to assess whether abstraction should be continued at the spring. Aerial photography appears to suggest that there has been a gradual shift in plant communities in the swamp to the drier end of the scale. Although the quantity of water abstracted by the Water Authority of Western Australia from the Leeuwin Spring has increased over the years to an average of 700 kL/d (equivalent to 250 000 kL per annum), the drying out of the swamp could be attributed to the fact that the yield of the Leeuwin Spring has declined from 4500 kL/d in the 1960's to 1400 kL/d currently (due to the lower rainfall levels). It is possible that this change in plant communities may have occurred even without abstraction. However, as the swamp appears to be drying out naturally any reduction in abstraction rates will reduce pressure on the plant communities, slowing further invasion by introduced species such as *Typha orientalis*. Therefore it is recommended that, with respect to vegetation, abstraction be reduced although it is not necessary to discontinue it fully. Further monitoring will assess the effect of reduced abstraction on vegetation and allow decisions to be made on whether abstraction should be discontinued.

It was concluded in Section D1.2 that is was not possible to assess whether the proposed reduction in the rate of abstraction after the new source becomes operational would result in a contraction of the apparent increase in local distribution of the snail, and this could only be established through long-term monitoring.

There are two options:

- discontinue abstraction as of now;
- continue abstraction at the reduced rate and monitor the effects of longer term inundation of the swamp.

The snails have coexisted with high abstraction rates over a long period of time and while there is the possibility of a population collapse once a critical point is reached, this seems unlikely given their persistence through long term abstraction combined with a period of low rainfall and subsequent decline in yield of the Leeuwin Spring. If in the future abstraction decreases and rainfall increases it is predicted that there will be a trend towards a wetter swamp environment, which could favour the stability of the snail populations. In the foreseeable future, there in no apparent reason why abstraction should not continue as long as it is coupled with periodic monitoring and a commitment of discontinue abstraction if adverse effects are observed.

Effects of Chlorinated Water: The integrity of the wooden section of the flume is maintained in summer by a sprinkler system supplying chlorinated scheme water. There is some concern that this water may be affecting the snail, an aspect that cannot be confirmed without long term monitoring. However, Figure C1 shows that the greatest number of live snails were recorded in the splash zone below the wooden flume and that, on the basis of the January 1994 survey this was prime habitat. Whether there has been a reduction in numbers since the earlier surveys by the Western Australian Museum cannot be established from the available literature, since no population estimates were given.

The chlorine may be dissipating through the fine wind blown spray which drifts form the sprinklers and settles as a film of moisture on vegetation (as in the removal of hydrogen sulphide in WAWA water treatment plants), but this has not been proven yet. Given this uncertainty, a cautious approach may be the best solution. It is therefore recommended that the current method of maintaining the integrity of the flume is discontinued and that plastic piping is laid from the weir to the flume to provide water of the original chemical composition. The height of the weir above the flume suggests that gravity may provide enough pressure to operate this system successfully. It also possible that once abstraction levels are reduced in the future water levels in the swamp may remain high enough to allow water to continue to flow naturally over the flume. The chlorine appears to have no adverse effect on surrounding native vegetation.

Waterwheel Preservation: Inspections of the waterwheel revealed the presence of algae and moss growing over it's surface. These are likely to be opportunistic salt tolerant species with no preservation importance. These will persist as long as the waterwheel remains moist.

Despite several searches no snails were found on or near the waterwheel. This site did not appear to be a preferred snail habitat at the time of survey, although there is a possibility that they may occur at this site in winter. To maintain the integrity of the waterwheel and continue the original accretion of limestone deposits, it is recommended that a pipeline from the weir is established as discussed above, as it is possible that the chlorinated water may be destroying this accretion. This can only be proven through further studies.

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APPENDIX B1: Summary of Vascular Plant Species Recorded at the Leeuwin Spring and Surrounding Area, January 1994.

