AUSTRALIAN WATER AND COASTAL STUDIES PTY LTD

in association with

THE ECOLOGY LAB PTY LTD

and

COASTAL & MARINE GEOSCIENCES

LAKE AINSWORTH LAKE PROCESSES STUDY

REPORT 96/07 AUGUST 1996

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Foreword

Australian Water and Coastal Studies Pty Ltd (AWACS), in association with The Ecology Lab Pty Ltd and Coastal and Marine Geosciences, was commissioned by Ballina Shire Council (BSC) to undertake a Lake Processes Study for Lake Ainsworth at Lennox Head on the north coast of NSW. The study was funded jointly by BSC, the Department of Land and Water Conservation (DLWC) under the Estuary Management Program, and the Department of Sport and Recreation.

Throughout this study local input was sought and obtained as the long-term management of the lake can only be successful through the ongoing work of the local people.

Personnel from BSC provided valuable advice in all aspects of the study. Council's study liaison officer, Graham Plumb, coordinated various aspects of the monitoring work, provided information on contacts and kept the consultant abreast of local issues as they arose. The Council's Engineering Department staff made valuable contributions to data collection, including levelling and monitoring of water levels in bores, installation of a piezometer at Camp Drewe and installation and monitoring of the traffic counter at the entry to the lake reserve. Other BSC departments provided assistance and comment which were valuable in the preparation of the report.

Local personnel who provided input to the study are listed in Section 1.4. Specific acknowledgment is given to Brian Smith and Don Apps of the Lake Management Committee who willingly gave of their time to assist with the monitoring work.

Colleen Twigg, a senior student at Southern Cross University, assisted with the monitoring programs funded under this project and also provided other information collected for her own studies.

Richard Hagley of DLWC Lismore provided valuable information and contacts in relation to government authorities in the area, including coordinating searches for information. Richard also provided an overview of important issues during the site inspection.

Summary

Ballina Shire Council proposes to prepare a management plan for Lake Ainsworth with funding assistance from the State Government's Estuary Management Program which is administered by the Department of Land and Water Conservation. Australian Water and Coastal Studies Pty Ltd was commissioned to undertake a Lake Processes Study to provide a basis for the subsequent preparation of a management plan.

Lake Ainsworth is a freshwater lake at Lennox Head, and provides educational and recreational opportunities and is important to the tourist industry in the area.

A Lake Management Committee was formed consisting of representatives of Ballina Shire Council, Department of Land and Water Conservation, North Coast Regional Algal Coordinating Committee (NCRACC), Department of Sport and Recreation, Ballina Environment Society and Lennox Head Residents Association. The Committee identified a range of issues considered relevant to the long-term management of the lake. These issues included the occurrence of algal blooms, lake water quality, disturbance to vegetation and high level of usage of the lake. The Management Committee undertook a preliminary collection of information to be used in the Lake Processes Study.

The study scope, objectives and methodology are set out in Chapter 1. Various government agencies and community representatives were consulted to provide information for the study, and these are listed in Table 1.1.

Chapter 2 provides a review of the information available at the commencement of the study, with the various sources of information listed in Appendix A. The review indicated a number of areas where there were gaps in the required data to define the processes. There was a lack of data on long-term trends (years). Reliable information on the occurrences of algal blooms was lacking. There was also a paucity of information on short-term trends and characteristics of the lake such as nutrient levels, stratification, biota composition, flora and fauna species and succession, and sediment type and quality.

A water level recorder operated by Manly Hydraulics Laboratory (MHL) has been in the lake for several years and a water quality recorder was added in 1995. Information from that installation has been used in the study.

Additional information was obtained during field data collection exercises conducted through the course of this study as outlined in Chapter 3. These exercises have included:

- An intensive field data collection exercise on 5-9 February 1996 by personnel from AWACS, DLWC and Southern Cross University. Elements of this field exercise included lake bathymetry, lake bed surface and core sediments, in-lake nutrients and algae, water temperature, groundwater levels and quality, flora and fauna survey, inspection of foreshore erosion and vegetation rehabilitation.

- Ongoing monitoring of groundwater levels and quality in bores to the south, east and west of the lake including installation of new bores, cores from which data were used for interpretation of local stratigraphy.

- Four weeks of monitoring of in-lake water quality including algal sampling in association with the groundwater monitoring.

- Monitoring of water quality of stormwater discharges to the lake during a rainfall events.

- Counts of traffic visiting the lake in March and April, including over the Easter weekend and over Anzac Day.

A description of the regional setting is provided in Chapter 4 to provide a context for assessment of lake processes.

The climate is characterised by high temperatures and humidity in summer with heavy periodic rains, and mild temperatures and some significant rain in winter.

The regional geology is described in detail in Appendix E and shown in Figures 4.4, 4.5, 4.6 and 4.7. The northern and western margins of the region consist of bedrock hills of metamorphic, sedimentary and volcanic rock type. Tertiary basalt hills occur on the coast between Ballina and Lennox Head. Between the hills and the coast is a sandy, swampy coastal plain with barrier and estuarine deposits within which the lake is situated.

Regional groundwater flows are shown conceptually in Figure 4.8. Groundwater flows away from the hills towards the coast or into North Creek and other water courses draining to the Richmond River.

Lake usage and cultural aspects are presented in Chapter 5 to provide an overview of the cultural value of the lake and a background for the impact of human activities on lake processes.

Land use zoning at Lake Ainsworth is presented in Figure 5.1. Land uses include the caravan park, the surf lifesaving club, the Department of Sport and Recreation Centre and urban areas to the south of the lake. Land surrounding the southern half of the lake is a public recreation reserve; and land at the northern end is both a "bird and animal" sanctuary and a reserve for national fitness and physical education.

A range of recreational uses is undertaken at Lake Ainsworth including sailboarding, sailing, ski paddling, swimming, picnicking, sunbathing and walking. Areas of particular activities are shown in Figure 5.3. During March and April 1996 the average number of vehicle visitations on Saturdays and Sundays was approximately 570 to 835 respectively; and total number of visitors on a Sunday has been estimated at over 3100, with nearly 1600 present at any one time. A survey conducted in 1988 indicated a social carrying capacity of about 560 persons. Accordingly, overcrowding and associated problems are experienced at Lake Ainsworth.

The Lake Ainsworth caravan park at the southern end of the lake can accommodate approximately 1200 people. Visitor numbers are in the range of 1500 to 2000 per week over the peak Christmas period. Over the last three years annual occupancy rate at the caravan park has remained relatively constant.

The Lake Ainsworth Sport and Recreation Centre, formerly the National Fitness Camp, was opened in 1944 and currently can accommodate 210 people. There are plans for its expansion. The centre occupies 12 hectares of the Crown reserve and has some 30 buildings and various recreational facilities. The estimated number of campers per year is currently 5500 with an average stay of 5.5 days.

While no Aboriginal archaeological studies were identified in this study, various Aboriginal sites including camp sites have been found in the vicinity of Lake Ainsworth. The sites are of a type well represented on the north coast. The Jali people are the traditional occupiers of land around Lake Ainsworth, and the area has significance to the contemporary Jali people.

The characteristics and processes affecting the lake are described through an interpretation of the available information in Chapter 6. For some processes, including those related to nutrients, there is a lack of long-term data which limits the level of understanding of the processes.

The flora of the lake and its environs includes coastal heath and paperbark swamps in the surrounding areas and large stands of macrophytes in the shallows. Blue-green algae blooms have been observed in recent years and a number of phytoplankton species have been identified in the lake. The few studies of aquatic fauna of the lake have found very few species and the exotic species may be out-competing the native species. It is thought that the mosquito fish, an exotic species, may have already altered the lake ecosystem. Invertebrates also exhibit low diversity and abundance with a single species of crustacean zooplankton and an occasional planktonic water mite.

The surface runoff catchment is about six times the lake surface area and is comprised of a relatively narrow band of less than 300 m width around the west, south and eastern sides and extends 1.5 km to the north (Figure 6.3). It is relatively flat and consists of grassed areas, coastal heath, urban area and the caravan park.

A conceptual model for the local hydrogeology has been developed in Section 6. Groundwater flows into the lake predominantly from the west and south, and flows out of the lake through the eastern dunes into the ocean (Figure 6.4). The surface and groundwater catchments are not completely coincident. After significant rainfall, the groundwater catchment to the west of the lake is limited by a groundwater mound within the western dune separating the lake from Newrybar Swamp. Following extended dry periods groundwater from sources west of the dune may flow to the lake at very low rates.

The Woodburn Sand Unit (WSU) which controls the local hydrogeology becomes indurated with humic matter at depth, which impedes groundwater flow. Accordingly, the majority of groundwater flow occurs in the aquifer above a level of 4 m below Australian Height Datum (AHD) as indicated in Figure 4.9. The groundwater is fresh and has a high total organic carbon content comprised mainly of humic substances. Total phosphorus concentrations in the groundwater are generally around 0.01 mg/L except in localised areas around the Bowling Club and near the Sport and Recreation camp. Total nitrogen concentrations vary between 0.7 and 5 mg/L. High total organic carbon levels (30-100 mgC/L) in porewaters sampled from lake sediments indicate the organic rich sediment typically associated with swampy ground and anaerobic microbial processes.

The lake morphology consists of a deep main basin (8-9 m deep) with a shallow arm extending northward along a swale within the ridge-swale system of the local dunes. A detailed bathymetric survey was completed in February 1996 and is presented in Figure 6.5. The variations in lake surface area and lake volume as functions of water depth were derived from the bathymetry (Figure 6.6).

Bottom sediments of the lake are comprised of two distinct types: well sorted medium grained quartz sands occur in shallower areas (< 4 m depth) and a gelatinous organic rich mud occupies the deeper central part of the lake. The organic rich muds are about 4-6 m deep in the central lake and shoal to about the 4 m depth contour. Nutrient analyses of sediment samples showed relatively low concentrations in the sandy sediments and very high concentrations in the organic muds.

A conceptual model of the initial formation and subsequent infilling of the lake has been postulated. The Pleistocene barrier was eroded by a storm surge to form the lake basin and subsequent deposition of the Holocene outer barrier blocked the eastern boundary of the basin. With rising sea level the associated rise in regional groundwater would have led to the flooding of the depression. The lake morphology appears to have changed little over the past 50 years. Carbon dating of the deeper organic sediments suggests an average sedimentation rate of 0.4 mm/year over the last 2500 years.

Estimates of sediment inputs from the catchment using the Universal Soil Loss Equation gave a maximum rate of infill for the shallow sandy perimeter of about 1 mm/year.

Estimates of the effect of surface waves on resuspension showed that for the sand particles this process is only important in the shallow areas (depths < 1.5 m) and for the finer organic particles down to depths of about 2.5 m. The limited fetch of the lake effectively inhibits the development of rough seas and hence effects such as foreshore erosion by waves are assumed to be negligible.

The lake water budget is determined by a balance between inflows due to direct rainfall, surface runoff and groundwater, and outflows due to evaporation and through the groundwater. Estimates of each of these contributions indicated that direct rainfall and evaporation were the most important from November 1994 to May 1996. The lake water level responds mainly to these contributions while the groundwater throughflow tends to balance (input ≈ output). The flushing of the lake occurs via groundwater outflow through the eastern boundary to the sea.

Lake water quality is strongly influenced by the stratification which is determined by a balance between thermal energy inputs (solar radiation) and mixing due to wind or convection. During stratified periods the deeper waters become depleted in dissolved oxygen, producing conditions favourable to the release of nutrients from the sediments. Subsequent mixing events transport the nutrient rich deeper waters to the near surface where they become available to algae. The algae require light and nutrients and prefer calm conditions for optimal growth and the occurrence of blooms.

The heat fluxes to the lake that determine the temperature signal were estimated from meteorological data collected at the lake in February 1996. Solar radiation causes heating of the near surface waters down to a depth determined by the water clarity. High levels of humic compounds in the lake cause a strong brown colouration that effectively inhibits the depth of penetration of surface light. As a consequence the stratification is comprised of a thin surface layer (~ 1-1.5 m) that heats up to about 33°C during the day and cools down to around 30°C overnight in February (Figure 6.16).

Vertical mixing in the lake is driven by a combination of wind events and convective processes introduced by an influx of relatively cold water by direct rainfall. It appears that wind and rainfall events continually erode the stratification while solar heating continually builds it up. Whether an event will completely mix the lake depends on the time since the last complete mixing event, the strength of wind and the rainfall intensity. Vertical profiles of temperature and dissolved oxygen reflect the current stratification and time since the previous complete mixing event (Figure 6.15).

Faecal contamination was assessed using the BSC data collected over the last 20 years and recent measurements during a rain event (Figure 6.19). The levels are generally within the recommended guidelines, with levels peaking around 1990. Stormwater drains near the south of the lake showed high faecal coliform bacteria concentrations during one rainfall runoff event that occurred during the study.

Nutrient concentrations in the lake have only been sampled over the past three years on an ad hoc basis. Concentrations are generally high and appear to fluctuate with mixing events (Figure 6.20). A phosphorus budget indicated that the major source of phosphorus for the water column was from the sediments. Annual estimates of the phosphorus loads due to sediment release were approximately 10 times larger than the combined loads due to runoff and groundwater.

Algal data have also only recently been collected on the lake and it was not possible to infer any long-term trends in algal characteristics. The microalgae community is comprised of a number of species of phytoplankton and cyanobacteria (blue-green algae).

Blue-green algae were identified in the lake in 1986 and anecdotal evidence suggests that the levels are increasing. Experience in similar systems suggests that water temperatures, strong stratification, calm conditions, high light and excess nutrients are favourable to cyanobacteria blooms. These conditions commonly occur in Lake Ainsworth but their relative magnitudes vary from year to year due to changing climatic conditions, and hence blooms may be common in some years but not in others. Algal cell counts exceeded the ANZECC and NCRACC guidelines in the summer of 1995/96 but not in the previous summer. The high nutrient levels in the lake suggest nutrients are not limiting algal growth.

The water quality criteria for nutrients set out in the ANZECC guidelines are generally exceeded although it is not possible to assess the frequency of exceedance. Application of the Organisation for Economic Co-operation and Development (OECD) classification scheme suggests that Lake Ainsworth is a eutrophic lake and the presence of high chlorophyll levels and algal blooms confirms this classification.

The continuation of the lake as a freshwater lake depends on the maintenance of the coastal frontal dune to prevent inundation by the ocean. Photogrammetric analysis indicates long-term recession of the dune scarp in front of the lake is of the order of 0.9 m per year. Short-term movements of the scarp due to storm action can be much greater, however there is subsequent recovery of the dune as sand is redistributed by the beach processes. A storm in May 1996 resulted in the dune scarp moving approximately 13 m landward. Predicted climate change and associated rise in sea level could further erode the frontal dune. Maintenance of an adequate store of sand in the frontal dune by maintenance of a good cover of dune vegetation, as is being implemented by the local Dunecare group, is the best way to retain the frontal dune.

A range of human activities has impacted on lake processes and these are listed in Section 6.9. Significant activities since the commencement of European settlement have included clearing of much of the native vegetation, the growth of Lennox Head township, the development of the Sport and Recreation centre, and sand mining of the frontal dune system. These activities have modified surface and groundwater flow patterns and quality, modified the lake nutrient budget and varied the composition and abundance of flora and fauna. The detailed impacts of human activities on processes need to be taken into account in planning management strategies.

To assist with the development of a management study and plan, significant issues are tabulated in Chapter 7. The occurrence of algal blooms and the consequential impact on recreation and the tourist industry is arguably the main issue at the present time. However, a well balanced management plan should take into account all significant issues due to the complexity of interactions between the lake processes and the effects on the values of the lake.

While the development of a management plan is not within the scope of the present study, some potential management options are outlined in Chapter 8, for management of foreshore erosion, frontal dune erosion and algal blooms.

Monitoring is required to further improve the understanding of the processes operating at Lake Ainsworth and to assess the performance of any management options that are implemented. Chapter 9 sets out a possible program for monitoring with three broad objectives: to satisfy public health requirements; to ensure maintenance of assets; and to understand processes including obtaining information for calibration and verification of any models of processes. It is envisaged that the monitoring could be undertaken jointly by Ballina Shire Council, local community groups and local educational institutions.

The extent of implementation of management strategies and monitoring will depend on the availability of funding. In later phases of development of a management plan, priorities will need to be assigned to the various management and monitoring requirements addressed in this report.

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1. Introduction

1.1 Background

Lake Ainsworth is a coastal freshwater lake at Lennox Head on the north coast of New South Wales. A location plan is presented in Figure 1.1. The only connection to the ocean is via the groundwater aquifer. The lake and surrounds provides recreational opportunities for swimming, canoeing, sailing and picnicking. The NSW Department of Sport and Recreation Centre adjacent to the lake provides educational and recreational opportunities associated with the lake environment.

Ballina Shire Council has resolved to prepare a management plan for Lake Ainsworth. This was prompted by a preliminary management study commissioned by the Lennox Head Residents Association and by recent blue-green algae blooms in the lake. Council has established a management committee to oversee formulation of the management plan. It is envisaged that this management plan will complement community initiatives such as the Dunecare program in which local residents have been taking an active role, for the management of the lake foreshore and coastal frontal dune.

The study is being jointly funded by Council, the State Government's Estuary Management Program and the Department of Sport and Recreation. The process outlined in the Estuary Management Manual is being used in the formulation of the plan of management for Lake Ainsworth. This process includes:

- Formation of an Estuary Management Committee;
- Collation of existing data;
- Undertaking of an Estuary Processes study;
- Undertaking an Estuary Management study;
- Drafting an Estuary Management plan;
- Reviewing the Estuary Management plan; and
- Adopting and implementing the Estuary Management plan.

Ballina Shire Council formed a Lake Management Committee and undertook a preliminary collation of information and prepared a consultant's brief for the process study. As set out in the brief, the long-term objectives for management of Lake Ainsworth are:

- To ensure the conservation, maintenance and rehabilitation of the lake and its environs in perpetuity at a sustainable and compatible level by developing and implementing a management plan;

- To provide for recreational needs of residents and tourists; and

- To encourage scientific research into the genesis, evolution and management of coastal freshwater lakes.

Members of the Lake Ainsworth Management Committee and Ballina Shire Council Staff assisting are:

Ballina Shire Council:

Councillor D Brennan (Chairperson) Mayor of Ballina
Councillor AJ Brown
Councillor AL Kennedy
Councillor P Moore

Department of Land and Water Conservation (Estuary Management):

Mr R Hagley (Alstonville Office)

North Coast Algal Co-ordinating Committee (DLWC Grafton):

Ms S Grau, (Water quality officer)
Ms J Fenton (alternate delegate - Water quality officer)

Department of Sport and Recreation:

Mr J Mills (Manager, Lake Ainsworth Sport and Recreation Centre)

Ballina Environment Society:

Mr G Rose
Mr H Webster (alternative delegate)

Lennox Head Residents Association:

Mr B Smith (Chairman)
Mr D Apps

The following Council staff provided assistance to the Committee:

Mr B Anderson (Chief Finance and Administration)
Mr P Busmanis (Deputy Chief Engineer
Mr G Faulks (General Manager)
Mr G Plumb (Senior Environmental Health Officer)
Mr A Smith (Town Planner)
Mr R Willis (Chief Town Planner)
Mr D Wilson (Chief Health and Building Surveyor)

1.2 Scope of Study

This process study is step three of a seven step procedure. The aim of the lake processes study is to assess, define and describe the lake's physical, chemical and biological processes and so provide a basis for the later development of management strategies.

Issues considered relevant to the long-term management of the lake and which should provide focus for this study are:

- occurrence of algal blooms;
- influence of groundwater on lake levels and water quality;
- high level of human usage of the lake and consequent potential for environmental pollution and damage;
- lake foreshore erosion;
- lake water quality;
- loss of foreshore vegetation;
- high level of disturbance to the frontal dune system immediately east of the lake; and
- sedimentation infill of the lake.

1.3 Study Objectives

The study objectives as outlined in the brief are to develop an understanding of:

- the various physical, hydraulic and sedimentary processes of the lake;
- the initiation and support mechanism of algal blooms in the lake;
- the water quality parameters of importance to the health of the lake and its mixing and flushing behaviour;
- the relationship between the lake and adjacent groundwater aquifer with respect to lake level and lake water quality;
- the interaction between the physical, chemical and biological processes;
- the impact of lake usage and catchment practices on lake processes;
- the extent and health of lake and adjacent terrestrial flora and fauna;
- the location and nature of significant natural, cultural, physical and scientific sites in the lake and its foreshores; and
- any additional data and studies necessary to aid in preparing the subsequent stages of a lake management study and plan.

The brief requires that the level of understanding of the current condition of the lake should be sufficient to develop and assess management options.

1.4 Study Approach and Methodologies

The study approach involved the collation, analysis and interpretation of existing data to elucidate the physical, chemical and biological processes affecting the health and attractiveness of Lake Ainsworth. The study program included consultation with government agencies and community representatives (Table 1.1), field inspections, drawing on experience from other coastal lakes, analytical modelling, and data collection.

Table 1.1 Personal Communications for Lake Ainsworth

Name	Organisation
Graham Plumb	Ballina Shire Council
Brian Smith	Lennox Head Residents Association/Lake Committee
Don Apps	Lennox Head Dunecare/Lake Committee
Yvette Chaseling	Resident, Lennox Head
Deliah Gibbon	Resident, Lennox Head
Marelle Lee	Resident, Lennox Head
Mick O'Connor	Teacher, Ballina
John Mills	Manager, Lake Ainsworth Sport and Recreation Centre
David Taylor	Asst Manager, Lake Ainsworth Sport and Recreation Centre
Len McDaid	Lake Ainsworth Sport and Recreation Centre
John Howard	Caravan Park Manager
Doug Jackwitz	Alstonville Driller
Richard Hagley	DLWC Lismore
Martin Fitzhenry	DLWC Estuary Management Program
Bruce Coates	DLWC Estuary Management Program
Sabu Dunn	NPWS Alstonville
Jolander Naywtah	Gungil Jindabah Centre, Southern Cross University
Nick Ashbolt	UNSW
Mark Kulmar	Manly Hydraulics Laboratory
John Butler	Bureau of Meteorology, Brisbane

The approach was focused at defining the processes rather than the management strategies, however it was mindful of the possibility of applying developed relationships and models to a future lake management study and plan.

The approach also sought to define the varying time scales over which processes can operate and the interactions between processes and the extent to which human activities have modified processes.

There was only a limited budget for the study, and accordingly not all processes can be assessed to the same level of detail. The significant issues are the occurrence of algal blooms and the influence of groundwater on lake levels and water quality. Based on the experience of the study team, on what practical management strategies are available to address those key issues, an emphasis has been placed on defining the relevant processes.

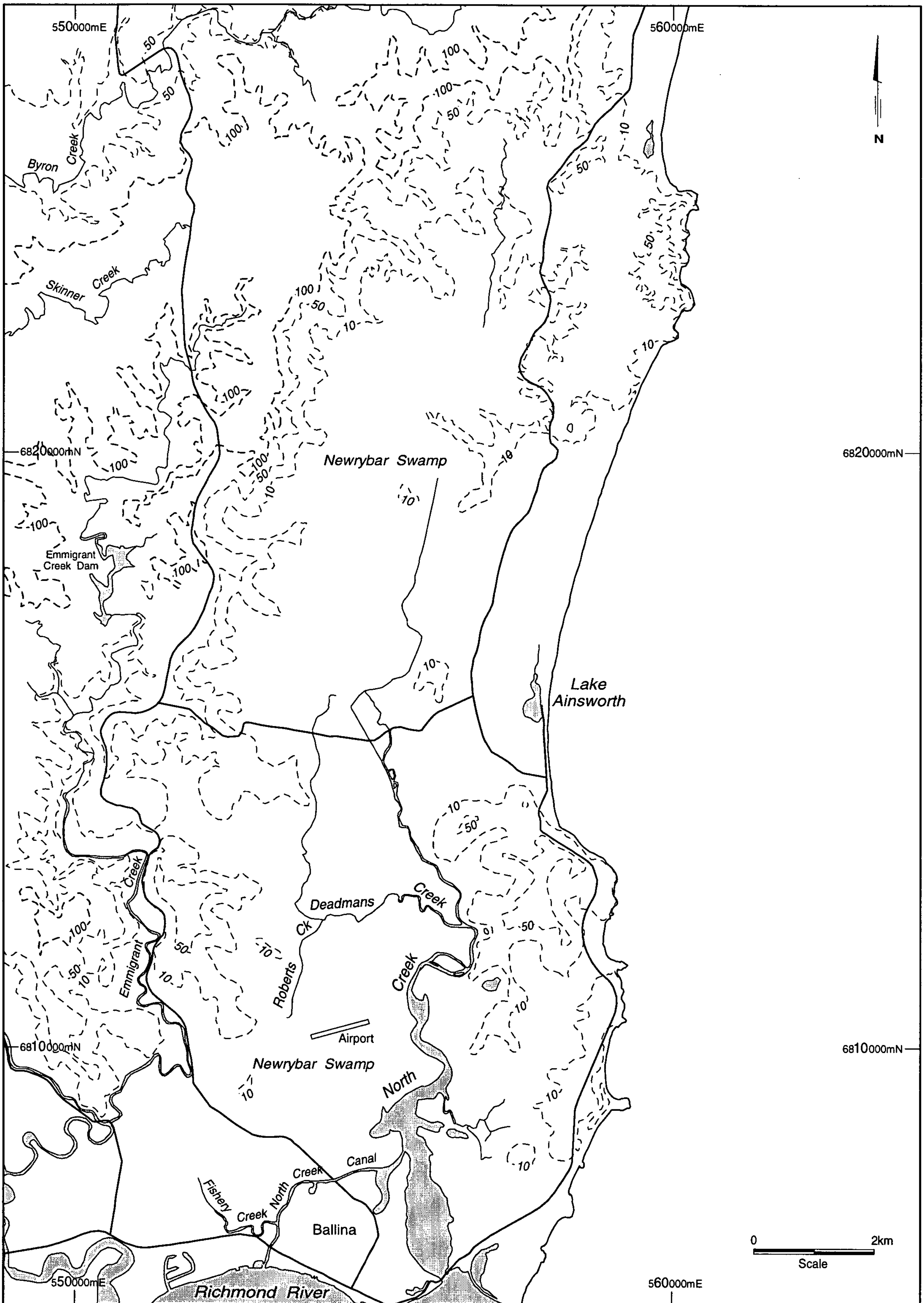
Steps involved in the study methodology have included:

- Initial collation and review of existing information to assess its usefulness and to identify important data gaps;
- Formulation of data collection programs;
- Consultant briefing and field inspections with the Committee to clarify issues of concern to the Committee and to organise data collection programs; and
- The undertaking of various data collection exercises at the lake, and the obtaining of information with the assistance of Council personnel from various government agencies, universities, local community groups and individuals.

Assessment of the available information indicated there was very limited data suitable for quantifying processes. For some items such as sediment cores and water column stratification, there was no data at all. The work therefore has drawn heavily on experience with similar systems and the final outcome contains some speculation about processes where no information was available and where field data could not be collected on such matters as inter-annual variability within the project time frame.

An intensive field data collation exercise was undertaken from 5-9 February 1996 in conjunction with a data collection program by DLWC. This exercise involved the collection of information on lake water quality, groundwater quality adjacent to the lake, in-lake core porewater quality, lake surface sediments, lake bathymetry, lake sediment cores, and flora and fauna. Information from this exercise is presented in Kadluczka et al (1996).

Two bores were drilled to the west of Lake Ainsworth; a piezometer was installed at Camp Drewe and two existing bores were identified to the south of the lake. A bore to the east of the lake had previously been installed for a study of coastal groundwater flows (Turner 1995). The locations of these bores are presented in Figure 1.2. Water level and water quality data were obtained from these bores in association with lake water quality over a four-week monitoring period, undertaken with the assistance of Southern Cross University and Council. Additional groundwater levels were monitored by Council, and Southern Cross University undertook additional monitoring of lake water quality and quality of water in drains flowing to the lake after a storm event.



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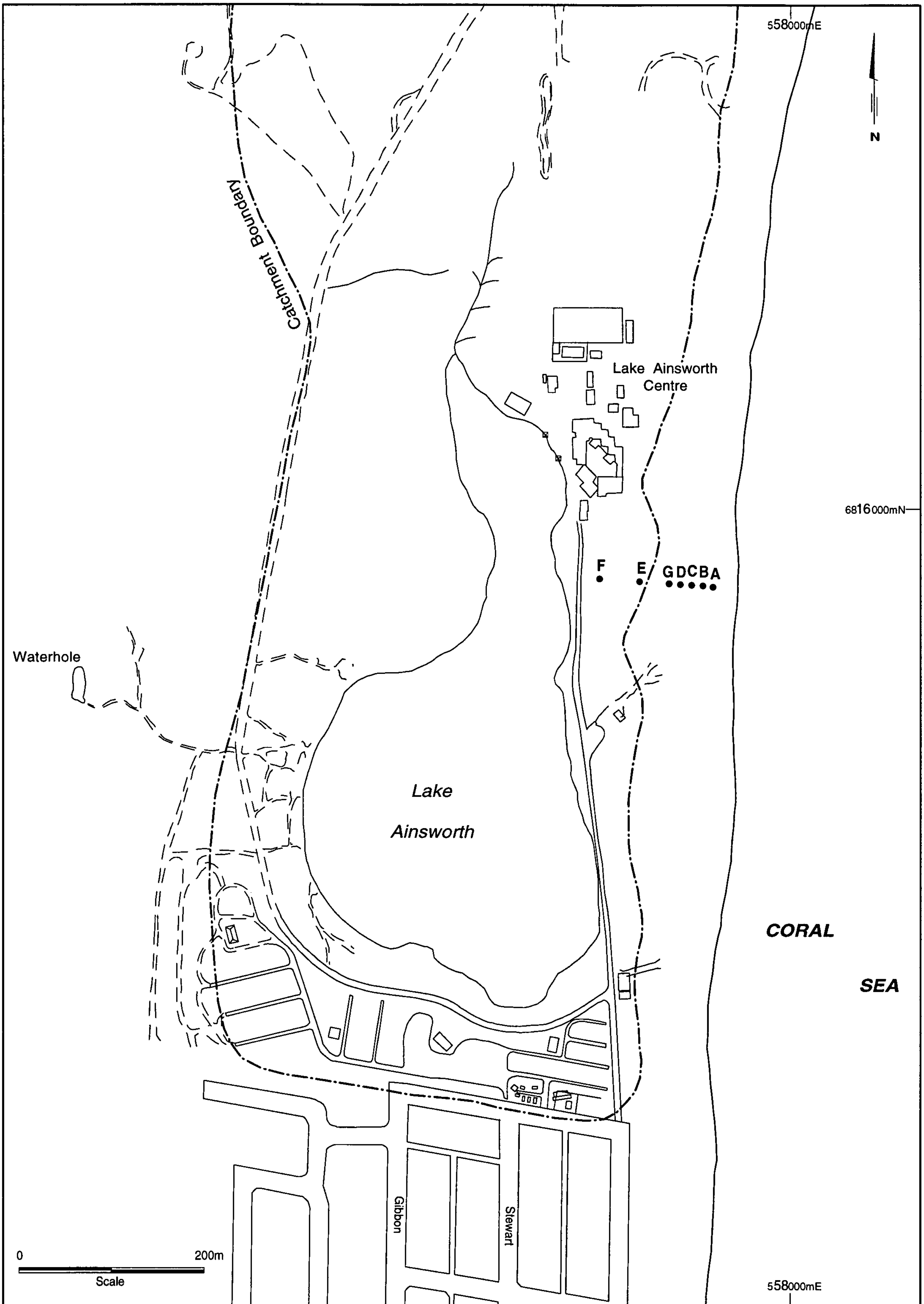
LOCATION PLAN OF LAKE AINSWORTH

Figure 1.1



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BORE SITES TO THE EAST OF THE LAKE

Figure 1.2

2. Review of Existing Information

2.1 Introduction

Lake Ainsworth has been the subject of a number of ad hoc studies on the general status of NSW lakes and in recent years a number of projects have been carried out by students from Southern Cross University at Lismore. There have been no comprehensive studies of the lake.

Sources of information and references relating to Lake Ainsworth are categorised by subject and documented in Appendix A. This section aims to outline the extent and the scope of the existing database, to identify data gaps and recommend data collection programs that may fill these gaps.

Available information collected and held by Council was forwarded to AWACS over the duration of the study. AWACS also sought information from other relevant sources during the course of the study. The information includes data sets, book and journal publications, internal reports, aerial photographs, other photographs, maps, files, newspaper articles, minutes of meetings and personal communications.

Data sets have been derived from a number of data collection exercises conducted by various authorities including Ballina Council and DLWC as well as by various individuals on behalf of Council or for scientific studies. The available data has been incorporated in the relevant sections of this report in tabular and/or figure form.

The lake has been the subject of a number of field trips for schools and universities, resulting in many unpublished reports that detail 'snapshots' in time of the lake characteristics as well as giving general descriptions. Information extends from the in-lake quality to the geology and geomorphology of the region to management issues. Data in these reports, whilst useful for confirming or questioning data collected by authorities, generally does not stand alone since the sampling/ investigation techniques are not documented or systematic and thus potential errors in the data are not possible to detect.

In general the information available can be divided into twelve topics:

- regional geologic and hydrogeologic information;
- regional topographic and hydrologic information;
- regional meteorologic information;
- lake hydrogeology;
- lake morphology and sediments;
- lake water levels and meteorology;
- lake water quality;
- lake mixing processes;

- flora and fauna;
- cultural factors and management;
- lake classification; and
- miscellaneous information.

The existing data set is divided into these twelve topics in Appendix A with information specific to Lake Ainsworth listed first, followed by information of a general nature. To assist in locating information the existing data has also been documented alphabetically by author.

2.2 Regional Geologic and Hydrogeologic Information

Geology, hydrogeology and geomorphology information has been reviewed by Hudson (1996) and Daniels and Beck (1996). These reports were prepared for the present study and are included as Appendix C and D respectively. A summary of their findings is included in Sections 4.2 and 4.3

2.3 Regional Topographic and Hydrologic Information

Topography of the region is mapped at a scale of 1:25 000 (CMA Maps Byron Bay 9640-4-S and Ballina 9640-3-N). At a larger scale, the topography is shown on 1:4000 orthophoto maps (CMA Maps Midgen Flat X5415-8 and Lennox Head X5407-2). From these maps it is possible to ascertain some of the hydrologic characteristics of the area such as main surface flow drainage paths and in combination with geologic maps the likely groundwater flow paths.

2.4 Regional Meteorological Information

Meteorological data for the area is available from a number of stations. This data is generally derived from Bureau of Meteorology (BOM) stations with the closest being located at Ballina Airport. This station records rainfall (daily), air temperature, humidity, wind speed and wind direction data on a three-hourly basis since 1992. Other data for this study including solar radiation and pan evaporation was obtained from the Bureau of Meteorology's station at Brisbane Airport.

Climatic analyses of BOM data are contained in a number of publications available from the Bureau (1975, 1977, 1978, 1986, 1994, 1995).

2.5 Lake Hydrogeology

An investigation by the Department of Land and Water Conservation into the flushing of closed estuaries involved installation of a transect of piezometers between Lake Ainsworth and the ocean, and resulted in an extensive data set of groundwater levels through the barrier (Turner 1995). The hydraulic conductivity for the barrier soils was determined allowing the groundwater outflow from the lake to be estimated.

Published information on the hydrogeology of similar systems was also gathered. The water budget for Lake Windermere (Jervis Bay, NSW) shows a strong dependence on groundwater flows (Jacobson and Schuett 1984) as do the coastal dune lakes of Fraser Island (Arthington et al 1989).

2.6 Lake Morphology and Sediments

Northern Rivers College for Advanced Education students undertook a basic bathymetric survey in 1986, however the data were not to Australian Height Datum or to a coordinate system and hence are of qualitative value. Thus a new survey was undertaken in February 1996 by DLWC (Plan Room Catalogue 10395). This survey allows for the morphometric features of the lake such as area, volume and maximum depth to be calculated.

Information on lake sediments, such as physical and chemical composition was limited (Timms 1982). This lack of information significantly influences the ability to understand the hydrogeological and sediment nutrient flux behaviour. Thus another data gap was identified.

2.7 Lake Water Levels and Meteorology

A continuous water level recorder has been deployed in Lake Ainsworth at the northern end of the lake since October 1994 by DLWC. Records indicate that the water level fluctuates around approximately 2 m AHD (MHL 1995). The fluctuations are not influenced by the tide and show that the lake level responds quickly to rainfall which is recorded at the same site by a tipping bucket pluviometer. More detailed examination of lake level and rainfall is given in Section 6.6.

Water currents were recorded at the lake in September 1993 as part of a preliminary investigation of mixing (MHL 1994). Wind data also was collected, but due to anemometer malfunction only wind direction could be determined and was comparable to that recorded at Ballina Airport.

There are no measurements of local (at the lake) meteorological data and thus for this study long-term data recorded at Ballina and Brisbane Airports were used to infer meteorological conditions of the lake. Ballina Airport is relatively close to the lake (≈6.5 km to the south-west), however Brisbane Airport is considerably further away from the lake (≈300 km to the north) but generally still within the same climatic zone (Lee and Gaffney 1986). Thus another data gap was identified and some historical data is required. Available data from these two sources was utilised for this study.

Examples of other lakes where the water levels and their fluctuation forces have been investigated include Lake Alexandrina on the Murray River, NSW (Geddes 1984) and Lake Windermere near Jervis Bay, NSW (Jacobson and Schuett 1984).

2.8 Lake Water Quality

Water quality is a somewhat nebulous term that broadly covers the physical, chemical and biological measures of the lake water. Physico-chemical variables consist of temperature, pH, dissolved oxygen, conductivity, salinity, phosphorus and nitrogen in various forms, chlorophyll-a and other trace elements. Biological measures include faecal coliform counts and algal cell counts for representative water samples. Physical, chemical and biological data processes are interdependent and hence observations of these variables usually require extensive data sets in order to interpret the underlying processes.

Temperature, conductivity, dissolved oxygen and pH data have been collected in the lake by a continuously logging instrument deployed by DLWC since December 1995 (discussed later in Section 6.7) and depth profiles by a hand held instrument (Horiba) have been carried out on a few days for Council.

Biological data in the form of faecal coliform counts (a measure of faecal contamination) has been collected by Council over the period 1977-1995. Other biological data in the form of algal cell counts has been collected by Council during algal blooms.

Nutrient samples have been collected during the Council's algal bloom monitoring exercises. This data set consists of some 30 samples of total phosphorus, ammonia nitrogen, nitrate nitrogen, algal cell counts and identification since 1993. These data are discussed in Sections 6.7.9 and 6.7.10.

Other data has been collected by individuals with accompanying discussion relating to nutrients, algae and physical variables of the lake. This is contained within several publications including Timms (1982), Timms (1986), Timms (1992), Bayly (1964), Outridge et al (1989), Artuphel (1993), Bowling (1989) and Barlow (1994).

Other general references for algae include Aquatic Weeds Research Unit (1994) and Department of Primary Industries, Water Resources (1994) and technical series produced by the Algal Task Force (blue-green algae task force 1992) and Murray Darling Basin Commission (MDBC 1993).

Information relating to nutrient cycling in similar systems is given in Cullen (1986), Arthington (1986), Arthington et al (1989), Geddes (1984) and Maher et al (1994).

Information relating to the occurrence and length of algal blooms is limited to local reports. No systematic documentation of blooms has occurred. In the past, Council generally sampled on a 'bloom' basis thus every sampling date is indicative of a bloom occurring. The only other source of information is contained within local newspaper reports, such as *The Northern Star* and *The Advocate*.

2.9 Lake Mixing Processes

An attempt to monitor lake mixing processes is documented in MHL (1994). This involved the deployment of current meters in the lake at various locations and depths coupled with an anemometer deployed at the edge of the lake. This exercise appears to have been fraught with difficulties as the anemometer speed data was not useful and in general the data is difficult to interpret.

General references on lake mixing include Imboden and Wuest (1994) and Imberger and Patterson (1990).

2.10 Flora and Fauna

Flora and fauna information has been reviewed in The Ecology Lab (1996) and is summarised in Section 6.2.

2.11 Cultural Factors and Management

The main cultural information is contained within the Masterplan study for the Sport and Recreation Centre (NSW Public Works 1994). This plan involves the consideration of existing cultural features for the purpose of assessing potential future development.

A preliminary management plan has been prepared for the lake (Warren 1994). This report includes a qualitative assessment of lake processes, from which a list of actions and a corresponding time frame is outlined.

2.12 Lake Classification

In a morphological sense, Timms (1986) classifies some 25 dune lakes of NSW into seven types of dune lakes which include perched dune lakes, lowland dune lakes, watertable windows, dune contact lakes, marine contact lakes, frontal dune ponds and tropical dune lakes. Lake Ainsworth is classified as a lowland dune lake, a type mainly found in northern New South Wales. Typical water chemistry for this type of lake is characterised by variables including ionic proportions, salinity, pH and optical density.

Consideration of the optical properties of a number of lakes led Bowling (1989) to classify Lake Ainsworth as 'dystrophic' which defines the lake as having water rich in organic matter, such as humic acid, but this consists mainly of undecomposed plant fragments, and nutrient salts are sparse (Collocott and Dobson 1974).

Arthington et al (1989) applied the OECD classification scheme (Vollenweider 1976) to Lake Freshwater in Queensland. This scheme relates phosphorus load to in-lake phosphorus sinks. The trophic status of Lake Ainsworth (which shows similarity to Lake Freshwater) may be inferred to be the same.

2.13 Miscellaneous

The development of the area can be seen in the available aerial photographs of the region for the dates 1947, 1958, 1966, 1967, 1972, 1973, 1976, 1977, 1978, 1979, 1980, 1981, 1983, 1984, 1986, 1987, 1991, 1994 and 1995. This photography allows for the assessment of changes in the region and the lake.

Local knowledge is another source of historical information. A number of local residents of the Lennox Head area were contacted. A newspaper advertisement for information on the lake was issued by Council and a number of responses received.

2.14 Data Gaps

The review of generally limited existing information highlighted a number of areas where information required to describe the lake processes is either non-existent or of limited use. Long-term trends (decades) in the lake processes can only be inferred from experience documented for similar systems and from anecdotal evidence from local residents. Information on previous occurrences of algal blooms, date of first occurrence and type of algae are probably not available. At shorter time scales (annual to seasonal) there is again a paucity of information on the variables that determine the lake status, eg nutrients, stratification, biota, species succession, sediments, etc. The processes operating at these time scales again can only be inferred from similar systems and the limited data set. To investigate the variability at time scales of days to weeks, a field investigation was instigated and the collected data are reported in Kadluczka et al (1996).

3. Overview of Data Collection Program

The review of existing information presented in the previous section demonstrated a need for additional data acquisition to provide an indication of processes affecting the lake. An intensive sampling program proposed by DLWC was supplemented by additional sampling carried out by Council and a team organised by AWACS and including Southern Cross University, The Ecology Lab and Coastal & Marine Geosciences.

Council investigations provided the following data:

- Spear points to the south of the lake in the Lennox Head area were identified (Figure 3.1). Nutrient concentrations and water levels were monitored at these points to provide information on the groundwater inflow to the lake;

- Groundwater levels to the west of the lake were monitored by Council surveyors who measured the water level in the water hole (Figure 3.1) which was assumed to provide a good representation of the groundwater level. Later in the study Council was advised that excavations for the installation of a water tank would be undertaken at Camp Drewe and a piezometer was installed at the site prior to backfilling, thus providing water levels and groundwater nutrients to the north of the lake; and

- A traffic counter was installed on the lake access road to allow a quantitative assessment of visitations to the lake.

To provide information on the processes affecting the lake an intensive field exercise was conducted between 5 and 9 February 1996 by DLWC personnel and the AWACS team. The aim of these AWACS field studies was to provide information on:

- lake bathymetry - to monitor the lake morphology;

- lake sediments - in-lake sediment cores and surface grab samples were collected to determine the sediment stratigraphy and sediment nutrient status;

- lake mixing characteristics - CTD profiles, thermistor chain and meteorological data were collected to assess solar heating and wind-induced mixing processes;

- in-lake nutrient and algal characteristics - to determine the lake trophic status and nutrient pathways water samples were collected and analysed for nutrients, algae and cyanobacteria;

- hydrogeology data for western side of lake - a piezometer was installed to the west of the lake to measure groundwater levels and nutrient concentrations; and

- local vegetation and lake flora and fauna surveys were conducted.

The data collection program is summarised in Table 3.1. DLWC conducted a detailed bathymetric survey of the lake, the results of which are shown in Figure 3.2, together with the lake sampling sites.

Sediment cores were collected at nine sites (Figure 3.2) by vibrocorer that penetrated to a maximum depth of 6 m below the sediment surface. The cores were split, logged, subsampled and porewater extracted for nutrient analysis. Surface grab samples were collected with a vanVeen grab from 40 sites around the lake and sediment nutrients, metals, particle size and settling rates determined for selected sites. These data are reported in the data report by Kadluczka et al (1996) and discussed by Hudson (1996) and Daniels and Beck (1996).

Table 3.1 Lake Ainsworth Sampling Schedule 5-9 February 1996

Date	Sampling Program
5 February 1996	Lake Bathymetry survey
6 February 1996	Lake Bathymetry survey Groundwater nutrient samples for bores In-lake sediment cores* Lake foreshore and Dunecare program inspection
7 February 1996	In-lake sediment cores* CTD survey Riparian and in-lake biota
8 February 1996	In-lake sediment cores* CTD survey Surface sediment grab sampling Lake nutrients and algae In-lake biota survey Groundwater nutrients and water levels
5-9 February 1996	Thermistor chain weather station.

* Results reported in Hudson, 1996.

To assess the lake mixing characteristics a thermistor chain (with 28 temperature sensors) was deployed in the lake for the five days and some 200 CTD (conductivity, temperature, depth, pH and turbidity) profiles were collected over a two-day period. In addition a weather station was deployed near the Sport and Recreation Camp (Figure 3.1) to monitor the solar radiation and wind speed to provide a measure of the thermal and mechanical energy inputs to the lake. These data are presented in Kadluczka et al (1996) and described in Section 6.7.

Southern Cross University honours student Colleen Twigg collected water samples at five sites in the lake (Figure 3.2) and conducted nutrient analyses on the samples. Algal counts and identification was analysed by the Tweed Council Laboratories. Results of the analyses are presented in Kadluczka et al (1996).

Water samples collected in five bores (sites G2 to G7 in Figure 3.1) in Lennox Head and the existing eastern bore (G1) were analysed for nutrients. Water levels were also monitored in the waterhole by Council surveyors. These data are discussed in Daniels and Beck (1996) included in Appendix D.

Riparian and in-lake flora and fauna surveys were conducted by The Ecology Lab on 7 and 8 February. Nearshore benthic fauna samples were collected and net tows were used to assess the presence of fish species. Results of the surveys are discussed in The Ecology Lab (1996) presented in Appendix E.

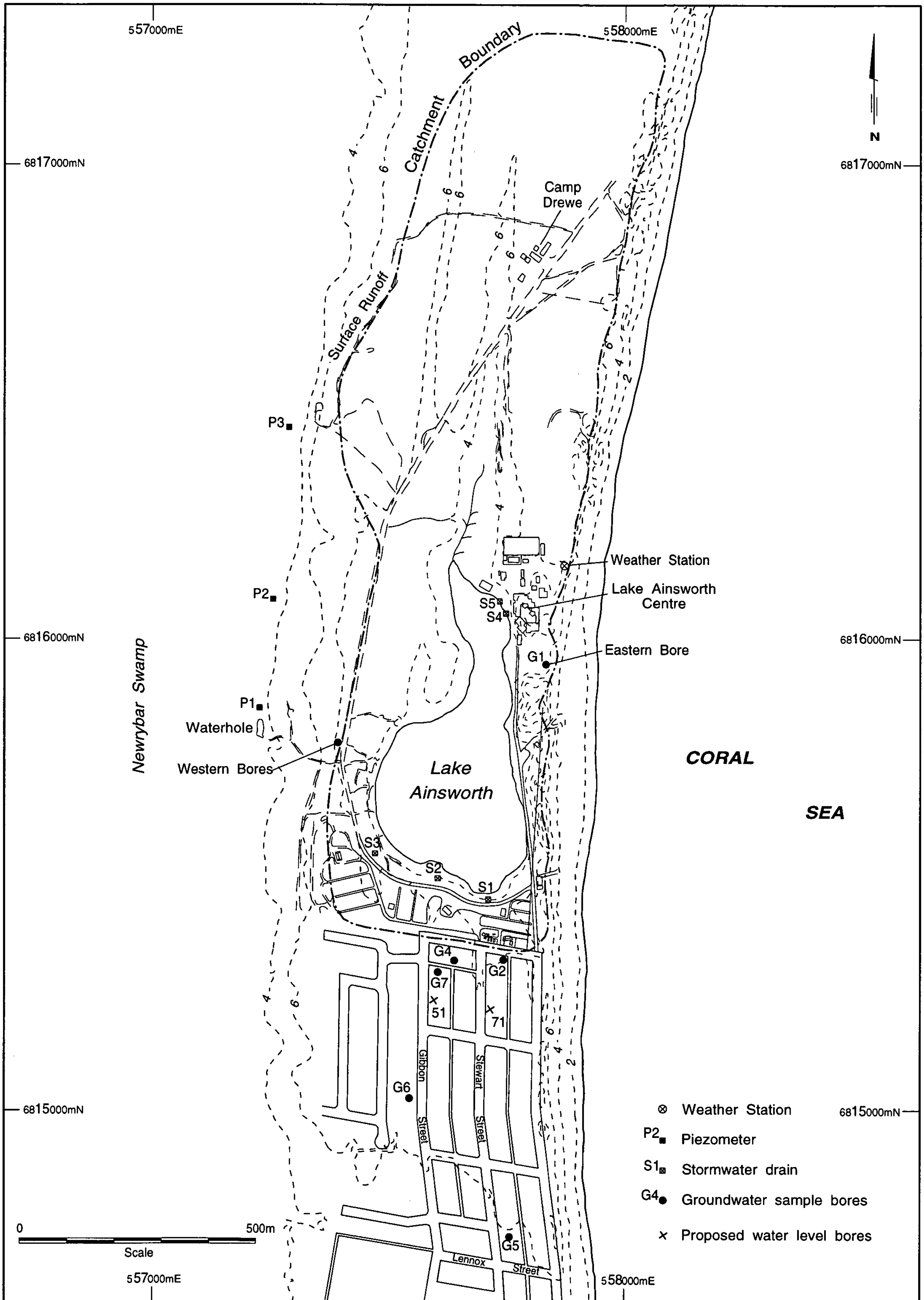
Inspections of the lake foreshore and assessment of human impacts on the lake were carried out during the preliminary project briefing with the committee on 6 February.

Lake water levels and water quality data collected at the lake over the past year had indicated that rainfall events play an important role in determining lake level and water quality. These data were not sufficient to quantify the various inputs, or their longer-term changes or the influence of events. To provide information on these issues an additional sampling program was instigated. This program involved collection of water samples from existing bores, from a new bore installed to the west of the lake and in-lake sampling. In addition water samples were collected from drains during a rainfall event. Colleen Twigg from Southern Cross University carried out the water sampling and nutrient analyses. Council surveyors have also monitored water levels in the bores each week since February. This data collection program is summarised in Table 3.2 and results are presented at a later stage in Appendix F.

Table 3.2 Groundwater and Rain Event Sampling
16 April to 24 May 1996

Date	Sampling Program
16/04/96	Installation of two boreholes to west of lake
02/05/96	Storm runoff sampling
03/05/96	Lake and bore water quality
10/05/96	Lake and bore water quality
17/05/96	Lake and bore water quality
24/05/96	Lake and bore water quality

As part of the sampling for her Honours project, Colleen Twigg also collected samples on 15, 21 and 23 February and has kindly provided these data for use in this report.



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GROUNDWATER AND STORMWATER SAMPLING LOCATIONS

Figure 3.1

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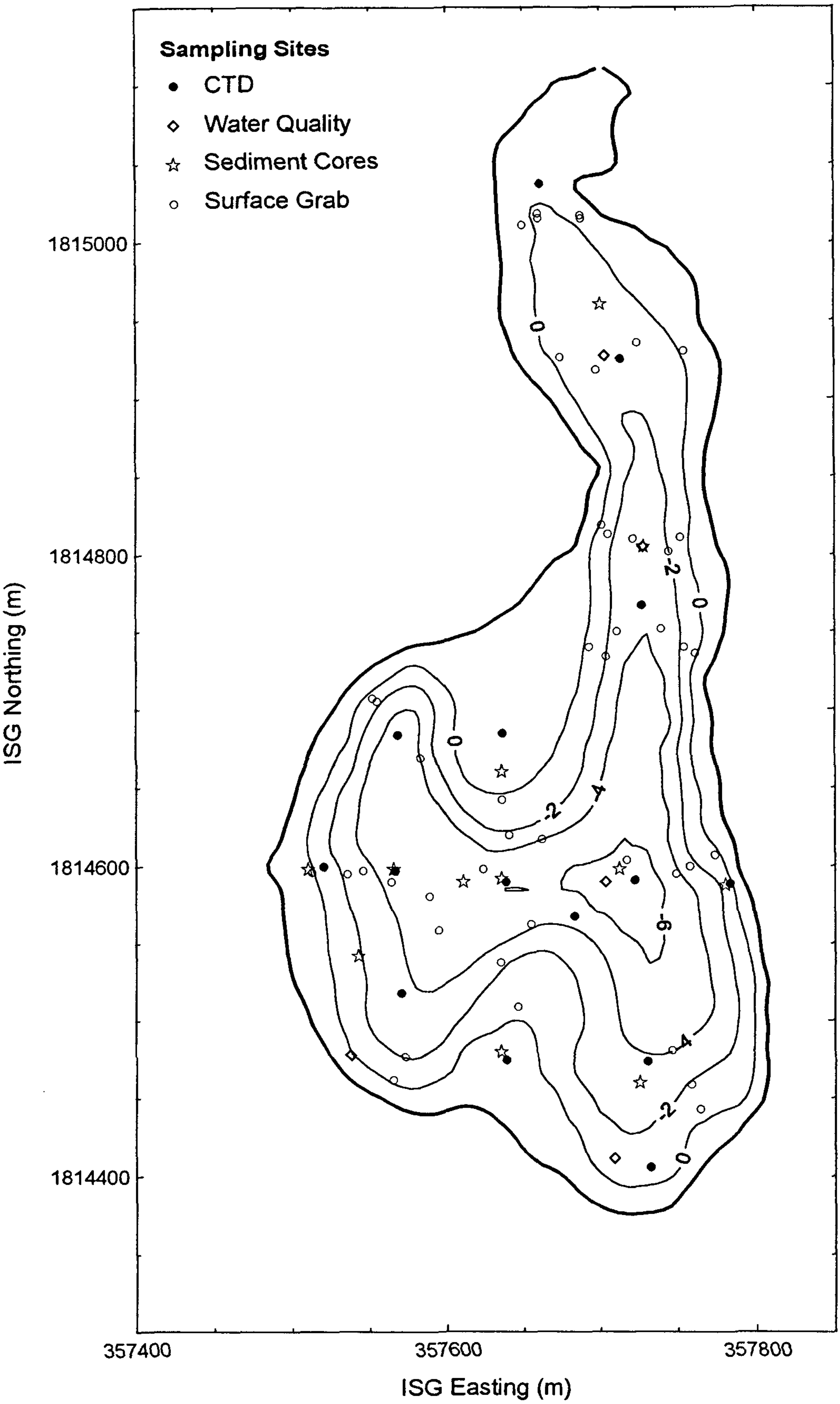

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SAMPLING SITES FOR LAKE AINSWORTH SURVEYS
5 TO 9 FEBRUARY 1996

Figure
3.2

4. Regional Setting

4.1 Climate

Lake Ainsworth is located within a region that experiences heavy periodic rains, hot temperatures and humidity in summer, and some significant rain and mild temperatures in winter.

Rainfall

The region falls within the Bureau of Meteorology Rainfall District 58, Upper North Coast. The rainfall trends for this area are shown in Figure 4.1 taken from Lee and Gaffney (1986). Specifically, median annual rainfall is 1689 mm with an average of 126 raindays per year (Ballina Pilot Station). The spread of rainfall over the year is uneven with 65% of rain falling in the summer months.

Drought

Drought is reported by the Bureau of Meteorology by considering a period of months, assigning a percentile rank and a percentage of the normal rainfall recorded over the period. Rainfall data for the period 1992 onwards was consistently less than normal, generally in the order of 60% of the long-term average (Bureau of Meteorology 1992-1996). Over the longer term, periods of drought are indicated by negative values of the Southern Oscillation Index (SOI) shown in Figure 4.2 for the period 1984 to 1996. Negative SOI values have occurred, on average, for the period 1992 to mid-1995, indicating dry years.

Temperature and Humidity

Average daily temperature ranges from 16.3-23.5°C (Cape Byron) with an average of 18.9°C recorded at Ballina Airport (just over three years of data period). The average humidity at Ballina Airport for the same period was 78%.

Wind Speed and Direction

From an analysis of the data from Ballina Airport (1992 to 1996) wind direction is on the average from the south-east with an average speed of 3.4 m/s. Between the months of January and April the region may be subject to tropical cyclones and associated extreme winds.

Analysing Brisbane records reported in Bureau of Meteorology (1993) indicates that there is not a large variation in average wind speed throughout the year. This analysis also indicates that the higher average speeds are observed in summer periods during the afternoon.

Strong wind gusts at Brisbane were found to all be accompanied by rain events, except for westerlies associated with Tasman Sea depressions.

Brisbane Comparison

Solar radiation data were required to assist with the interpretation of the lake processes. Long-term global radiation measurements were available from Brisbane Airport and to assess whether these data were representative of conditions at the lake meteorological data from Ballina Airport and Brisbane Airport were compared. This comparison is shown in Figure 4.3 and illustrates a strong correlation between the two sites and hence Brisbane Airport data provide a good representation of the conditions at the lake.

4.2 Regional Geology

Catchment geology is described in detail in the report prepared by Coastal & Marine Geosciences for this study, and reproduced as Appendix E. A summary of that work is presented here.

The Lake Ainsworth groundwater catchment is defined by the bedrock hills of the Main Coastal Range in the north and west, the Pacific Ocean in the east, and the Richmond River channel in the south (Figure 4.4).

The bedrock hills forming the northern and western margins of the Lake Ainsworth catchment rise to a maximum height of around 600 m and consist of a variety of metamorphic, sedimentary and volcanic rock types. Tertiary basalts outcrop along the coast between Ballina and Lennox Head. A sandy, low relief, swampy coastal plain extends east from the bedrock hills to the coast and forms the main portion of the lake catchment (Figure 4.4). Lake Ainsworth occurs within marine sand deposits of the coastal lowlands immediately to the north of Lennox Head.

Drury (1982) presents stratigraphic sections to the west and north of Lake Ainsworth (Figure 4.5). The major depositional units recognised by Drury (1982) are listed from oldest to youngest below:

- Doonbah Clay - 250,000 years before present;
- Gundurimbah Clay - 135,000 to 118,000 years before present;
- Woodburn Sand - also referred to as the "inner barrier" (Thom 1965) - c 120,000 years before present;
- Broadwater Sandrock - from at least 35,000 years ago and up to the present day;
- Pimlico Clay - Holocene estuarine clays (<10,000 years old). These deposits are associated with the courses of North, Deadmans and Roberts Creeks to the south-west of the Lennox Head township and have been identified as high-risk acid sulphate soils areas (DLWC 1995);
- Recent marine - Mid-Late Holocene coastal sand barrier deposited since the end of the postglacial marine transgression around 6,500 years ago. Also referred to as the "outer barrier" (Thom 1965); and
- Floodplain - Alluvium deposited during the late Pleistocene-Holocene.

Successive phases of marine and estuarine sedimentation over the past 300,000 years have infilled the bedrock basement, forming a broad coastal plain which extends east from the foothills of the coastal range to the present day coast.

Barrier and estuarine deposits formed at relatively high sea levels have survived reworking, while similar deposits formed at lower sea levels have been built and dispersed with the advance and retreat of the sea across the continental shelf. The study area, like other coastal lowlands of many of the river catchments in northern NSW, contains the legacy of past sea level fluctuations and associated changing patterns of marine and coastal sedimentation.

Roy (in prep) mapped the distribution of the major depositional units within the late Quaternary sequence at Lake Ainsworth (Figure 4.6). The mapping identifies a narrow Holocene barrier (beach and dune deposits - outer barrier) along the coast of Seven Mile Beach backed by a complex sequence of prograded barriers (foredune ridge lineations) and relatively featureless back barrier sand flats which extend west from the coast to the foothills of the coastal range. In the north of the catchment, the relict barrier deposits are overlain by around 3 m of alluvial clay washed down from the adjacent bedrock hills (Newcrest 1993). To the south, the barrier deposits have been dissected and infilled with Holocene estuarine clays in the vicinity of North and Deadmans Creeks. These areas of estuarine infill are identified as high-risk acid sulphate soils on the DLWC 1:25,000 Lismore/Ballina Sheet (9640N3). The northern limit of potential acid sulphate soils is indicated by the heavy dashed line some 1.5 km west of Lake Ainsworth on Figure 4.6.

The Pleistocene barrier immediately west of Seven Mile Beach is presumed to be of Last Interglacial Age (c 120,000 years old; Drury 1982). Lake Ainsworth occupies a depression within this barrier system. The narrow (receded) Holocene barrier forming the present day Seven Mile Beach onlaps the older Pleistocene barrier. The barrier systems are likely to date back to at least 300,000 years (Roy et al 1992).

While the prograded barrier deposits retain much of their original morphology, such as foredune ridge-swale topography (Figure 4.7), albeit subdued due to superficial reworking, there has been in fact significant modification of the coastal plain through the formation of thick groundwater podzols or indurated sands (Broadwater Sandrock Unit; Drury 1982). The indurated sands occur within the marine sand unit, appear to thicken to the north of the catchment where they reach a maximum thickness of around 13 m, and dip to the east extending below sea level at the present day coast (Figure 4.5).

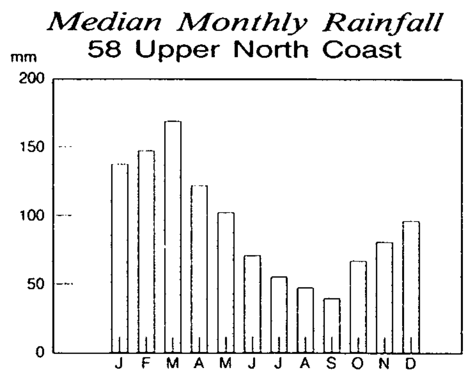
The coastal plain consists of a thick (c 48 m) sediment sequence consisting of sand, indurated sand, and clay overlying bedrock. To the west of Lake Ainsworth, the general level of the upper surface of the indurated sand unit varies from around 0 m AHD up to a maximum of around 5 m AHD in the northern part of the catchment. East of Lake Ainsworth a sand/indurated sand sequence occurs to a maximum depth of -17.5 m AHD with depths to the top of the indurated sequence varying from -1.8 m down to -7.5 m AHD. The indurated sand unit dips to the east and extends below present sea level in the lower Richmond River valley. The indurated sand sequence is contained within the older barrier sequences and is not found within the Holocene barrier.

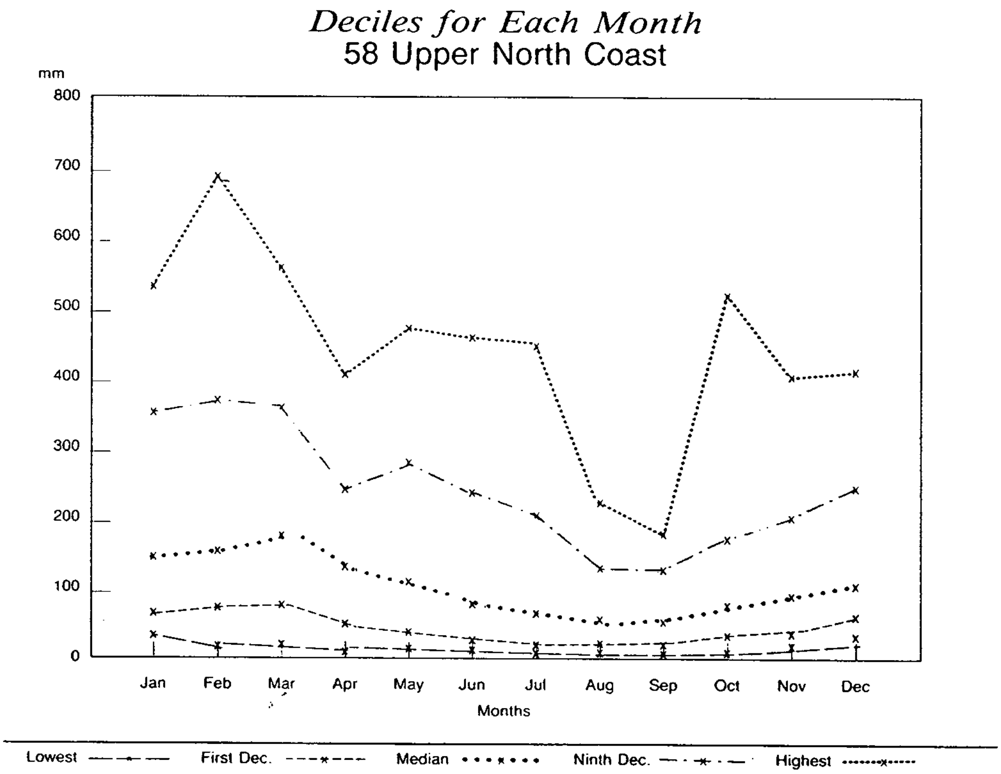
4.3 Regional Hydrogeology

The detailed hydrogeological study undertaken by AWACS for this project is presented in Appendix D and an overview of the regional and local hydrogeology based on that study is presented below.

Groundwater flows away from the hills to the west of Lake Ainsworth, either travelling eastward to the ocean or being intercepted by watercourses draining to the Richmond River. Immediately west of Lake Ainsworth, groundwater flows from the higher ground in a westerly direction towards Newrybar Swamp (Figure 4.8). It has been concluded that the groundwater divide around the lake coincides approximately with the boundary of the surface water catchment (Figure 6.3).

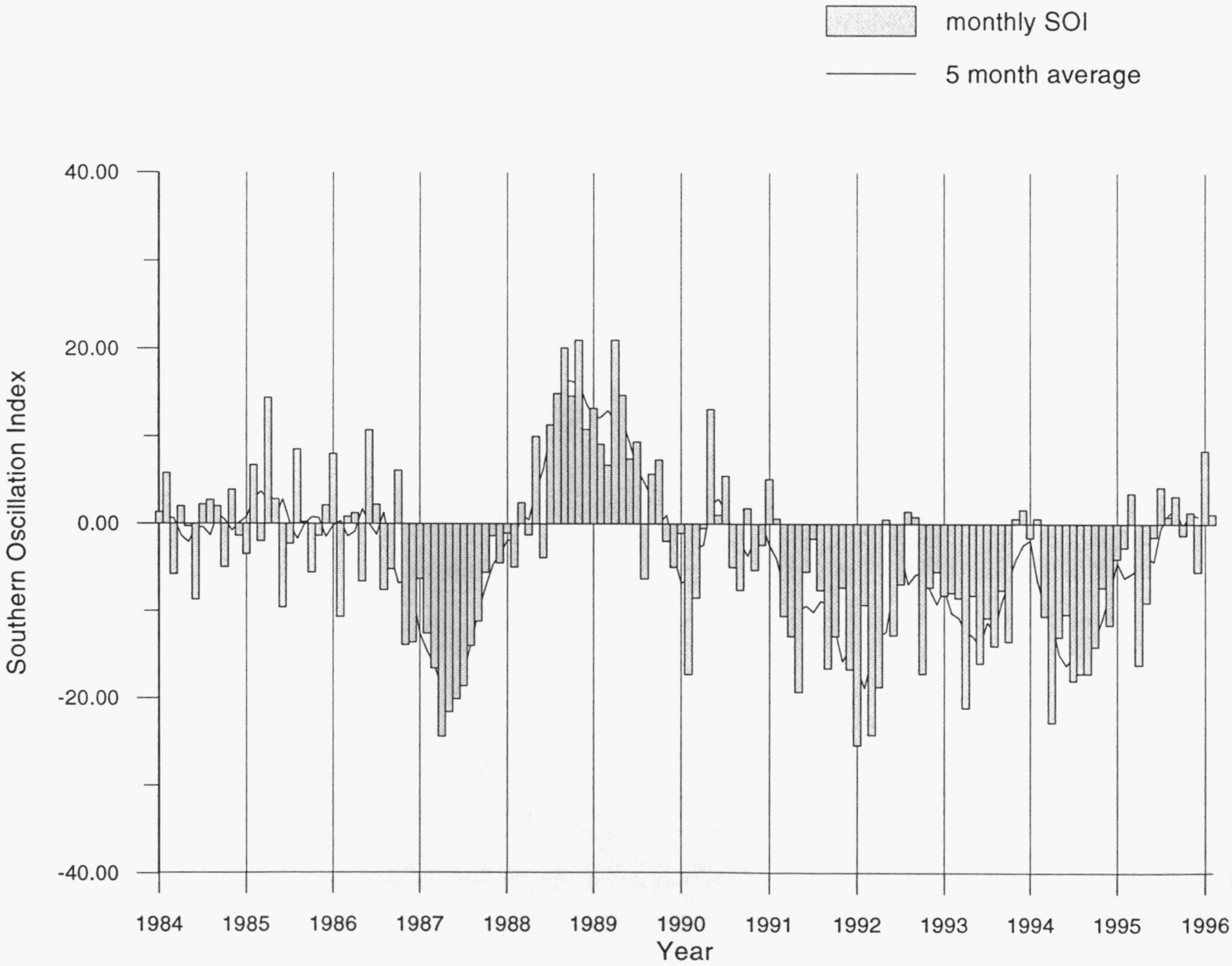
The geological units that control the hydrogeology of the area are the Pleistocene age, Woodburn Sand Unit (WSU) which becomes indurated with humic matter at depth, and the overlying Holocene Coastal Sand Barrier (Figure 4.5). The WSU forms the major aquifer around the lake. To the west of the lake this unit is divided into an upper and lower aquifer by the indurated sands (Figure 4.9).





Reference: Lee and Gaffney 1986

AWACS Report No. 96/07	MEDIAN MONTHLY RAINFALL AND RAINFALL DECILES FOR EACH MONTH FOR THE UPPER NORTH COAST OF NSW	Figure 4.1



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SOUTHERN OSCILLATION INDEX
1984 TO 1996

Figure 4.2

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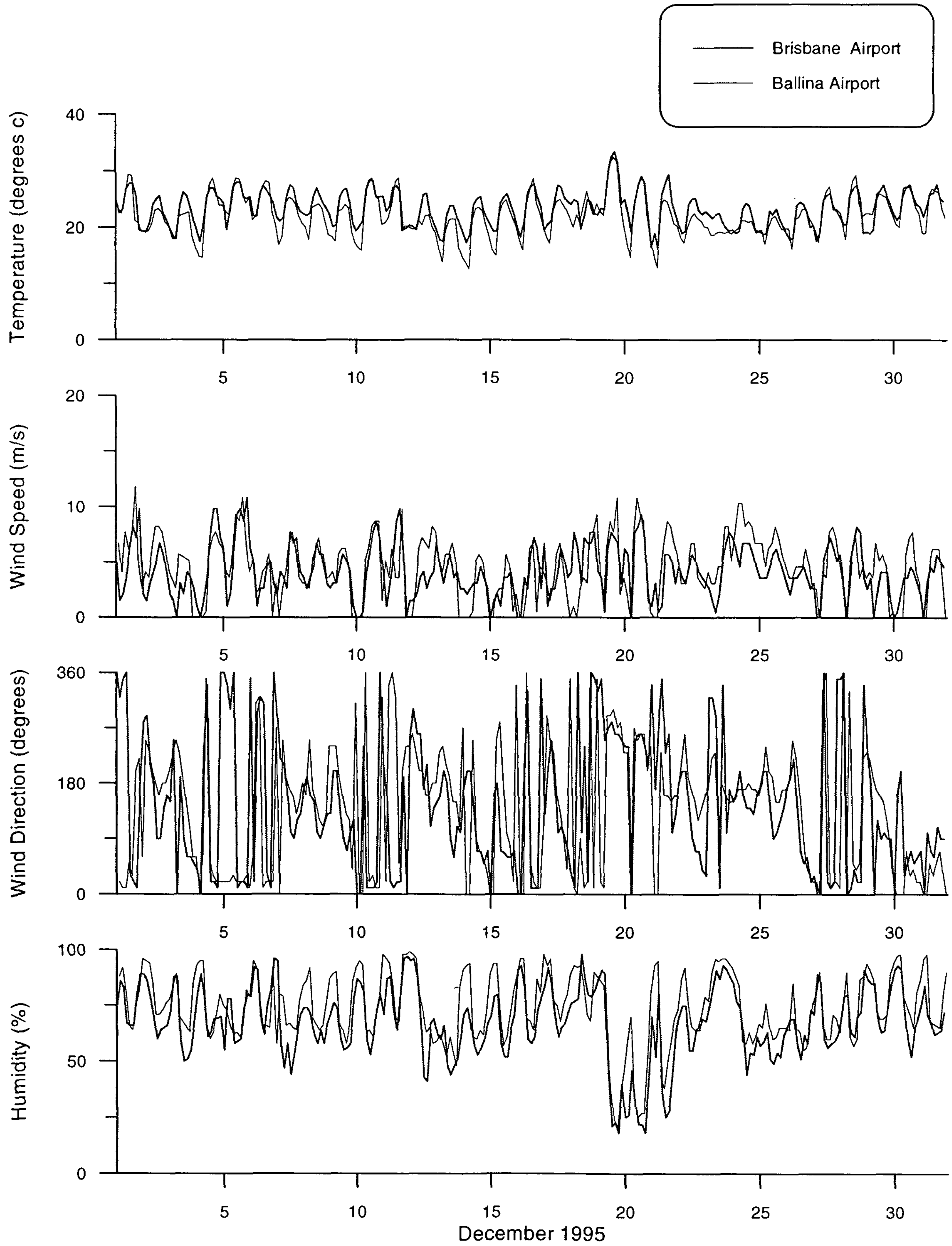

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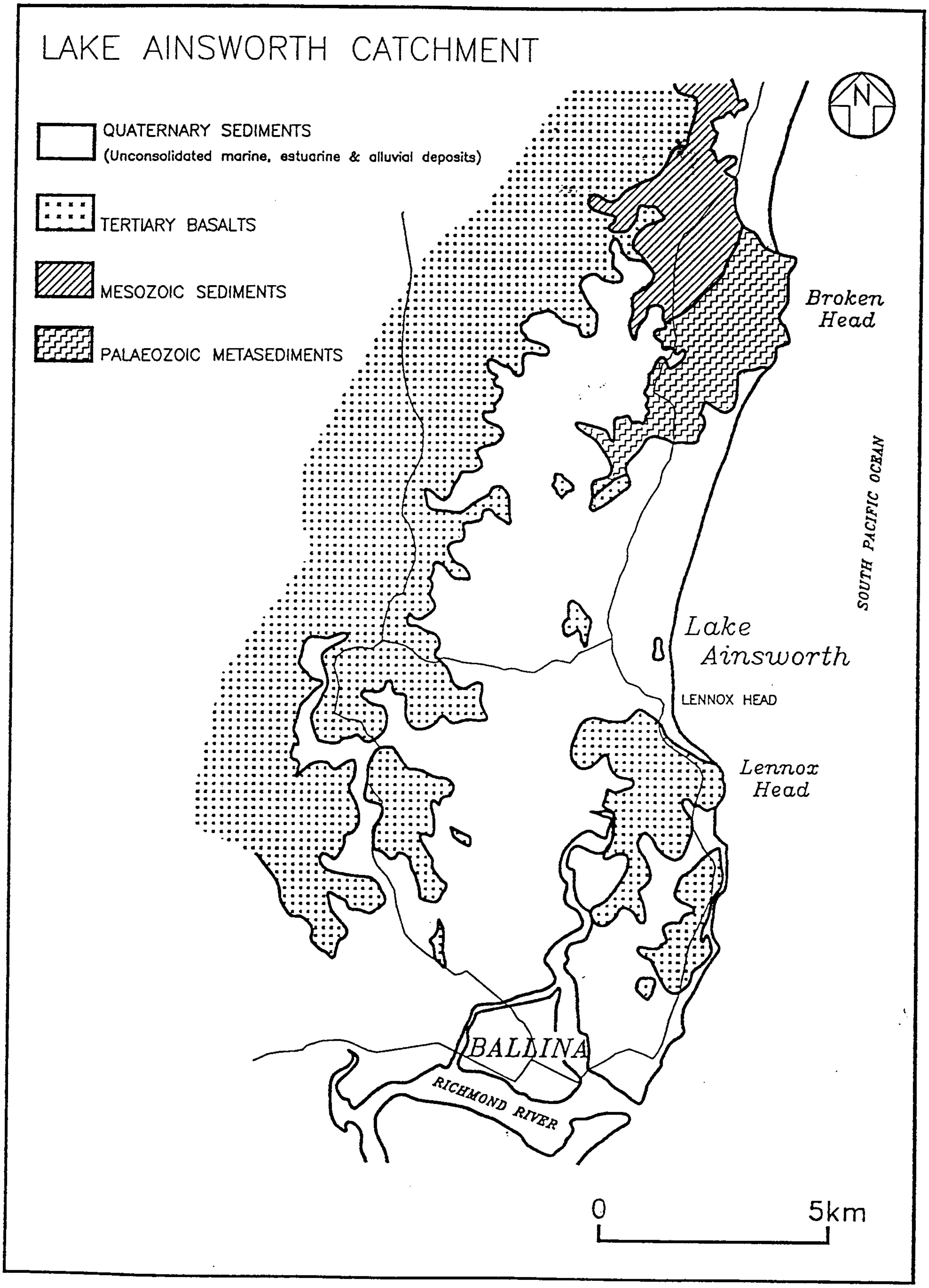
COMPARISON OF METEOROLOGICAL DATA FROM BRISBANE AIRPORT AND BALLINA AIRPORT

Figure 4.3



Reference: Coastal & Marine Geosciences - April 1996

AWACS Report No. 96/07	GEOLOGY OF THE LAKE AINSWORTH REGION	Figure 4.4

AWACS
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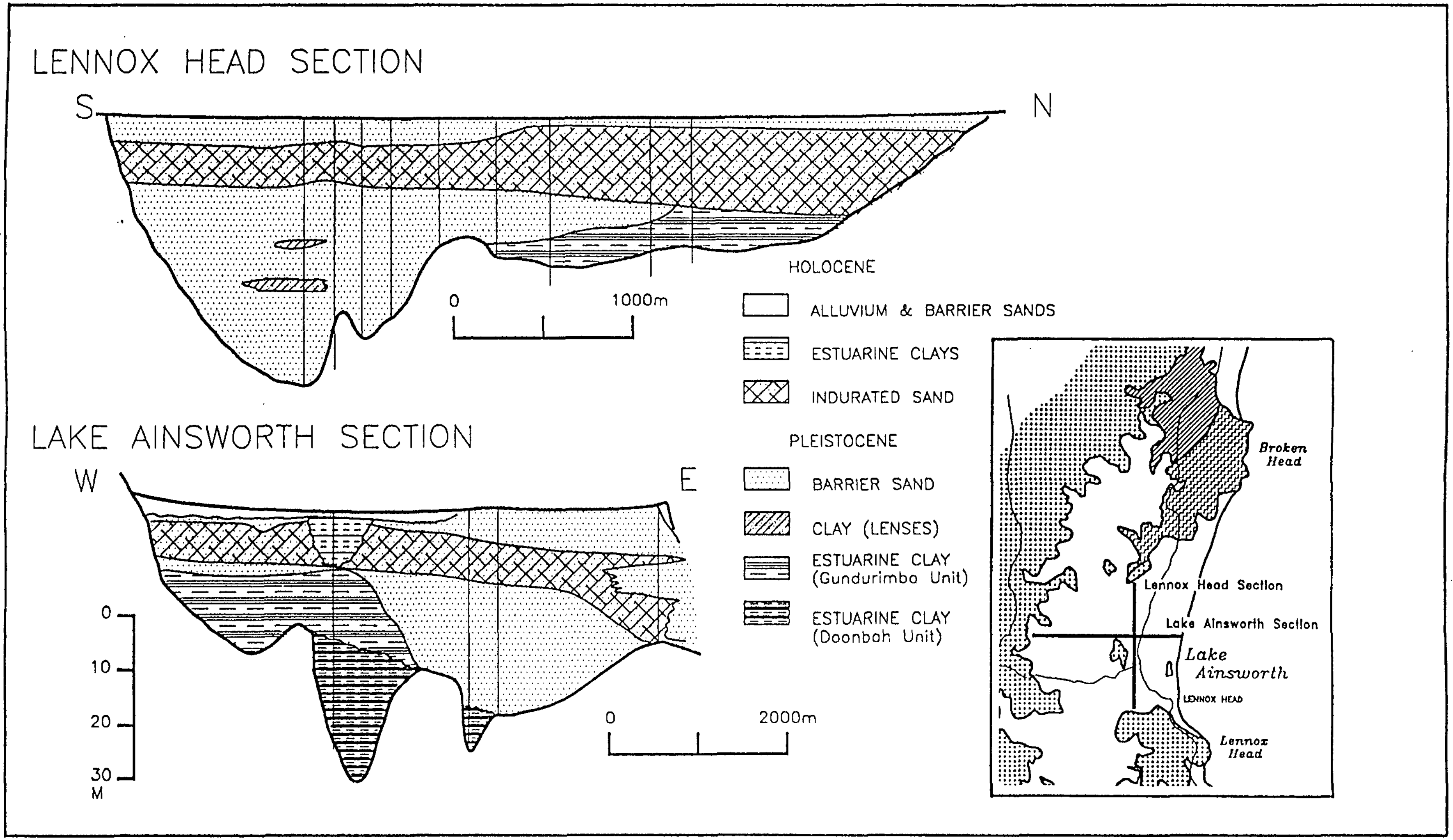
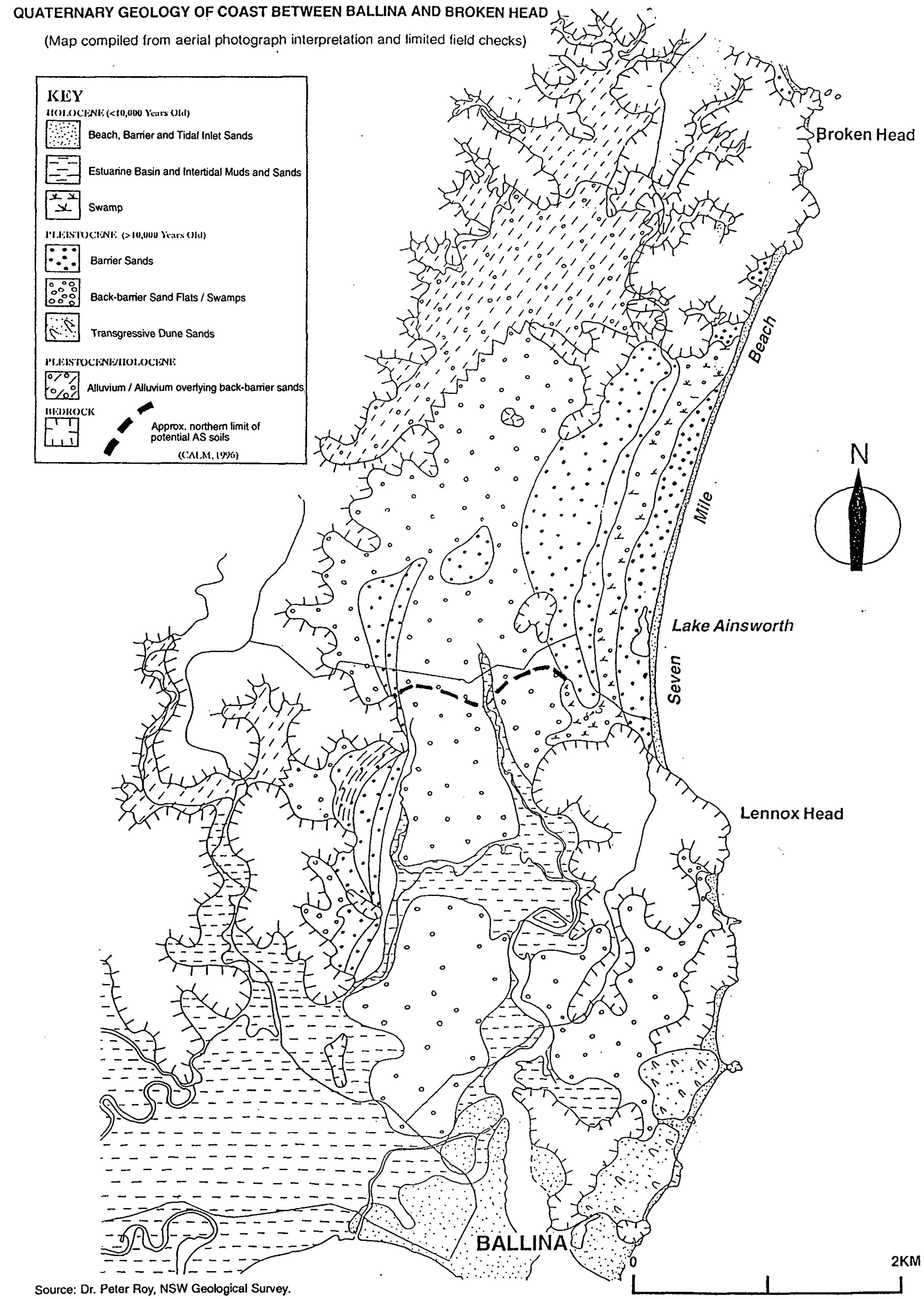
Reference: Drury 1982