FAMILY		GENUS	SPECIES
DENNSTAEDTIACEAE		*Pteridium*	*esculentum*
TYPHACEAE	*	*Typha*	*orientalis*
POACEAE		*Agrostis*	sp.
	*	*Avena*	*fatua*
	*	*Bromus*	*diandrus*
	*	*Cynodon*	*dactylon*
	*	*Holcus*	*lanatus*
	*	*Lagurus*	*ovatus*
	*?	*Lolium*	sp.
CYPERACEAE		*Baumea*	*articulata*
		Baumea	*juncea*
		Gahnia	*trifida*
		Isolepis	*nodosa*
		Lepidosperma	*?effusum*
		Lepidosperma	*gladiatum*
		Schoenoplectus	*validus*
JUNCACEAE		*Juncus*	*kraussii* ssp. *australiensis*
PHORMIACEAE		*Dianella*	*revoluta*
SANTALACEAE		*Exocarpus*	*sparteus*
POLYGONACEAE		*Muehlenbeckia*	*adpressa*
CHENOPODIACEAE		*Rhagodia*	*baccata*
AIZOACEAE		*Carpobrotus*	*?virescens*
	*	*Tetragonia*	*decumbens*
LAURACEAE		*Cassytha*	*racemosa*
BRASSICACEAE	*	*Rorippa*	*nasturtium-aquaticum*
PITTOSPORACEAE		*Sollya*	*heterophylla*
MIMOSACEAE		*Acacia*	*littorea*
		Paraserianthes	*lophantha*

APPENDIX B1: **Summary of Vascular Plant Species Recorded at the Leeuwin Spring and Surrounding Area, January 1994.**

FAMILY		GENUS	SPECIES
PAPILIONACEAE		*Chorizandra*	sp.
		Hardenbergia	*comptoniana*
		Sphaerolobium	*macranthum*
		Templetonia	*retusa*
RUTACEAE		*Boronia*	*alata*
		Phebalium	*anceps*
RHAMNACEAE		*Spyridium*	*globulosum*
THYMELAEACEAE		*Pimelea*	*ferruginea*
MYRTACEAE		*Agonis*	*flexuosa*
		Eucalyptus	*diversicolor*
		Melaleuca	*lanceolata* ssp. *occidentalis*
ONAGRACEAE		*Epilobium*	*billardierianum* ssp. *billardierianum*
APIACEAE		*Centella*	*asiatica*
	*	*Foeniculum*	*vulgare*
		Hydrocotyle	*plebeja*
EPACRIDACEAE		*Leucopogon*	*parviflorus*
PRIMULACEAE		*Samolus*	*repens*
LAMIACEAE	*	*Mentha*	*spicata*
SOLANACEAE	*	*Solanum*	*nigrum*
PLANTAGINACEAE	*	*Plantago*	*lanceolata*
GOODENIACEAE		*Lobelia*	*alata*
		Scaevola	*nitida*
ASTERACEAE		*Calocephalus*	*brownii*
		Olearia	*axillaris*
		Olearia	*muelleri*
		Senecio	*ramosissimus*
		Asteraceae	sp.

APPENDIX B2: Transect Data for Cape Leeuwin, January 1994.

T	Q		Species	Percentage Cover Alive	Percentage Cover Dead	Height (cm)	Water Depth (cm)
1	1		Asteraceae sp.		2.5	10	0
1	1	*	*Cynodon dactylon*		0.2		
1	1		*Hardenbergia comptoniana*	2			
1	1		*Muehlenbeckia adpressa*	1		100	
1	1		*Olearia muelleri*	8		140	
1	1		*Pteridium esculentum*	15	1	90	
1	1		*Rhagodia baccata*	0.5		100	
1	2		*Hardenbergia comptoniana*	5			0
1	2		*Muehlenbeckia adpressa*	50	10	140	
1	2		*Pteridium esculentum*	30	10	140	
1	2		*Rhagodia baccata*	0.5		100	
1	2		*Schoenoplectus validus*	0.5		220	
1	2	*	*Typha orientalis*	1		220	
1	3		*Hardenbergia comptoniana*	5			0
1	3		*Muehlenbeckia adpressa*	5	10	120	
1	3		*Pteridium esculentum*	2	0.5	150	
1	3		*Rhagodia baccata*	3		120	
1	3		*Schoenoplectus validus*	20	5	300	
1	3	*	*Typha orientalis*	20	20	300	
1	4		*Gahnia trifida*	60	1	180	10
1	4		*Muehlenbeckia adpressa*	1.5		100	
1	4		*Pteridium esculentum*	7		140	

APPENDIX B2: Transect Data for Cape Leeuwin, January 1994.