STRATIGRAPHIC SECTIONS OF THE LAKE AINSWORTH REGION

Figure 4.5



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INTERPRETED LATE QUATERNARY GEOLOGY OF THE LOWER RICHMOND RIVER VALLEY IN THE VICINITY OF LAKE AINSWORTH

Figure 4.6

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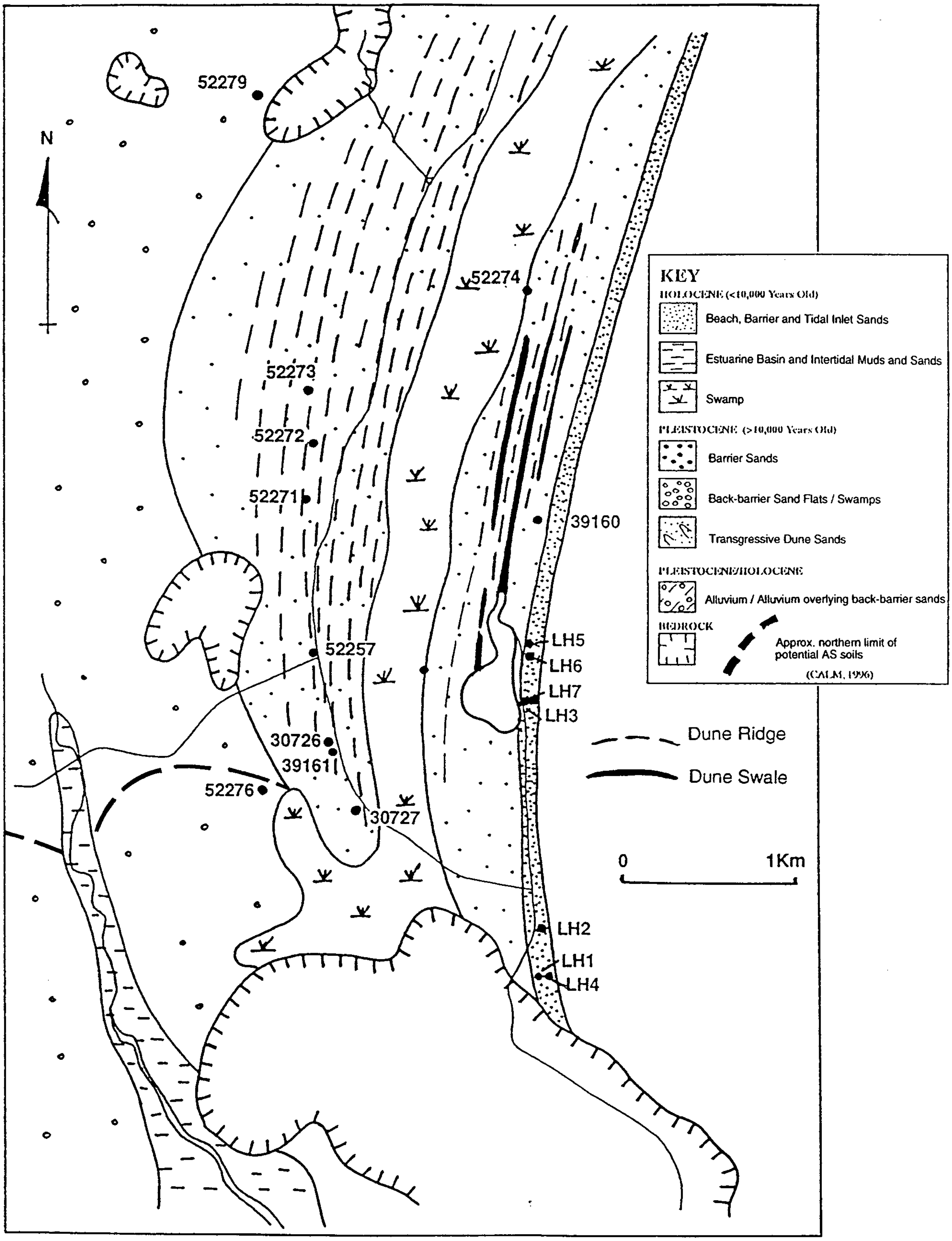

Note: Location of boreholes in the vicinity of Lake Ainsworth. Boreholes 30726 to 52279 Dept of Water Resources bores, boreholes LH1 to LH7 from unpublished Geological survey of NSW report on coastal erosion at Seven Mile Beach

Reference: Coastal & Marine Geosciences - April 1996

AWACS Report No. 96/07	BARRIER DEPOSITS IN THE VICINITY LAKE AINSWORTH	Figure 4.7

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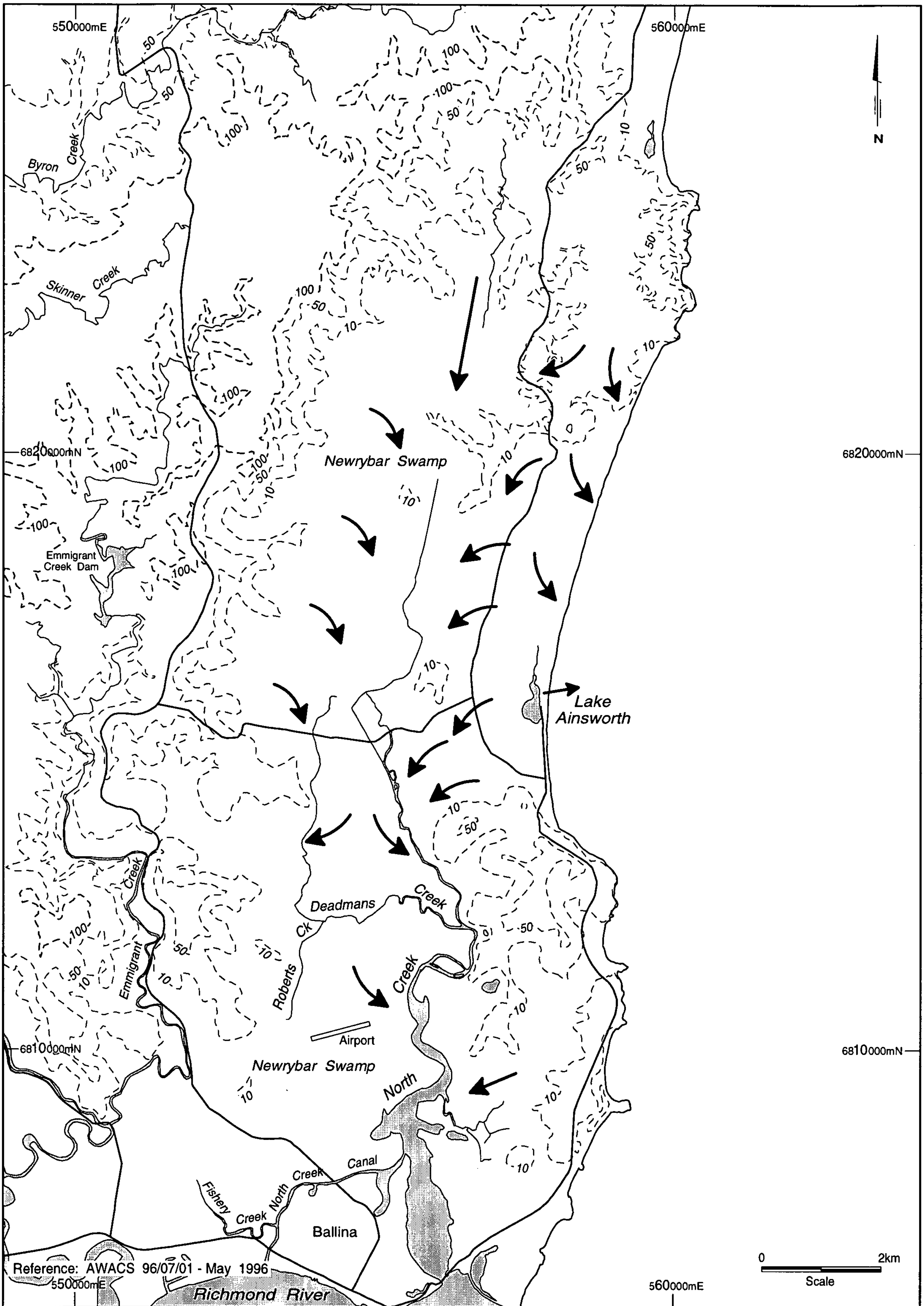

AWACS
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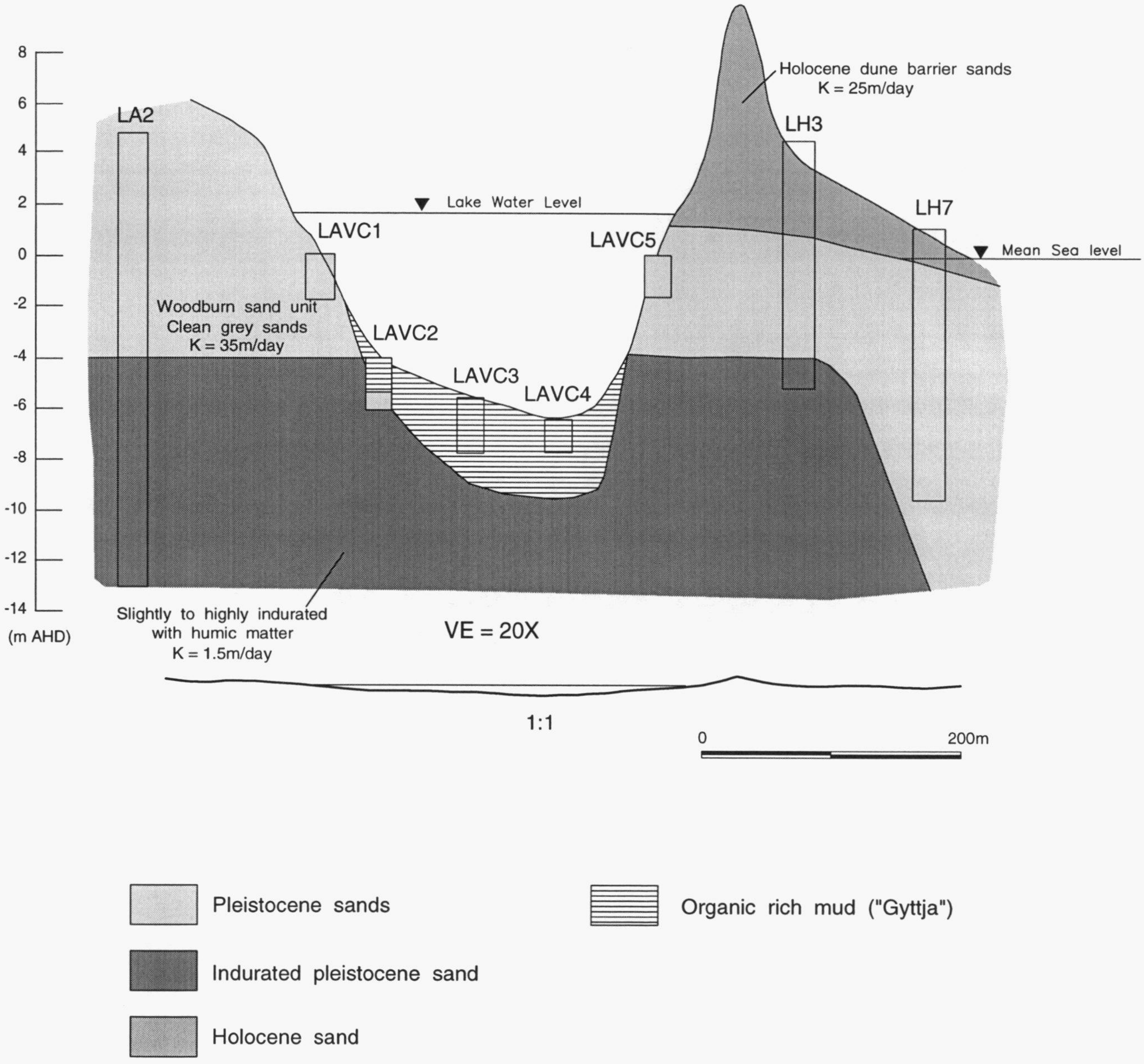
REGIONAL GROUNDWATER FLOW

Figure 4.8



Reference: AWACS 96/07/01 - May 1996

AWACS
Report No. 96/07

GEOLOGICAL CROSS-SECTION THROUGH LAKE AINSWORTH FROM WEST TO EAST

Figure 4.9

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5. Lake Usage and Cultural Aspects

5.1 Land Use

Land uses adjoining Lake Ainsworth are:

- Lake Ainsworth Caravan Park directly to the south and urban development further south;
- Lennox Head Surf Life Saving Club to the south-east;
- Lake Ainsworth Sport and Recreation Centre land to the north and west, and Camp Drewe further to the north; and
- Aboriginal land further to the north and west.

Crown Reserve 82783 for Public Recreation covers the southern half of Lake Ainsworth and the caravan park and is managed by Ballina Council. Crown Reserve 84109 for National Fitness and Physical Education is managed by the Department of Sport and Recreation. A Bird and Animal Sanctuary was proclaimed in 1927 and covers all of the Reserve for Public Recreation, the waterbody of Lake Ainsworth and part of the Sport and Recreation land. Under the Ballina Local Environmental Plan (LEP) the Crown reserves are zoned 7 (f) Environmental Protection (Coastal Lands) and along the western edge, 7 (a) Environmental Protection (Wetlands). The wetlands (Newrybar Swamp) are designated under State Environmental Planning Policy (SEPP 14). See Figure 5.1 for zoning and reserve boundaries.

Recreational activities centre on the lake, at the southern end of the lake and at the Sport and Recreation Centre. In the area to the north of the centre recreational use is low and there are no facilities. Land to the west of the lake, which is under the control of the Department of Sport and Recreation, is at present undeveloped.

5.2 Services

Reticulated water is available to the caravan park and Sport and Recreation Centre to water the centre's gardens. In the future it is proposed to either tap groundwater or capture rainwater to supplement mains supply for the purposes of garden watering and cleaning. All of the Sport and Recreation Centre is sewered and the caravan park was connected to the sewerage system 12 years ago. Holiday units and a laundry in the north of the Sport and Recreation site which were previously connected to two septic tanks and shared a common absorption trench were connected to the sewer system two years ago. Two stormwater lines from the lodges and amenities block drain directly into the north-eastern area of the lake, and all surface runoff from the centre drains into the lake (NSW Public Works 1994). Three stormwater pipes discharge into the lake via overland flow from the caravan park in the south (Warren 1994). The locations of these five stormwater lines are shown in Figure 3.1. Fuel is also stored at the Sport and Recreation Centre in underground tanks containing diesel and regular fuel. The tanks are located between the Programme Director's residence and the recreation hall/boatshed. Information on their age, capacity and condition is not readily available but the tanks and fuel pumps are in regular use.

5.3 Population, Tourism and Recreation

At the 1991 census, Lennox Head had a population of 3,036, with the Ballina local government area as a whole having a population of 30,200. The population projections for the Ballina area under a medium growth scenario are 35,100 in 1996, over 40,000 by the year 2000 and rising to 62,400 in 2021 (ABS 1993, DoP 1994).

According to the Tourism Commission of NSW (1987) typical visitors to the north coast are low to middle income families who generally stay in budget forms of accommodation and travel to the region by car, visiting mostly during school holidays. In 1985/86 the number of estimated visits to the Ballina area was 236,130, involving 985,843 visitor nights. Between 1984/85 and 1986/87 visits increased by 1.4% and visitor nights increased by 8.3% for the far north coast, which includes the local government areas of Tweed, Byron, Ballina, Lismore, Kyogle, Casino and Richmond River. In the year 1986/87 most visits occurred in January (14.8%).

Visitors to Lennox Head can choose from a range of accommodation in caravan parks, hostels, motels and holiday units. The Lake Ainsworth Caravan Park can accommodate nearly 1,200 people, based on four people per site for 300 sites and 13 cabins with a capacity of 48 people. The permitted length of stay in the caravan park is three months with a possible extension of two months, depending on circumstances. The manager of Lake Ainsworth Caravan Park estimates caravan park visitor numbers to be between 1,500 and 2,000 per week over the peak Christmas holiday break.

The current capacity of the caravan park is 13 onsite vans, 177 other power sites and 110 unpowered sites. Statistics on occupancy rates are kept in terms of site nights; a site night is every night a van is occupied or reserved. Site nights for each three-month period from January 1985 to March 1996 are plotted in Figure 5.2a. Over this time the number of site nights in a three-month period has ranged from about 5,000 to 14,000. There is an apparent trend of a slight decrease in occupancy rates from 1985 to 1990 and a slight increase to the present. Monthly occupancy rates for the years 1985, 1990 and 1995 are plotted in Figure 5.2b. The typical annual pattern is for occupancy rates to peak in December-January, with smaller peaks in April and September.

The Lake Ainsworth Sport and Recreation Centre can accommodate 210 people and is planning to expand. Other accommodation in Lennox Head includes many holiday units, three motels (capacity 161 people), hostels (capacity 140 including Camp Drewe, about 100 people) and the Headland Caravan Park (18 sites, say 72 people plus accommodation for 100 in cabins). Visitation is very seasonal with occupancy rates provided by the Sante Fe Motel and the Lennox Head Backpackers being about 60% to 70% during January and ranging from about 20% to 40% for the remainder of the year, school holidays accounting for the higher end of the occupancy rates.

Recreational use of Lake Ainsworth itself and the southern reserve is high as it provides a safe freshwater swimming area for young children, safe waters for novice sailors, and planting within the reserve provides shelter from the wind and sun throughout the day (Warren 1994). A floating line and signs designate the southern part of the lake for swimming and the remainder for watercraft. Facilities include picnic tables, barbeques, two toilet blocks and a kiosk. Markets are held at the lake on the second and fifth Sunday of the month except at the peak Christmas and Easter holiday times. Dogs are permitted at Lake Ainsworth, provided they are leashed. Popular activities on and around the lake include:

- sailboarding
- sailing (catamarans)
- ski paddling
- swimming
- picnicking
- sunbathing, and
- walking.

Sailboards, five catamarans, and single and double skis are available for hire on the eastern shores of Lake Ainsworth. The hire operator also offers sailboarding lessons. Both the hire operator and the Sport and Recreation Centre have 6 hp power boats, primarily for emergencies.

Although there is little data on recreational use of Lake Ainsworth, Council has advised that organisations from as far away as south-east Queensland are known to visit. The Lennox Head Residents Association (undated) estimated that on top of consistent use year round, during peak days in summer over 1,000 people may visit the lake. Jones (1988) estimated a similar number of people visiting the lake (800) during peak days, based on "business records".

To give an indication of the number of vehicles and current number of people visiting Lake Ainsworth (excluding those staying at the caravan park), Ballina Council installed a traffic counter on the access road and traffic counts are available for March and up to the end of April 1996 (including the Easter weekend). The weather conditions during this period were generally fine and warm.

Traffic counts were not continuous over the survey period as the counter was tampered with and disconnected on a few occasions. The counter measures vehicle movements, so the data obtained were divided in two to give vehicle numbers (Table 5.1). The average number of vehicles visiting Lake Ainsworth during week days over the survey period was about 400 (386 cars and 11 heavy vehicles). On Saturdays the average number of vehicles was about 567 (558 cars and eight heavy vehicles) and on Sundays this rose to about 835 vehicles (817 cars and 18 heavy vehicles). Over the Easter holiday weekend an average of 657 vehicles visited Lake Ainsworth each day (638 cars and 19 heavy vehicles). Sunday again was the most popular day, with about 1,110 vehicles recorded. On Anzac Day 538 vehicles visited the lake. Council noted that about ten buses, carrying about 600 students in total, visited Lake Ainsworth for a cross-country event on 17 April 1996. Alstonville High School conducts this event annually.

Table 5.1 Lake Ainsworth Traffic Counts for March/April 1996
N.B. Counter does not cover caravan park, only entry to Lake Ainsworth Reserve

Day	Date	Total	Cars	Trucks/Buses
Friday	01/03/96	501	476	25
Monday/Friday	08/03/96	3015	2933	82
Thursday	14/03/96	730	712	18
Friday	15/03/96	707	674	33
Monday/Friday	22/03/96	3124	3041	83
Thursday	23/03/96	640	632	8
Tuesday	02/04/96	780	768	12
Wednesday	03/04/96	922	897	25
Thursday	04/04/96	944	930	14
Friday	05/04/96	2165	2131	34
Monday	08/04/96	2097	2011	86
Tuesday	09/04/96	986	964	22
Wednesday	10/04/96	1150	1121	29
Thursday	11/04/96	1188	1145	43
Tuesday	16/04/96	529	520	9
Monday	22/04/96	590	572	18
Tuesday	23/04/96	411	398	13
Wednesday	24/04/96	370	357	13
Friday	26/04/96	599	575	24
	Total:	21448	20857	591
Average traffic counts/day		794	772	21
Average no. of vehicles/day		**397**	**386**	**10**
Saturday	02/03/96	965	957	8
Saturday	09/03/96	694	687	7
Saturday	16/03/96	1037	1020	17
Saturday	06/04/96	2140	2099	41
Saturday	27/04/96	831	820	11
	Total:	21448	20857	591
Traffic movements/day				
No. vehicles/day		**566**	**558**	**8**
Sunday	03/03/96	1265	1240	25
Sunday	10/03/96	1324	1286	38
Sunday	07/04/96	2422	4905	106
	Total:	5011	4905	106
Average traffic counts/day		1670	1635	35
Average no. vehicles/day		**835**	**817**	**17**

Table 5.2 Lake Ainsworth Traffic Counts Easter and ANZAC Day 1996

Easter

Day	Date	Total	Cars	Trucks/Buses
Friday	12/04/96	1176	1138	38
Saturday	13/04/96	1180	1159	21
Sunday	14/04/96	2220	2160	60
Monday	15/04/96	678	648	30
	Total counts	5254	5105	149
Average traffic counts/day		1313	1276	37
Average no. of vehicles/day		**656**	**638**	**18**

Anzac Day

Day	Date	Total	Cars	Trucks/Buses
Thursday	25/04/96	1079	1053	26
No. of vehicles/day		**538**	**526**	**13**

* Number of traffic movements/day = total number of traffic movements/no. of days.

* No. vehicles/day = no. traffic movements per day/2. This assumes that all traffic entering the park leaves the same day.

A student survey in 1988 (Blainey et al) found that 85% of visitors drove to Lake Ainsworth, accordingly more people would visit the lake than the traffic data suggests, eg those staying at the caravan park. No information is available on the average length of stay or number of people per vehicle, although observations by Jones (1988) suggest that about 70% of visitor groups are families (participating in swimming and picnics) with the remainder being individuals or groups of two (sunbathing and sailboarding/sailing). As shown in Table 5.3, assuming an average half-day stay per group (not overlapping) up to 1,500 people may use the lake at any one time on a Sunday. This estimate is indicative, given the unknowns, but it is consistent with numbers estimated by the Lennox Head Residents Association.

Table 5.3 Estimated Visitor Numbers on Sundays - March/April 1996

No. of cars (817)	85% of Visitors Reaching the Reserve by Car	Total No. Visitors
Groups of four 70%	2288	2,692
Groups of two 15%	245	288
Individuals 15%	123	144
	Total per day	3,124
	Total at any one time	**1,562**

The social carrying capacity of Lake Ainsworth was estimated by Jones (1988) based on observations of the distance between groups of people and a questionnaire survey undertaken over the Easter weekend of 2, 3 and 4 April 1988. Jones noted that the weather was poor during this time and that several people surveyed said visitor numbers were low for a holiday weekend. A total of 84 visitors were surveyed over the three days, plus those involved in management of the reserve and Sport and Recreation Centre, and the catamaran and sailboard hire operator. Table 5.4 shows the maximum desirable number of people for various lake activities.

Table 5.4 Estimated Social Carrying Capacity

Activity	Group No. and Other Factors Taken into Consideration	Estimated Social Carrying Capacity
Picnicking	40 tables (say four people per table)	160
Sunbathing	25 areas (1-2 people per area)	38
Swimming	Less than 72 groups (most groups were families, say four people per group and 60 groups)	240
Sailboarding	Depends on winds - light winds more, heavy winds less, 120 reflects an average	120
Sailing	Based on area required for safe navigation of catamarans	5
	Total	**563**

(after Jones 1988)

The information in Table 5.4 suggests a social carrying capacity of about 560 people overall for Lake Ainsworth. Given this estimate suggested by Jones (1988) it is not surprising that overcrowding and associated problems have been noted as a concern for Lake Ainsworth.

During his study, Jones (1988) noted that the reserve was under-utilised for walking, and that the development of walking trails through adjoining heathland and boardwalks around the lake would encourage this activity. He also noted that the Sport and Recreation Centre had little effect on lake recreation as sailing was rarely undertaken on busy weekends and activities were restricted to the northern end of the lake.

The camp at the Sport and Recreation Centre was formally opened in 1944 but lodges, the kitchen and hall were destroyed by a cyclone in 1948. Construction of a 120 bed lodge, family units and staff accommodation was undertaken in 1985, the amenities block and barbecue shelter in 1989 and the administration office in 1990. The centre currently occupies approximately 12 ha of the 118 ha Crown reserve site. Land on the north and western sides of the centre is unused, except for a two lane unfinished road. The centre comprises 30 buildings and structures which provide accommodation for visitors and staff, amenities, equipment storage, parking and shelter for specific activities. The complex also includes a swimming pool, cricket practice runs, tennis courts, an adventure playground and wetland track for environmental awareness programs. Other activities include formal games, free play, archery, grass skiing, camping, water sports (sailing and canoeing), marine studies, carnivals and night shows (usually held indoors). The centre is also used for conferences and Southern Cross University's Sports Development Program. The tennis courts and swimming pool are available for community hire (NSW Public Works 1994). Areas where particular activities are carried out in and around Lake Ainsworth and the Sport and Recreation Centre are shown in Figure 5.3.

The programs conducted at the Sport and Recreation Centre are as follows:

- primary school children outdoor education programs, catering for groups of up to 120 students over nine years of age accompanied by seven to eight teachers;
- secondary school adventure programs for groups of about 30 students;
- weekend and community programs (usually on weekends) for 20 to 120 participants;
- seven day family and vacation programs; and
- five day senior adult programs for groups of 10 to 20 participants, which run concurrently with the primary program.

An estimate of the number of camper days per year for each of the centre's programs is provided in Table 5.5.

Table 5.5 Estimated Camper Days per Year at Sport and Recreation Centre

Program	No. of weeks held per year	Estimated Occupancy Rate or No. of Participants	Camper Days per year
Primary and Secondary	41	93% occupancy rate	22,755
Weekend and Community	not stated	20 to 120 (ave 25 participants)	2,020
Family and Vacation	10	79 participants (ave)	5,530
Senior	12 (assumed)	10 to 20	1,200
		Total	**31,505**

(after NSW Public Works 1994)

The total estimated usage is 64% of the Centre's total annual capacity of 49,000 camper days (based on 100% utilisation of the lodges and holiday units).

A master plan (NSW Public Works 1994) provides details on increasing usage and the proposed expansion of the centre and its programs. Table 5.6 shows the proposed program expansion.

Table 5.6 Proposed Sport and Recreation Centre Program Expansion

Program	Participants per week	Assumed Occupancy or No. of Weeks per year	Camper Days
Primary and Secondary	200	93%	38,000
Weekend and Community	200	80%	13,000
Family and Vacation	95 - 110	N/A	7,700
Senior	20	40 weeks/year	4,000
		Total	**62,700**

(after NSW Public Works 1994)

Annual camper days of 62,700 would be a 99% increase on current utilisation levels.

Other potential activities and markets which have been identified for the centre are:

- marine and/or environmental studies for secondary school students;
- marine studies in conjunction with programs offered by Southern Cross University;
- adventure based/peer support programs; and
- corporate management/team building programs.

Long-erm expansion of the centre's facilities includes:

- additional general purpose accommodation for 64 beds;
- additional lodge accommodation for 80 students and five teachers; and
- additional parking (20 overflow spaces, one bus space).

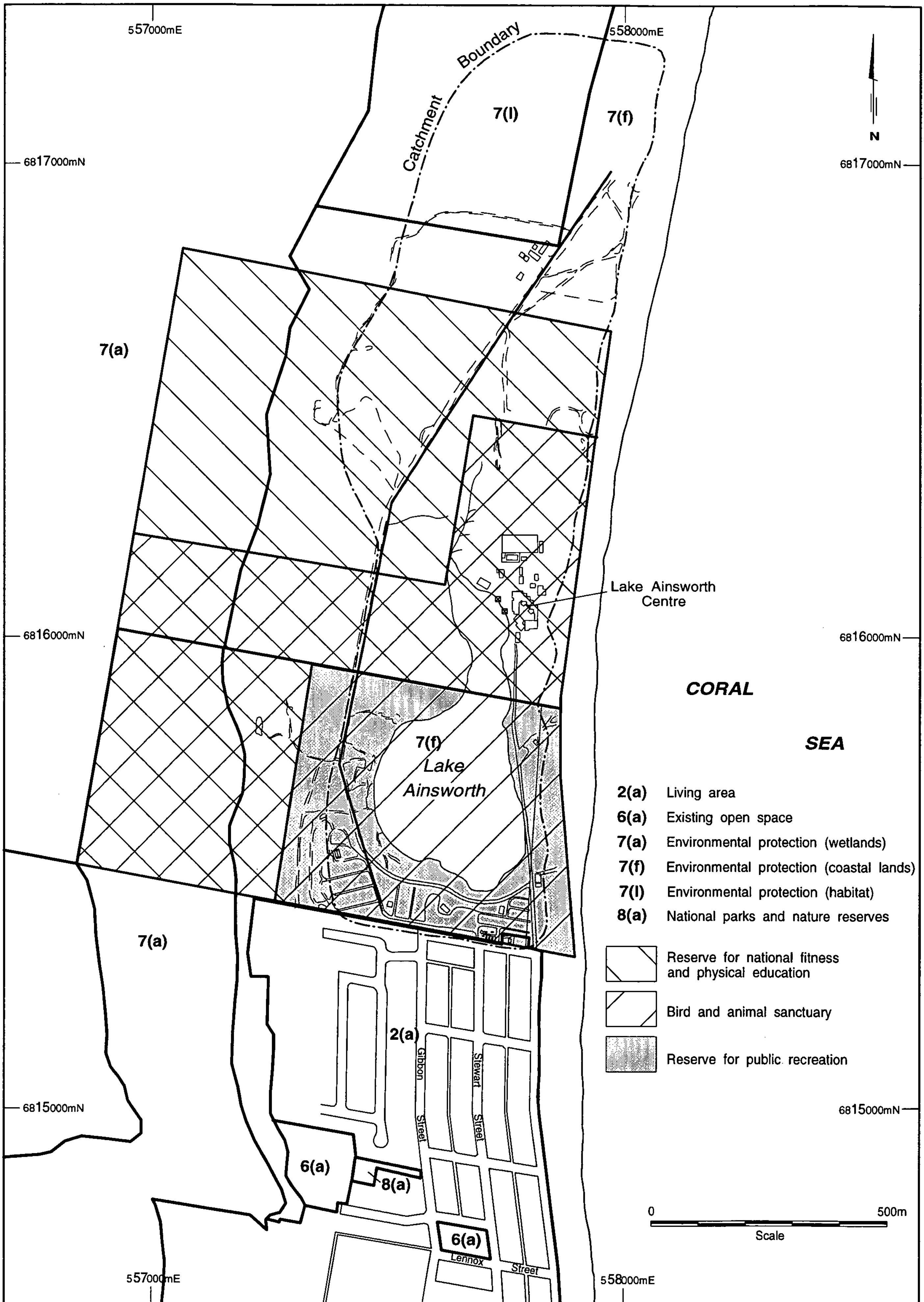
5.4 Aboriginal Archaeology

Aboriginal sites identified within the Ballina local government area include middens, burial sites, campsites, ceremonial grounds, massacre sites and fish traps. Campsites have been recorded to the north of swamp land (Newrybar Swamp) north of Lake Ainsworth, burial grounds to the south of Lake Ainsworth, and the Lennox Head Bora Ring is a short distance to the south-west of the lake (Ballina Shire Council 1982). Six middens have also been recorded at Lennox Head (Collins 1992).

There do not appear to have been any archaeological studies undertaken for Lake Ainsworth, however a survey was carried out by Collins (1992) for a subdivision to the south of the lake. Four open camp sites containing stone artefacts were identified in the subdivision area and a few artefacts were found outside the site, two on a shell midden.

Based on the distribution of known sites and those identified during the survey, Collins concluded that it was likely that groups which were involved in initiations and other bora-related activities camped in discrete localities around the margins of the swamp and along the coastal foredunes. The open campsites identified were of a type well represented on the north coast and most of the artefacts were thought to have suffered some disturbance due to land clearing, with other sites possibly covered by landfill. Collins also noted that sites in Lennox Head had either been completely destroyed or badly disturbed by urban development. In addition, sites to the north and east of Lake Ainsworth would have been destroyed or disturbed by mining for mineral sands. Middens may also have been covered by drifting sands and vegetation.

The Jali people are the traditional owners of the land around Lake Ainsworth. Although there are no known people with traditional knowledge of the Lennox Head area, the area has significance to the contemporary Jali people because of the existence of the bora ring (National Parks and Wildlife Service (NPWS) site register No. 4-5-29) and the large open campsite adjoining swamp land which contains an in situ burial (site register No. 4-5-94) (Collins 1992). Jolander Nayutah (pers. comm.) from the Gungil Jindabah Centre at Southern Cross University also advised that Lake Ainsworth is the subject of a dreaming story relating to three Bundjalung brothers, which has been documented by NPWS officers.



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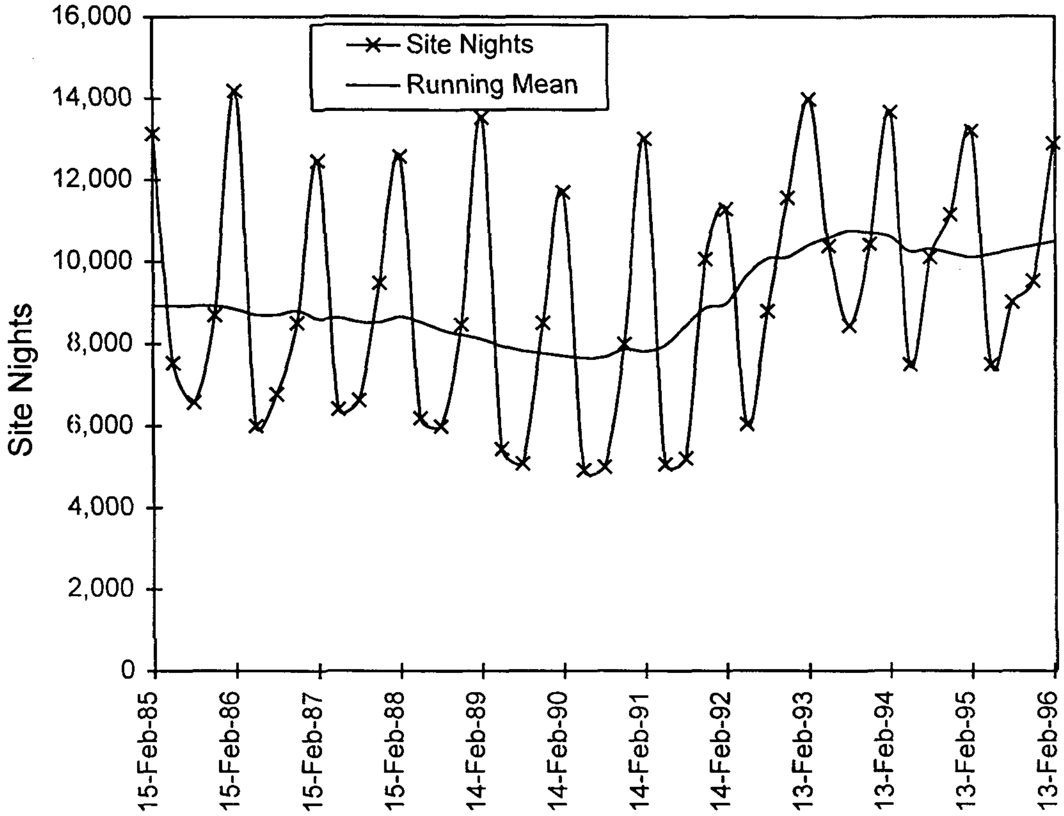
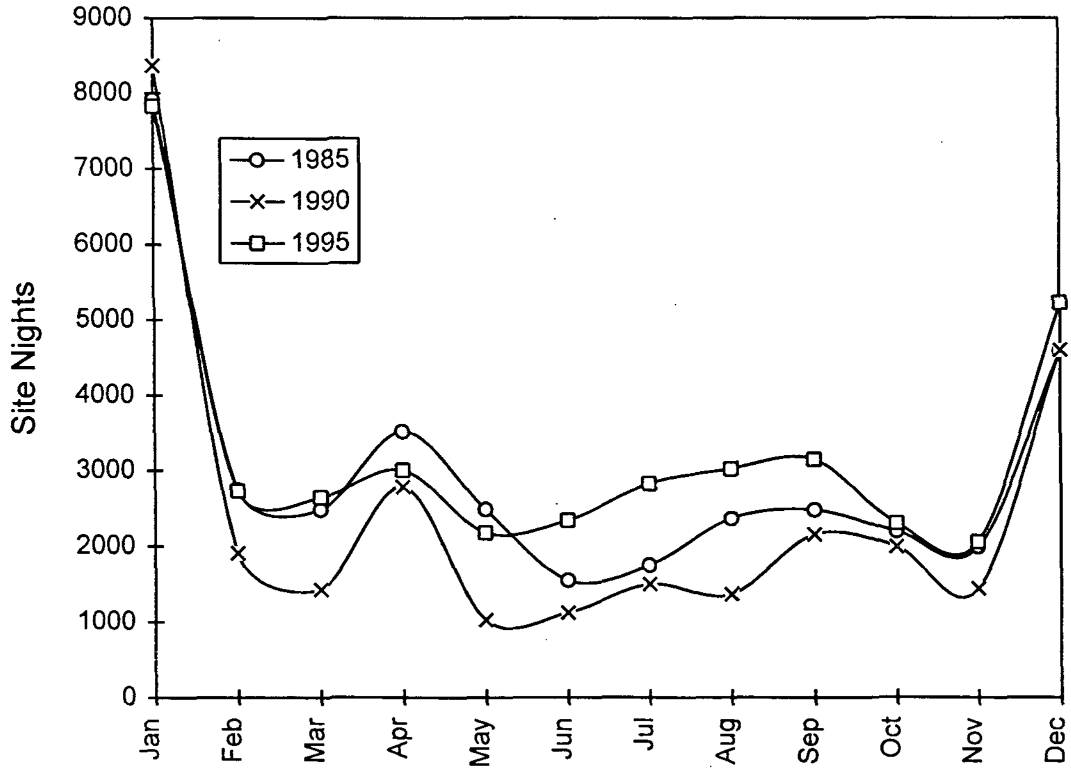
BALLINA COUNCIL ZONING AND RESERVE BOUNDARIES

Figure 5.1





AWACS Report No. 96/07	LAKE AINSWORTH CARAVAN PARK ACCOMMODATION DATA	Figure 5.2

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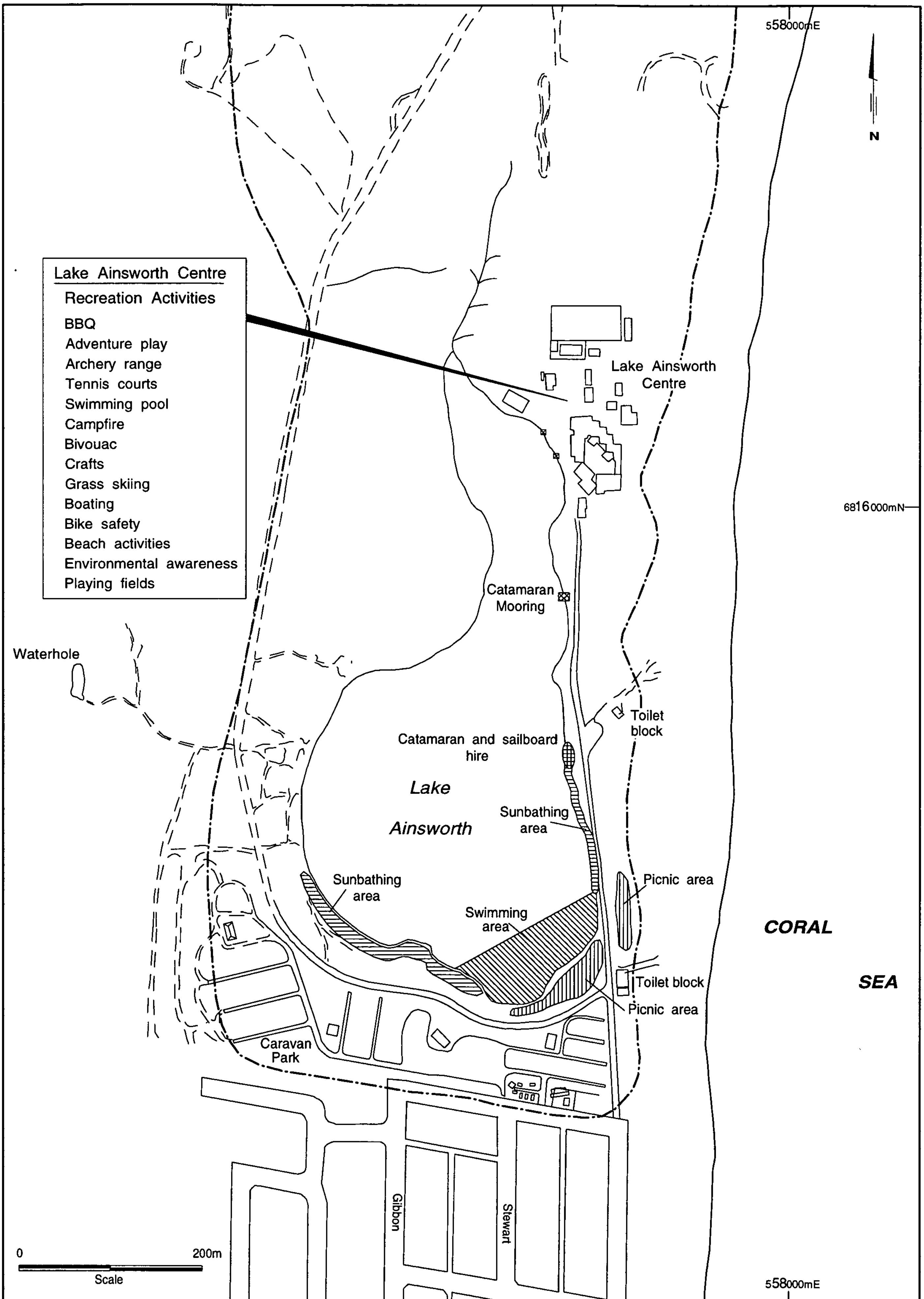

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RECREATIONAL USE

Figure 5.3

6. Lake Ainsworth Characteristics and Processes

6.1 Overview of Processes

The processes affecting the lake are depicted in Figure 6.1. The lake is subject to changes in water throughflow due to rainfall, surface runoff and groundwater which import nutrients and other matter into the system. The nutrients enter the lake in different forms that are either available for uptake by plants, macrophytes at the lake edge or microalgae (phytoplankton and cyanobacteria) in the water column, or settle to the lake bed. Microbial processes at the lake bed consume oxygen and convert the nutrients into different forms that again become available for release from the sediment (under the right conditions) to enter the water column where they may again be taken up by the plants.

Energy inputs including solar heating (thermal energy), wind (kinetic energy) and inflows determine the vertical stratification that is important for mixing and transport of material (eg. oxygen) between the surface and deeper waters.

Other processes affecting the lake include sedimentation, foreshore erosion, coastal dune erosion and variations in composition and abundance of flora and fauna species.

All of the processes are affected to varying degrees by human impacts.

The following sections attempt to quantify the magnitude of the various processes and to assess the relative importance of each for Lake Ainsworth. Through this process the important issues for lake management can be identified. In many cases there is a lack of long-term data which restricts the extent of understanding of processes.

6.2 Flora and Fauna

An assessment of flora and fauna was carried out by The Ecology Lab (Appendix E) and those results are summarised here.

Much of the littoral and riparian vegetation of Lake Ainsworth has been cleared to provide space for recreational activities, such as swimming, camping, boating and tennis; and since there is no data on the status of the lake prior to clearing, it is not possible to quantify what impact, if any, this has had on the lake.

The catchment to the north of the lake includes extensive areas of low-lying coastal heath, dominated by coast banksia (*Banksia integrifolia*) and other heath species such as tea trees (*Leptospermum laevigatum*), broom heath (*Monotoca* sp.) and wattles (*Acacia* sp.). The area to the north-east has been cleared for the Sport and Recreation Camp.

The dunal complex to the east includes Bitou bush (*Chrysanthemoides monilifera* ssp. *rotundata*), coast banksia, wattles and tuckeroo (*Cupanopsis anacardioides*). The land south of the lake comprises the village of Lennox Head, and the only vegetation remaining is a few paperbark (*Melaleuca quinquenervia*) trees near the water's edge. The Lennox Head Caravan Park occupies the area immediately south of the lake and is comprised of grassed areas with a few trees.

Low heath vegetation (as described above) stretches for about 500 m west of the lake, and further west is a SEPP 14 Wetland that appears to be dominated by paperbarks and eucalypts.

During the 1960s most of the eastern and southern portions of the lake were cleared of nearly all riparian and littoral vegetation to provide areas for recreation. The southern corner is occasionally dredged to replenish the lake's "beaches" with sand. The few remaining exceptions are stands of cumbungi (*Typha orientalis*) and some paperbarks (Don Apps, pers comm). Recreational use of the foreshore may be preventing the cumbungi from recolonising more of the south-western corner. The Lennox Head Residents Association has recently planted 13 clusters of trees on the eastern shoreline, comprising paperbarks and some self-sown casurinas, in an attempt to restore the foreshore and the water quality of the lake (Don Apps, pers comm). Trampling prohibits the growth of emergent macrophytes, such as rushes or sedges, although some exist around the paperbarks that hang over the water's edge in the north-eastern corner. In this area there is also a large stand of waterlily, probably *Nymphaea violacea*.

The western fringe of the lake is bordered almost completely by cumbungi, except for areas that appear to have been cleared for boating and/or camping purposes. Growing on the land behind the cumbungi are paperbarks, tea-trees and banksias. The north-western corner consists of a mosaic of macrophytes, particularly waterlilies, creepers (water primrose, *Ludwigia peploides* ssp. *montevidensis*), rushes (Family Juncaceae and Cyperaceae), grasses (Family Gramineae) and several free-floating species (Family Azollaceae and Lemnaceae). The riparian vegetation in this area is mostly paperbark swamp, with an understorey of ferns (Family Dennstaedtiaceae), tea-trees and other heath species, and in the north-eastern corner there were also a few cycads.

The few aquatic fauna studies done on Lake Ainsworth have not been comprehensive. They suggest, however, that very few species inhabit Lake Ainsworth and that exotic species may be out-competing the native species (Timms 1982). Native fish previously found in Lake Ainsworth include firetailed gudgeons (*Hypseleotris galii*) and the freshwater or eel-tailed catfish (*Tandanus tandanus*) (Timms 1982, Saenger 1988). The only other fish known to inhabit the lake is an exotic species, the mosquitofish (*Gambusia holbrooki*), an adaptable and aggressive feeder that is believed to have already modified the Lake Ainsworth ecosystem (Timms 1982). Although several native species of amphibians are known to inhabit Lake Ainsworth, cane toads (*Bufo marinus*), an exotic species which is a very successful breeder, dominate the foreshore of the lake (Warren 1994).

During the field investigations in February only two species of fish, firetailed gudgeon (*Hypseleotris galii*) and mosquitofish *Gambusia holbrooki*), were caught in the beach seines and dip nets. In addition, cane toad (*Bufo marinus*) tadpoles and dragonfly larvae (Odonata) were collected in the seine.

The grass area in front of the Sport and Recreation Centre had hundreds of juvenile cane toads on it, and there were easily as many tadpoles at the water's edge. Staff from the Centre said that the drought had drastically reduced their numbers, but the recent break in the drought had triggered their spawning.

Invertebrates in Lake Ainsworth were studied by Bayly (1964), Timms (1982) and Saenger (1988). Timms suggested that the presence of the fish and the paucity of littoral vegetation account for a reduction in diversity and abundance of invertebrates compared to what he expected. The benthos sampled included several species of insect larvae (see Timms 1982; Saenger 1988), and the zooplankton contained a single species of crustacean, the copepod *Calamoecia tasmanica*, and occasionally an identified planktonic watermite (Timms 1982). *Eucyclops nichollsi* was often found in the littoral region, occasionally accompanied by *Macrocyclops albidus* (Bayly 1964). Sampling on 8 February found very small numbers of organisms with only 11 individuals from four insect orders collected. The lack of plants that act as refuges may be very important in increasing the grazing pressure on zooplankton by fish, such as Gambusia.

Assessment of a series of aerial photos from 1947 indicate the lake has changed very little in size or shape over the period. The littoral vegetation in the northern and south-western corners appears to have extended further into the lake over time. In the south-western corner, between 1984 and 1994, this increase was estimated to be approximately 25 m. The most notable change in the lake vegetation is the extent of cover in the north-western corner, and the length of the channel that stretches into the adjacent heathland. This corner of the lake is probably less exposed to the wind, which may promote plant growth. During 1980 the lake was considerably longer than in the 1994 photo, based on the extended 'wet' area far into the north-western corner. This extended area still existed in 1984. The only other notable feature observed in the 1947 photos is a possible breach in the dune, connecting the lake to the beach. It is not possible to determine from the photo if seawater entered the lake at this time.

The aerial photos suggest that the vegetation of the catchment has undergone continual change, particularly to the south and more recently to the south-west of the lake. Roads exist to the west and east of the lake, and clearing on a large scale has taken place during the construction and subsequent expansion of the Sport and Recreation Camp which now includes sports fields to the north of the camp. The photos show that the village of Lennox Head has expanded westward, removing more of the heath and wetland in the catchment and exposing the sandy soil.

Results of the present survey confirmed the findings of earlier studies, particularly with respect to the relatively depauperate nature of fish and aquatic invertebrates. There were, however, some flora and fauna that were not encountered in this study, including salvinia in the wetlands, oligochaetes in the benthic samples and catfish and crayfish in the seine or dip net samples.

The western and northern sections of Lake Ainsworth are considered to be well vegetated in the catchment and in the riparian zone. The clearing that has occurred in the outer catchment may have contributed to increased nutrients entering the lake but it is not possible to quantify these changes.

6.3 Surface Runoff Catchment Characteristics

The surface runoff catchment of Lake Ainsworth consists of mainly urban and natural catchment areas. The catchment boundary shown in Figure 6.3 was defined after examining orthophoto maps for the locality and from information supplied by Council's drainage engineers. The extent of the catchment to the north is difficult to define and may be considered as arbitrary since the area has limited topographic definition to assist with the boundary definition. To the south the catchment extends to Ross Street, to the west the catchment extends to the unsealed road leading to Camp Drewe and to the east to the dune system. This produces a total catchment area of 76.3 hectares. The catchment was divided into 10 subcatchments (Figure 6.3) to consider the urbanised nature of some areas. The catchment in general is of relatively flat slopes except on the eastern side.

Catchment one consists of a large grassed area, natural areas, half of Camp Drewe. Catchment two consists of the Lake Ainsworth Sport and Recreation Centre which has a network of sealed roads, grassed areas and a number of buildings. Catchment three consists of a flat grassed area and steep dune areas. Catchment four has mainly the sealed road access to the Sport and Recreation Centre along with a lower dune area. Catchments five, six and seven incorporate the caravan park which is mainly a grassed area with a few sealed roads. Catchment eight is partly taken up with the caravan park and partly natural areas of relatively dense vegetation. Catchments nine and ten are mainly natural areas of dense scrub vegetation with Catchment ten having the other half of Camp Drewe.

6.4 Local Hydrogeology

A conceptual model for the local hydrogeology has been developed.

The lake occupies a depression entirely within the WSU. Below a level of about 4 m below AHD the WSU becomes indurated with humic matter that significantly reduces groundwater flows. The majority of inflow to and outflow from the lake will therefore occur through the upper sands.

As discussed in Section 6.5 a thick gelatinous organic rich layer is present on the lake base and lower side walls. Consolidation of organic matter has formed a dense organic silt layer at the interface with the aquifer sands. This layer is believed to act as an obstruction to groundwater flow further lowering the flow of groundwater to and from the lake through its base and lower side walls.

Groundwater flows into the lake predominantly from the west and south, and flows out of the lake through the eastern dunes into the ocean. Outflow can, however, be significantly affected by high tides and storm surges and at times groundwater flow can be in the direction from the ocean to the lake. However, these events are relatively short and saline intrusions are unlikely to penetrate to the lake with the present dunal system. A conceptual model of flows to and from the lake is presented in Figure 6.4. It can be seen that the groundwater catchment does not coincide with the surface runoff catchment.

The groundwater in the upper part of the aquifer is generally acidic and strongly coloured by humic substances, while water in the lower aquifer shows no colouration at depth below the indurated layer.

Fresher water tends to move from the north-west towards the lake, and there is a slightly fresher mound of water beneath the town.

Humic substances make up the majority of total organic carbon (TOC) in the groundwater. TOC is a measure of the amount of "food" available to microbes in the groundwater. TOC is highest in the swampy area west of the lake and reduces towards the ocean.

Total phosphate concentrations in the groundwater are generally less than 2 mg/L. Apparent sources of phosphates are in the township west of Gibbons Street and the State Sport and Recreation Camp site.

Total nitrogen concentrations in the groundwater are generally less than 4 mg/L. The area west of Gibbons Street also appears to be a source of total nitrogen, possibly associated with the bowling club and house gardens.

Porewater samples from cores taken from the bed of Lake Ainsworth had TOC levels in the range of 30-100 mg/L of carbon, indicating sediments rich in organics of leaf litter origin associated with swampy ground or shallow surface waters. Anaerobic microbiological processes usually occur in such environments. Porewater in sediments in the deepest parts of Lake Ainsworth have higher nutrient levels than in sediments in shallower water.

6.5 Lake Morphology, Sediments and Sedimentation

Lake sediments, morphology and sedimentation are discussed below based on the report by Coastal & Marine Geosciences reproduced as Appendix E. Much of the data used in describing these topics was collected during the field exercise from 5-9 February 1996.

6.5.1 Lake Morphology

The lake bathymetry is presented in Figure 6.5. At the time of the survey the greatest water depth was approximately 8 metres or 6 metres below AHD. There are in effect two basins; a deep eastern basin elongated north-south and a shallower and shorter western basin with the same north-south alignment. The bathymetry appears to closely reflect the adjacent barrier morphology, with the lake basins being extensions of the barrier swales, and the submerged separating ridge being extensions of the dune ridge (Figure 4.7).

The lake surface area and volume at 0.5 m depth intervals were estimated from the bathymetric data (Figure 6.6) using the trapezoidal rule as implemented in the SURFER™ software package (Golden Software 1994). The lake balance calculations require a relationship between lake water level, h, and lake surface area, A, and lake volume, V. Third order polynomials were fitted to these data using the least squares method to optimise the polynomial coefficients resulting in the relationships

$$\text{Lake area } A(h) = 86465 + 22117\,h + 2211\,h^2 + 131\,h^3 \quad (6.1)$$

and

$$\text{Lake volume } V(h) = 237508 + 86999\,h + 10433\,h^2 + 415\,h^3 \quad (6.2)$$

These lines of best fit are shown in Figure 6.6.

6.5.2 Lake Sediments

The lake bed has two distinct surface sediment types as shown in Figure 6.7. Sandy sediments, consisting of well sorted medium grained quartz sands occur in the shallower depths down to about 4 m below AHD around the perimeter of the lake, and are similar to the sediments in the adjacent barrier deposits. Gelatinous organic rich muds consisting mainly of decaying plants occur in the deeper central part of the lake.

Generalised stratigraphy of the lake is presented in Figure 4.9. While the thickness of the organic rich muds is uncertain, the data available indicates that at the deepest parts of the lake it is in the range of 4-6 metres.

Surface sediment samples taken from the lake for this study were analysed for total phosphorus (TP), total kjeldahl nitrogen (TKN), total organic carbon (TOC) and total inorganic carbon (TIC) as documented in Appendix D. Analyses of metals concentrations on selected samples showed very low concentrations except for analysis of zinc.

Inorganic carbon was low in all samples, indicating very little shell material in the sediments.

A sample taken from the sandy sediments around the margins of the lake had low organic carbon content and low total phosphorus. Sediment samples from the organic rich muds in the central portions of the lake have relatively high organic carbon content as well as relatively high TKN and TP concentrations, presumably from the accumulation of plant litter and the associated biological activity.

Generally concentrations of heavy metals within the sediments are within background levels for NSW coastal and estuarine sediments.

6.5.3 Lake Formation and Sedimentation

Hudson (1996) presents a conceptual model of the initial formation and subsequent infilling of the lake. Erosion of the Pleistocene barrier by storm surge to form the lake basin has been postulated. Subsequent deposition of the Holocene outer barrier would have blocked the eastern boundary of the basin. With rising sea level, the associated rise in regional groundwater would have led to the formation of the lake in the depression.

Recent historical data indicates there has been little modification to the lake in the last 50 years. Aerial photography from 1947 to 1994 indicates there has been little change to the shape of the shoreline, and there is no evidence of delta-type features to indicate sedimentation due to local runoff. Lake sedimentation is characterised by accumulation of organic material in the deeper sections of the lake with little modification of the shallower sandy areas around the lake's margin. Based on radiocarbon dating described in Appendix C, it has been estimated that the sedimentation rate for the organic material is about 0.4 mm per year.

An estimate of contemporary sediment input to the lake has been undertaken using the Universal Soil Loss Equation.

USLE

The sediment input from the surface runoff catchments (Figure 6.3) to Lake Ainsworth has been estimated using the Universal Soil Loss Equation (USLE). The USLE is an empirical equation for prediction of long-term, average annual soil loss from sheet and rill flow at a nominated site. Its origin was in the USA where there was a need to estimate the soil loss from agricultural areas. It was subsequently adapted for Australian agricultural conditions by the Soil Conservation Service (now DLWC) and packaged in a computer program SOILOSS (Rosewell and Edwards 1988) and for urban conditions by the NSW Department of Housing (1993).

The limitations of the USLE are that it only predicts sediment entrained, not sediment yield, is effective for sheet and rill flow only and not for concentrated flow and does not adequately account for soil dispersibility in the assessment of the K factor. However, there are few alternatives for the prediction of sediment loss from a catchment and thus the USLE is used here with due regard to its limitations.

The USLE is written as:

$$A = R\,K\,L\,S\,P\,C \qquad (6.3)$$

where: A = Computed soil loss (tonnes/ha/yr)

Soil loss can be equated to the sediment flux into a retardation basin given certain assumptions. The main assumption is that all soil entrained during runoff is transported off the site and directly into the sediment retardation basin (Lake Ainsworth). Clearly it will over-estimate the sediment input into the lake. In this instance the volume of sediment entering within a year (m^3) is given as :

Volume = (mass of dry delivered sediment / density of saturated sediment)

The conversion factor for tonnes/year to m^3/year is 1.3.

R = rainfall erosivity factor

A measure of the ability of rainfall to cause erosion. R is dependent upon the rainfall intensity of the two-year average recurrence interval (ARI), six-hour storm event (I) (Rosewell and Turner 1992), such that

$$R = 29.22\, I^{1.89}$$

The rainfall intensity was calculated using the method and values from Australian Rainfall and Runoff (Pilgrim 1987) for the Lake Ainsworth area and found to be 15.22 mm/hour. The rainfall erosivity factor was calculated to be 5017.

K = slope erodibility factor

A measure of the susceptibility of soil particles to detachment and transport by rainfall and runoff. K is a quantitative value experimentally derived and site specific. It is obtained from laboratory test results or from tables equating K with various soil landscapes. K values generally range between 0.01 and 0.045 (NSW Department of Housing 1993). In the case of Lake Ainsworth the soils in the catchment are generally sandy and poorly sorted (SP). For SP soils Table 12.1 (ibid) gives values for K ranging from 0.005-0.042. A value of 0.015 is assumed to be appropriate.

LS = slope length-gradient factor

A description of the effect of slope length and gradient upon soil loss. Slope length and gradient can be determined from orthophoto maps, Table 12.2 (ibid) is then used to get LS. The choice of L involves judgement; different users choose different slope lengths for similar situations. As a guide to sensitivity, a 10% error in slope length translates as a 5% error in computed soil loss and a 10% error in gradient gives a 20% error in computed soil loss (Lab 1994).

For Lake Ainsworth, LS varies for each sub-catchment. L was taken as an average of what was judged to be the largest, smallest and mean slope length for each site. S was taken as an average of what was judged to be the largest, smallest and mean slope for each site. LS is determined from Table 12.2 in NSW Department of Housing (1993), Figure 4.2 in Beasly (1972) and Table 5.5 in Goldman et al (1986).

P = erosion control practice factor

A measure of how surface conditions affect flow paths and flow hydraulics on the site. A description of the surface condition is determined from the site or from aerial photographs and P is estimated from tables (Goldman et al 1986).

It has been assumed that P = 1.0 for all sub-catchments. Values range from 0.8 to 1.3 in the literature thus an estimate of 1.0 will give a small error in relation to other assumptions. There is limited data for estimates of P for naturally vegetated and urbanised catchments.

C = ground control and management factor (cover factor)

The ratio of soil loss from a site under specified crop or mulch condition to the loss from tilled, bare soil. C is the most easily determined factor of the USLE. The cover type is determined from the sub-catchment and C taken directly from or estimated from tables. Values for C range from 0.01 for undisturbed native vegetation (99% reduction in soil loss) to 1.0 for uncovered soil.

C varies between sub-catchments. C was taken as 0.01 for native vegetation catchments and the sealed surface caravan park area, 0.1 for the ovals to the north-east of the lake and 1 for the eroded foreshore areas to the south. An average value was assumed for sites with more than one cover type.

The values for each variable and the computed loss in cubic metres per year is shown in Table 6.1.

Table 6.1 Application of USLE to Lake Ainsworth Sub-Catchments

No	L (m)	S (%)	LS	K	R	P	C	A	Area (ha)	Loss (m^3/yr)
1	416	2.5	2	0.015	5017	1	0.055	8.28	10	63.68
2	146	5.8*	1.4	0.015	5017	1	0.04	4.21	2.36	7.66
3	92	9.3*	2.16	0.015	5017	1	0.04	6.50	1.81	9.07
4	71	7.3	1.35	0.015	5017	1	0.208	21.13	2.45	39.88
5	123	2.9	0.64	0.015	5017	1	0.109	5.25	1.00	4.03
6	120	2.1	0.45	0.015	5017	1	0.208	7.04	1.54	8.32
7	161	3.1	0.75	0.015	5017	1	0.307	17.33	2.05	27.37
8	131	2.2	0.55	0.015	5017	1	0.01	0.41	3.48	1.11
9	196	1.4	0.4	0.015	5017	1	0.01	0.30	4.95	1.15
10	733	0.8	0.45	0.015	5017	1	0.01	0.34	27.74	7.23
									Total	**169.49**

Results indicate a sensitivity to amount of cover and slope:

- Assuming the ovals to the north-east are fully covered all year (C=0.01) total sediment input to the lake becomes 105 m^3/year.

- Taking this assumption and combining it with the assumption that the exposed foreshores to the south are covered at least half the year gives a total sediment input of 66 m^3/year.

- The estimate of exposed foreshore affects sediment input significantly. A 5% overestimate gives an input of 187 m^3/year, while a 5% underestimate gives an input of 152 m^3/year.

- A slope of 1% at site 1 gives 104 m^3/year while a slope length of 1160 m and slope of 1% gives 107 m^3/year.

Comparing the calculated volume of sediment entering the lake per year with the total lake volume it is of the order of 0.05% of the total lake volume. If the calculated sediment load was to persist it would take 2500 years for the lake to be infilled. Considering the depth rate of change per year the sediment analysis contained in Hudson (1996) suggests that sandy material deposition is restricted to the perimeter of the lake. Assuming that this area is approximately two thirds of the lake area it can be calculated that this area will infill at a maximum rate of approximately 1 mm per year. The empirical nature of the USLE and its inherent limitations mean that the estimate is indicative only and the morphological evidence suggests the rate may be significantly less than this estimate.

It appears that local wave climate restricts the accumulation of the organic-rich muds to the deeper and more protected portions of the lake. Layers of fine sand within the organic muds may be the result of sand blown from the barrier to the east.

It is concluded that there are slow rates of lake sedimentation dominated by the accumulation of organic-rich material.

6.5.4 Foreshore Erosion

Foreshore erosion along the southern shore has been highlighted as a problem by local residents. Some 18 months ago sand was dredged from the eastern side of the lake to nourish the beaches along the lake's foreshore and some areas were turfed to control erosion. Areas of foreshore erosion have been observed to develop where lake water level rises after rain inundating the foreshores and killing the grass cover. When lake water level recedes, bare sand areas are eroded by foot traffic and wind (B. Smith pers comm). Regular maintenance of bare areas will be required to reduce this form of foreshore erosion.

In general, one might expect that significant foreshore erosion would be caused by wind waves and boating activity. The dominant wind climate for Lake Ainsworth is from the south-east which would only lead to erosion on the northern side of the lake. This would only occur if the distance across the lake was significant, in this case it is not. Boating activity on the lake is not of the nature that would lead to foreshore erosion. The reported erosion is most likely to be related to runoff from the sealed access road to the Sport and Recreation Centre and at locations where piped stormwater from the caravan park is discharged to the lake. This road is within 10 m of the lake and its impervious nature will convey runoff to the lake in a faster way than pervious areas. This flow has erosive potential and since the strip of land between the road and the lake has no erosion control the foreshore can be eroded.

From assessment of aerial photographs of this area it would appear that the foreshore has not been significantly eroded, with the road being in place from the earliest historical photographs in the late 1940s. Extensive foreshore erosion would be indicated by the undermining of this road. However, following discussions with Council personnel and local residents it would appear that the road has not been undermined and hence extensive foreshore erosion has not occurred.

To curb any erosion that may occur in these areas it is suggested that erosion control measures, such as planting a strip of vegetation along the edge of the road, be considered.

6.6 Lake Water Levels and Water Budget

The lake water volume and surface level are determined by a balance between inflows to the lake and outflows from the lake. Direct rainfall on the lake surface, surface water runoff from the local catchment and groundwater flows into the lake through the western and southern boundaries contribute to the total inflow. Outflows from the lake are comprised of evaporation from the lake surface and groundwater discharge through the eastern boundary toward the sea (Figure 6.8). The relative importance of each of these contributions is described below.

6.6.1 Lake Levels

The lake water levels have been monitored by a water level gauge operated by Manly Hydraulics Laboratory since October 1994. Rainfall is also recorded at the same site.

The immediate response of the lake water level to the intense rainfall event of 21 February 1996 is shown in Figure 6.9.

The water level recorder has a resolution of 1 cm and the small fluctuations between 22 and 23 February are an artefact of this resolution. Total daily rainfall on 21 February was 104 mm which caused an increase in lake water level of about 7 cm.

The longer-term water level variability is shown in Figure 6.10 and Appendix B (Figures B1 to B6). The groundwater level to the east of the lake from Bore C (Figure 1.2) and the daily mean ocean water level are also presented. The influence of intense rainfall is again obvious. The decrease in water level during dry periods is also indicated. Note the water table levels (as indicated by Bore C) show a similar long-term trend to the lake level but the response to rainfall recharge is larger and the decrease after the event is more rapid than in the lake.

The implications of these observations for the lake water budget are discussed in the following sections.

6.6.2 Rainfall and Evaporation

The rate of change of lake volume due to direct rainfall (Figure 6.9) on the lake surface, Q_{Rain} ($m^3 d^{-1}$), may be estimated from:

$$Q_{Rain} = R \frac{A(h)}{1000} \tag{6.4}$$

where R is the rainfall in mm/day and
A(h) is the lake surface area in m^2 given by equation (6.1)

Daily rainfall data have been recorded at the lake since November 1994 and using these data in equation (6.4) the flow into the lake has been computed and is shown in Figure 6.11.

The loss of volume due to evaporation from the lake surface was estimated using the monthly average evaporation rates for Brisbane as no local recordings of evaporation were available. Evaporative losses from the lake, Q_{Evap} ($m^3 d^{-1}$), are estimated from

$$Q_{Evap} = \frac{E\,A(h)}{1000} \tag{6.5}$$

where E is monthly average evaporation in mm/day.

6.6.3 Groundwater and Lake Level

Groundwater flows form an important contribution to the lake water, heat, nutrient and chemistry budgets. Groundwater flows into the lake, Q_{Gin} ($m^3 d^{-1}$), and out of the lake, Q_{Gout} ($m^3 d^{-1}$), were estimated using Darcy's equation:

$$Q = k\,i\,A \tag{6.6}$$

where k is the hydraulic conductivity in $m\ d^{-1}$
i is the hydraulic gradient, and
A is the cross-sectional area of the aquifer.

Daniels and Beck (1996) discuss the determination of K, *i* and A for inflow regions to the west and south of the lake and for the outflow aquifer to the east.

The hydraulic gradient to the east of the lake, between the lake and the ocean, has been estimated for the period 1994 to February 1996 using the water levels monitored in the coastal bore C (Turner 1995) and in the lake:

$$i(t) = \frac{h(t) - h_C(t)}{L} \quad (6.7)$$

where $h(t)$ is the lake water level in m (AHD) at time t
$h_C(t)$ is the water level in bore C in m (AHD) at time t, and
L is the separation distance between the lake and bore C (144 m).

Assuming a hydraulic conductivity of k = 35 m/day for the sandy aquifer to the east of the lake (Turner 1995) and cross-sectional area of aquifer 5 m deep x 500 m long (Daniels and Beck 1996), then the groundwater discharge from the lake calculated using (6.6) and (6.7) is shown in Figure 6.11.

There are no concurrent time series data on the water table levels to the west of the lake to match the lake water level measurements. Recent measurements taken in bores to the south of the lake and in the water hole to the west may be used to provide an estimate of the hydraulic gradient of the groundwater inflow only at those times.

Daniels and Beck (1996) describe the measurements and procedure for estimating the groundwater inflow Q_{Gin}. The measurements from the south gave a hydraulic gradient of 0.0020 (1 in 500) and 0.0017 (1 in 600) from the west. The contributions to groundwater inflow from the south (Aquifer area 1200 m^2) and west (aquifer area 2855 m^2) were estimated as 170 m^3 d^{-1} for the western shore and 84 m^3 d^{-1} for the southern shore giving a total inflow Q_{Gin} = 254 m^3 d^{-1}.

Daily estimates of the inflow for the period November 1994 to March 1996 may be gleaned from the water balance and are discussed below (Section 6.6.5).

6.6.4 Surface Runoff

As discussed in Chapter 3 the surface runoff catchment for the lake is very small (76.4 ha) and there are no perennial surface water inflows to the lake. Much of the local catchment is comprised of coastal heath with sandy soils (~51.5 ha) and the urban areas to the south of the lake cover the remaining 24.9 ha of the surface inflow catchment.

Assuming the surface runoff responds directly to the rain and that rainfall must exceed a threshhold value prior to the initiation of runoff (ie drizzle will not generate runoff because it seeps into the soil) then the runoff discharge, Q_{Runoff} (m^3 d^{-1}), may be calculated (Phillips et al 1992):

$$Q_{Runoff} = (0.22R - 0.15)10\,A_{urban} + (0.05R - 0.04)\,10\,A_{heath} \quad (6.8)$$

where R is the daily rainfall in mm
A_{urban} is the urban catchment area (24.92 ha), and
A_{heath} is the coastal heath catchment area (51.45 ha).

The coefficients in the above equation were taken as representative values for runoff from urban areas and sandy coastal heath (Anderson et al 1996).

6.6.5 Lake Water Budget

The water budget for the lake may be described by a balance between inflows due to direct rainfall, surface runoff and groundwater inflows and outflows associated with groundwater and evaporation from the lake surface. This balance affects the lake volume and may be expressed by:

$$\underbrace{\frac{dV}{dt}}_{\text{Rate of change of lake volume}} = \underbrace{Q_{Runoff}}_{\text{Surface Runoff}} + \underbrace{Q_{Rain}}_{\text{Direct Rainfall}} + \underbrace{Q_{Gin}}_{\text{Groundwater Inflow}} - \underbrace{Q_{Gout}}_{\text{Groundwater Outflow}} - \underbrace{Q_{Evap}}_{\text{Evaporation from Lake Surface}} \qquad (6.9)$$

where $V(h)$ is lake volume in m^3 at time (t)
Q_{Runoff} is surface runoff from the local catchment (m^3/day)
Q_{Rain} is direct rainfall on the lake surface area
Q_{Gin} is the groundwater inflow
Q_{Gout} is the groundwater outflow, and
Q_{Evap} is the water loss to evaporation.

The lake level data may be used to calculate the change in lake volume from simple differences:

$$\frac{dV}{dt} = V(t+1) - V(t) \qquad (6.10)$$

where $V(t)$ is the lake volume computed from equation (6.2) using the lake water levels, h(t) on day t and the following day, h(t+1).

The rate of change of volume is shown in Figure 6.11.

Monthly averages of the various terms is equation (6.9) are presented in Table 6.2 along with the estimate for groundwater inflow:

$$Q_{Gin} = \frac{dV}{dt} - Q_{Runoff} - Q_{Rain} + Q_{Gout} + Q_{Evap} \qquad (6.11)$$

These data presented in Figures 6.11 and in Table 6.2 indicate the relative importance of each contribution to the water budget and the dependence on rainfall.

Date	Height (m)	Area (m^2)	Volume (m^3)	Total Rainfall (mm)	dV/dt	Direct Rainfall (m^3 day^{-1})	Surface Runoff (m^3 day^{-1})	Evaporative Losses (m^3 day^{-1})	Groundwater Outflow (m^3 day^{-1})	Groundwater Inflow [1] (m^3 day^{-1})
Oct 1994	2.04	142031	462468	55.0	- 785	249	89	741	479	55
Nov 1994	1.83	135251	434625	11.0	- 1115	49	16	807	438	64
Dec 1994	2.03	141573	460586	280.5	730	1243	519	929	413	311
Jan 1995	1.86	136248	438711	65.5	- 427	288	99	809	394	388
Feb 1995	1.80	134153	430120	180.5	258	863	337	709	324	90
Mar 1995	1.89	137053	442015	122.0	91	537	200	645	428	427
Apr 1995	1.82	134711	432403	123.0	- 156	551	213	538	406	24
May 1995	1.83	135285	434759	116.5	49	508	172	371	399	138
Jun 1995	1.83	135111	434044	78.5	- 56	353	142	304	377	130
Jul 1996	1.76	133051	425598	13.5	- 494	58	20	318	351	97
Aug 1995	1.68	130405	414753	51.0	- 299	215	81	430	325	160
Sep 1995	1.57	127080	401149	22.5	- 536	95	32	565	321	222
Oct 1995	1.42	122741	383420	40.5	- 573	160	57	641	332	182
Nov 1995	1.41	118439	369788	231.5	677	957	408	684	262	225
Dec 1995	1.54	122318	385496	135.5	- 83	555	228	803	370	271
1995 Average	1.70	130550	416021	1180.5	- 129	428	166	568	357	196
Total					-47138	156382	60487	207312	130389	71607
Jan 1996	1.77	133308	426661	302.0	1354	1292	515	791	449	787
Feb 1996	1.89	132403	427089	217.5	691	1030	395	675	486	384
Mar 1996	2.06	137887	449349	179.0	- 129	824	297	649	514	- 130

[1] Calculated as the residual of the water balance.

Table 6.2 Monthly Averages of the Water Budget Components

During wet months the major inflow to the lake is via direct rainfall on the surface of the lake and during dry periods the groundwater flow is the major source of inflow.

The outflow from the lake is dominated by evaporative losses during periods of low rainfall and by the groundwater discharge when the lake level rises following periods of heavy rainfall.

The magnitude of the various components of the computed water budget requires verification against direct measurements. Recent water level measurements were taken from a number of bores located around the lake (Appendix F). These data were used to derive an estimate of the groundwater inflow, which showed good agreement with the estimates for 1995 computed from equation 6.11.

During the recent monitoring program outlined in Appendix F, the data collected in April and June are considered inadequate, and the data collected in May are considered atypical due to the very high rainfall (Appendix F) to modify the water budget estimated for 1995 with any confidence. However, it would appear that estimates of evaporation and groundwater outflow may be low and estimates of groundwater inflow may also be low.

As discussed in Appendix F, the 1995 rainfall was less than average, being 86% of the median rainfall, and therefore the derived 1995 water budget is reasonably representative of the long term.

6.7 Lake Water Quality and Mixing

6.7.1 Water Quality Time-Series Measurements

A Hydrolab™ quality meter has been deployed at the water level site since November 1995. The instrument records water temperature, conductivity, dissolved oxygen and pH each 15 minutes. The instrument is deployed in a frame fixed to the bottom at a height 1.1 m AHD and hence the water depth to the sensors has varied between 0.2 m and 1.0 m since November 1995. The dissolved oxygen sensor is unreliable after about 1-3 weeks of deployment. The data for the period January to March 1996 with unreliable data removed are presented in Figure 6.12 and the complete data set is shown in Appendix B.

Dissolved oxygen of the near surface waters generally varies between 4 and 8 mg O_2/L with occasional events of lower values down to 2 mg O_2/L. Conductivity (at 25°C) varies between .23 and .28 mS/cm with sudden decreases during rainfall events (compare figures in Appendix B). pH varies diurnally and a slight decline from around 6 in early January to around 5-6 at the end of March was observed. The water temperature shows periods of relatively large (~2°C) diurnal fluctuations and longer period fluctuations.

These data may be used to infer mixing and these aspects are described in Section 6.7.4.

6.7.2 *Solar Radiation and the Heat Budget*

Solar insulation forms an important contribution to the lake processes in two ways; as a source of heat influencing the thermal stratification in the lake and as a source of sunlight for photosynthesising aquatic plants and algae (eg phytoplankton).

The lake heat budget and turbulence mixing within the lake determine the level of vertical stratification in the water column at any given time. The components of the heat budget are illustrated in Figure 6.13. The net flux of heat into the lake is given by (Imboden & Wüest 1994)

$$H_{net} = H_S + H_A + H_W + H_E + H_C + H_P + H_{Gin} + H_{Gout} \qquad (6.12)$$

where the terms on the right side are defined in Table 6.3.

The heat fluxes for the period 6-9 February when a meteorological station was deployed at the lake (Kadluczka et al 1996) are shown in Figure 6.14. As there was no rainfall during this period the precipitative heat flux was zero, $H_P = 0$.

The largest heat flux is associated with short wave radiation and evaporative losses are also large at times. Note the infrared heat fluxes tend to balance. During high rainfall the precipitation heat flux and groundwater inflow may also be contributing significant heat to the lake.

These latter two contributions generally import colder water to the lake and as this water enters the lake either through the surface or through the bottom it mixes with the warmer lake water but has a natural tendency to sink toward the bottom. Because it mixes with the warmer lake water it only sinks to its level of neutral temperature (buoyancy) causing destabilisation of the vertical stratification. This effect has implications for vertical mixing and the transport of deeper waters to the near surface levels.

Table 6.3 Thermal Energy Fluxes to the Lake

(All H-terms are chosen as positive if directed from the air into the water)

Short wave radiation from the sky (direct and diffusive) H_s from measurements	
Infrared radiation from the sky $H_A = (1 - r_A) E_A \sigma T_A^4$	
r_A [-]	reflectance of infrared radiation at water surface. Typical value 0.03
E_A [-]	Emissivity of atmosphere. Typical values between 0.6 and 0.9
σ [W m^{-2} K^{-4}]	Stefan-Boltzmann constant, $\sigma = 5.67\ 10^8$ W m^{-2} K^{-4}
T_A [K]	Absolute temperature of atmosphere
Infrared radiation from the water surface $H_W = E_W \sigma T_W^4$	
E_W [-]	Emissivity of water, approximately 0.97
T_W [-]	Absolute temperature of water surface
Flux of sensible heat (convection) $H_c = -f(u,...) (T_W - T_A)$	
f(u,...) [Wm^{-2} K^{-1}]	Transfer function, depends on wind velocity u and other meteorological parameters, typical values between 3 (u=0) and 15 Wm^{-2} K^{-1} (u≈10 ms^{-1})
Flux of latent heat (evaporation, condensation) $H_E = -f^*(u,...) (e_W - e_A)$	
e_W [mbar]	Water vapor saturation pressure at temperature of water, T_W.
e_A [mbar]	Atmospheric water vapor pressure
f^*(u,..) [Wm^{-2}mbar^{-1}]	Transfer function, Note: f/f* (Bowen coefficient) is roughly constant (≈0.61 mbar K^{-1})
Flux of heat through groundwater inflow $H_{Gin} = \frac{Q_{Gin} \rho C_p T_{in}}{V}$	
Q_{Gin} [m^3 s^{-1}]	inflow flow rate
T_{in} [° C]	inflow temperature
ρ [kg m^{-3}]	water density
Cp [J kg^{-1} K^{-1}]	specific heat of water
V [m^3]	volume of the lake
Flux of heat through groundwater outflow $H_{Gout} = \frac{Q_{Gin} \rho C_p T_{in}}{V}$	
Q_{Gout} [m^3 s^{-1}]	groundwater outflow
T_W [° C]	average water temperature
Flux of heat through precipitation $H_p = \frac{R}{h} \rho C_p T_R$	
R [m s^{-1}]	rainfall
T_R [° C]	temperature of the rain
h [m]	lake level

6.7.3 Water Clarity

Lake Ainsworth is often referred to locally as the 'Coca Cola' lake because of its brown colour which is derived from humic compounds associated with the surrounding Melaleuca vegetation. As a consequence the photic depth is very shallow, typically less than 1 m (Bowling 1989), and the Secchi depth is also very low at 0.3 to 1 m (Bowling 1989; Barlow 1994).