T	Q		Species	Percentage Cover Alive	Percentage Cover Dead	Height (cm)	Water Depth (cm)
1	4		*Schoenoplectus validus*	10	1	230	
1	4	*	*Typha orientalis*	15	2	200	
1	5		*Cassytha racemosa*	5	2		0
1	5		*Gahnia trifida*	3	1	120	
1	5		*Isolepis nodosa*	4	1	150	
1	5	*?	*Lolium sp.*	6	1	100	
1	5		*Muehlenbeckia adpressa*	30	5	130	
1	5		*Pteridium esculentum*	2	12	140	
1	5		*Samolus repens*	1		100	
1	5	*	*Typha orientalis*		1	180	
1	6		*Cassytha racemosa*	2			0
1	6		*Isolepis nodosa*	1		150	
1	6		*Lepidosperma gladiatum*	5		250	
1	6		*Muehlenbeckia adpressa*	15	1	140	
1	6		*Olearia muelleri*	2		140	
1	6		*Phebalium anceps*	40	2	140	
1	6	*	*Typha orientalis*	3	2	300	
1	7		*Acacia littorea*	4		120	0
1	7	*	*Avena fatua*		4	200	
1	7	*	*Bromus diandrus*		1	150	
1	7		*Cassytha racemosa*	1			
1	7	*	*Cynodon dactylon*	30	5	100	

APPENDIX B2: Transect Data for Cape Leeuwin, January 1994.

T	Q		Species	Percentage Cover Alive	Percentage Cover Dead	Height (cm)	Water Depth (cm)
1	7	*	*Lagurus ovatus*		0.2	30	
1	7		*Olearia muelleri*	40		140	
1	7		*Pimelea ferruginea*	20		100	
1	7	*	*Plantago lanceolata*	0.2		40	
1	7		*Senecio ramosissimus*	0.1		80	
1	7		*Sollya heterophylla*	2		100	
2	1		*Cassytha racemosa*	3			0
2	1		*Lepidosperma gladiatum*	10	15	170	
2	1		*Muehlenbeckia adpressa*	20	5	140	
2	1		*Pteridium esculentum*	10	2	140	
2	1		*Rhagodia baccata*	35	1	180	
2	1	*	*Typha orientalis*	20	3	240	
2	2		*Cassytha racemosa*	1			10
2	2		*Muehlenbeckia adpressa*	2	4	150	
2	2		*Pteridium esculentum*	3	1	150	
2	2		*Schoenoplectus validus*	30	40	260	
2	2	*	*Typha orientalis*	15	3	260	
2	3		*Cassytha racemosa*	1			15
2	3		*Muehlenbeckia adpressa*	1		140	
2	3		*Schoenoplectus validus*	60	30	210	
2	4		*Cassytha racemosa*	2			15
2	4		*Muehlenbeckia adpressa*	5		150	

APPENDIX B2: Transect Data for Cape Leeuwin, January 1994.

T	Q		Species	Percentage Cover Alive	Percentage Cover Dead	Height (cm)	Water Depth (cm)
2	4		*Schoenoplectus validus*	60	30	240	
2	5		*Agrostis sp.*	0.5		120	5
2	5		*Cassytha racemosa*	0.5			
2	5		*Isolepis nodosa*	4		120	
2	5		*Lepidosperma gladiatum*	0.5		200	
2	5	*?	*Lolium sp.*	1		120	
2	5		*Muehlenbeckia adpressa*	60	10	240	
2	5		*Pteridium esculentum*	3	2	180	
2	5	*	*Solanum nigrum*	5		140	
2	6		*Agrostis sp.*	2		90	0
2	6		*Cassytha racemosa*	1			
2	6		*Isolepis nodosa*	5	2	100	
2	6		*Lepidosperma gladiatum*	2		220	
2	6	*?	*Lolium sp.*	5	5	90	
2	6		*Muehlenbeckia adpressa*	10	2	180	
2	6		*Phebalium anceps*	5	1	140	
2	6		*Pteridium esculentum*	1		100	
2	7		*Lepidosperma gladiatum*	70	1	250	0
2	7		*Muehlenbeckia adpressa*	15		120	
2	7		*Phebalium anceps*	5	1	160	
2	7		*Pteridium esculentum*	1	0.2	90	
2	8		*Agrostis sp.*	15	2	90	0

APPENDIX B2: Transect Data for Cape Leeuwin, January 1994.