The high light attenuation also affects the depth of penetration of solar radiation. Since solar radiation is absorbed in a shallow surface layer the net effect is for relatively large diurnal fluctuations of the surface temperature. This also tends to develop a linear stratification as compared to clear water lakes where step like structures are more commonly observed (Imberger 1985).

6.7.4 Temperature and Density Stratification

Water circulation plays an important role in the water quality of the lake. Water flow and currents in the lake result from wind forcing, horizontal density differences, inflows and outflows. The presence of vertical stratification causes a layering effect in which horizontal exchange and mixing occurs fairly rapidly (time scales in the order of hours to days) but because vertical mixing is inhibited by the stratification the vertical mixing time is in the order of days to weeks or months (Imberger & Patterson 1990; Imboden & Wüest 1994). Limnologists use the terms epilimnion, metalimnion and hypolimnion to describe the surface mixed layer, the strong density gradient layer immediately below the surface layer and the deeper water, respectively.

The temperature and dissolved oxygen stratification in Lake Ainsworth on 8 February 1996 demonstrate this classic layering with a surface mixed layer, the epilimnion of 1.5 m depth, the metalimnion between 1.5 m and about 4 m depth and the hypolimnion below 4 m (Figure 6.15).

These layers are determined by the water density which, in a fresh water lake is calculated by applying an equation of state to temperature and conductivity (or salinity) measurements as described in the data report (Kadluczka et al 1996). Since the conductivity variations are relatively small its contribution to the water density may be neglected and the temperature signal provides a good approximation to the density

$$\rho(z) = \alpha(T)\, T(z)$$

where $\rho(z)$ is the density at depth z, $T(z)$ the temperature and $\alpha(T)$ the thermal expansion coefficient given by a polynomial (see Kadluczka et al 1996).

The vertical stratification may assist some forms of algae to maintain their position in the near surface photic zone where they attain maximum production. Vertical stratification inhibits vertical mixing that in turn affects the dissolved oxygen and nutrient concentration gradients. Hence it is important to understand the processes that lead to the development and breakdown of vertical stratification.

Development of vertical stratification in the lake occurs in direct response to the daily heating and cooling of the surface waters. During the day solar insolation effectively heats the water causing the temperature to rise while at night convective cooling transfers heat from the lake surface to the atmosphere resulting in a drop in temperature. Because the cooler water is heavier it cascades into and mixes with the warmer water below to form a well mixed layer in the near surface waters. These effects were captured by the thermistor string deployed in the lake from 5 to 9 February 1996 shown in Figure 6.16. The near surface thermistors respond directly to the daily heat flux cycle (Figure 6.16) with the temperature at 0.2 m depth rising to a maximum of around 32.5 °C between 3 and 4 pm and dropping during the night to around 29 °C. Vertical profiles of temperature constructed from the eight thermistors shown in Figure 6.16 indicate the maximum and minimum surface temperatures on 7 and 8 February, respectively. Note that the water temperature below about 2 m depth appears to remain fairly constant over the period of measurements.

The breakdown of stratification or vertical mixing occurs in response to external energy inputs such as wind or large inflows. Note the temperature time series shown in Figure 6.16 at the deeper thermistors (4.2 and 5.8 m depth) show fluctuations of about 0.3°C over periods of around 30 minutes to hours. These fluctuations are typical of internal waves that cause vertical and horizontal motion within the layers and importantly transfer energy from the surface to the deeper layers resulting in mixing at depth. Careful inspection of the temperature at 3.1 m depth indicates that the temperature rises steadily over the last day of the record, 8-9 February. This slight rise is an indication of mixing resulting in heat transfer from the surface to the deeper water but not to the 4.2 m level where the temperature remains roughly constant throughout the five days of deployment.

6.7.5 Vertical Mixing and Dissolved Oxygen

The wind blowing on the lake surface also causes mixing of the surface layer and through energy transfer via internal waves some mixing may result in the deeper layers. Winds during the deployment consisted of a sea breeze cycle with calm overnight conditions followed by gradual build-up of the sea breeze through the morning from around 9 to a peak at around 2 pm that persisted for some five hours before dropping to calm at around 7 pm (Figure 6.17).

The stratification is thus determined by a balance by the thermal energy budget (solar radiation inputs versus convective and evaporative heat losses) and kinetic energy inputs (wind). Solar radiation effectively produces stratification while the convective losses and wind stirring effectively cause mixing. Another contribution to the mixing process is the influx of heat associated with inflows; direct rainfall, surface runoff and groundwater.

The water budget (Section 6.6.5) demonstrated that direct rainfall contributes a significant water volume to the lake. Because rain drops originate in the higher cooler air their temperature is usually colder than the surface temperature, typically around 20°C or cooler during summer. Hence during large rainfall events a significant amount of relatively (to the lake) cold water may enter the lake causing vertical mixing.

The description of the processes affecting stratification may be used to interpret events that lead to the vertical profiles shown in Figure 6.15. Consider the temperature and dissolved oxygen profiles on 8, 21 and 23 February (Figure 6.15). The profile on 8 February is strongly stratified with an anoxic layer below 4 m depth. This anoxic layer implies that the stratification had persisted for some time as dissolved oxygen is depleted most rapidly in the organic-rich sediment.

Between 8 and 21 February two relatively large rainfall events occurred, with 103.5 mm of rain on 15 February and 53.5 mm of rain on 21 February. The event of 15 February resulted in a complete mixing of the water column with near bottom temperature decreasing from 23.5°C to 22°C and an associated replenishment of the dissolved oxygen concentration. Between the events on 15 February and 21 February the stratification developed due to daily heating and the dissolved oxygen depletion in the deeper waters resulted in the formation of an anoxic layer below 8 m. These observations indicate an extremely large dissolved oxygen depletion rate for the organic-rich bottom sediments. The rainfall event on 21 February was not sufficient to completely mix the water again but the strong winds associated with a storm on 22 February (Figure 6.17) resulted in complete mixing as shown in the homogeneous profiles for 23 February which shows vertically homogeneous temperature of 22.4 °C and dissolved oxygen of 8 mg/L.

Profiles collected in the lake on four occasions in May 1996 indicate that the lake was completely mixed (Appendix F). The extreme rainfall that occurred during the period coupled with autumn cooling caused the rapid mixing and hence high dissolved oxygen concentrations in the deeper waters. The lower temperatures also cause a reduction in microbial metabolic rates and hence the oxygen consumption rate is less than in summer.

6.7.6 Waves and Resuspension

Surface waves effectively transfer energy from the surface to the deeper waters causing mixing within the water column and stirring of bottom sediments. The depth to which the effect of surface waves can penetrate depends on the wave height and period. Surface waves are formed by the action of wind stress on the water surface.

Lake Ainswoth is surrounded by vegetation and buildings that effectively shelter the lake water surface from the wind. To the north-east, large stands of Norfolk Island pines in the Sport and Recreation Camp inhibit winds from the northerly quadrant. The southern boundary is somewhat more exposed and winds from the southerly quadrant are most likely to cause the largest waves.

Resuspension of bottom material affects the particulate concentrations in the water column that in turn affects light attenuation and can also lead to significant exchange of pure waters, thereby affecting nutrient concentrations (Arfi et al 1993, Luettich et al 1990).

Particle resuspension may be estimated from the procedure described by Luettich et al (1990) and others (Arfi et al 1993, Gloor et al 1994).

The critical shear velocity for initiation of particle motion may be estimated for the Shield's diagram that relates particle size and density to the lift force required to initiate particle motion. The particle size analysis indicated the inorganic component of the sediment consists of quartz sand with characteristic:

median particle size	$d_{i50} \sim 225\ \mu m$
particle specific gravity	$s_{gi} \sim 2.65$

The organic fractions were not resolved by the particle sizing method and we assume a similar distribution as found in Lake Alpnach, Switzerland (Gloor et al 1994)

$$d_{o50} \sim 10\ \mu m$$
$$s_{go} \sim 1.05$$

Gloor et al (1994) extended the Shield's diagram to low flow range and for the above particle sizes and assuming a bottom shear velocity of $u_* = 1$ mm s^{-1} gives critical shear velocity, u_*, for mobilising the inorganic and organic particles:

$$u_{*ci} \sim 16\ mm\ s^{-1}$$
$$u_{*co} \sim 1.2\ mm\ s^{-1}$$

where subscripts refer to the inorganic and organic fractions respectively.

Assuming the bottom shear stress is dominated by surface waves (occasionally internal seiches may also produce relatively large stresses) then the bottom shear stress may be estimated using the procedure in CERC (1984). For a lake fetch length of F = 500 m and typical wind event $W_{10} = 10$ m s^{-1}, the significant wave height and period in 8 m water depth are:

$$H_s \sim 0.11\ m$$
$$T \sim 1.05\ s$$

The depth is then calculated where the wave friction velocity, U_{*w}, at the bottom is equivalent to the critical particle friction velocity. Using the values above the critical depths h_c, for initiating particle motion by surface waves are:

$$h_{ci} \sim 0.5\ m$$
$$h_{co} \sim 2\ m$$

These estimates indicate that the heavier inorganic sand particles will only be resuspended by waves breaking near the shore and in water depths less than 0.5 m. The fine organic particles will be resuspended to depths of around 2 m and since their settling velocity is low, these particles will be redistributed by horizontal motions leading to accumulation in the deeper waters.

6.7.7 Seasonal Variations in Mixing and Stratification

Wind blowing on the lake surface causes turbulent mixing of near surface waters resulting in a surface mixed layer. As the wind continues the mixed layer deepens at a rate that may be approximated by (Imberger 1985):

$$h(t) = \left(\frac{u_*^4 t^2}{C^2 g'} \right)^{1/3} \tag{6.13}$$

where u_* is the surface friction velocity, t is time from the commencement of the wind, C (~2.2) is a constant and $g' = g\ \Delta\rho/\rho$ is the reduced gravitational acceleration. For a given wind speed (6.13) indicates the rate of deepening depends on the density gradient (g'). This is shown in Figure 6.18 for typical values of the density stratification, $\Delta\rho$.

During autumn and winter, cooling at the lake surface effectively destabilises the stratification and additional energy inputs from the wind will completely mix the lake. That is, for small $\Delta\rho$, weak winds will cause complete mixing to the lake bottom.

After a long dry period (eg in spring) the stratification will have developed to a level such that a strong wind event will only cause the surface mixed layer to deepen to a depth of approximately 4 m. However during winter or soon after a large summer rainfall when the stratification is weak the same wind event will cause mixing over the whole water column.

The development of the stratification, followed by rapid oxygen depletion in deeper stagnant waters, leads to conditions favourable to release of nutrients into the deeper waters. Following a mixing event these nutrient rich deeper waters are transported to the surface layers where the nutrients are available for uptake by phytoplankton and cyanobacteria.

If the dry period is extended then it is likely that deoxygenation will occur to within a few metres of the surface and partial mixing by wind or night time convection may lead to increased nutrients in the surface layers on a diurnal basis.

The seasonal variations in solar heating, rainfall and wind are key factors for the stratification and mixing. Rainfall and wind effectively cause mixing while solar radiation leads to development of stratification. Due to large rainfall events in summer complete mixing occurs roughly fortnightly in response to large downpours (~ 100 mm). Prolonged dry periods lead to strong stratification and release of nutrients to the deeper waters. This pattern probably occurs mainly in spring.

6.7.8 Faecal Contamination

One means of indicating faecal contamination is through the use of faecal coliform counts for a representative sample. Ballina Council has undertaken such sampling and testing from 1977 to 1995 giving a microbiological status of the lake. A variable number of samples have been taken on any one sampling day, with sampling days up to six times in any one year. The data supplied by Council was in the form of minimum count, maximum count, number of samples and geometric mean (the product of n sample counts raised to the power 1/n – a common statistical measure of faecal coliforms). This data is shown in Figure 6.19.

It is important to note that faecal coliforms are only an indicator of faecal contamination and the standard testing procedure assumed to have been used does not distinguish between human and other faecal contamination sources (animals, birds etc). The presence or absence of faecal coliforms cannot be taken as a definitive measure of microbiological contamination since their behaviour does not behave exactly the same as other pathogens.

The Department of Health, NSW bacteriological standard for bathing waters has been applied by BSC since 1982. The standard states that waters are considered unsuitable for bathing where the faecal coliform count - calculated as the geometric mean of the number of organisms in three water samples taken at the same time from the area being examined - exceeds 300 organisms per 100 ml, with an upper limit of 2,000 organisms per 100 ml in any one sample.

In the event of non-compliance with the above standard, BSC practice is to undertake an immediate re-test. If the re-test indicates non-compliance, consideration is given to issuing warnings.

Council has consistently monitored unprotected bathing areas during the swimming season. The current protocol provides for three samples to be taken from Lake Ainsworth (as well as from other areas including the ocean) in the fourth week of every month from October to March inclusive. Tests may be taken at other times, for instance, in the event that the routine test should fail the Health Department criteria, or if a complaint is lodged alleging unsatisfactory standards. Ear infections have been blamed on swimming in the lake.

The data are plotted in Figure 6.19 showing the range of values recorded, the geometric mean of each sampling and the median of all the geometric means (50th percentile). Superimposed on this figure is the Department of Health standard. Since the late 1970s there have only been three occasions in which the standard has been exceeded. Also shown in Figure 6.19 is the ANZECC (1992) guideline for faecal coliforms for primary contact in recreational waters (150 counts/100 mL). This figure shows that the ANZECC guideline has been exceeded on about 20 percent of the samplings.

There are a number of times when the counts do reach high values, with these appearing to peak around 1990. By identifying the possible sources of contamination and their relative significance, management options to possibly reduce these events can be better assessed.

Possible sources of faecal contamination are:

- Sport and Recreation Centre amenities;
- Leakage from sewer pipes connecting Sport and Recreation Centre to town sewer;
- Caravan park amenities;
- Public toilet block near the 4WD accessway;
- Public toilet at the south-eastern edge of the lake;
- Direct contamination by lake users;
- Animal faeces; and
- Surface runoff.

The Sport and Recreation Centre is directly connected to the town sewer system (John Mills pers comm). Should this system overflow, contamination could be carried by the surface drainage towards the lake. The likelihood of this having a significant impact on the lake is considered limited based on observation. It should be noted that further development of the Centre has been considered in the Masterplan (NSW Public Works 1994) which incorporates recommendations and requirements by Council for the provision of sewer for the expanded site to inhibit impact on the lake. Within the main centre area there is the possibility of blockages leading to overflows from the sewer system. These would generally drain to the lake via the surface runoff paths.

As mentioned above, the Centre is connected to the town sewer system, the line running adjacent to the access road along the eastern side of the lake (NSW Public Works 1994). A pumping station is located within the grass field south of the Centre buildings. There is the possibility of this pipe becoming cracked giving rise to leakage through the ground. However the groundwater gradient is in the opposite direction and thus would indicate that this means of contamination would only present a problem during a reversal of gradient which is a relatively infrequent occurrence (Turner 1995).

The caravan park amenities and various toilet blocks around the lake will also only present a significant problem if they are blocked and overflow. It is assumed that this could be a problem in wet weather conditions, however it has not proven to be the case.

Recently sampling of the drains entering the lake during a rain event on 2 May 1996 showed very low flows within the drains and some high faecal coliform counts, particularly in the drain near the caravan park (Appendix F). These data are listed in Table 6.4 and the sampling sites shown in Figure 3.1.

Table 6.4 Faecal Coliform Data and Estimated Flows in the Stormwater Drains on 2 May 1996

Site	Flow Rate (L/s)	Faecal Coliform (cfu/100 mL)
S1	.10	10,000
S2	.10	77,000
S3	.60	16,750
S4	.12	300
S5	.15	9,300

Direct contamination from lake users is not considered to pose a significant problem given the proximity of generally well maintained amenities to the lake. However it is a potential source and should not be ruled out along with animal contamination (generally dogs) which is also a possible source.

Camp Drewe is located within the surface runoff catchment of Lake Ainsworth. The camp is not connected to the sewerage system and relies for disposal of both sullage and septic wastes on subsoil disposal. The camp can accommodate at least 100 persons, although occupation by large numbers is intermittent rather than continuous. Based on the available data, the majority of groundwater in this area appears to flow towards the coast rather than directly to Lake Ainsworth.

6.7.9 Nutrients

The main plant stimulating nutrients are nitrogen and phosphorus which result naturally from the decay of plant and animal (organic) matter. The nutrient status of the lake is affected by inputs from the catchment via surface runoff and groundwater as well as internal cycling of nutrients between sediments and biota. Catchment activities such as clearing land and fertilising lawns may influence the nutrient loads entering the lake.

The fate of nutrients entering the lake is determined by the following processes:

- uptake of soluble nutrients by plants and animals;
- accumulation of particulate nutrients, especially phosphorus, on the bed or attached to the sediments;
- discharge from the lake.

The nutrients on the lake bed can be resuspended by mixing events or released during biological reactions under anaerobic (zero oxygen) conditions.

Available nutrient data collected by Council and during the present study by Colleen Twigg from Southern Cross University are shown in Figure 6.20. The main objective of Council's monitoring programme is to assess whether lake water quality meets the health regulation guidelines for recreational use. Consequently, the data collection strategy is biased toward monitoring during times when problems may arise (algal blooms) and concentrations are likely to be higher than on average. This data collection strategy provides useful information on the levels of nutrients but it is difficult to use to interpret the underlying processes that lead to the higher concentrations. Collected data consist of total phosphorus, TP, nitrate nitrogen, NO_3, ammonia nitrogen, NH_3 and algal cell counts and identification.

Data collected during the current investigations includes the suite of nutrients NO_3, NH_3, ammonium nitrogen, NH_4, total nitrogen, TN, total dissolved nitrogen, TDN, phosphate, PO_4, TP and total dissolved phosphorus, TDP. Analyses for total organic carbon, TOC, total suspended solids, TSS, and chlorophyll-a as well as algal counts and identification were also carried out.

To assess the potential for either phosphorus or nitrogen to limit algal production the ratio of nitrogen to phosphorus, N:P, may be used as a guide. It must be noted, however, that N:P ratios provide little information about nutrient limitation at any particular point in time. If N and P concentrations are always high (possibly due to internal fluxes) then neither may ever limit algal growth, irrespective of whether the ratio is low or high. In low nutrient conditions if the N:P ratio is greater than about 7 then the algal growth may potentially be phosphorus limited and conversely for low N:P ratios the algal growth may be potentially nitrogen limited. The ratio of total nitrogen to total phosphorus is used here as the basis for the N:P ratio. To derive total nitrogen from the Ballina Council data the following procedure was adopted.

Total nitrogen may be estimated as the sum of inorganic forms and the organic forms of nitrogen in the water. The inorganic forms consist of nitrate nitrogen, nitrite nitrogen and ammonia nitrogen while the organic forms are usually analysed using total Kjeldahl nitrogen, TKN. TKN was derived for the recent measurements from $TKN = TN - NO_3$. For the three days of measurements this gave a value TKN = 0.8 mg N / L. Total nitrogen for the BSC data spanning some two years was then estimated as $TN = TKN + NO_3$. The total nitrogen data and the derived N:P ratio are shown in Figures 6.19d and e, respectively.

The concentrations are generally very high and exceed the ANZECC guidelines (ANZECC 1992) for TP and TN in lakes and reservoirs. Since the N:P ratio is generally greater than 7 it may be assumed phosphorus is more likely to limit algal biomass at some unspecified point in the future, although the high concentrations suggest it is unlikely either will limit algal growth.

Total organic carbon, TOC, measurements in the lake on 8 February were very high, around 19 mg C/L indicating a good source of organic matter in the lake. This material settles to the bottom of the lake and is degraded by microbial activity, a process that consumes oxygen and converts the organic forms of nutrients into inorganic forms which then become available for release into the water column. This recycling process appears to operate at a very high rate in Lake Ainsworth as evidenced by high TOC in the water and sediments, high nutrient concentrations in the sediment porewater and presence of algal blooms.

Nutrient concentrations in the groundwater were sampled recently and are discussed by Daniels and Beck (1996). Total phosphorus, total nitrogen and total organic carbon concentration isopleths (or contours) are shown in Figures 6.21, 6.22 and 6.23. The TP contours are generally around 100 μg/L to the west and immediately south of the lake with higher values in the urban areas most likely associated with fertiliser use. These higher values appear to be well south of the lake and Daniels and Beck (1996) deduce from water table levels that the flow of this higher concentration water is probably toward the sea rather than the lake.

6.7.10 Nutrient Budget

It is well known that nutrients are an important component of a lake ecosystem and that increasing nutrients often leads to excessive growth of aquatic plants and phytoplankton (eutrophication). This process has been recognised by Council and point sources of nutrients such as the public toilets that originally operated on septic tanks have now been diverted to the WWTP via deep sewerage. The major nutrient inputs to the lake are from diffuse sources such as the groundwater and possibly surface runoff. The various contributions to the total phosphorus budget are illustrated in Figure 6.8.

The total phosphorus concentration in the lake may be expressed by a balance between phosphorus sources; inflow plus release of phosphorus from the sediment, and phosphorus sinks; outflow through groundwater plus settling of particulate phosphorus plus uptake of phosphorus by plants. The rate of change of the total phosphorus concentration in the lake may be expressed as:

$$V\frac{d[P]}{dt} = Q_{In}\,P_{Inflow} + \text{Sediment Release} - Q_{Out}\,[P] - \text{Settling} - \text{Uptake}$$

Estimates of the loads for each of the compartments described by this equation are calculated as follows. The phosphorus loads entering the lake originate in rainfall, surface runoff and groundwater. The total load entering the lake is given by:

$$Q_{In}\,P_{Inflow} = Q_{Gin}\,P_{Gin} + Q_{Rain}\,P_{Rain} + Q_{Runoff}\,P_{Runoff} \qquad (6.14)$$

where subscripts refer to groundwater inflow, Gin, direct rainfall input, Rain, and surface runoff. Measurements taken during February 1996 (Kadluszcka et al 1996) may be used to infer the phosphorus concentrations for each component.

During the rainfall event of 15 February five stormwater drains around the lake were sampled and total phosphorus concentrations ranged between 0.32 and 0.02 mg/L with the two drains at the southern end of the lake draining the shower and toilet block areas of the caravan park recording the larger values. Similar values were recorded during a rainfall event on 7 September 1993 (Artuphel 1993) and recently on 2 May 1996 (Appendix F) when total phosphorus concentrations varied between 0.01 and 0.09 mg/L. For the purpose of estimating phosphorus load, the higher values measured by Artuphel (1993) are used and represent a conservative estimate.

Assuming the areas of higher concentration account for about 10% of the total runoff then the average concentration in the runoff may be estimated as

$$P_{Runoff} \sim (0.1 \times 0.32 + 0.9 \times 0.02) = 0.05 \text{ mg P/L}$$

Nutrient loads from surface runoff may increase during rain events following scrub fires when ash deposits may contribute to nutrient wash off.

Total phosphorus concentrations in the rainfall were below the detection limit of 0.01 mg P/L on 15 February and on 21 February a concentration of 0.02 mg P/L was recorded. For the purposes of estimating the load it is assumed

$$P_{Rain} \sim 0.01 \text{ mg P/L}$$

Total phosphorus concentrations in the groundwater have been discussed by Daniels and Beck (1996) and TP isopleths are shown in Figure 6.21. For the groundwater inflow to the lake it is assumed

$$P_{Gin} = .1 \text{ mg P/L}$$

Substituting these concentrations into (6.14) and using the annual inflows for 1995 (Table 6.2) the derived estimates of the annual phosphorus load are listed in Table 6.5.

These estimates may vary due to activities in the catchment. The groundwater nutrient concentration may increase after application of fertiliser. This is likely to be a localised effect that disperses within the groundwater such that when the groundwater flow actually reaches the lake the concentration is of similar order to the background value. Further, very little of the groundwater beneath the housing to the south of the lake appears to flow into the lake. Hence the load estimates are probably accurate within a factor of 2-3.

The runoff load was probably considerably higher prior to the deep sewer connections to the various facilities surrounding the lake. It is difficult to estimate the additional loads during that time but it may have been around five times the present estimate.

Export of phosphorus from the lake occurs through the groundwater discharge along the eastern side of the lake. Assuming the average concentration (Figure 6.20).

$$[P] \approx 0.07 \text{ mg P/L}$$

and using the annual discharge for 1995 listed in Table 6.2 yields the groundwater export for 1995 listed in Table 6.5.

The uptake of phosphorus by emergent macrophytes along the lake shore and by phytoplankton in the central lake is not presently well understood. Given the lack of extensive submerged aquatic macrophytes in the lake, it is unlikely that plants contribute significantly to the overall phosphorus budget. Uptake represents a loss of phosphorus from the water column and is typically modelled as a component of a generalised settling rate. The settling term may be represented by (Chapra and Canale 1991).

$$\text{Settling} = v_s \, A \, [P]$$

where v_s is the settling velocity, A the area (Figure 6.6) and [P] the total phosphorus concentration in the water column. Assuming an apparent settling velocity of $10 \, m \, yr^{-1}$ and using the average lake area for 1995 (Table 6.2) the total phosphorus settling load is presented in Table 6.5.

The exchange of phosphorus between sediments and the overlying water is a major component of the phosphorus cycle in lakes. There is an apparent net movement of phosphorus into the sediments (Wetzel 1983). The effectiveness of the net phosphorus sink to the sediments versus the recycling of phosphorus to the water depends upon an array of physical, chemical and metabolic factors. Exchanges across the sediment/water interface are regulated by mechanisms associated with mineral-water equilibria, sorption processes (ion exchange), oxygen dependent redox interactions, and the activities of bacteria, fungi, plankton and invertebrates. One of the most important regulatory features of the sediment-water phosphorus exchange is the oxygen content at the interface. Oxygen consumption of organic matter by bacteria on and in the sediment leads to the depletion of oxygen in overlying water under stratified conditions. As the oxygen microzone at the sediment interface is depleted, the changing redox conditions favour release of a range of ions including phosphate. This process is referred to as anaerobic release.

The sediment release or phosphorus recycling is also represented by a release velocity

$$\text{Sediment release} = v_r \, A \, [P_s]$$

where v_r is the release velocity and $[P_s]$ the sediment porewater concentration. The release velocity depends on the oxygen concentration at the sediment water interface. During periods of low dissolved oxygen concentrations, the release rate increases while under well oxygenated conditions the release is diminished. Chapra and Canale (1991) estimated the release velocity for a temperate lake of 0.0115 m/yr during the period of summer anoxia and during well mixed winter conditions a release velocity of 0.00494 m/yr was reported. For warmer tropical lakes these release rates are probably larger than for temperate lakes. Since it is not clear how long the stratification and associated depleted oxygen conditions persist, an average release velocity of 0.015 m/yr is assumed for the purpose of estimating the recycling load. The total phosphorus concentration in the sediment porewater was measured in

February 1996 in both the sandy sediments occupying the nearshore zone, depths <4 m, and in the organic mud in the deeper part of the lake. Porewater concentrations ranged from 0.01 mg P/L^{-1} to 0.932 mg P/L^{-1} in the organic rich muds. Assuming that the release occurs from the organic rich sediments below 4 m depth then using the sediment area at 4 m (A = 48000 m^2) gives the release load shown in Table 6.5.

Table 6.5 Annual Phosphorus Budget for 1995

Groundwater Inflow (kg)	Rain (kg)	Runoff (kg)	Groundwater Outflow (kg)	Inflow-Outflow (kg)	Settling (kg)	Sediment Release (kg)
7.2	1.6	3.0	9.1	2.7	91.4	0.7 (88.7)*

*(88.7) - The balance of net inflow-outflow and settling.

This budget has been derived from limited data and assumes that the phosphorus concentrations measured on one occasion (8 February 1996) form a good representation of the annual average. Phosphorus concentrations measured in May 1996 were similar but slightly lower than the February data. There are insufficient data to assess the inter-annual variability.

The relative magnitude of the direct rainfall and runoff contributions are sensitive to the rainfall events, but the other components are not so sensitive. Hence it may be inferred that during wet years there will be larger net loading than in dry years. However, the in-lake cycling would still be the major component in the phosphorus budget.

The components of the annual phosphorus budget listed in Table 6.5 indicate that the settling term dominates the budget. Under average conditions, the main source of phosphorus is via the groundwater, however during wet months runoff and direct rainfall are also important. The net loading to the lake is 2.7 kg for 1995 but this is only a small fraction of the internal cycling component given by the settling term.

As there are very few measurements of release for similar sub-tropical lakes the sediment release term is probably most prone to error. If the lake is at steady state then the rate of change of phosphorus is zero and since the inflow is similar to the groundwater outflow then the sediment release must be of similar magnitude to the settling value and is shown in brackets in Table 6.5. For sediment release to balance settling then the release velocity would be around 2 m/yr or about one fifth of the settling velocity.

Since the 1995 annual rainfall was slightly less than the average, the derived phosphorus budget is considered reasonably typical of an average year.

The phosphorus budget has important implications for management. Since internal cycling of phosphorus is much larger than the external loading the management actions should be focused in the lake rather than at attempting to reduce the external loads. Possible actions are discussed further in Chapter 8.

6.7.11 Algae and Cyanobacteria

Algal cell counts for the period 1993 to present are shown in Figure 6.24 by cell count for each algal species and as total cell counts. The North Coast Algal Co-ordinating Committee (NCACC) has recommended a standard that warning signs be erected when the cell counts of blue-green algae exceed 15,000 cells/ml. Chlorophyll-a and cell counts for 8 February are listed in Tables 6.6a and 6.6b.

Table 6.6a Water quality data for Lake Ainsworth Sampled on 8 February 1996

Site	Sample Depth	Temp (° C)	pH	Cond (µS/cm)	DO (mg/L)	TOC (mg/L)	Chloro-a (µg/L)	Cell Count
W1	0.1	29.5	5.7	246	6.2	19.5	12	425
	2.5	29.5	5.1	243	5.5	19.6	10	
W2	0.1	30.0	5.5	243	6.4	19.5	13	1096
	4.0	24.8	5.5	236	<0.1	16.6	7	
	8.5	23.4	5.5	251	<0.1	18.5	6	
W3	0.1	30.3	5.2	243	6.2	18.7	28	437
	4.5	25.3	5.0	236	<0.1	17.6	5	
W4	0.1	29.7	5.1	243	5.9	19.4	28	759
	2.75	28.3	4.8	241	1.1	19.4	5	
W5	0.1	30.9	5.2	243	6.7	18.7	15	613
	4.0	25.3	4.9	234	<0.1	17.3	3	

Table 6.6b Algal Cell Counts and Identification for Water Samples from Lake Ainsworth, 8 February 1996

Parameter	Lake Ainsworth Site No.				
	W1	W2	W3	W4	W5
Ceratium	33	54	44	98	40
Tribonema (filaments)	10	15	9	15	11
Unidentified green algae	22	37	23	75	20
Anabaena	360	990	360	570	540
Oscillatoria (filaments)	*	-	1	1	2
Total	425	1096	437	759	613

Only very limited monitoring data are available for Lake Ainsworth, but in general the phytoplankton population does not appear to be typical of coastal dystrophic lakes of northern NSW. The shifts from dominance of one species to another are probably part of the normal seasonal succession. These successions may be driven by many factors - the more common being depletion of a key nutrient such as silicate, zooplankton grazing of susceptible species, water temperature changes, or the onset of stratification.

It is common in many water bodies, especially those which are turbid or highly coloured (such as Lake Ainsworth) for summer or late summer stratification to give rise to the predominance of cyanobacteria or dinoflagellates. Under well mixed (ie windy or cool, cloudy) conditions, all algae have some access to the "photic zone" (the upper illuminated layer of the water column). Cyanobacteria generally do not seem to prosper under these conditions. However, when the water body stratifies those algae which have no way of staying at or near the surface (eg by swimming or floating) sink into the poorly illuminated depths where they cannot grow. With few competitors for light or nutrients, motile species such as dinoflagellates (*Ceratium*) or buoyant cyanobacterial species such as *Anabaena, Microcystis* and *Oscillatoria* may flourish. In June 1995 there was a marked benthic growth of filamentous *Oscillatoria.* This was present as little feathery clumps, almost black in colour, growing out of the lake (Lee Bowling pers comm).

This is probably the situation in Lake Ainsworth, although this claim cannot be substantiated without further monitoring data. The fact that there is not a bloom every year is not surprising as cyanobacterial blooms are very closely linked to water column stratification and, therefore, the local climate. In other words, some summers are better than others for bloom formation.

Wind and current patterns can cause accumulation of phytoplankton. Blooms in a particular water body are influenced by the "seed" source, the general climatic conditions and the characteristics of the water body. Of particular importance are the degree of turbulence and mixing within the water column (Queensland Water Quality Task Force 1992).

The cyanobacterial blooms appear to commence during late winter-spring which is typical for lakes and reservoirs in the subtropical climate of south-east Queensland and northern NSW. As noted in Section 6.7.7, subtropical depressions and rainfall events in summer tend to cause complete mixing on a roughly fortnightly basis. Thus, the summer, particularly from January onwards, is most likely to be a time of cyanobacterial decline in wet or average years. This may not be the case in dry years, however. The effect of summer mixing can be seen in the Lake Ainsworth cyanobacterial data - the population goes into steady decline from maxima around 80,000 cells/mL in spring and early summer to only around 100 cells/mL by early March. However, these periods of intermittent stratification may be important in replenishing the surface layers with phosphorus and nitrogen, and probably stimulate the growth of other non-toxic algae.

It should also be noted that some species are much larger than others. For example *Ceratium* may be more than one hundred times bigger than *Anabaena* (depending on the species). Thus 100 cells/mL of *Ceratium* may be the equivalent of 10,000 cells/mL of *Aebaena* on a biomass basis. Although the abundance of *Ceratium* seems low from the available data (30-100 cells/mL) it is also a very important part of the algal community.

It is quite possible that cyanobacterial dominance during the warmer months of the year is a natural occurrence in this humic-rich dune lake. Furthermore, Lake Ainsworth appears to be sufficiently rich in nutrients to support the formation of a cyanobacterial bloom at any time. The main limiting factor is probably stratification coupled with water temperature. Other factors such as zooplankton grazing, or the lack of it, cannot be excluded without further examination. Gambusia is a strong predator of large zooplankton, which themselves are "keystone" species for control of algal biomass (Matveev et al 1994). Firetail Gudgeon, which is the other common fish species, may also be a key predator.

Transfer of nutrients to the phytoplankton cell is affected by the degree of mixing in the water. In stratified waters, the phytoplankton growth rate is often limited by the rate of transfer of nutrients from deeper water to the cells that prefer to maintain their position in the near surface photic zone.

Whilst high light provides the key stimulus for the development of algal biomass in general, it appears that *low light penetration* may be a key factor favouring buoyant cyanobacteria. In other words, the more turbid or highly coloured the water body, the higher the probability that cyanobacteria will dominate during the warmer months of the year. A key question is this . . . 'if there are excess nutrients available in a water body, why do cyanobacteria tend to dominate at certain times rather than other harmless algae?' Stratification seems to be one of the key factors, but the answer to this question still eludes scientists.

The history of the algal blooms is difficult to ascertain from the available information. It is likely that algal blooms have been occurring in the lake for many years. In November 1986 there was a major cyanobacterial bloom in the lake composed of *Anabaena, Microcystis* and *Oscillatoria.* Chlorophyll-a levels in the lake at that time were as high as 42 µg/L.

6.7.12 Lake Trophic Classification

The trophic status of an ecosystem is described by Wetzel (1993):

> "In most cases, energy required for growth and maintenance of organisms enters ecosystems as light and is converted to chemical energy by plant photosynthesis (auto-trophy). Biological communities are based on the photosynthetic production of organic matter, produced either within a community (autochthonous production) or derived from an external source (allochthonous production) and transported in dead or decomposing state to a community for utilization (heterotrophy).
>
> In self-sustaining biological communities, functionally similar organisms can be grouped into a series of operational levels. Each level, which usually consists of many species competing with each other for available resources, forms a *trophic level.* The *trophic structure* of a community

refers to the pathways by which energy is transferred and nutrients are cycled through the community trophic levels.

Photosynthetic organisms are primary producers, and they represent the first level of the trophic structure. The primary producers are eaten by primary consumers or herbivores, which in turn are successfully consumed by secondary, tertiary etc consumers (carnivores). Since energy is lost in each transfer, more than six trophic levels can rarely be sustained.

Organisms exist in complex *food webs*, in which nutrients and energy of one trophic level are utilized by organisms from several different trophic levels. Although greatly oversimplified this conceptualisation is useful for understanding the general patterns of ecosystem structure and energy flow."

A relatively simple scheme for classifying lakes according to their trophic status was developed by Vollenweider (1975). The scheme assumes the mean annual phosphorus concentration is controlled by a balance between the phosphorus load entering the lake and the load exiting the lake due to outflows and phosphorus settling.

$$P_{Load} = Q_{Out}\,[P] - v_a\,A\,[P] \qquad (6.15)$$

where P_{Load} is the annual phosphorus load to the lake, Q_{Out} is the annual discharge from the lake, v_a is the apparent settling velocity, A the area and [P] the average concentration in the lake. This classification arises from a compilation of chlorophyll and phosphorus and loading data for a number of lakes which indicates a critical phosphorus concentration above which the lakes were classified as eutrophic (high chlorophyll-*a*) and below which the lake waters were relatively clear or oligotrophic (low chlorophyll-*a*).

This scheme may be applied to Lake Ainsworth using the data presented in Section 6.7.9. Typical lakes have a surface water outflow where discharge measurements of Q_{out} are often available. Since the outflow from Lake Ainsworth occurs via the groundwater, this value is used for Q_{out}.

The data are plotted in Figure 6.25 as areal loading and assuming a settling velocity of 10 m/yr.

The figure suggests the lake may be classified as oligotrophic, however, the average in-lake phosphorus concentration (in the range $20<TP<70$ μg P/L) and the high chlorophyll-*a* concentrations, (in the range $10<chla<13$ μg Chl-*a*/L) are typical of eutrophic lakes. The OECD (Vollenweider 1975) classification scheme breaks down because the dominant loading affecting the in-lake TP concentration is derived from sediment release that is not incorporated in the classification scheme. By incorporating an annual load due to sediment release (~90 kg/yr) the lake condition falls into the eutrophic range (Figure 6.25).

Lake Ainsworth has also been classified as a dystrophic lake which implies high organic matter and humic acids and also low nutrients. While organic matter (TOC ~ 19 mg/L) and acidity (ph ~ 5) are typical of dystrophic lakes, the high nutrient concentrations are atypical. It is argued that while the lake may be classified as dystrophic on the basis of its high organic matter and humic content, it also exhibits the symptoms of a eutrophied lake.

6.7.13 Water Quality and the ANZECC Guidelines

Water quality guidelines for the maintenance of aquatic ecosystems consist of a range of values of water quality variables. These values need to be interpreted in terms of the particular system being considered, however, where there are insufficient data to assess the long-term status of the system the guidelines may be used as broad indication of the ecosystem health. The guidelines appropriate for Lake Ainsworth fall into two categories; ecosystem maintenance and recreational use. The first category recommends concentrations of the physico-chemical variables that are generally not exceeded in 'healthy' systems. The second category arises from public health issues and consists of recommended concentrations that relate to human immersion criteria.

The physico-chemical criteria and typical values for the lake are:

Dissolved oxygen DO_2

ANZECC criterion: $DO_2 > 6$ mg /L (> 80 - 90 % saturation)
Figure 6.15 indicates that in the lake surface waters the criterion is satisfied but it is exceeded in the deeper waters on two of the four occasions when measurements were made. Barlow (1994) presents dissolved oxygen data that show deep water DO depletion and where the criteria are not satisfied.

Total phosphorus TP

ANZECC criteria: TP in the range 5 - 50 μg P/L indicates the lake may experience algal problems.

The data presented in Figure 6.20.1a indicate that the total phosphorus in the lake was rarely less than the upper limit of 50 μg P/L over the period 1993 to present. Previous measurements listed in Table 6.7 indicate a similar trend.

Table 6.7 Total Phosphorus Measurements in Lake Ainsworth

Origin of Data	Date of Measurements	TP (μg P/L)
Bowling (1989)	27 November 1986	78
Artuphel (1993)	6 samples between 16 August and 20 October 1993	[1]range 40 - 160 average 96
Barlow (1994)	2 May 1994	53.5

[1] Artuphel measured phosphates and it is assumed TP = 2 PO_4 is a conservative estimate as recent data showed TP = 2.4 PO_4.

Total nitrogen TN

ANZECC criteria: TN in the range 100 - 500 μg N/L indicates the lake may experience algal problems.

The data presented in Figure 6.20 indicate that the total nitrogen in the lake was rarely less than the upper limit of 500 μg N/L over the period 1993 to present. Previous measurements listed in Table 6.8 indicate a similar trend.

Table 6.8 Total Nitrogen Measurements in Lake Ainsworth

Origin of Data	Date of measurements	TN (μg N/L)
Bowling (1989)	27 November 1986	1240
Barlow (1994)	2 May 1994	520

Chlorophyll-a Chla

ANZECC criteria: Chla

The few measurements of Chla in Lake Ainsworth are presented in Table 6.9. The data indicate that the lake is in the mesotrophic to eutrophic range.

Table 6.9 Chlorophyll-*a* Measurements in Lake Ainsworth

Origin of Data	Date of measurements	Chla (μg/L)
Bowling (1989)	27 November 1986	42
Artuphel (1993)	6 samples between 16 August and 20 October 1993	range 21 - 113 average 65
Present programme	5 samples, 8 February 1996	range 13 - 28 average 19.2
Present programme	5 samples, 21 February 1996	range 9 - 25 average 18.2
Present programme	2 samples, 23 February 1996	range 2 - 9 average 5.5

The Recreational Use Criteria are summarised as follows:

Microbiological criteria are expressed as faecal coliform counts. The ANZECC criteria are:

- Primary contact — Median value < 150 counts/100 ml
- Secondary contact — Median value <1000 counts/100 ml

The faecal coliform data presented in Figure 6.19 indicate that the criteria for primary contact has been exceeded since about 1988, however, in recent years there is a trend towards lower concentrations and compliance with the criteria.

Nuisance organisms including phytoplankton and bacteria that form surface scums are thought to become problematic at algal cell counts in the range 15-20k cells/ml which has occurred in spring 1995 (Figure 6.24).

Physico-chemical variables are also relevant to human health issues and the recreational use guidelines state:

Visual clarity and colour

The guidelines are expressed as visibility through the water and should exceed 1.6 m. It is difficult to apply this to Lake Ainsworth as horizontal visibility has not been measured. Given the lake's humic content and high colour staining, this criteria is probably not appropriate. Secchi disk measurements (a measure of vertical penetration of light/clarity) range from .9 (Bowling 1989) to a range of .25 to .7 (Barlow 1994).

pH

The ANZECC criteria recommend a range of 5 to 9 as safe for recreational use. It is well known that Lake Ainsworth is an acidic lake and its pH is normally in the range 5 to 6 but apparently only rarely falls below pH 5. Hence this criterion is satisfied.

Temperature

The guidelines recommend a temperature range of 15-35. The lake temperature varies between 17 in winter to 34 in high summer and hence this criterion is well satisfied.

6.8 Beach Processes and Dune Management

Beach processes and their driving forces are a complex subject and this section aims to briefly cover the issue of oceanic inundation that may occur as a result of a number of processes. More detailed treatment of this subject for the Seven Mile Beach embayment and other references to this topic can be found in Lennon (1983), Geomarine (1990), NSW Public Works (1994) and Warren (1994). More recent photogrammetric work (March 1995) has been undertaken but not reported.

The processes that would affect the lake include changes in the dune system as a result of long-term recession (the progressive landward movement of the escarpment), short-term storm 'bite' (the volume of sand removed by storm activity), sea level variation and wind erosion. While the dune system can recover following short-term storm 'bite', a net landward movement of the dune scarp has been noted at various locations along the NSW north coast. These changes to the dune system may lead to increased risk of oceanic inundation which can occur by wave overtopping of the reduced barrier or through the existing 4WD track. Beach processes can be aided or exacerbated by human intervention to increase the risk of oceanic inundation. These processes and accompanying human activity are discussed for the lake below.

6.8.1 Long-term Recession

Photogrammetric assessment of the recession is summarised in NSW Public Works (1994). The calculated recession for the beach at the lake is estimated at 0.9 m/year. A preliminary study (Lennon 1983) indicated that the rate of recession was 1.0 m/year. If the beach had been receding at this rate over the period from the study to date (13 years) then the escarpment would have moved 13 m. No investigation to validate this movement has been reported, however photogrammetry has been done up to 1994 by DLWC Coastal Branch. Recent observations as part of the DLWC Estuaries study indicate that the scarp has been stable over the period of the study ($\approx$two years). The success of this stability can be attributed to the good dune management undertaken within the area, and to a recent period relatively free of major storm events.

6.8.2 Storm Bite

Ocean storm activity with its associated wave energy results in the natural process of the removal of sand from the dunes during the storm with the sand being stored offshore and returned to the beach during calmer conditions. Most recently this has been seen (May 1996) with the dune scarp moving approximately 13 m landwards and incised about 2 m into the dune (Graham Plumb, pers comm). The recurrence interval of this storm has been estimated at an upper limit of one in two years (Mark Kulmar, MHL pers comm) which is relatively low, however the direction of the wave attack (ENE) and elevated ocean levels were determining factors in the erosion. Whilst the likelihood of a succession of such storms is unknown and possibly of a low probability, it is important to note that there is a possibility of such occurrences leading to less dune available to resist oceanic inundation in subsequent storms. The volume of sand available for removal is assisted by good dune management involving dune stabilisation with vegetation and the provision of controlled accessways.

6.8.3 Sea Level Variation

Extreme water levels as a result of coincident phenomenon such as tide, storm surge, barometric setup, wave setup and sea level rise as a result of climate change will all contribute to a greater possibility of inundation. These phenomenon are defined within Geomarine (1990) and no further discussion will be made of them here.

6.8.4 Wind Erosion

Without vegetation to stabilise the dune system it can quickly be eroded by wind and the protective barrier lost (aeolian transport). This leads to the migration of dunes by wind action which can be extensive along an embayment or localised (a 'blowout'). For the case of Lake Ainsworth the dunes are well vegetated and thus wind transport only occurs from the oceanward beach area and is then caught in the vegetation, building the dune. Whilst the dune remains well vegetated (as it is currently) aeolian transport and migrating dunes or blowouts (which will also allow for inundation through one place) will not present a problem of sand moving into the lake.

It has been suggested (Warren 1994) that the 4WD accessway acts as a 'wind tunnel' allowing for the blowing of sand from the beach area to the lake. The predominant wind climate for the area is from the south-east and since the accessway is oriented to the north-east this problem is not of a serious nature. However, it is suggested that consideration be made of the formalising of the accessway to prevent aeolian transport.

6.8.5 Inundation Mechanisms

Whilst the quantitative consideration of the possibility of oceanic inundation was not part of this study it is important to note that oceanic inundation may occur in an extreme storm event if the barrier has been degraded/removed to such an extent that it allows overtopping after a succession of storms. Anecdotal evidence suggests that the lake was open to the ocean in the 1940s, Warren's (1994) assessment of the 1993 photogrammetry by the Public Works Department suggests that this cannot be ruled out for the southern end of the lake and Hudson (1996) also discusses the possibility of the lake formation by storm surge at the southern end. The risk of inundation as a result of erosion was first documented in *The Northern Star* in 1967 and reproduced in Geomarine (1990). In the same year a rock revetment was placed to protect the Sport and Recreation buildings (NSW Public Works 1994). Other attempts at beach protection are documented in Geomarine (1990).

Barrier overtopping would result from an extreme event. Oceanic inundation may occur as a result of inundation through the existing 4WD track since this is already at a lower level than the surrounding dune system. This track has a north-easterly aspect which is of concern for cyclone generated storm activity, however the dominant wave climate for the area is from the south-east and thus on a broader scale the likelihood of inundation through this track is less. There are no known reports of inundation of the lake through this track however a large amount of scour at this track was observed in the May 1996 storms (Graeme Plumb, pers comm). The uncontrolled nature of this track may be a factor that exacerbates storm erosion and could lead to eventual inundation.

6.8.6 Protection against Inundation

The dune stabilisation work undertaken by the Dunecare group has afforded good protection from inundation. Removal of bitou bush, planting of natives and spinifex have helped stabilise the dunal system which acts to protect the lake from inundation. However, possible ongoing shoreline recession presents a potential threat to the integrity of the dunes and subsequent ocean inundation. The most apparent means by which the lake could be inundated at present is through the 4WD entrance to the beach.

6.9 Impact of Human Activities on Processes

A range of impacts of human activities on the physical, biological and chemical processes affecting Lake Ainsworth have been noted in this report.

Significant activities since the commencement of European settlement have included:

- Clearing of much of the original native vegetation;
- The expansion of the township of Lennox Head which impacts on the drainage patterns and the water quality of Lake Ainsworth;
- The development of the National Fitness Camp, now the Department of Sport and Recreation Centre, with impacts on clearing of vegetation and Lake Ainsworth water quantity and quality; and
- Sand mining in the 1960s and 1970s with impacts on the vegetation and topography of the beach dune system including the introduction of exotic vegetation in the dune rehabilitation process.

A list of impacts of human activities is set out in Table 6.10.

Table 6.10 Impacts of Human Activity

Issue	Impacts
Water Quality (lake and ground water)	• Effect of runoff and stormwater pipe discharge from caravan park and Sport and Recreation Centre and from domestic animals on lake water quality including high phosphorus loads and faecal coliform bacteria contamination. • Nutrients from the town west of Gibbons Street and from Sport and Recreation entering lake through the groundwater. • Non use of fertiliser within the Sport and Recreation Centre for the last eight years would have reduced any previous nutrient load from this source entering the lake through surface or groundwater flows. • Diversion of septic systems to town sewer system and foreshore remediation work resulting in reduced nutrient loads to the lake. • Possible leakage from fuel tanks in Sport and Recreation Centre. • Possible higher phosphorus levels from decaying vegetation on lake bed (may be exacerbated by exotic species?) • Higher nutrient levels in recent years - possibly related to previous septic and sullage systems.
Water Quantity	• Alteration of drainage patterns by catchment development. • Effect on water table of using bore water for maintenance of gardens within the Sport and Recreation Centre. • Possible future increase in surface water runoff to the lake and impacts on the water table through the proposed development of the Sport and Recreation Centre.
Aquatic Ecosystem	• Affected by lake usage and alterations to drainage patterns and flora composition.
Fauna	• Clearing of littoral and riparian vegetation causing decrease in diversity and abundance of invertebrates. • Introduction of mosquito fish may have modified ecosystem including the overgrazing of zooplankton. • Fish kills - possibly associated with lake overturning in winter/spring. • Prevalence of cane toads. • Dog owners ignore 'dogs prohibited' signs. Dogs have been observed to behave viciously around picnickers and dog excrement can be a problem. Jones (1988) found that 73% of those interviewed considered the presence of dogs to detract from their recreational experience.

Table 6.10 Impacts of Human Activity (continued)

Issue	Impacts
Native Vegetation	• Loss/damage to native vegetation through inappropriate or intensive recreational use (eg pedestrian access, informal car parking, four wheel driving, clearing for caravan park). • Removal of fringing vegetation to facilitate recreational activities. • Previous use of the introduced Bitou Bush to stabilise dunes after sandmining (1960s/70s) which has not permitted native vegetation to regenerate (Bitou Bush removal and planting with native species has commenced). • Past planting of exotic species in the Sport and Recreation Centre instead of natives (redevelopment guidelines now include replacing exotic species with natives). • Potential minimal loss of native vegetation through future expansion of the Sport and Recreation Centre.
Nuisance Aquatic Plants and Aquatic Weeds	• Periodic? outbreaks of salvinia (declared noxious plant), water primrose (native) and *Azolla* sp. (native) in the lake affecting water sports?. **Note Azolla may be confused with salvinia so they may have been incorrectly identified.** • Salvinia being managed by control measures.
Erosion and Sedimentation	• Catchment development affecting sediment runoff. • Erosion of unfinished Sport and Recreation Centre road to the north of the lake and perceived sedimentation in the northern portion of the lake. • Removal of stabilising vegetation for construction of the sealed road along the eastern perimeter of the lake and runoff from the road eroding land between the road and lake. • Removal of fringing vegetation and intensive recreational use (eg launching sailcraft) exposing the south and east banks of the lake to erosive processes. • Gullies on south-west side of lake from road construction and pedestrian tracks on western side resulting in gully erosion. • Pedestrian traffic contributes to coastal dune erosion. • 4WD track through dune could increase erosion. • Rehabilitation of dune vegetation stabilising dune movement and reducing wind blown sand entering lake.
Wind	• Wind effects on lake inhibited by buildings and Norfolk Island Pines.
Aboriginal Sites	• Possible past destruction or disturbance of Aboriginal sites by land clearing and mineral sands mining. • The disturbance of as yet unrecorded sites (particularly burials) as a result of development of land around Lake Ainsworth is a concern to the Jali people.
Future Urban Development	• Potential pressure on western side of lake. • Potential further overuse of lake and adjacent beach area.

Table 6.10 Impacts of Human Activity (continued)

Issue	Impacts
Overcrowding/ Overuse	• Overcrowding of the three main areas around the lake (south, south-east and east sides of lake) during peak periods - as discussed in Section 5.3 the estimated usage far exceeds estimated social carrying capacity during peak usage periods. • Overuse of water body. • Of those surveyed by Jones (1988), 69% felt there were not enough rubbish bins.
Traffic and Parking Problems	• Traffic congestion during peak periods. • Inadequate parking during peak periods (although provision of more parking would increase traffic congestion problems). Blainey et al (1988) found that parking was the facility most visitors wanted to see upgraded and Jones (1988) found that 58% of those interviewed thought the present method of uncontrolled parking was undesirable. • Alienation of grassy areas which could be used for recreation due to haphazard parking arrangements. • Child safety crossing the eastern road to the beach. Sight distance is poor due to informal car parking along the road. Jones (1988) found that 89% of those surveyed felt the risk of children being involved in an accident was too high.
Conflicts between swimmers and sailcraft and between sailcraft	• Sailcraft moving into designated swimming area (this is thought to occur because of the inexperience of most sailors). • Risk of collision between catamarans and sailboards (again thought to be because of the inexperience of most sailors and sailboard riders). Jones (1988) found that 98% of sailboarders interviewed felt threatened by the presence of catamarans but this may have been exaggerated due the windy weather conditions.
Rubbish	• Disposal of rubbish around lake by Sport and Recreation and others in the past.

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SCHEMATIC DIAGRAM OF PROCESSES AFFECTING LAKE AINSWORTH

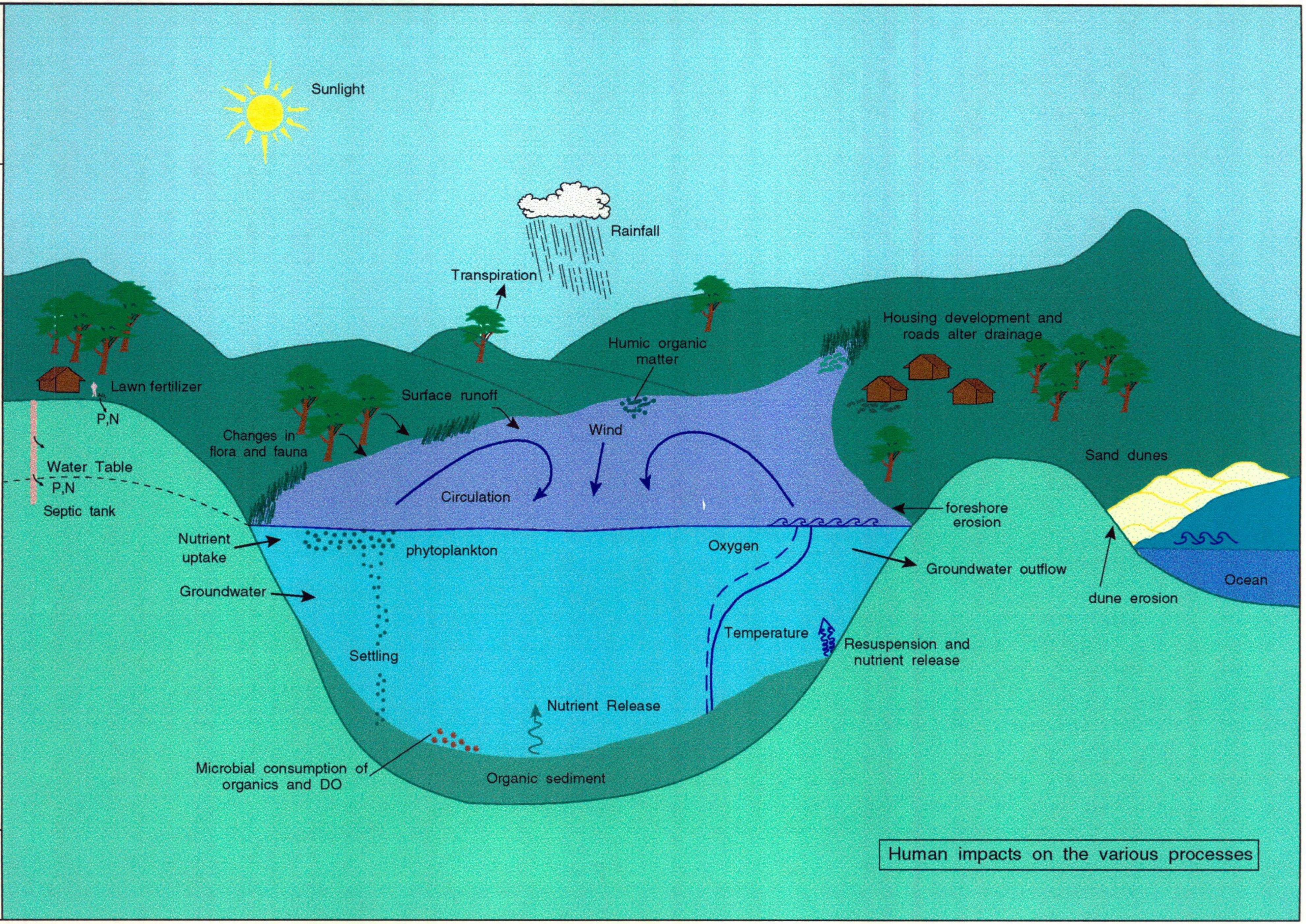
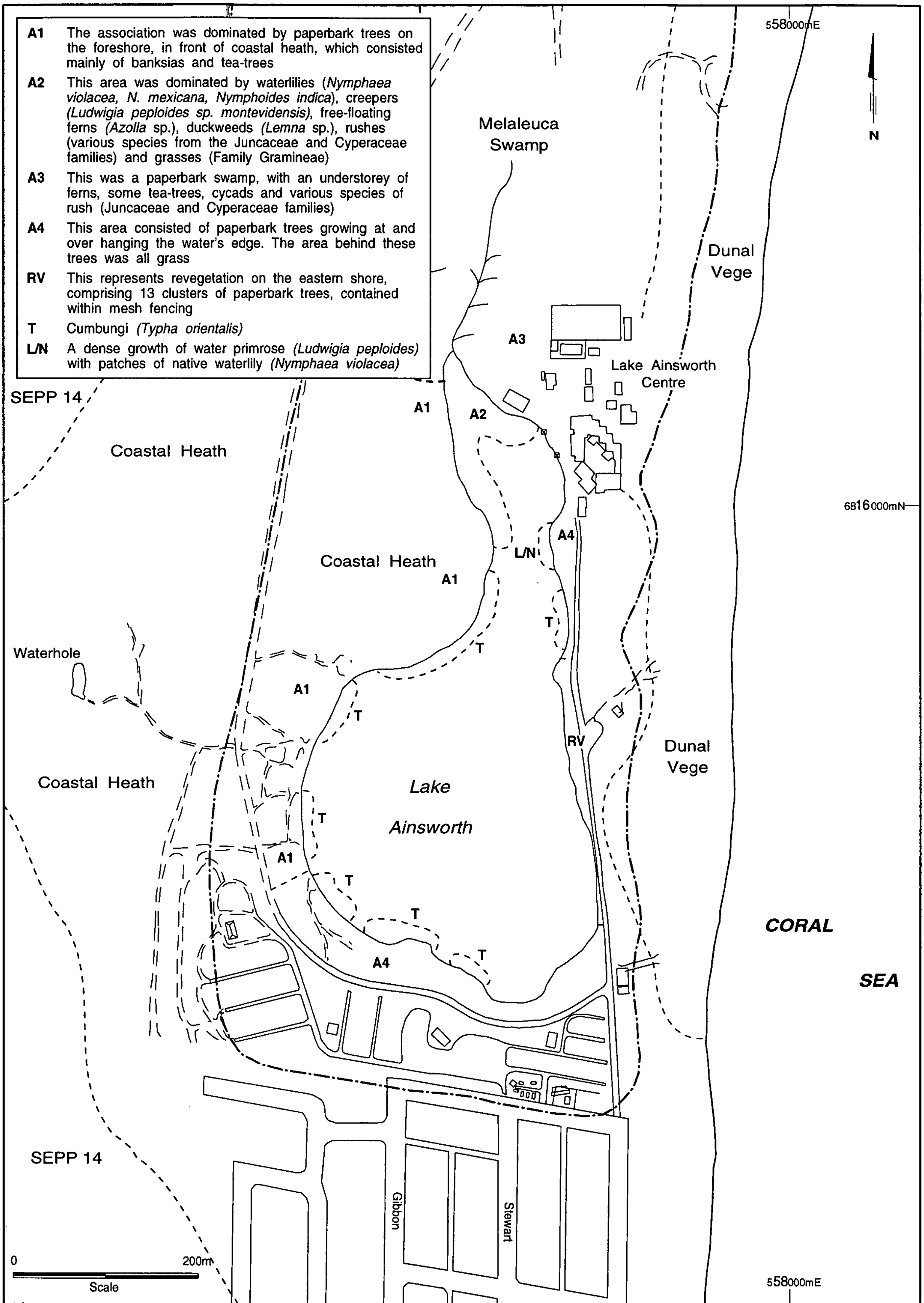


Figure 6.1



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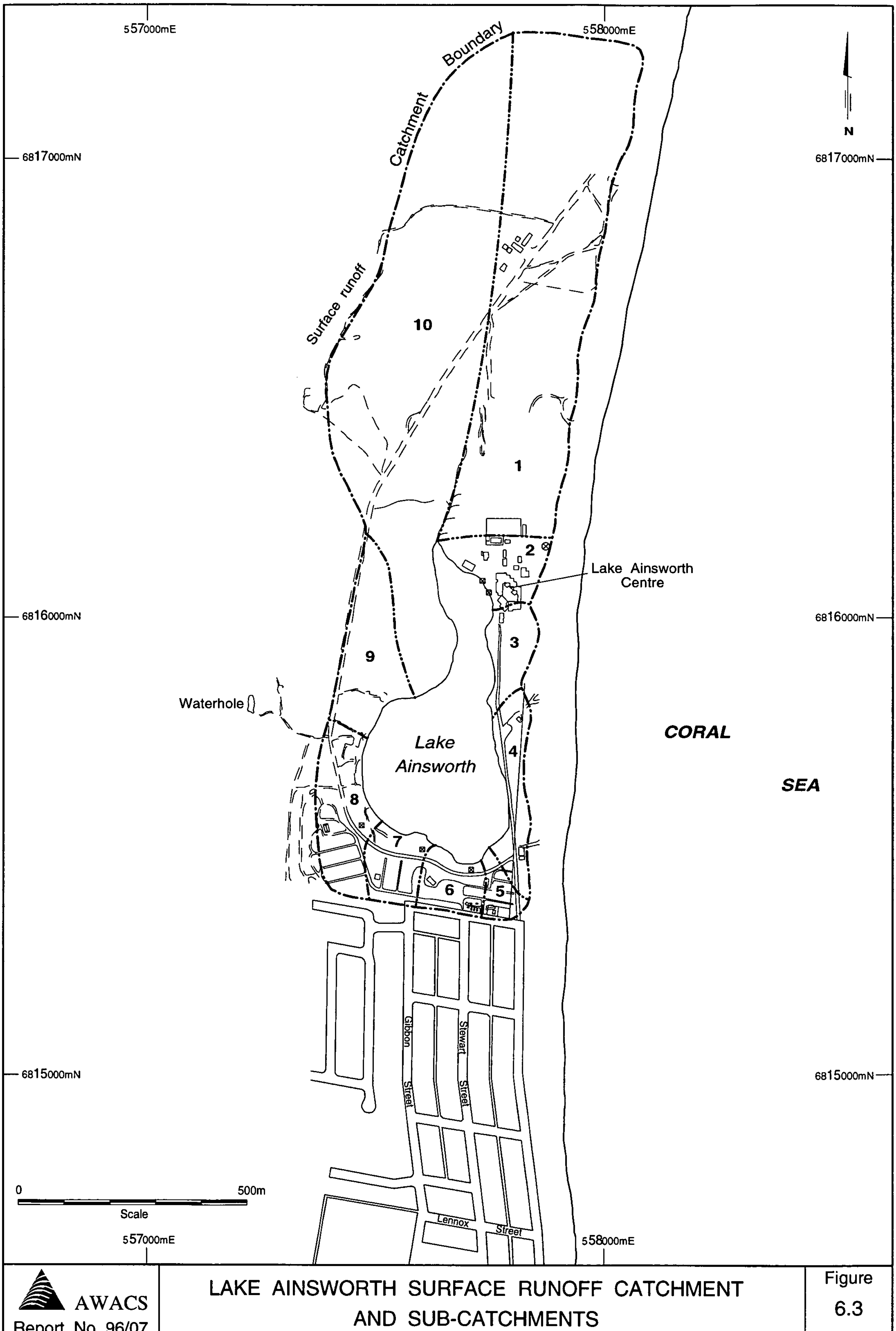
LAKE AINSWORTH RIPARIAN, LITTORAL AND CATCHMENT VEGETATION ASSOCIATIONS

Figure 6.2

DRAWING 9607AI62.DRW



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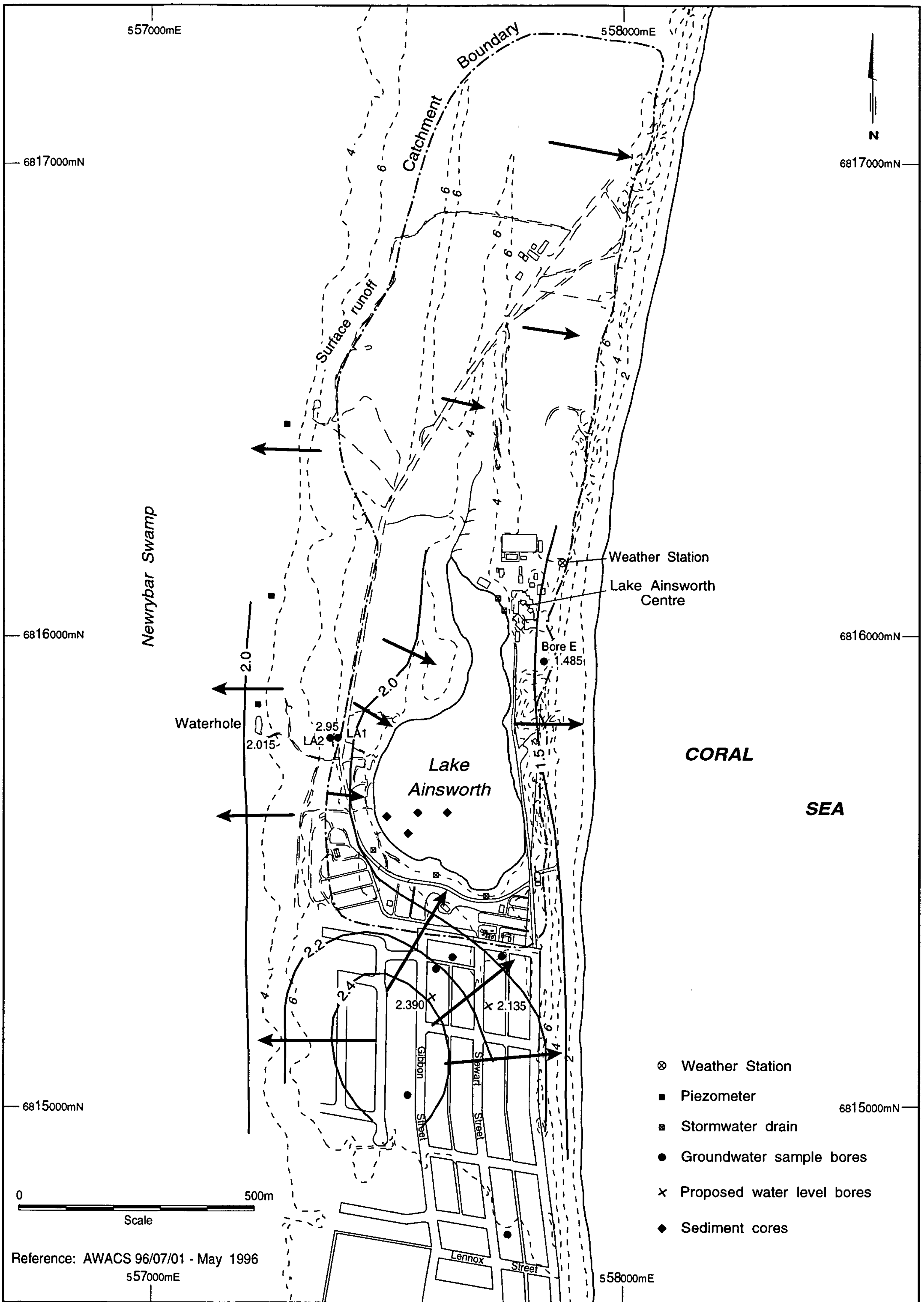
LAKE AINSWORTH SURFACE RUNOFF CATCHMENT AND SUB-CATCHMENTS

Figure 6.3



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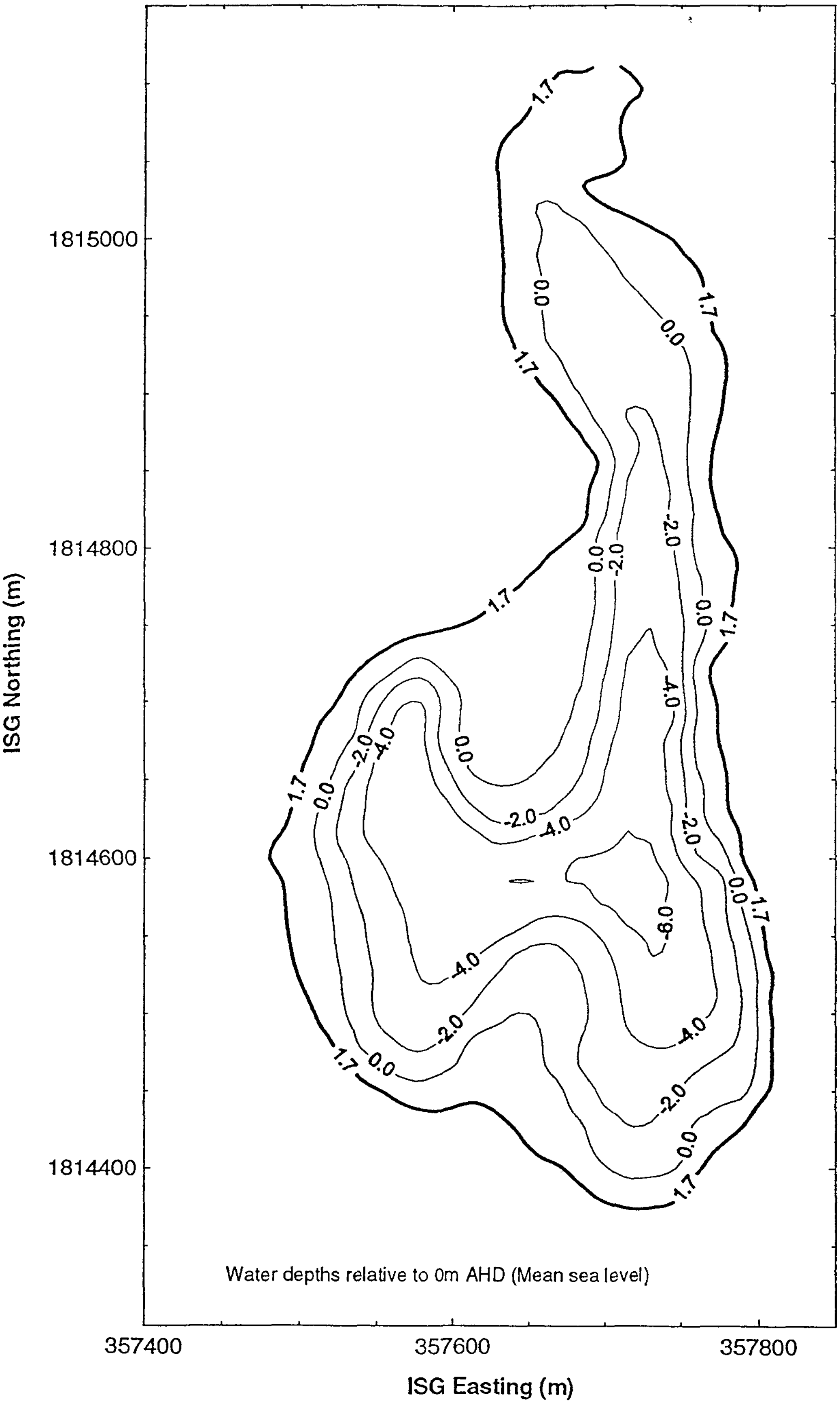
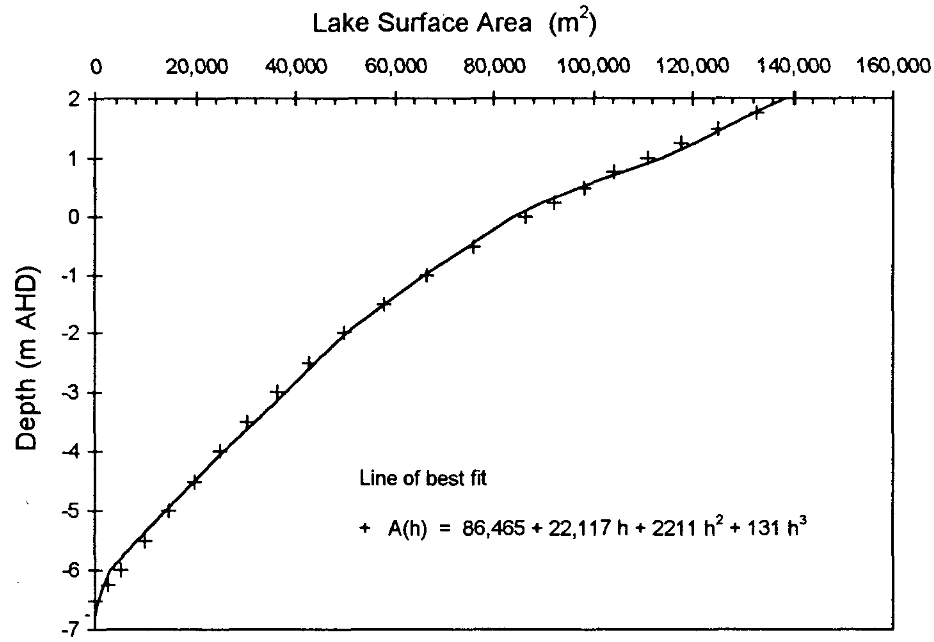
WATER TABLE LEVELS (m AHD) AND GROUNDWATER FLOW DIRECTION - 6 FEBRUARY 1996

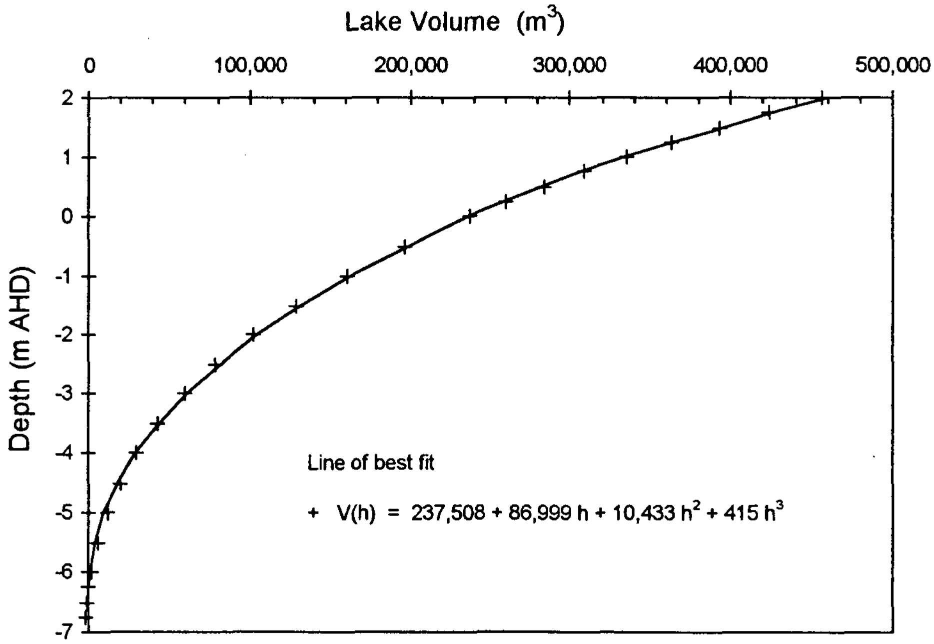
Figure 6.4



Reference: Coastal & Marine Geosciences - April 1996

AWACS Report No. 96/07	LAKE AINSWORTH BATHYMETRY (mAHD) - 6 FEBRUARY 1996	Figure 6.5





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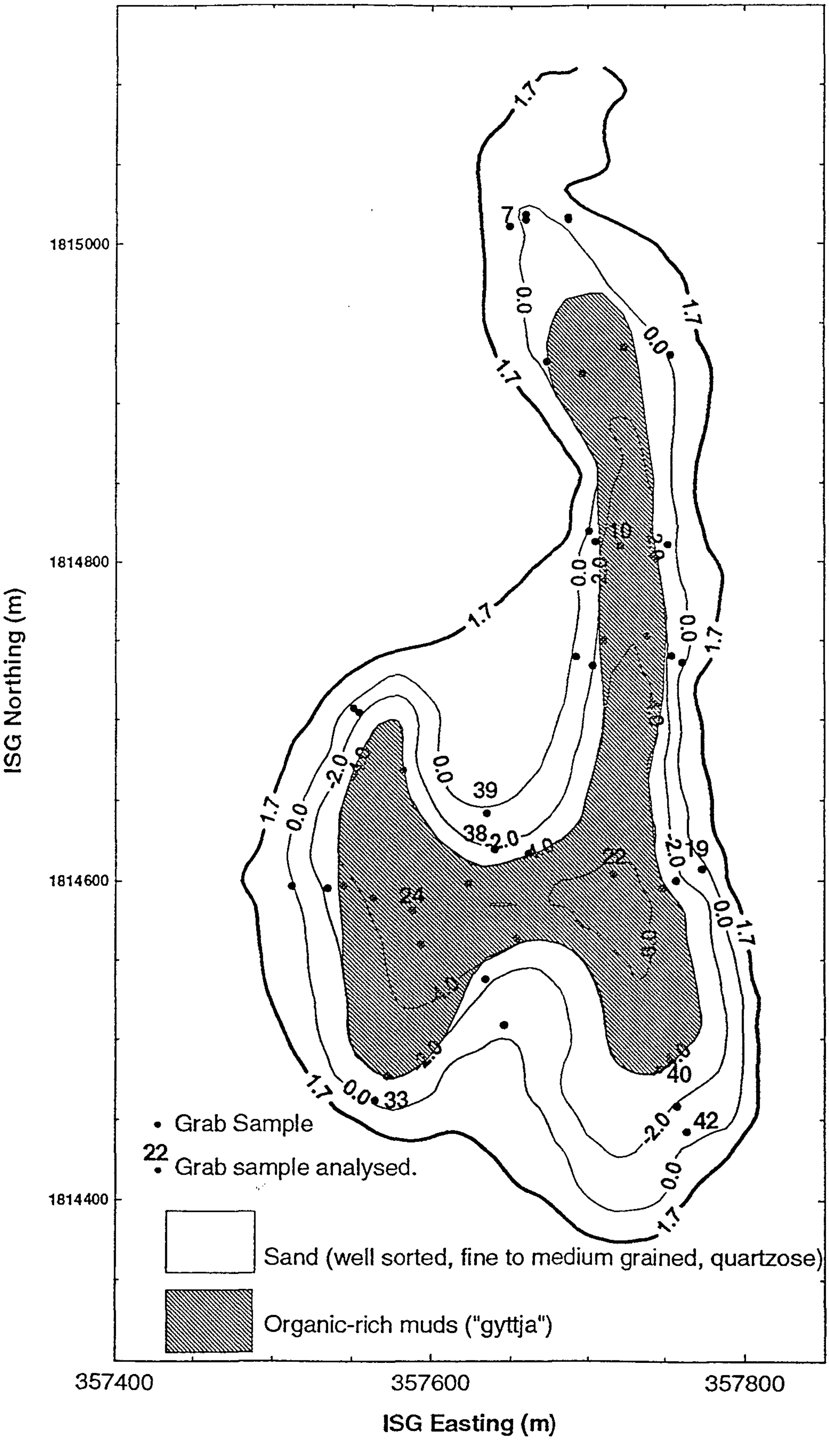
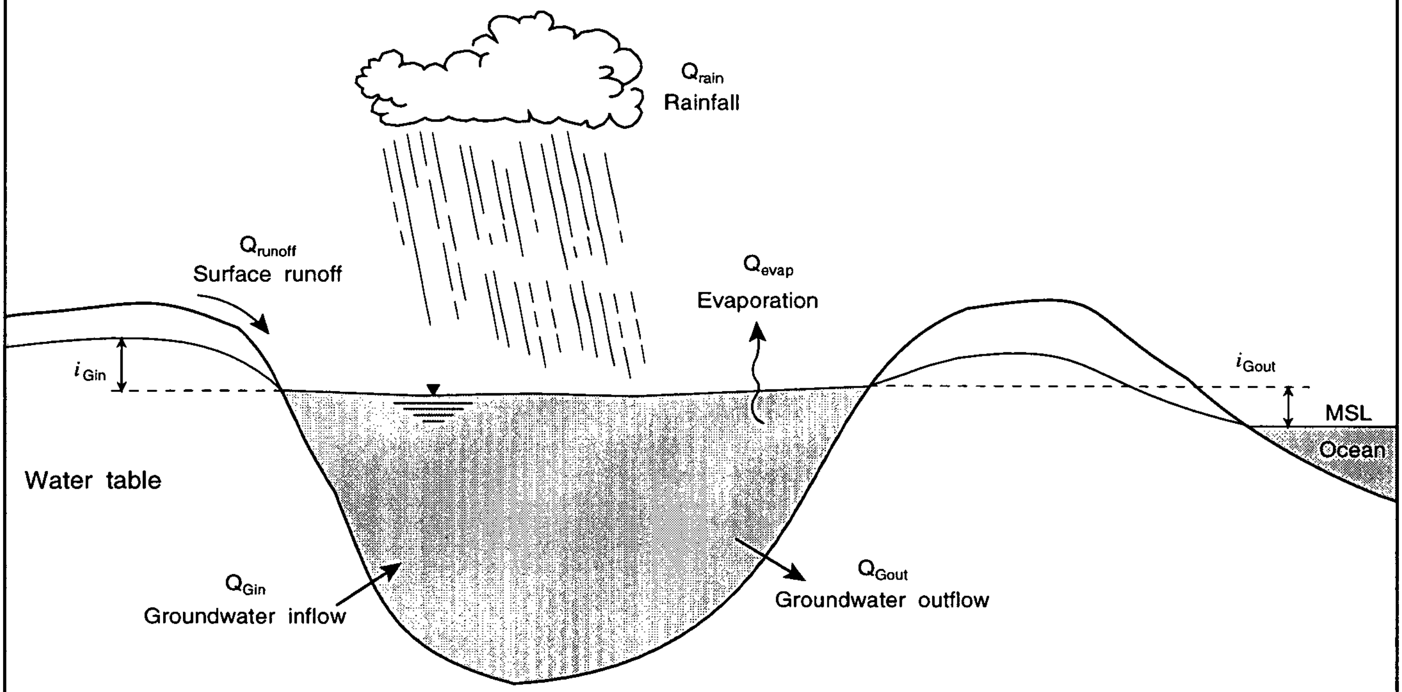
LAKE VOLUME AND AREA AS A FUNCTION OF DEPTH