T	Q		Species	Percentage Cover Alive	Percentage Cover Dead	Height (cm)	Water Depth (cm)
2	8		*Cassytha racemosa*	0.2			
2	8		*Gahnia trifida*	0.2		50	
2	8		*Juncus kraussii ssp. australiensis*	20		90	
2	8		*Muehlenbeckia adpressa*	10	5	150	
2	8		*Phebalium anceps*	0.5		100	
2	8		*Pteridium esculentum*	5	4	90	
2	8		*Samolus repens*	0.5		40	
2	9		*Agrostis sp.*	15	3	90	0
2	9		*Cassytha racemosa*	0.2			
2	9	*	*Cynodon dactylon*	1		40	
2	9		*Gahnia trifida*	5		110	
2	9		*Juncus kraussii ssp. australiensis*	1		90	
2	9		*Muehlenbeckia adpressa*	8	0.2	90	
2	9		*Phebalium anceps*	5		90	
2	9		*Pteridium esculentum*	5	3	90	
2	9		*Samolus repens*	1		40	
2	9		*Sphaerolobium macranthum*	1	0.5	90	
2	10		*Cassytha racemosa*	2	1		0
2	10		*Gahnia trifida*	5		100	
2	10	*?	*Lolium sp.*	8		80	
2	10		*Muehlenbeckia adpressa*	0.5		50	
2	10		*Olearia muelleri*	60	20	250	

APPENDIX B2: Transect Data for Cape Leeuwin, January 1994.

T	Q		Species	Percentage Cover Alive	Percentage Cover Dead	Height (cm)	Water Depth (cm)
2	10		*Phebalium anceps*	7		140	
2	10		*Samolus repens*	0.2		40	
2	10		*Sphaerolobium macranthum*	1		50	
3	1		*Centella asiatica*	20	1	30	0
3	1		*Chorizandra sp.*	30	40	100	
3	1	*	*Mentha spicata*	2		30	
3	2		*Centella asiatica*	6		25	0
3	2		*Chorizandra sp.*	20	60	100	
3	2		*Samolus repens*	10	1	25	
3	3		*Chorizandra sp.*	15	80	110	0
3	3		*Samolus repens*	10	1	40	
3	4		*Chorizandra sp.*	20	70	110	0
3	4		*Olearia muelleri*	2.5		110	
3	4		*Samolus repens*	0.2		40	
3	5		*Chorizandra sp.*	25	70	120	0
3	6		*Baumea juncea*	25	5	85	0
3	6		*Chorizandra sp.*	15	40	120	
3	6		*Epilobium billardierianum ssp. billardierianum*	5	5	50	
3	6		*Lobelia alata*	0.2	20		
3	6		*Senecio ramosissimus*	10	1	140	
3	7		*Baumea juncea*	1		40	0
3	7		*Chorizandra sp.*	30	40	120	

APPENDIX B2: Transect Data for Cape Leeuwin, January 1994.

T	Q	Species	Percentage Cover Alive	Percentage Cover Dead	Height (cm)	Water Depth (cm)
3	7	*Epilobium billardierianum ssp. billardierianum*	5	1	50	
3	7	*Olearia muelleri*	4		100	
3	7	*Senecio ramosissimus*	2		100	
3	8	*Chorizandra sp.*	35	60	160	0
3	9	*Baumea juncea*	2		80	0
3	9	*Chorizandra sp.*	45	50	120	
3	9	*Senecio ramosissimus*	0.2		20	
3	10	*Baumea juncea*	2		80	0
3	10	*Chorizandra sp.*	35	50	150	
4	1	*Isolepis nodosa*	40	10	90	0
4	1	*Lepidosperma gladiatum*	15	2	310	
4	1	*Muehlenbeckia adpressa*	7		110	
4	1	*Pteridium esculentum*	10	3	110	
4	1	*Rhagodia baccata*	2	1	90	
4	2	*Agrostis sp.*	10	1	80	0
4	2	*Baumea juncea*	30	20	80	
4	2	*Centella asiatica*	2		30	
4	2	* *Foeniculum vulgare*	1		80	
4	2	*Muehlenbeckia adpressa*	15	1	90	
4	2	*Pteridium esculentum*	5	2	110	
4	2	*Schoenoplectus validus*	2	1	90	
4	3	*Baumea articulata*	5	0.5	220	0

APPENDIX B2: Transect Data for Cape Leeuwin, January 1994.

T	Q		Species	Percentage Cover Alive	Percentage Cover Dead	Height (cm)	Water Depth (cm)
4	3		*Baumea juncea*	55	20	110	
4	3		*Muehlenbeckia adpressa*	7	5	90	
4	3		*Schoenoplectus validus*	2	1	90	
4	4		*Baumea articulata*	5	1	210	0
4	4		*Baumea juncea*	70	10	90	
4	5		*Baumea articulata*	20	2	220	0
4	5		*Baumea juncea*	85		110	
4	6		*Baumea articulata*	45	50	250	0
4	6		*Baumea juncea*	0.5		110	
5	1		*Eucalyptus diversicolor*	1		100	0
5	1		*Hydrocotyle plebeja*	40		20	
5	1		*Lepidosperma gladiatum*	10		260	
5	1		*Paraserianthes lophantha*	5		210	
5	1		*Pteridium esculentum*	3		100	
5	2	*	*Foeniculum vulgare*	10		120	0
5	2		*Gahnia trifida*	10		120	
5	2		*Hydrocotyle plebeja*	55		20	
5	2		*Muehlenbeckia adpressa*	2		40	
5	2	*	*Rorippa nasturtium-aquaticum*	2		40	
5	2	*	*Typha orientalis*	3		280	
5	3	*	*Foeniculum vulgare*	15		100	15
5	3		*Gahnia trifida*	5		100	

APPENDIX B2: Transect Data for Cape Leeuwin, January 1994.

T	Q		Species	Percentage Cover Alive	Percentage Cover Dead	Height (cm)	Water Depth (cm)
5	3		*Hydrocotyle plebeja*	5		20	
5	3		*Muehlenbeckia adpressa*	1		25	
5	3	*	*Rorippa nasturtium-aquaticum*	50		50	
5	4		*Gahnia trifida*	5		110	0
5	4	*?	*Lolium sp.*	1		100	
5	4		*Muehlenbeckia adpressa*	35		120	
5	4	*	*Rorippa nasturtium-aquaticum*	10		40	
5	4	*	*Typha orientalis*	5		250	
5	5		*Foeniculum vulgare*	5		160	0
5	5		*Hydrocotyle plebeja*	40		40	
5	5		*Lepidosperma gladiatum*	20		200	
5	5	*?	*Lolium sp.*	10	1	55	
5	5		*Muehlenbeckia adpressa*	1		100	
5	5	*	*Typha orientalis*	5		250	
6	1		*Cassytha racemosa*	1			0
6	1		*Chorizandra sp.*	2		120	
6	1		*Muehlenbeckia adpressa*	5		100	
6	1		*Schoenoplectus validus*	80	5	160	
6	2		*Cassytha racemosa*	1			0
6	2		*Chorizandra sp.*	1		100	
6	2		*Lepidosperma ?effusum*	3	1	100	
6	2		*Muehlenbeckia adpressa*	1		100	

APPENDIX B2: Transect Data for Cape Leeuwin, January 1994.

T	Q		Species	Percentage Cover Alive	Percentage Cover Dead	Height (cm)	Water Depth (cm)
6	2		*Schoenoplectus validus*	70	2	150	
6	3		*Cassytha racemosa*	4			0
6	3		*Muehlenbeckia adpressa*	6		140	
6	3		*Schoenoplectus validus*	45	5	200	
6	3	*	*Solanum nigrum*	0.2		20	
6	4		*Agrostis sp.*	1	6	150	0.1
6	4		*Cassytha racemosa*	3			
6	4		*Chorizandra sp.*	40	5	150	
6	4		*Epilobium billardierianum ssp. billardierianum*	5		40	
6	4	*	*Holcus lanatus*	0.3		100	
6	4		*Muehlenbeckia adpressa*	1		90	
6	4		*Schoenoplectus validus*	25	1	120	
6	4	*	*Typha orientalis*	0.2		100	
6	5		*Cassytha racemosa*	5			0.1
6	5		*Epilobium billardierianum ssp. billardierianum*	1		45	
6	5		*Isolepis nodosa*	90	5	140	
6	5		*Muehlenbeckia adpressa*	1		100	
6	6		*Agrostis sp.*		1	140	0.1
6	6		*Cassytha racemosa*	5			
6	6		*Chorizandra sp.*	1		120	
6	6		*Epilobium billardierianum ssp. billardierianum*	5		70	
6	6		*Isolepis nodosa*	50	1	140	

APPENDIX B2: Transect Data for Cape Leeuwin, January 1994.