Figure 6.6

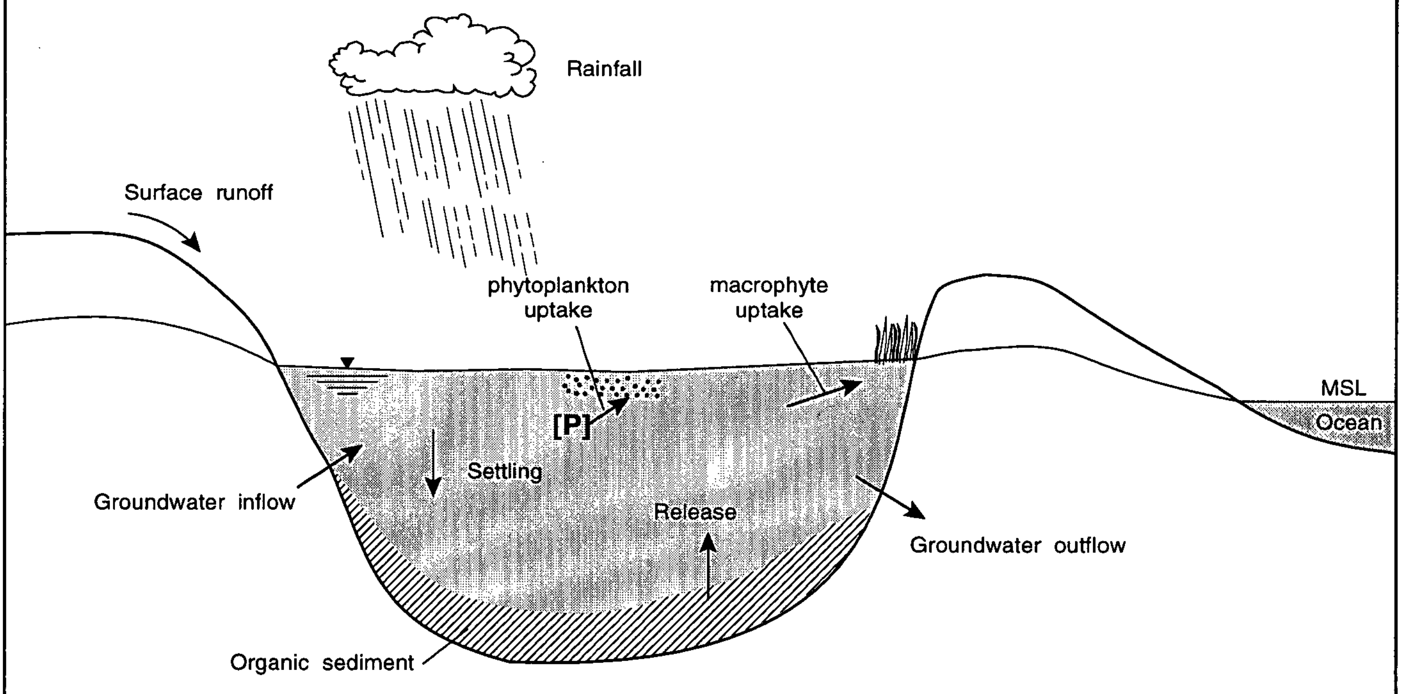


Reference: Coastal & Marine Geosciences - April 1996

AWACS Report No. 96/07	SURFACE SEDIMENT TYPES IN LAKE AINSWORTH	Figure 6.7



Water Budget



Phosphorus Budget

AWACS Report No. 96/07	SCHEMATIC OF THE WATER BUDGET AND THE TOTAL PHOSPHORUS BUDGET	Figure 6.8

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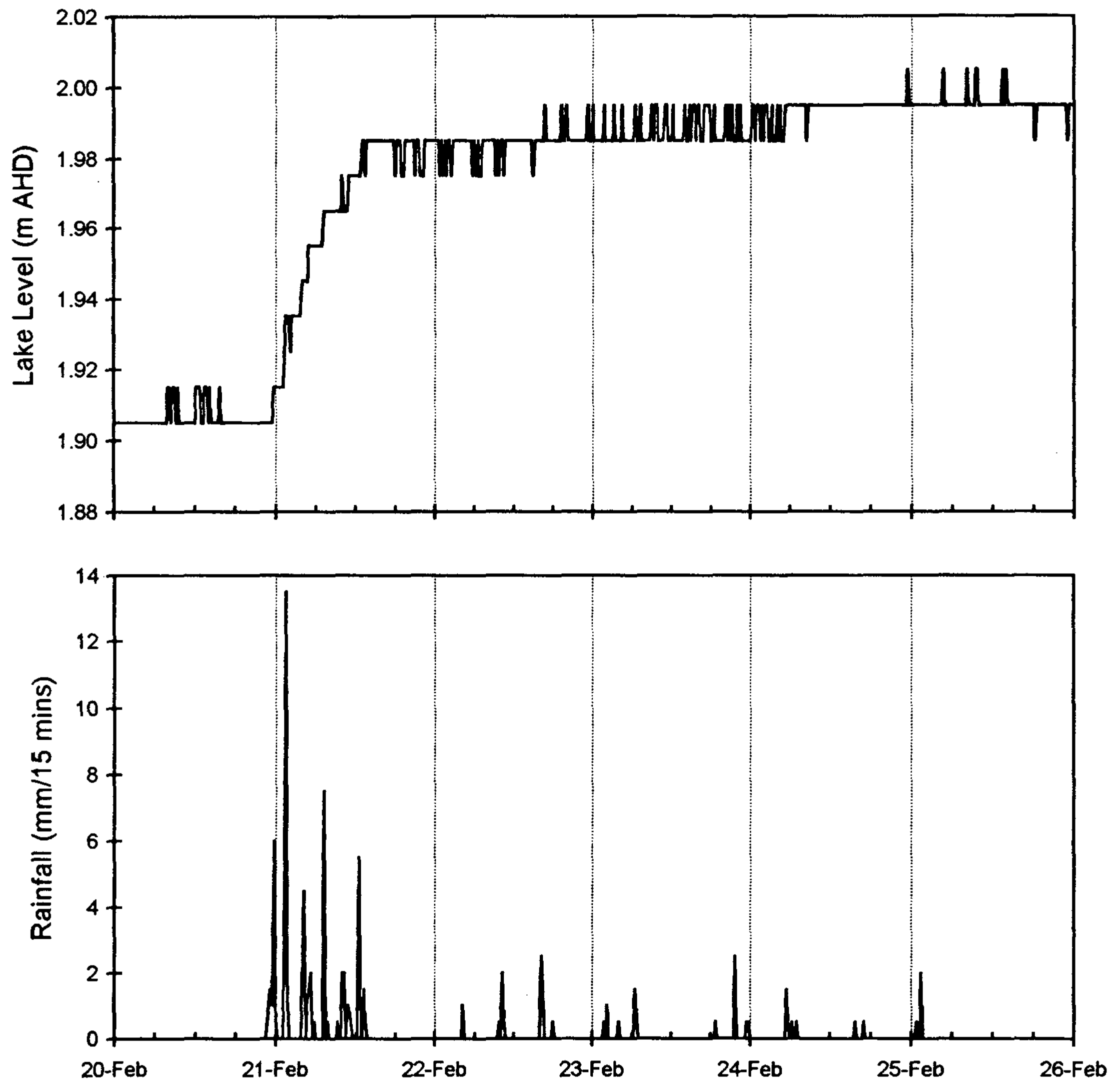
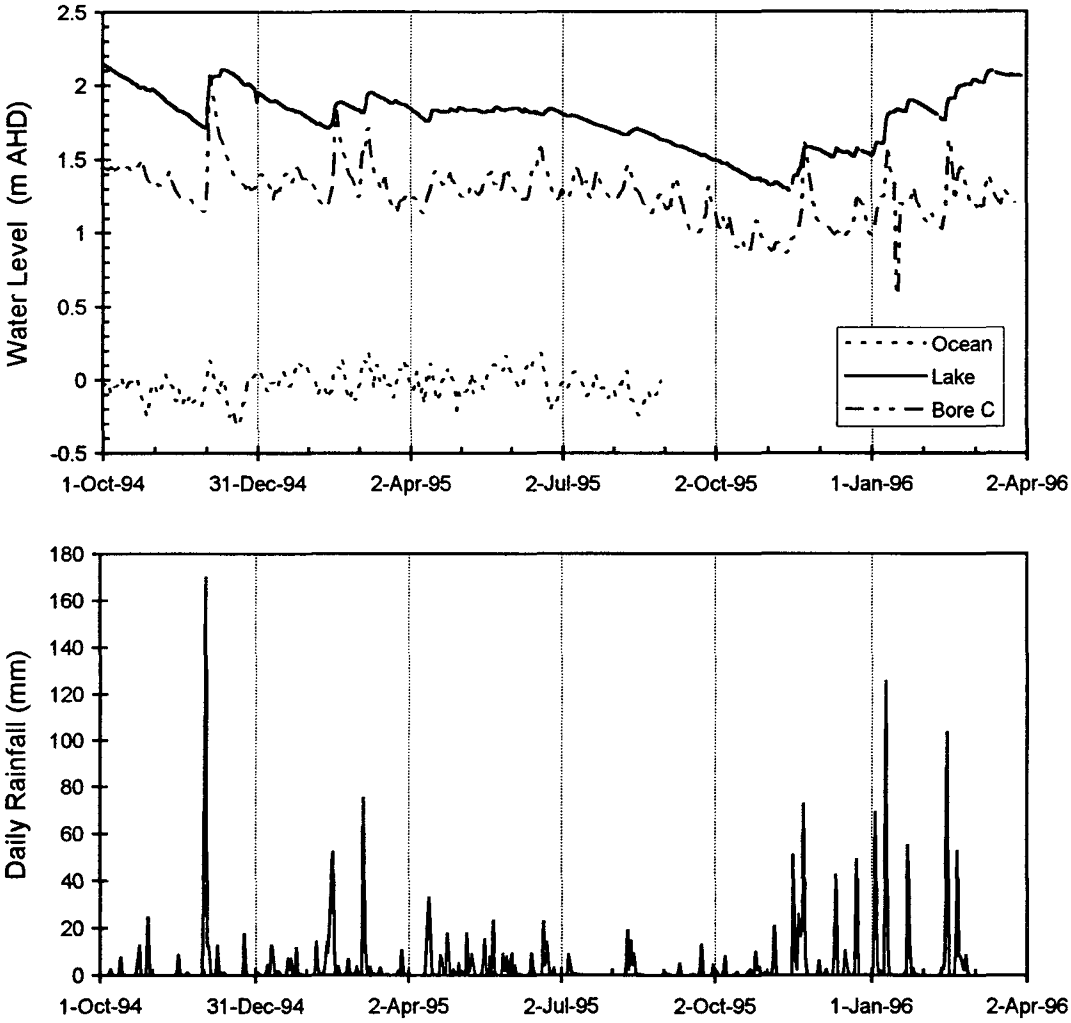


AWACS Report No. 96/07	LAKE WATER LEVELS AND RAINFALL 20 TO 25 FEBRUARY 1996	Figure 6.9



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LAKE WATER LEVELS AND RAINFALL

Figure 6.10

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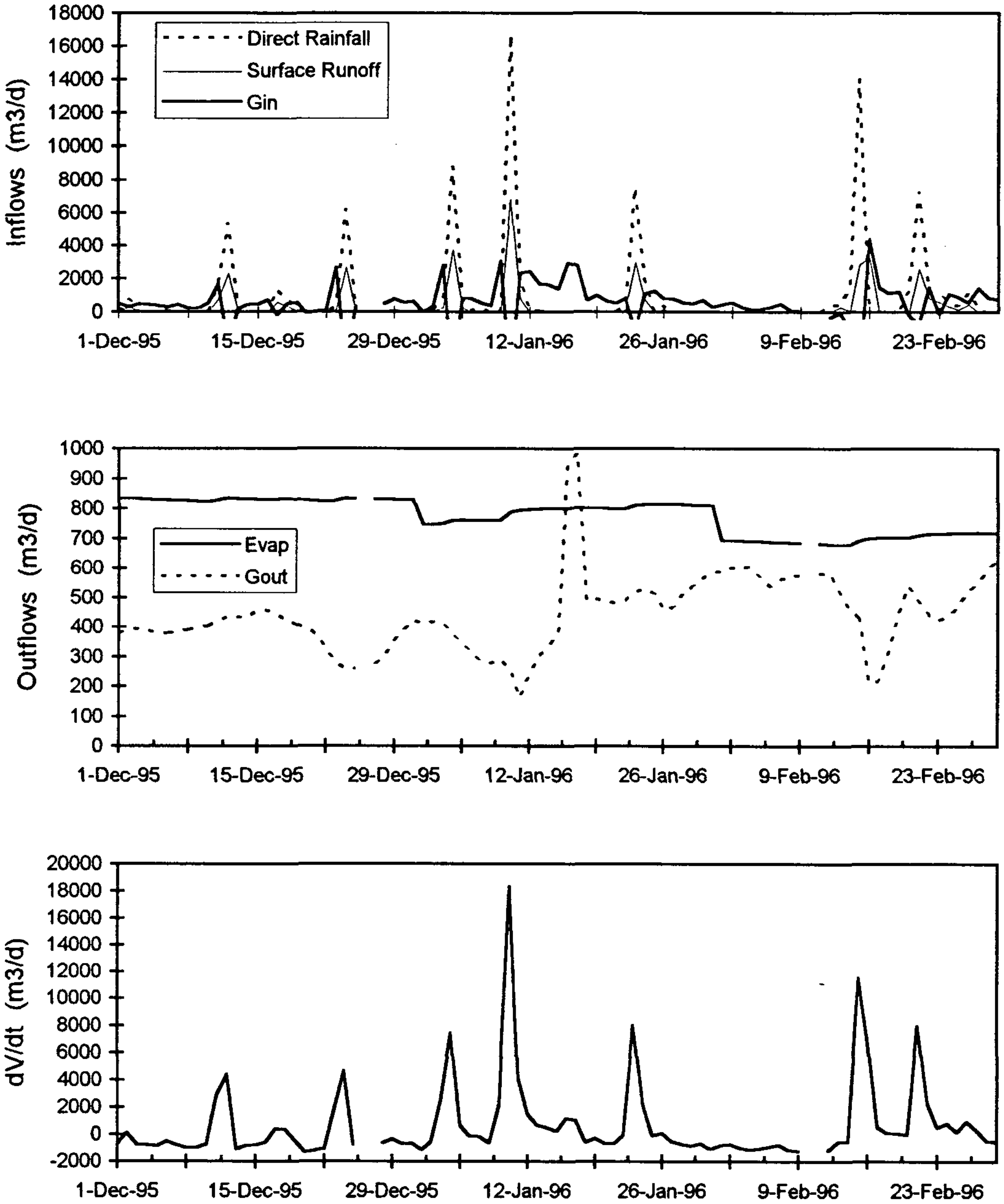

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LAKE WATER BUDGET COMPONENTS

Figure
6.11

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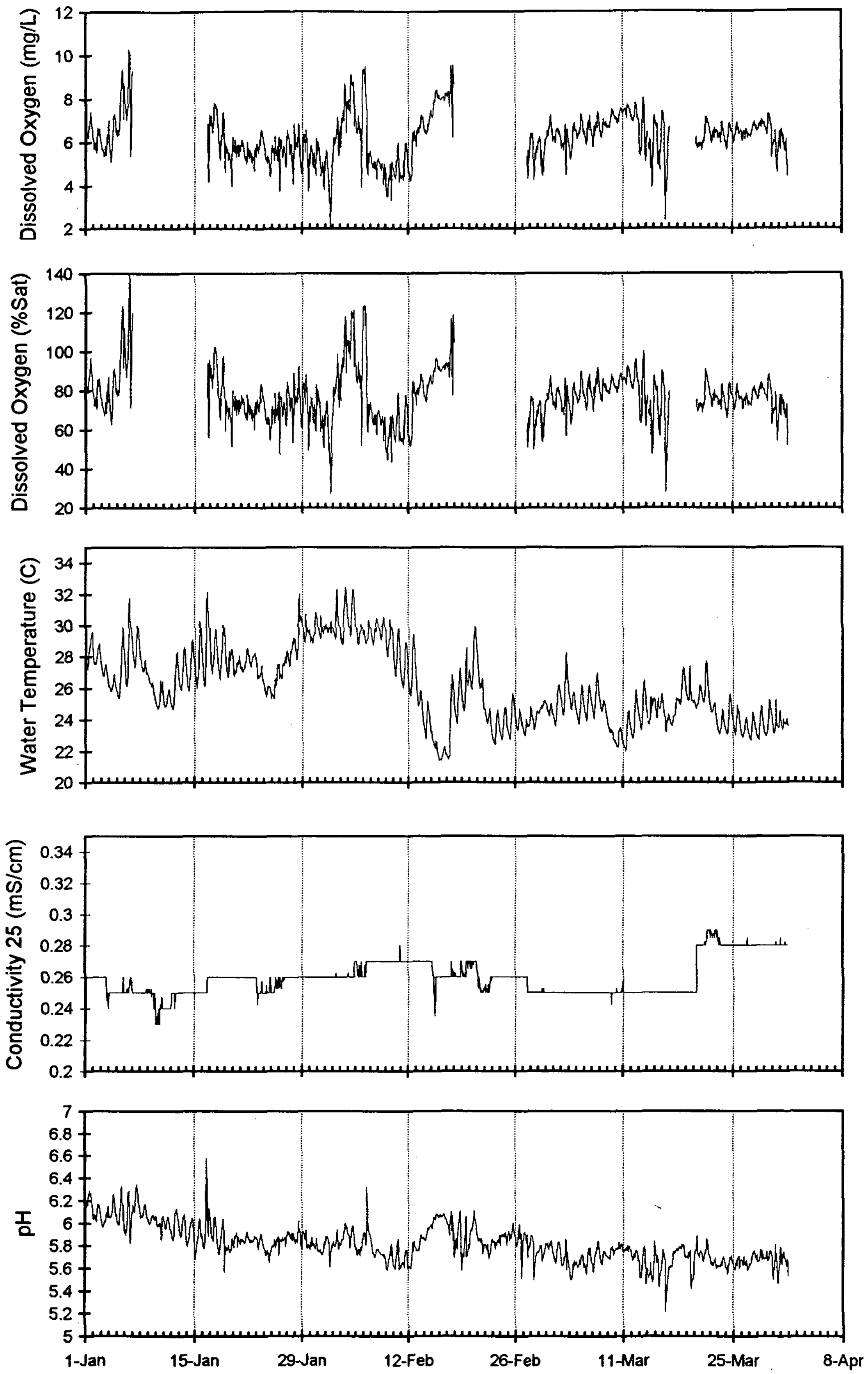
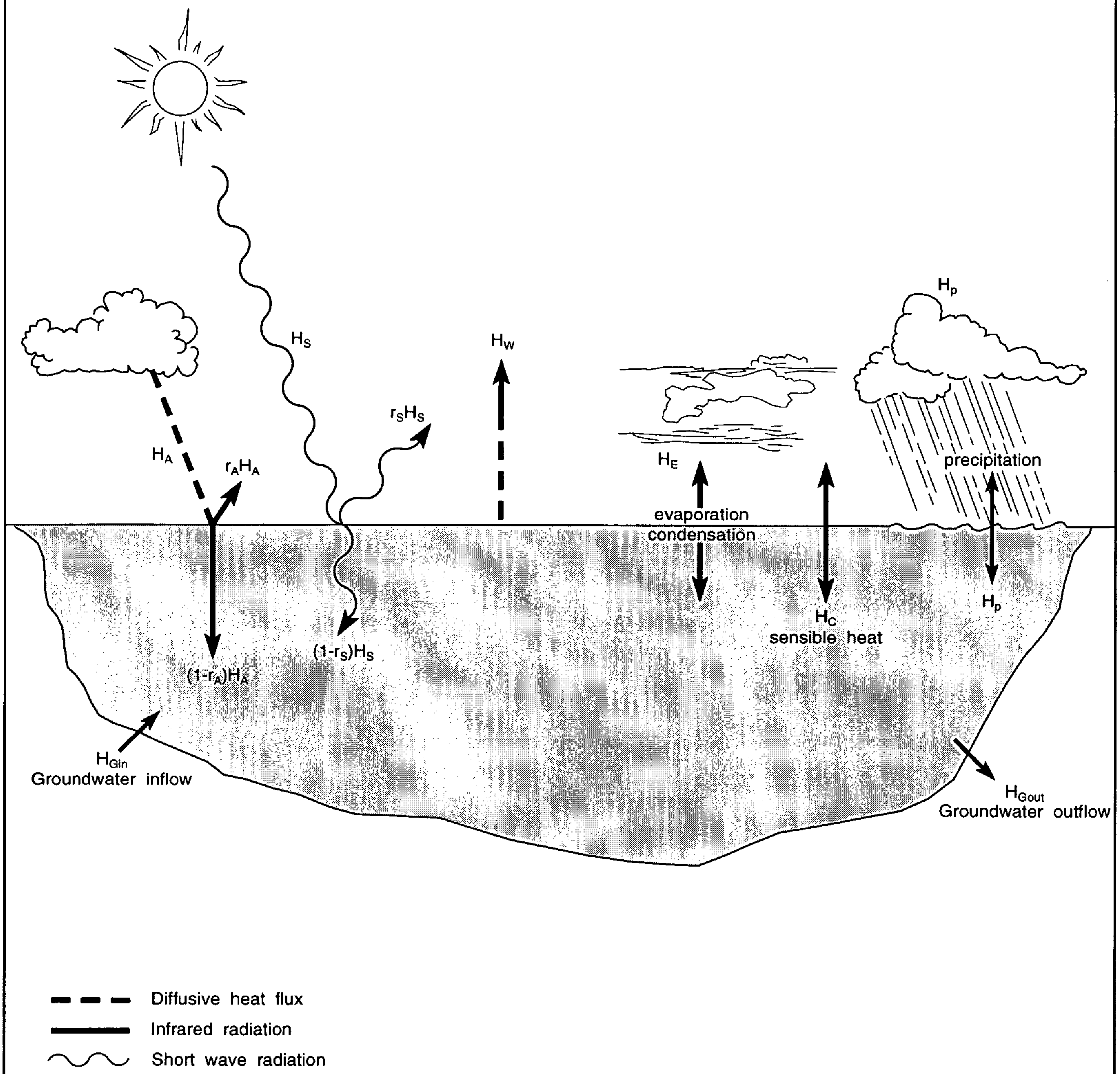


AWACS Report No. 96/07	TIME SERIES OF WATER QUALITY VARIABLES MEASURED AT LAKE AINSWORTH 1 JANUARY TO 31 MARCH 1996	Figure 6.12



AWACS Report No. 96/07	SCHEMATIC OF CONTRIBUTION TO THE LAKE HEAT FLUX	Figure 6.13

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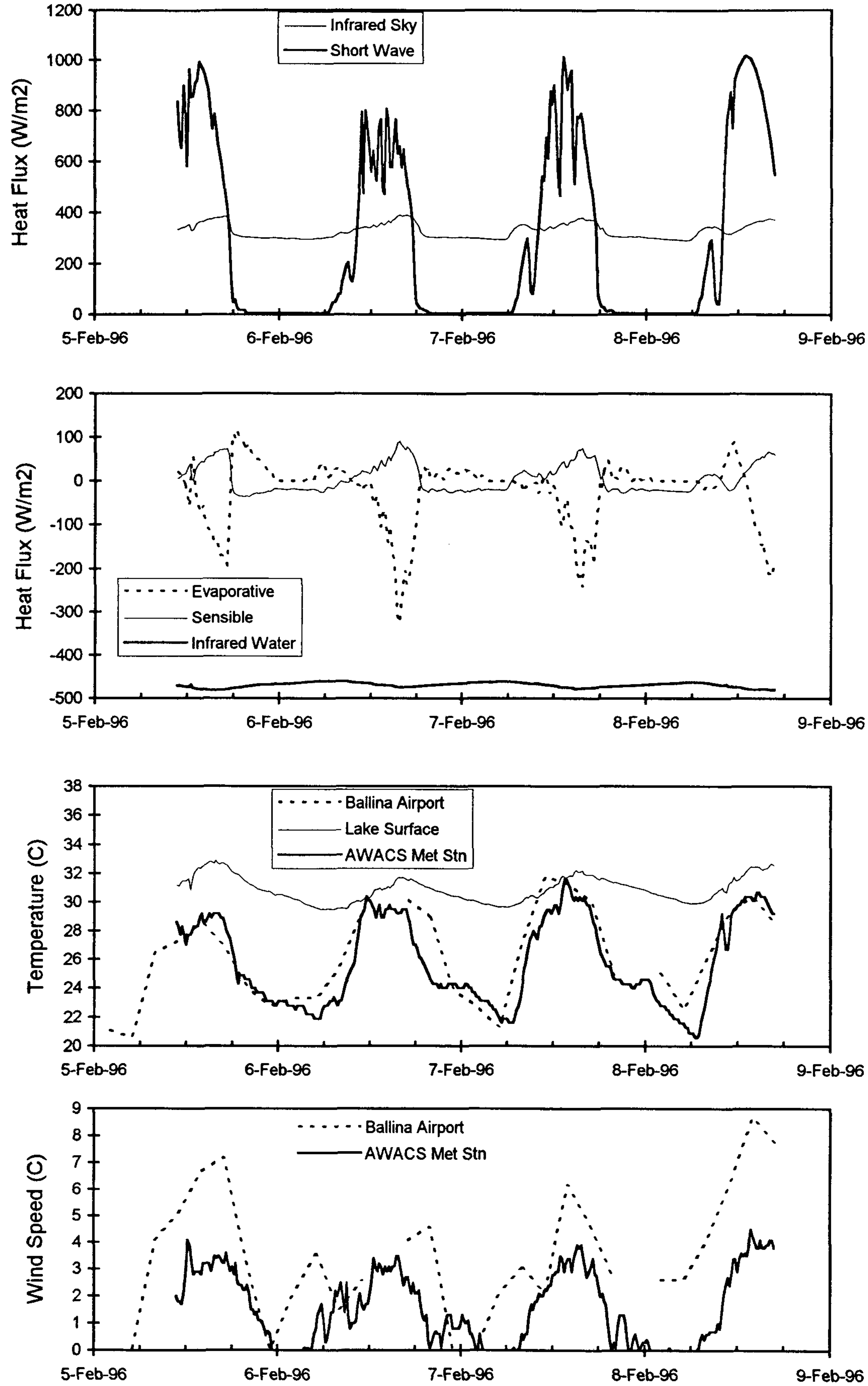

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HEAT FLUX CONTRIBUTIIONS
(NEGATIVE HEAT LOST FROM THE LAKE)

Figure
6.14

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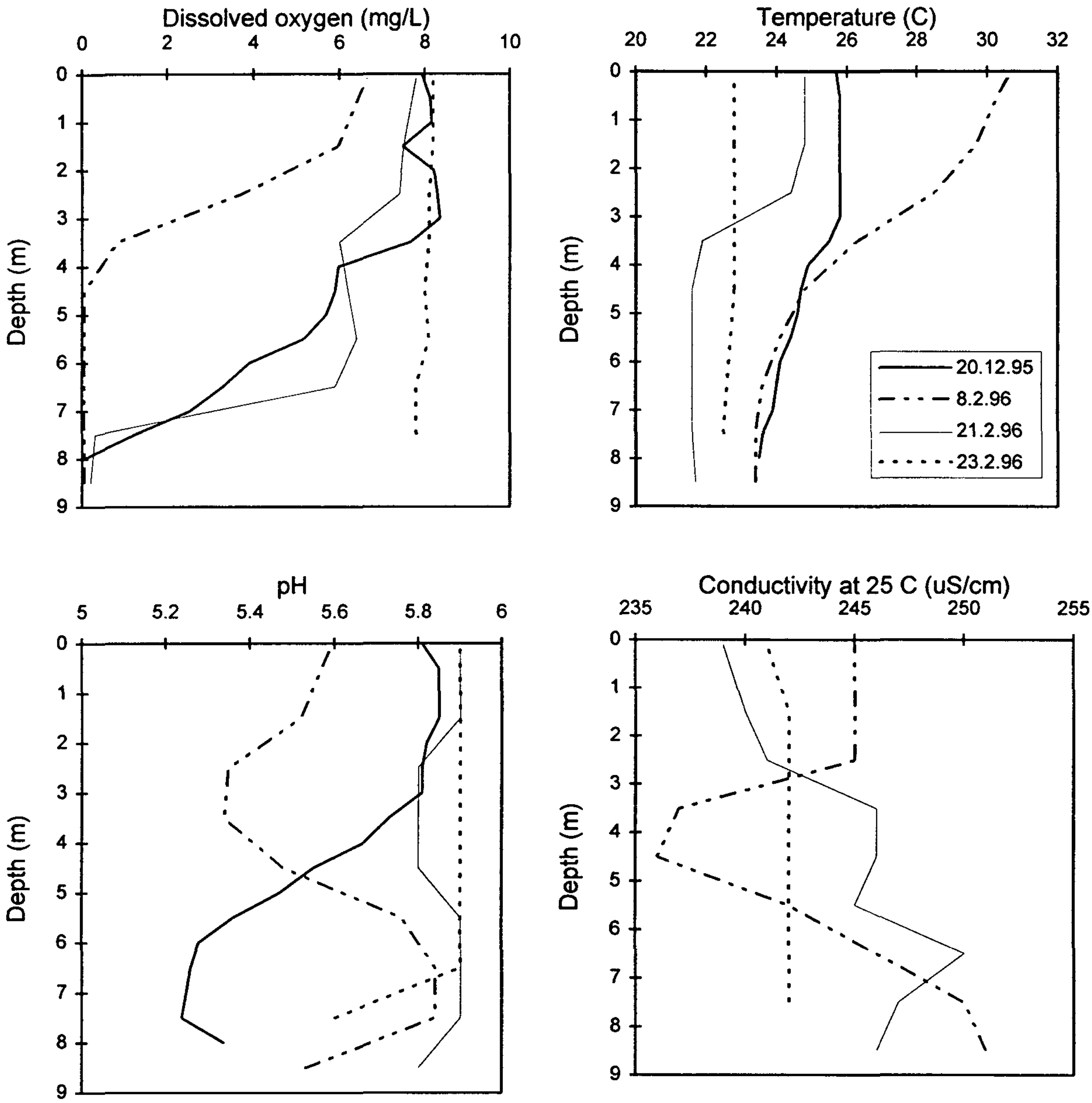

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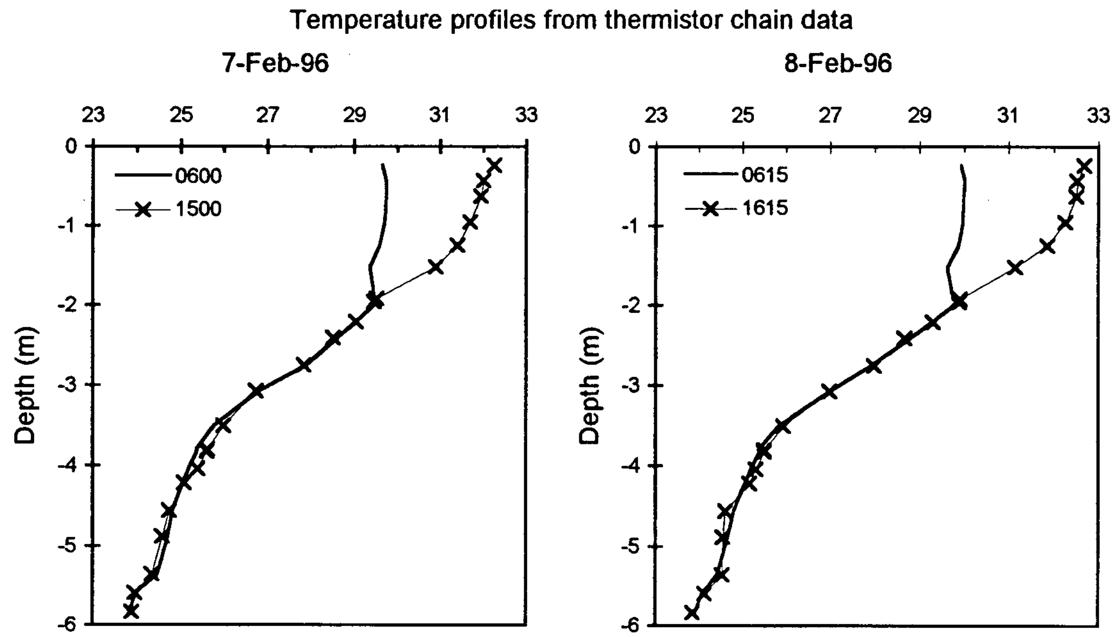
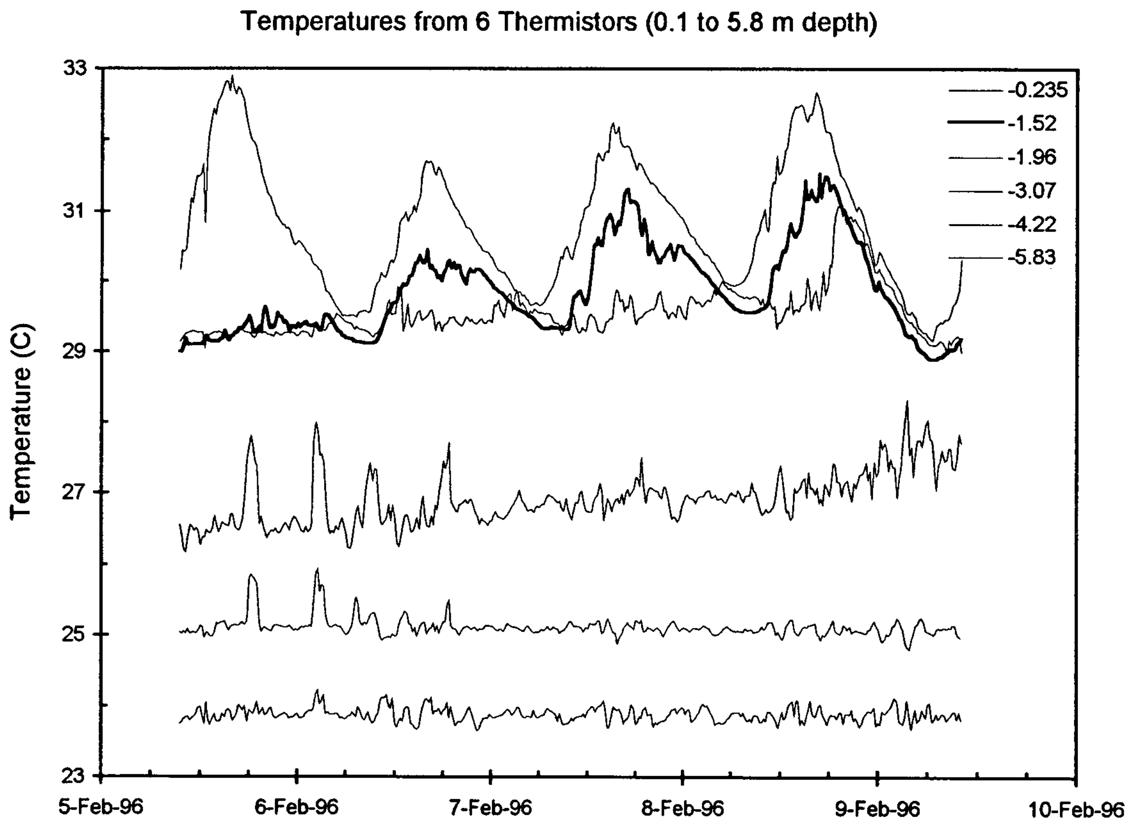
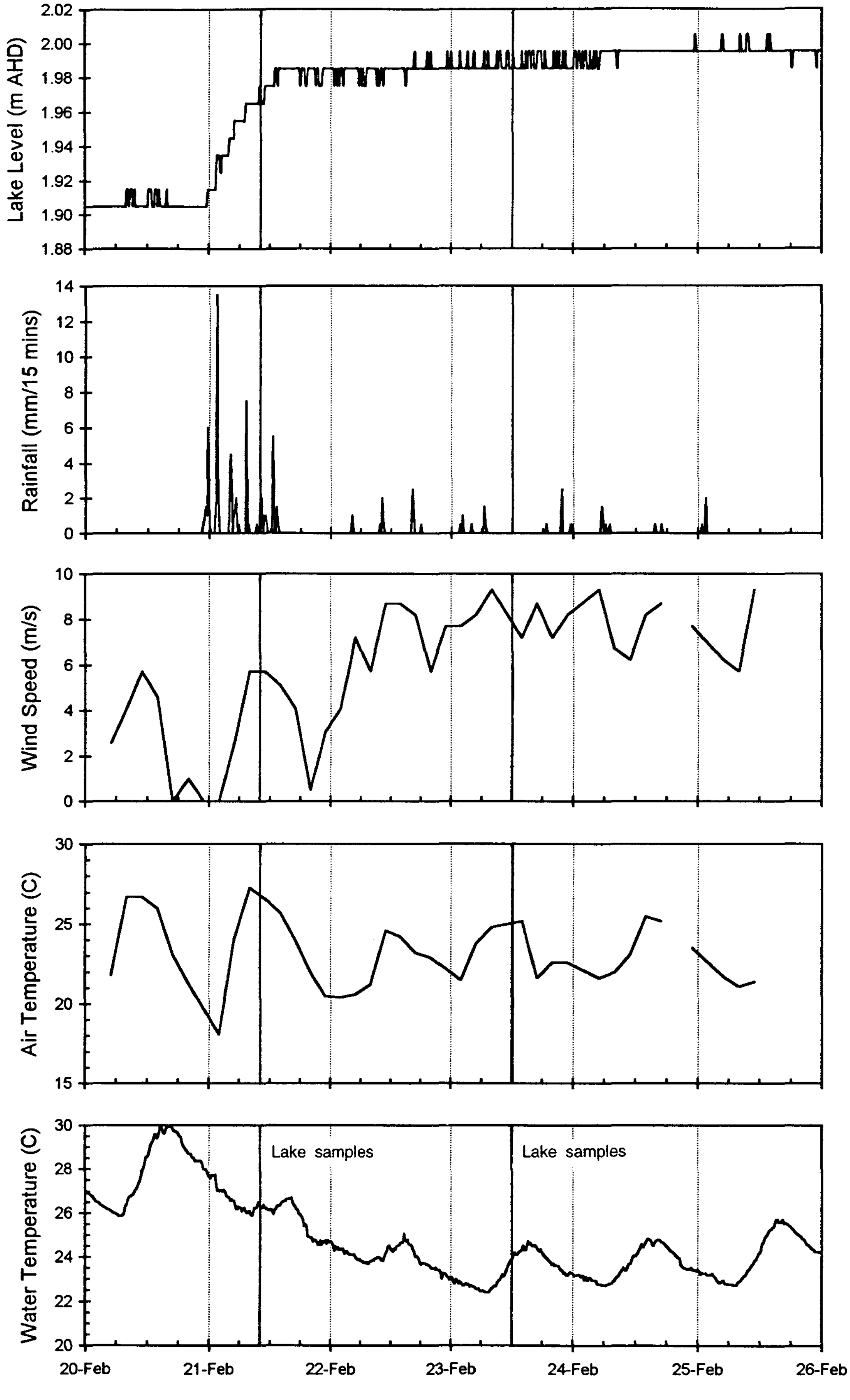
VERTICAL PROFILES OF DISSOLVED OXYGEN, TEMPERATURE, pH AND CONDUCTIVITY IN THE DEEPEST PART OF THE LAKE