				Percentage Cover		Height	Water Depth
T	**Q**		**Species**	**Alive**	**Dead**	**(cm)**	**(cm)**
6	6		*Lepidosperma ?effusum*	3		120	
6	6		*Muehlenbeckia adpressa*	1		100	
6	6		*Phebalium anceps*	1		120	
6	6		*Schoenoplectus validus*	20	2	180	
6	6	*	*Typha orientalis*	3		180	
6	7		*Cassytha racemosa*	10			0.2
6	7		*Isolepis nodosa*	20		180	
6	7		*Lepidosperma ?effusum*	3		140	
6	7		*Muehlenbeckia adpressa*	40	3	160	
6	7		*Schoenoplectus validus*	5		160	
6	7	*	*Typha orientalis*	15	5	350	
6	8		*Cassytha racemosa*	10			0.2
6	8		*Isolepis nodosa*	2		140	
6	8		*Muehlenbeckia adpressa*	35	2	160	
6	8		*Schoenoplectus validus*	1		160	
6	8	*	*Typha orientalis*	40	10	360	
6	9		*Cassytha racemosa*	5			1
6	9		*Lepidosperma ?effusum*	0.1		140	
6	9		*Muehlenbeckia adpressa*	30	2	160	
6	9		*Phebalium anceps*	5		160	
6	9		*Schoenoplectus validus*	0.5		160	
6	9	*	*Typha orientalis*	60	5	360	

APPENDIX B2: Transect Data for Cape Leeuwin, January 1994.

T	Q		Species	Percentage Cover Alive	Percentage Cover Dead	Height (cm)	Water Depth (cm)
6	10		*Cassytha racemosa*	2			1
6	10		*Isolepis nodosa*	1		160	
6	10		*Schoenoplectus validus*	5		160	
6	10	*	*Typha orientalis*	80	10	340	

* denotes introduced species

APPENDIX B3: Photographic Summary of the Vegetation at the Leeuwin Spring and Surrounding Area, January 1994.

Photograph 1: The pumphouse and weir at the Leeuwin Spring. Note low level of water flowing through drain.

Photograph 2: View of pumphouse and weir from Transect 1.

APPENDIX B3: Photographic Summary of the Vegetation at the Leeuwin Spring and Surrounding Area, January 1994.

Photograph 3: Looking east along Transect 1. Note high density of *Pteridium esculentum* and *Typha orientalis* due to disturbance.

APPENDIX B3: **Photographic Summary of the Vegetation at the Leeuwin Spring and Surrounding Area, January 1994.**

Photograph 4: **Looking east along Transect 2. Note high density of *Typha orientalis* due to disturbance and changing water levels.**

APPENDIX B3: **Photographic Summary of the Vegetation at the Leeuwin Spring and Surrounding Area, January 1994.**

Photograph 5: **Looking northeast along Transect 3. Note dominance of species preferring low water levels, eg. *Baumea juncea*.**

APPENDIX B3: Photographic Summary of the Vegetation at the Leeuwin Spring and Surrounding Area, January 1994.

Photograph 6: Looking south along Transect 4. Note dominance of species preferring high water levels, eg. *Baumea articulata*.

APPENDIX B3: **Photographic Summary of the Vegetation at the Leeuwin Spring and Surrounding Area, January 1994.**

Photograph 7: **Looking north along Transect 5. Note dominance of introduced species due to tourist activity.**

APPENDIX B3: Photographic Summary of the Vegetation at the Leeuwin Spring and Surrounding Area, January 1994.

Photograph 8: Looking north along Transect 6. Note open areas due to water ponding during the winter months.

APPENDIX B

Historical Photography of the Leeuwin Spring

28 August 1963

APPENDIX B

Historical Photography of the Leeuwin Spring

20 May 1980

APPENDIX B

Historical Photography of the Leeuwin Spring

15 February 1993

APPENDIX C1: **Field data sheet designed for monitoring of the rare snail *Austroassiminea letha* at Leeuwin Spring and surrounding locations.**

SNAIL DATA SHEET

TRANSECT:

DATE OF SURVEY:

STATION:

MOISTURE GRADIENT:

	0	1-10	10-50	50-100	100-500	500 +
ADULTS (LIVE/DEAD):						
JUVENILES (LIVE/DEAD):						

VEGETATION:

NOTES:

TRANSECT:

DATE OF SURVEY:

STATION:

MOISTURE GRADIENT:

	0	1-10	10-50	50-100	100-500	500 +
ADULTS (LIVE/DEAD):						
JUVENILES (LIVE/DEAD):						

VEGETATION:

NOTES:

TRANSECT:

DATE OF SURVEY:

STATION:

MOISTURE GRADIENT:

	0	1-10	10-50	50-100	100-500	500 +
ADULTS (LIVE/DEAD):						
JUVENILES (LIVE/DEAD):						

VEGETATION:

NOTES:

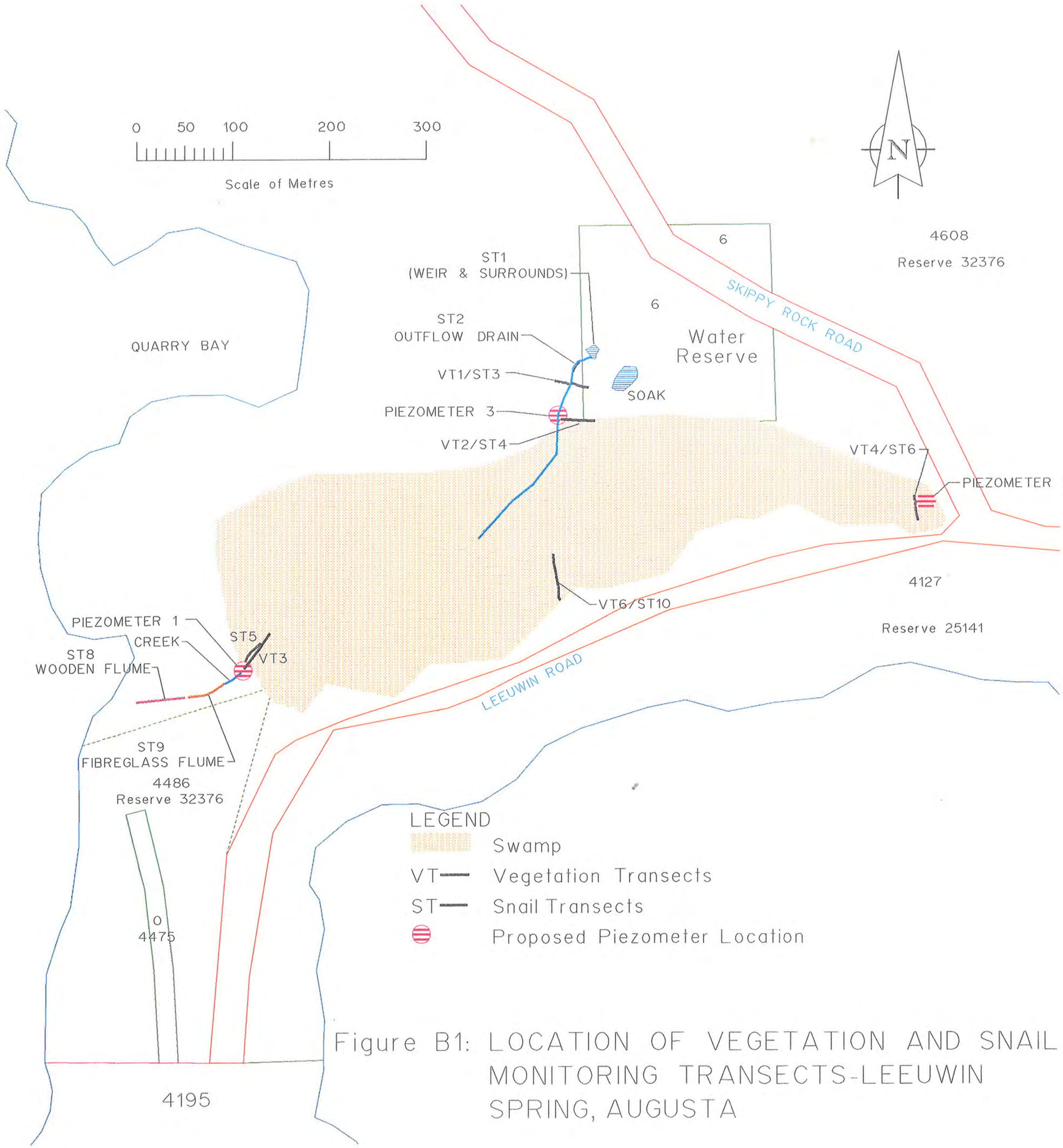
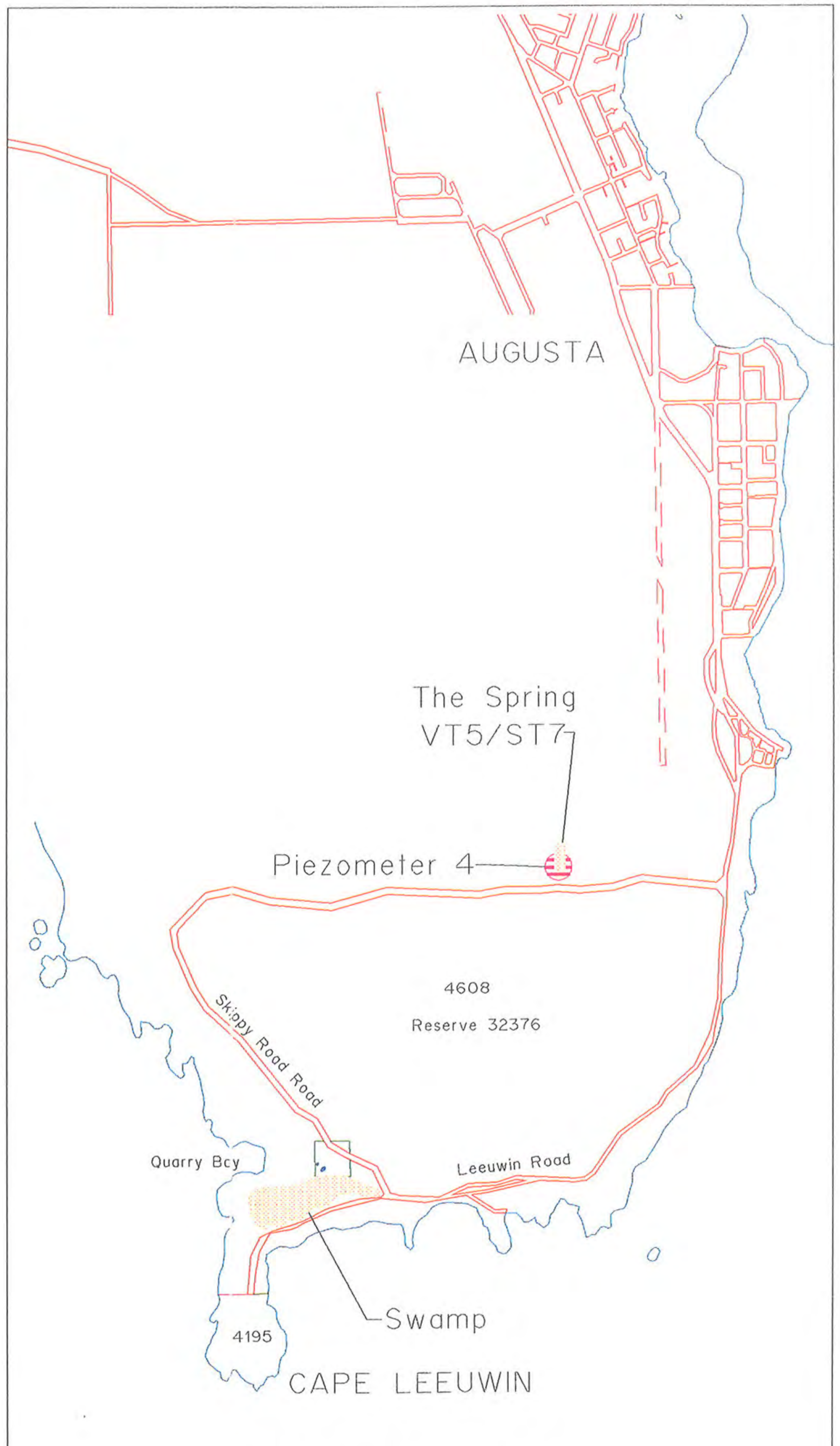


Figure B1: LOCATION OF VEGETATION AND SNAIL MONITORING TRANSECTS-LEEUWIN SPRING, AUGUSTA



ENLARGEMENT