Figure 6.15





AWACS Report No. 96/07	WATER TEMPERATURES AT DIFFERENT DEPTHS RECORDED BY THE THERMISTOR CHAIN	Figure 6.16



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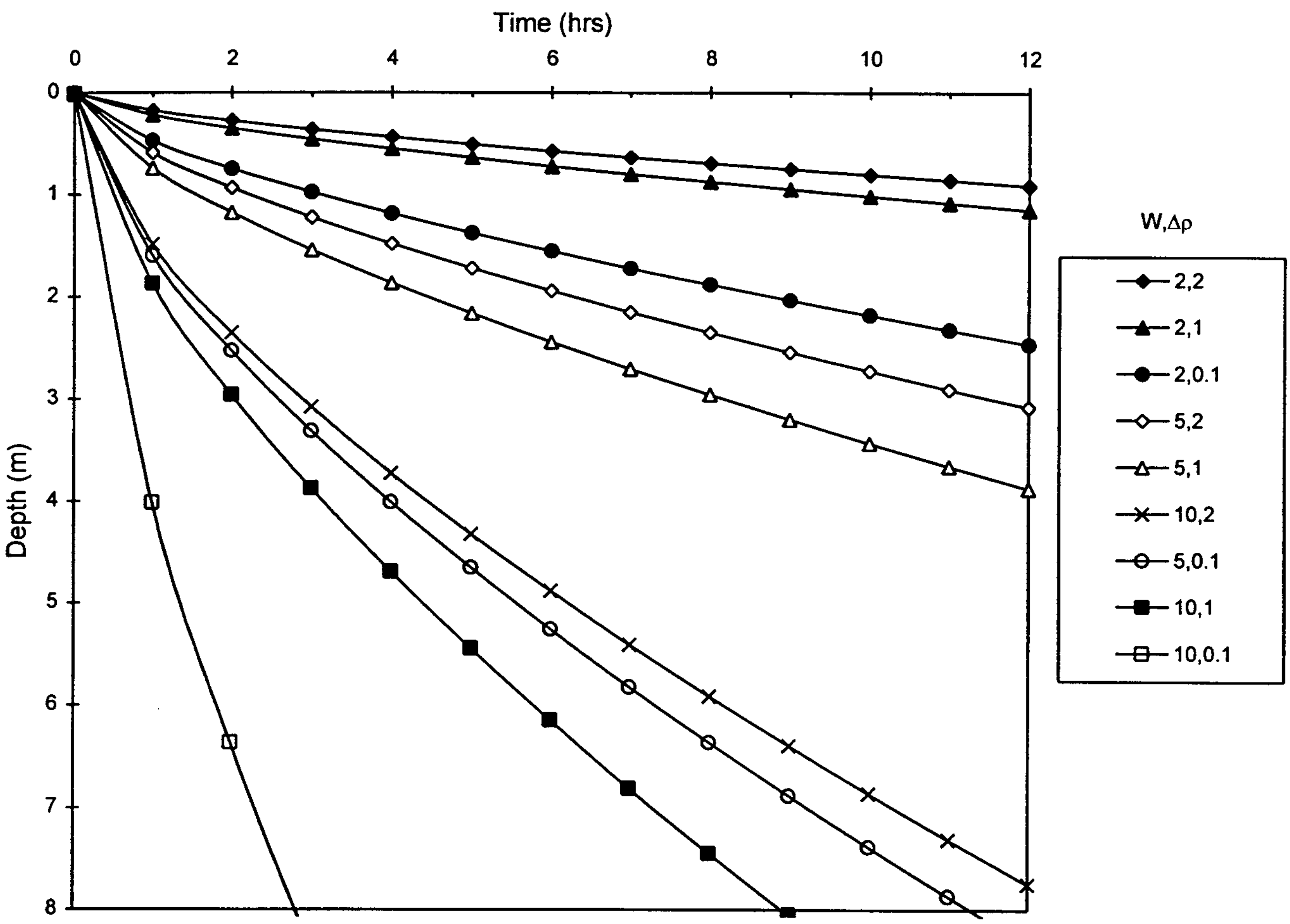
WIND SPEED AND AIR TEMPERATURE AT BALLINA AIRPORT

Figure 6.17



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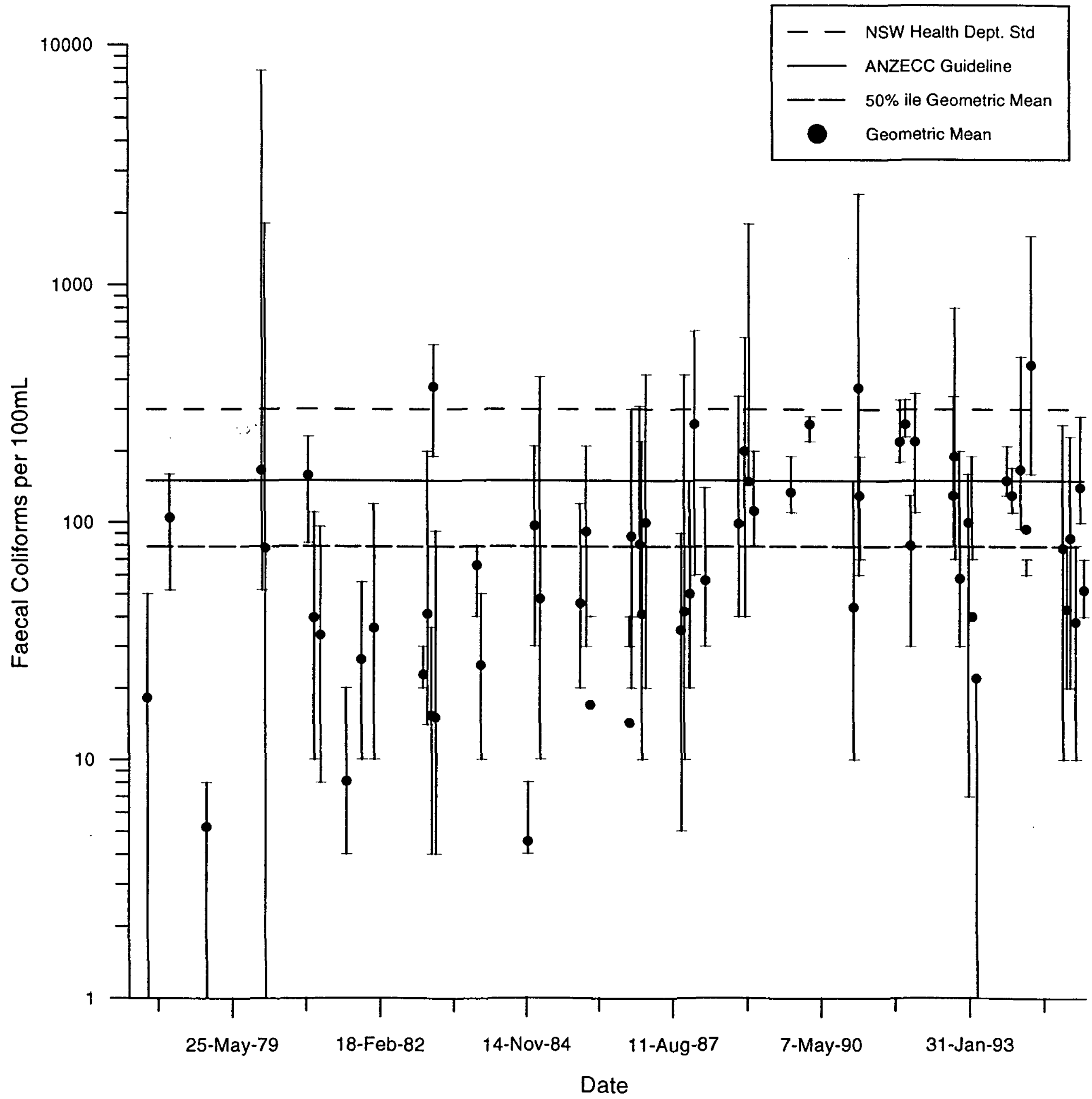
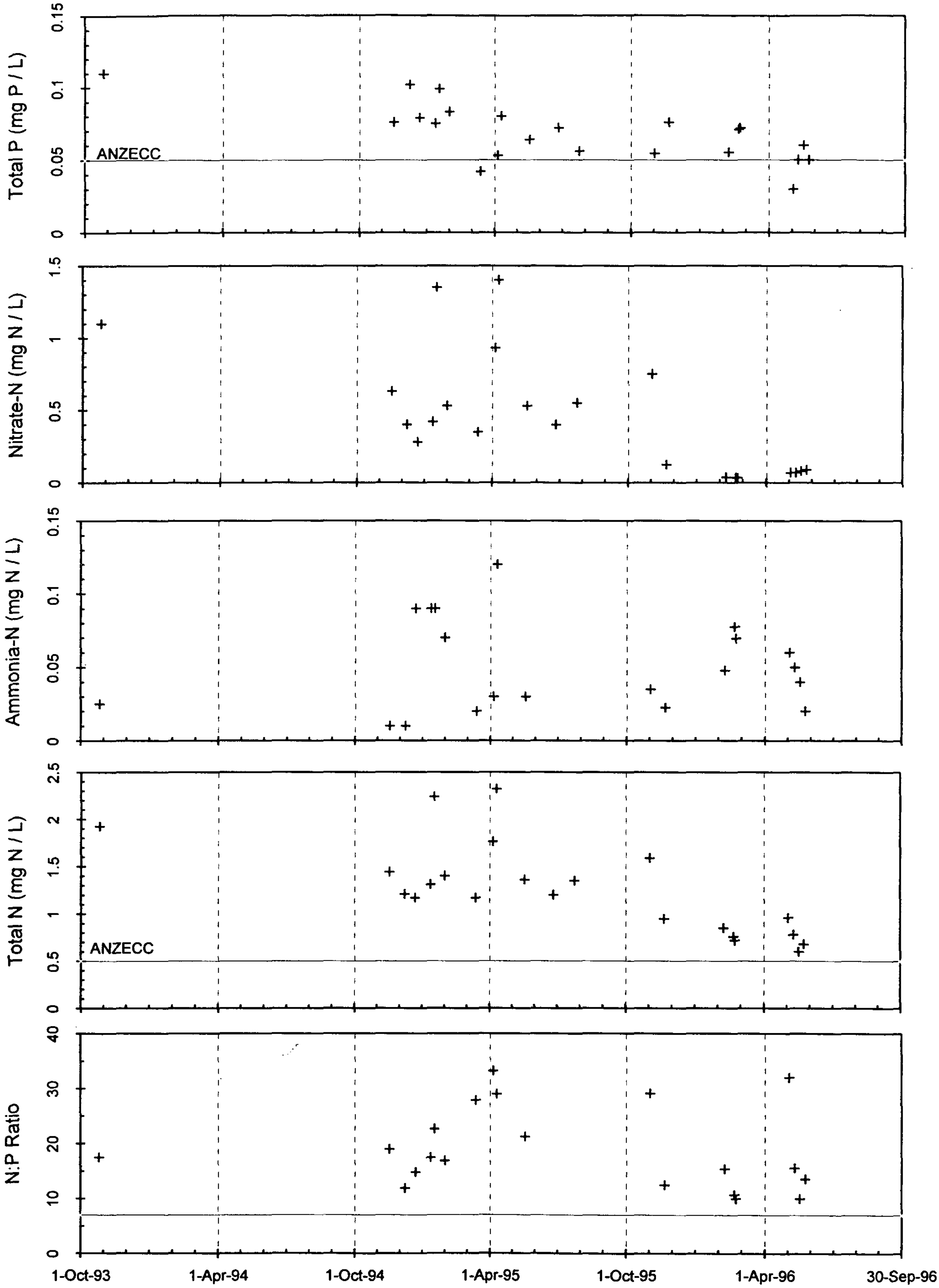
MIXED LAYER DEPTH VERSUS TIME FOR DIFFERENT COMBINATIONS OF WIND SPEED AND INITIAL STRATIFICATION

Figure 6.18



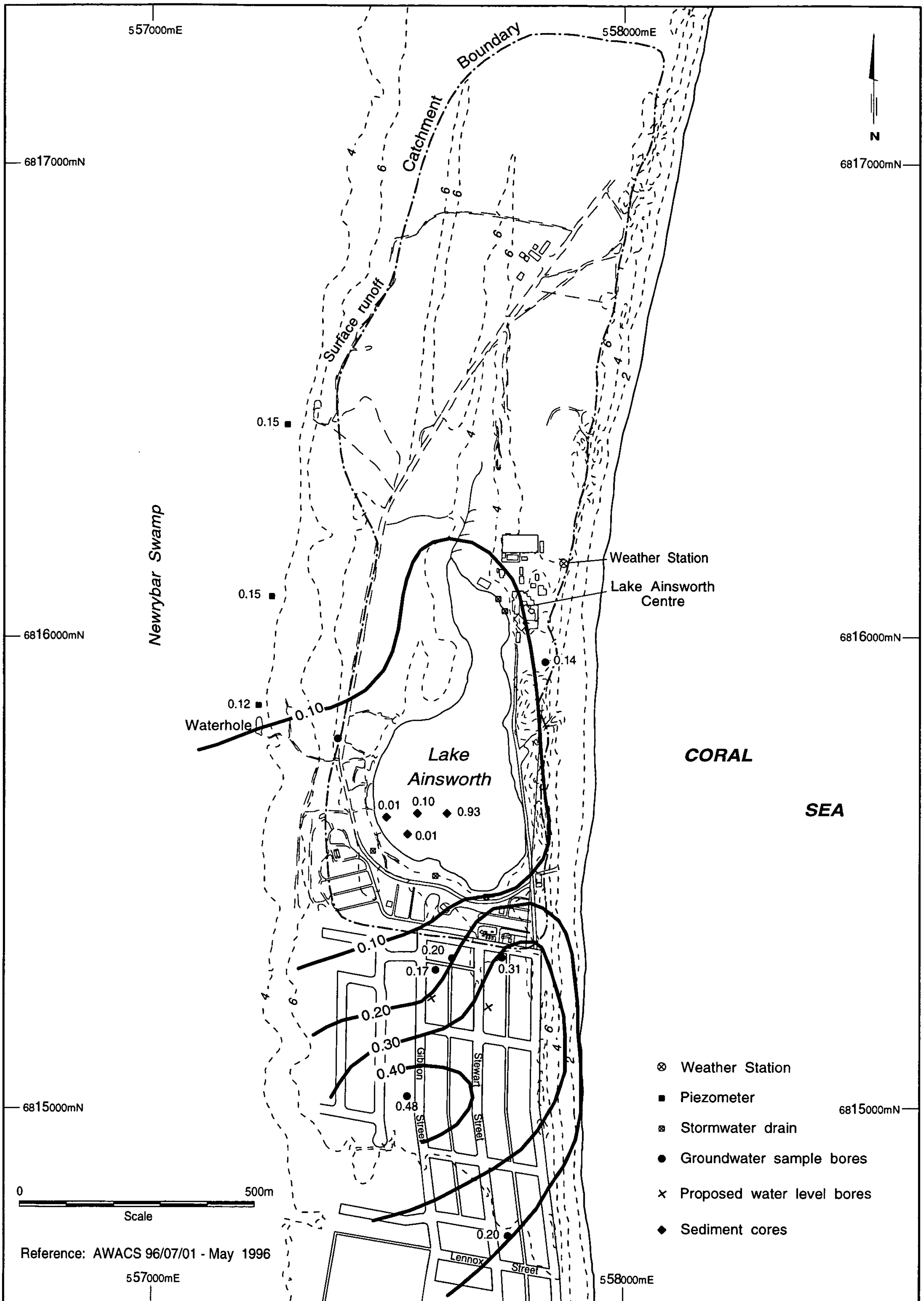
Reference: Ballina Shire Council

AWACS Report No. 96/07	FAECAL COLIFORM DATA	Figure 6.19



Reference: Data from Ballina Shire Council

AWACS Report No. 96/07	NUTRIENT CONCENTRATIONS IN THE LAKE AND NITROGEN TO PHOSPHORUS RATIO	Figure 6.20



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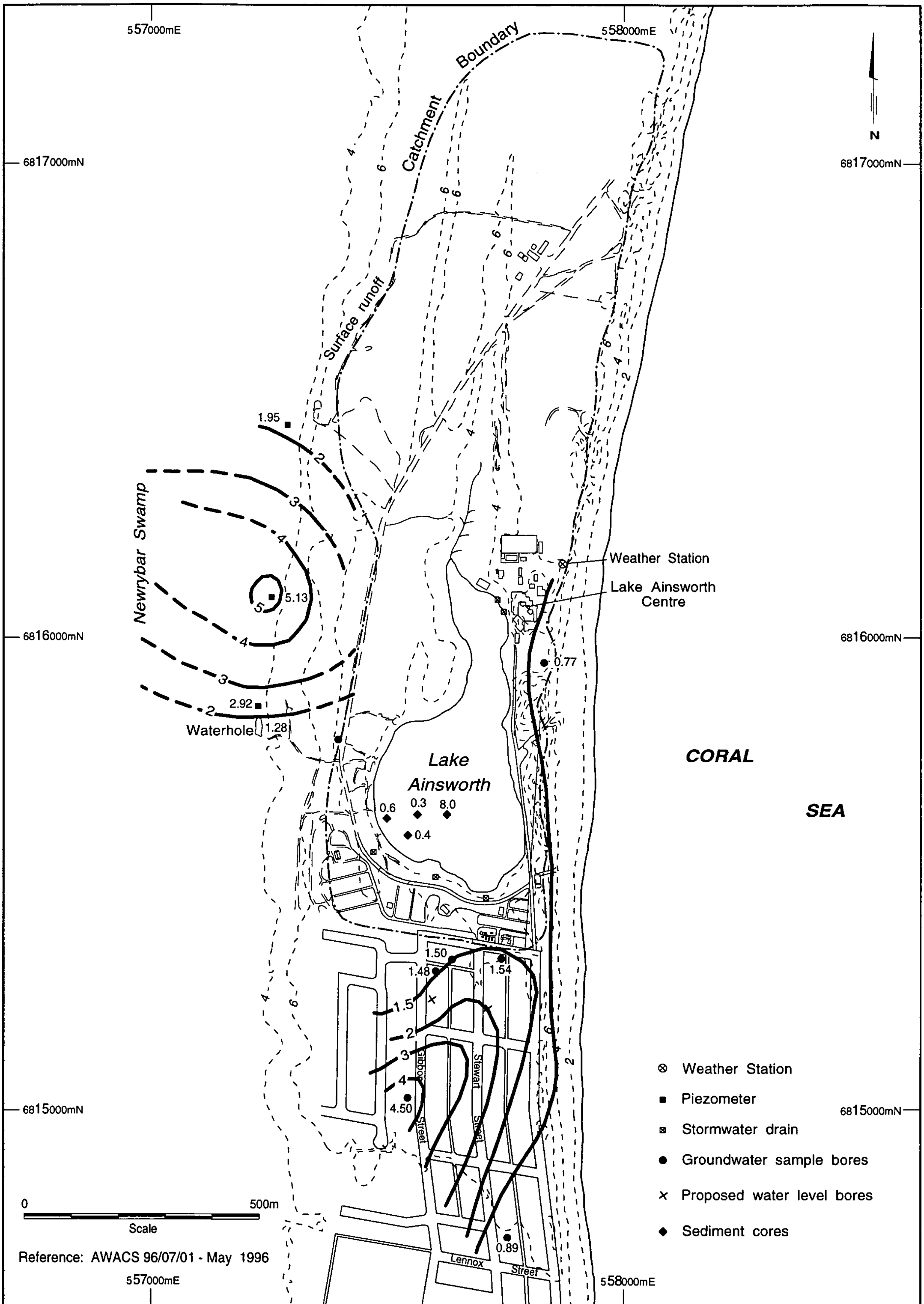
TOTAL PHOSPHORUS (mg/L) CONCENTRATION IN GROUNDWATER - 6 FEBRUARY 1996

Figure 6.21



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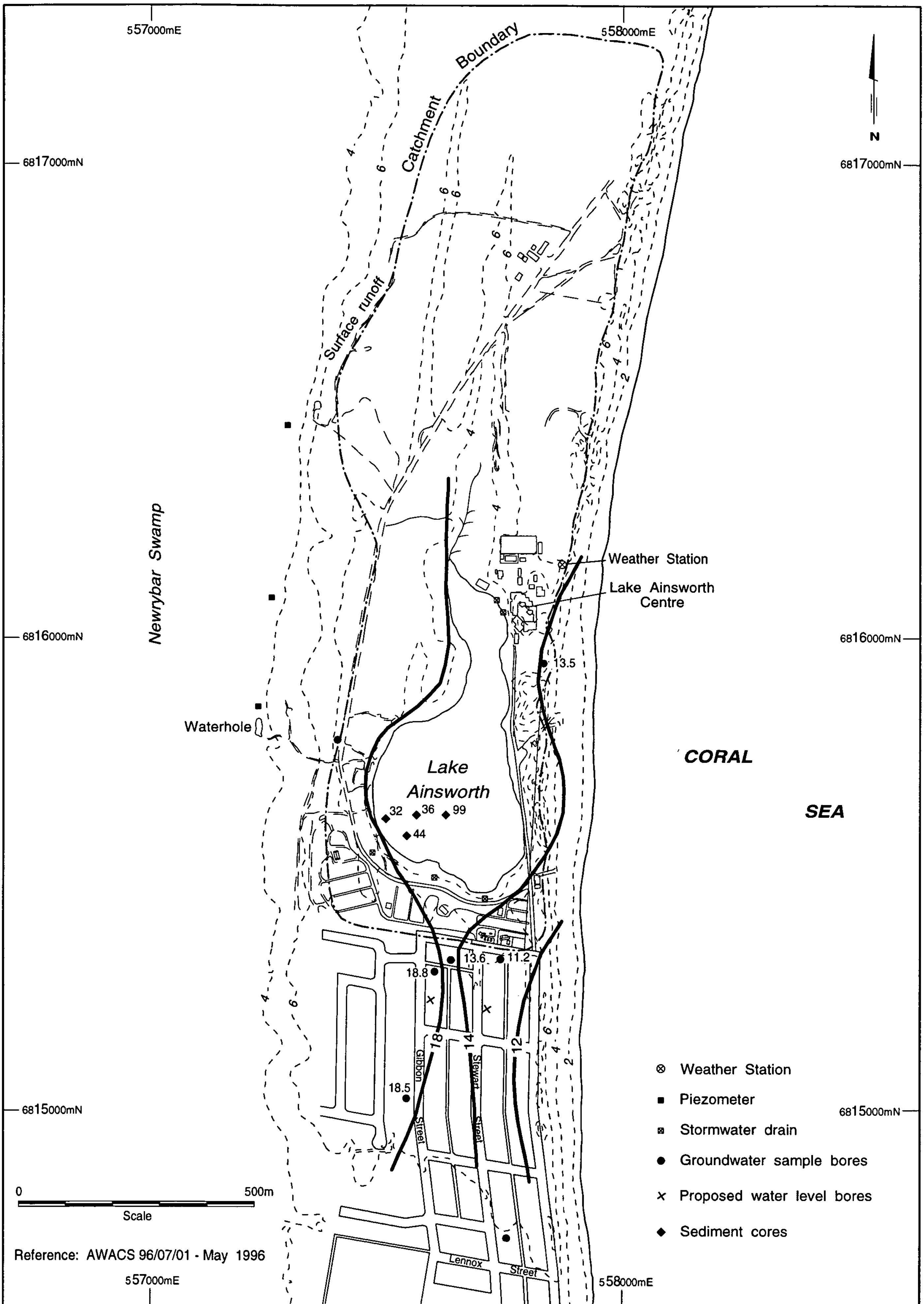
TOTAL NITROGEN (mg/L) CONCENTRATION IN GROUNDWATER - 6 FEBRUARY 1996

Figure 6.22



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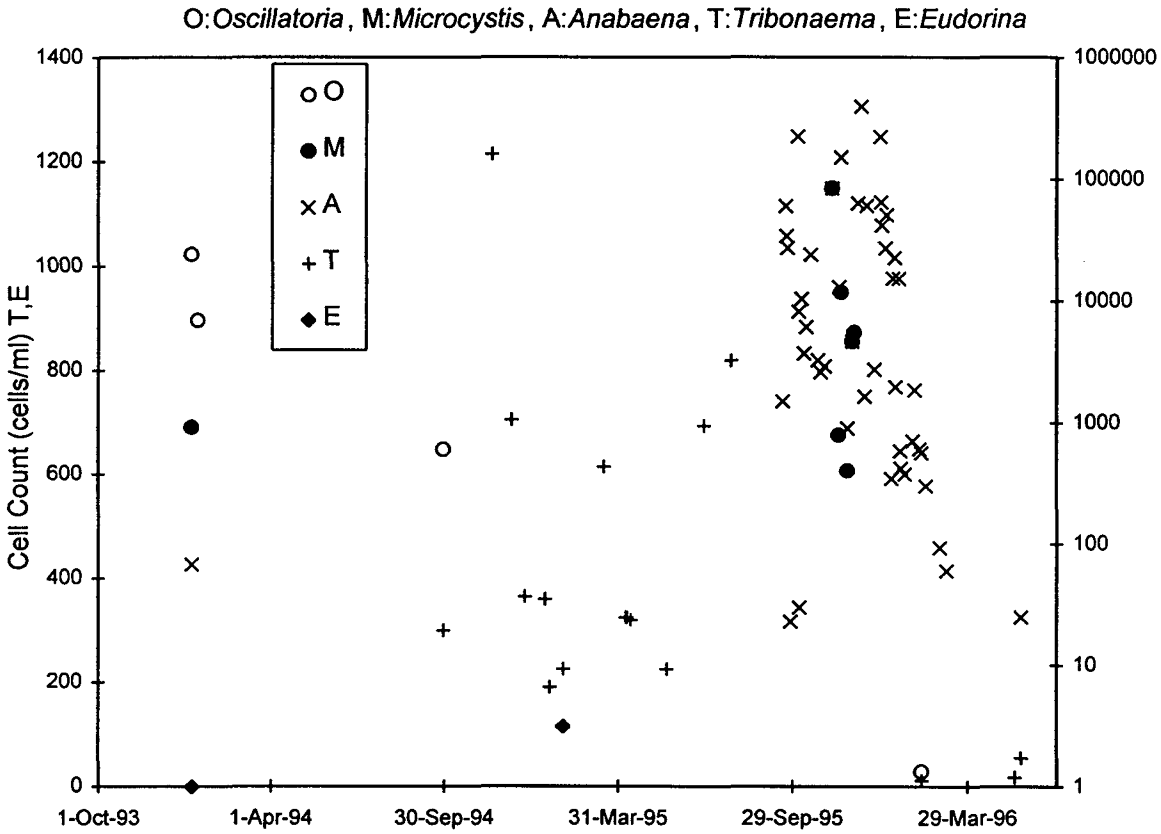
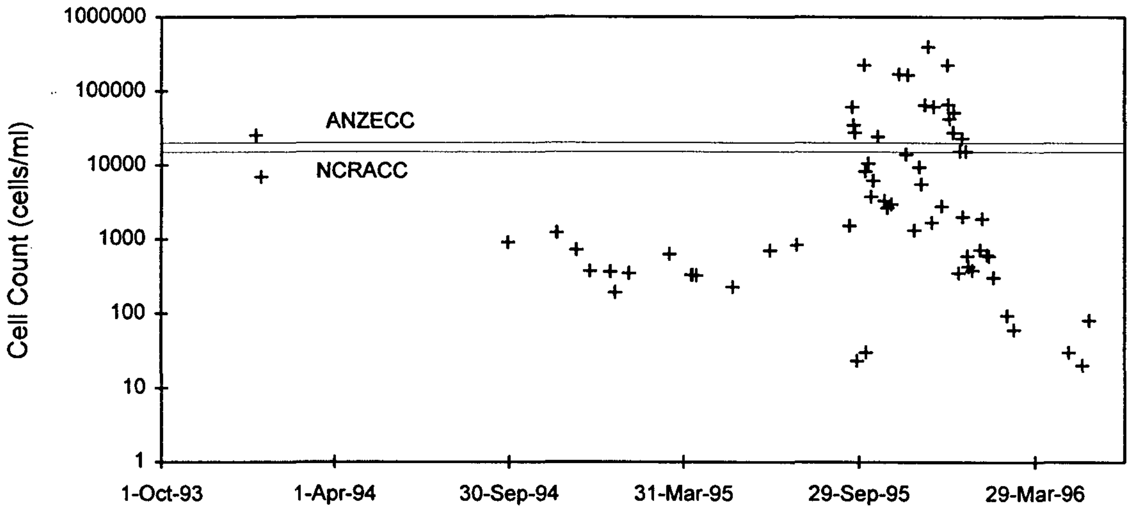
TOTAL ORGANIC CARBON CONCENTRATION (mg/L) IN GROUNDWATER - 6 FEBRUARY 1996

Figure 6.23



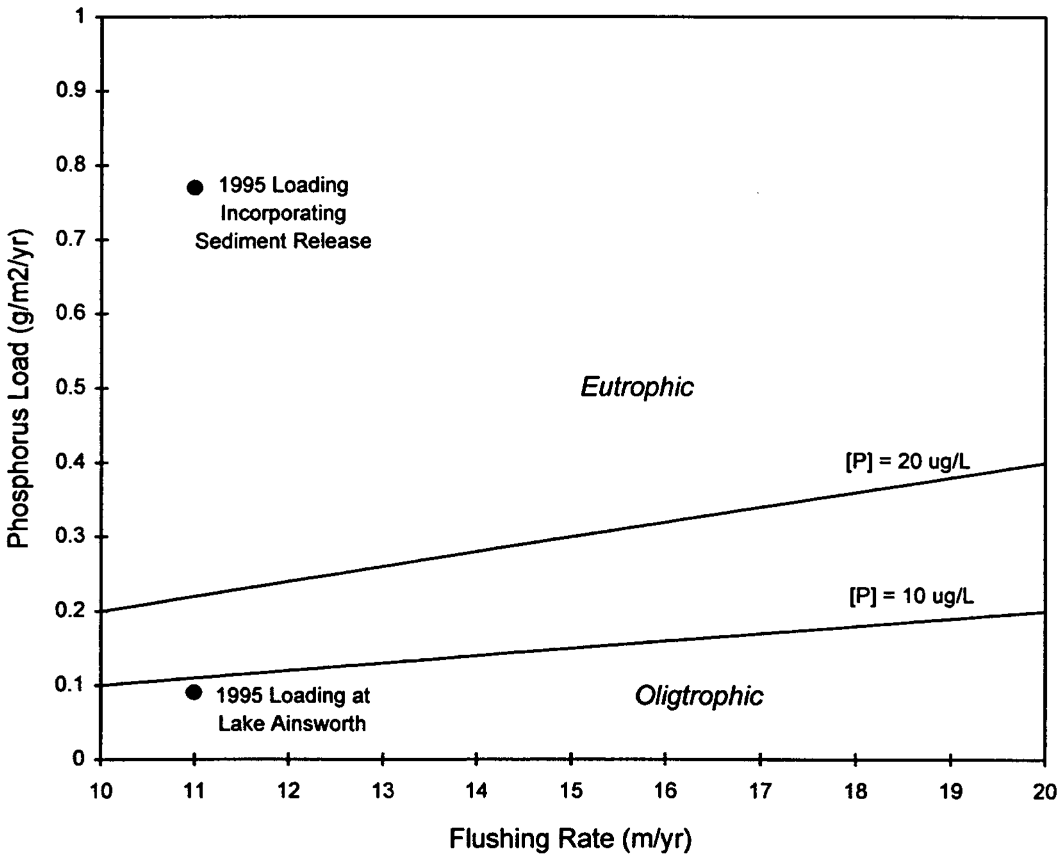


ANZECC - Australian and New Zealand Environment and Conservation Council guideline

NCRACC - North Coast Regional Algal Co-ordinating Committee Standard

Reference: Data from Ballina Shire Council

AWACS Report No. 96/07	ALGAL CELL COUNTS BY SPECIES AND TOTAL COUNTS	Figure 6.24



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LAKE TROPHIC CLASSIFICATION FOR 1995

Figure 6.25

7. Significant Issues

From this study a range of significant issues has been identified including recommendations on matters to be addressed in subsequent stages of development of a management study and plan. Significant issues are listed in Table 7.1

Table 7.1 Significant Issues

Issue	Comment/Recommendation
Alienation of Crown Land	• Restricted public foreshore use due to the proximity of the caravan park. • Large area of undeveloped Crown land under the control of the Department of Sport and Recreation which could be developed sensitively for passive recreation (eg walking trails) to decrease pressure on the developed reserve (encroachment of picnickers onto Sport and Recreation Centre already occurs). Jones (1988) noted that the Crown land reserves were under-utilised for walking.
Inadequate Reserve Facilities	• Lack of facilities or unacceptable facilities. Blainey et al (1988) found that 50% of those surveyed thought that picnic tables and the toilets required upgrading, while Jones (1988) found that 39% of picnickers thought the tables were 'unpleasant' and the barbeques inadequate and 'unsightly'. Since 1988, however, two modern amenity blocks have been constructed for day use. Additional rubbish bins have been installed also, and are supplemented at peak usage periods. • Jones (1988) suggested that the swimming area did not include enough shallow shoreline area to cater for the number of children using the lake.
Multiple Control of Lands	• Sport and Recreation control the lands at the northern end of the lake and Ballina Shire Council controls lands at the southern end. Impedes coordinated management of the lake and its surrounds. The Lake Ainsworth Management Committee should facilitate improved management of the lake and its surrounds.
Lake Usage	• Overuse of the lake decreases recreational amenity at peak times. While overuse does not appear to have significant deleterious effects on lake processes, it does cause some localised foreshore erosion. • Services should be provided that are commensurate with the desired level of usage.
Aboriginal Sites	• There appears to be a need for further identification of Aboriginal sites, however these may have been significantly affected by land clearing.

Table 7.1 Significant Issues (continued)

Issue	Comment/Recommendation
Flooding	• Periodic minor flooding of the low lying basin to the south of the main building complex of the Sport and Recreation Centre. • Infrequent flooding of the main access road to the Sport and Recreation Centre.
Climate Change	• Possible increase in sea level could increase risk of breaching the frontal dune; it would increase lake water levels, and may lead to a shift in dominant algal species with positive or negative effects.
Flora	• The impact of riparian flora on the nutrient budget is unclear, ie whether it is a source or sink. The creation of fringing wetlands may result in uptake of nutrients. • There is a continuing need to manage exotic flora and encourage regrowth of native flora including around the lake foreshore.
Fauna	• There is a continuing need to manage introduced fauna and to encourage native fauna. • Little is known about microbial processes and associated sediment-nutrient release processes.
Surface Runoff	• The surface runoff catchment for the lake is relatively small, suggesting that management strategies related to control of surface runoff could be given lower priority compared to in-lake management strategies.
Hydrogeology	• Groundwater entering the lake is mainly from a very localised area; with most of the regional groundwater flowing elsewhere. • There are high nutrient levels in the groundwater within Lennox Head township, however the majority of this groundwater flow does not enter the lake.
Sedimentation	• There has been a slow but gradual accumulation of sediment in the lake since its formation several thousand years ago with an estimated sedimentation rate of 0.4 mm per year. • There is a thick organic rich layer of fine sediment on the lake bed, with high levels of nutrients that have accumulated from decaying vegetation. This sediment is the major source of nutrients in the present lake processes.
Lake Foreshore Erosion	• While there is some localised foreshore erosion from concentrated drainage paths and pedestrian movements, it is generally being controlled by the present vegetation rehabilitation programs, which need to be maintained.
Lake Water Levels and Water Budget	• There is a direct and rapid response of lake water levels to rainfall. • The major processes controlling the lake water budget are rainfall and evaporation.

Table 7.1 Significant Issues (continued)

Issue	Comment/Recommendation
Lake Water Quality and Mixing	• The long-term and seasonal variability in lake water quality is unclear due to the lack of long-term data. • Faecal coliform contamination of the lake appears to have peaked in about 1990. The NSW Health Dept guidelines for recreational waters have rarely been exceeded. However there is a need to continue monitoring. • Heating of a thin water surface layer occurs due to the staining of the water restricting penetration of solar energy. • Stratification of the lake is broken down by cooling, rainfall and wind. It is likely that in long periods of dry weather, stratification is persistent. • Algal blooms have discouraged use of the lake with some impacts on the local recreation and tourist industry. This is a major issue to be managed. Algal cell counts at times exceed ANZECC and NCRACC guidelines. • Lake water quantity per se does not affect algal blooms; rather the important processes are light availability and mixing. • Groundwater does not appear at the present time to be a major source of nutrients to the lake. Prior to the construction of the reticulated sewerage systems, there may have been high nutrient loads to the lake for several decades, from septic systems and sullage drains involving inter alia phosphate based detergent, promoting a regime of high productivity of phytoplankton within the lake. • Sediment nutrients have accumulated over a long period due to loading from groundwater and surface runoff. • The lake sediments are the major source of nutrients for the present nutrient budget. Management strategies need to focus on this issue. • At low lake water levels, a possible mechanism is that water drains from areas with riparian macrophytes, resulting in high nutrient concentrations in surface waters. • Levels of nutrients and chlorophyll-a exceed the ANZECC guidelines. There is a need to review the appropriateness of general guidelines and to consider development of site specific guidelines taking into account lake usage and values. There is general compliance with ANZECC recreational use criteria for physico-chemical parameters, however there have been several times when the criteria for faecal coliform bacteria has not been satisfied.
Coastal Dunes	• The maintenance of Lake Ainsworth as a freshwater lake is dependent on maintaining the integrity of the coastal dunes. • Coastal recession and lowering of the frontal dune could result in the lake being connected to the ocean. • Management of the coastal dune system to control wind and wave erosion is extremely important, and the present efforts of the Dunecare group need to be maintained.

8. Potential Management Options

Recommendations on lake management strategies are beyond the scope of this study and will be considered in later stages of the estuary management process. However, the following brief discussion is provided on several of the issues to assist in future management decisions. For all management options, consideration needs to be given to the way the natural processes are operating and the influence of human activities on these processes.

Lake foreshore erosion has been identified by the Management Committee as an issue and that the inundation and killing of exotic grass reduces ground cover leading to erosion. While this study has found that at present foreshore erosion is not a significant problem there are localised areas of erosion associated with runoff from roads and from pedestrian activity and wind erosion. The work undertaken to re-establish native vegetation around the lake assists in reducing foreshore erosion. Future work should seek to spread, rather than concentrate, both stormwater runoff and pedestrian access.

Stabilisation and maintenance of the frontal dune between the lake and the beach is essential to prevent inundation from the sea. Current activities by the Dunecare group are providing excellent maintenance measures in these regards. However, due to the dynamic nature of dune processes, these measures need to be maintained on an ongoing basis. Consideration needs to be given to further surface treatment or re-location of the 4WD access track to the beach to prevent it becoming a "weak point" for dune erosion.

The management of algal blooms in Lake Ainsworth is arguably the most important management issue to be addressed at the present time. Dr Gary Jones (pers comm) has indicated that in general the main strategies available to control algal blooms are:

- to reduce the total algal biomass by catchment management;
- to manipulate algal species composition to cause a shift away from blue-green algae by such methods as artificial mixing of the lake body; and
- to remediate lake sediments that are a source of nutrients.

The nutrient budget presented in Section 6.7.10 illustrates the relative importance of each of the contributing processes. The nutrient loads to the lake listed in Table 6.4 clearly show the sediment nutrient release is the major source of phosphorus to the lake. Hence management actions should target options that effectively reduce the sediment release.

Given that sediment release is the major source of nutrients it is likely that the lake has experienced high nutrient concentrations and high primary production including blooms of green algae for many years. We speculate that during the development of Lennox Head and the use of septic tanks and disposal of sullage and laundry waste in the 1950s, 60s and 70s relatively large nutrient loads entered the lake leading to higher productivity and larger recycling rates within the system than previously.

It is likely that this shift to higher primary production is part of the natural eutrophication process and the additional inputs from septics may have accelerated the process.

While the management actions to date have reduced the nutrient loads entering the lake, this has not affected the persistence of the algal blooms. From a management perspective a number of in-lake options may be targeted that may lead to a reduction in algal blooms. Essentially there are four options:

- artificial destratification
- oxygenation of deep water
- sediment remediation, and
- biomanipulation.

Artificial destratification by bubble plume aerators or mechanical devices aims at mixing the lake to maintain high oxygen concentrations in the deeper waters, thereby reducing the nutrient release rate. The basic principle is that by maintaining a homogeneous water column oxygen transfer from the atmosphere (the major source of oxygen to the lake) is then mixed down to the bottom where microbial consumption occurs. Another effect of destratification is that the continuous vertical mixing tends to be unfavourable to the cyanobacteria that prefer calmer strongly stratified systems.

Similarly oxygenation of deeper waters by pumping oxygen into the lake via diffusers maintains high oxygen concentration in the deeper water but does not break down the stratification. This technique has been used in Europe and North America in lakes where the temperature stratification is maintained for certain fauna. The objective with this approach is to pump oxygen into the bottom waters at a rate slightly higher than the microbes consume it, thereby reducing the role of nutrient release.

Sediment remediation may involve a number of techniques including lime dosing to essentially cap the sediments and bury the nutrients below the sediment surface, removal of sediments by dredging, or treatment of sediments by pumping them onshore, removing the nutrients and then returning the cleaned material to the lake. Prior to implementing any sediment remediation techniques more detailed measurements of the depth of high nutrient concentrations in the sediments need to be undertaken.

In a small lake such as Lake Ainsworth, biomanipulation - ie the control of fish types and species so as to benefit algae-eating micro-crustaceans - may be of significant benefit. The high abundance of Gambusia and Gudgeon, the low abundance of large cladocerans, and the lack of aquatic vegetation is indicative that biomanipulation may be successful at Lake Ainsworth. Biomanipulation trials have shown positive results in Europe and North America, although the probability of success is variable.

While this study has highlighted the need to manage the release of nutrients from sediments as an immediate priority, catchment management is important for the long-term health of the lake. A range of catchment management practices has already been implemented. It is important that these strategies continue and be augmented in the future, taking into account the extent of both the surface runoff and groundwater catchments.

Any developments including earthworks and roadworks should be done sympathetically to prevent any major alterations to surface and groundwater flow paths relative to Lake Ainsworth. Other possible management strategies canvassed during the study are:

- Use a catcher when tractor mowing all grassed areas to prevent wash off of grass clippings to the lake;
- Ban dogs and horses from the reserves and Sport and Recreation Camp;
- Bund fuel storage and refuelling area to provide insurance against hydrocarbon contamination. Bund and drain any machinery maintenance areas to ensure dirt and hydrocarbon spillage or excess cannot accidentally cause contamination.

To assist in the prioritisation of possible management options it is helpful to identify both short-term and long-term options. Short-term options are ones that can be implemented immediately and tend to be high-risk options in that they may or may not provide a successful outcome. An example of a short-term option would be the use of an aerator or mechanical mixer. Long-term options tend to target the source of the problem and require monitoring to assess their effectiveness. Long-term options would include sediment remediation techniques and catchment management strategies.

Prior to implementation of management actions, assessment of their likely outcome or performance will be necessary. This assessment may require monitoring and/or modelling of present and possible future processes.

9. Monitoring Requirements

Monitoring is required to better understand the processes operating at Lake Ainsworth, to assist in the selection of management strategies and to gauge the performance of any management strategies to be implemented. Prior to any monitoring it is important that clear objectives for the monitoring be established and agreed to by the various stakeholders. A detailed monitoring program could be formulated at later stages of the estuary management process, however various aspects of monitoring requirements are set out below.

Broad objectives for monitoring include:

- to obtain information to satisfy public health requirements;
- to ensure there is proper maintenance of assets and that these are not having deleterious effects on the lake; and
- to understand various physical, chemical and biological processes including obtaining information for calibration and verification of models of processes.

To satisfy these different objectives, different sampling strategies are required and the different forms of monitoring could be undertaken by different groups.

Monitoring to assess compliance with public health regulations is best undertaken by the Council. Monitoring to assess the performance and condition of assets could be done by a combination of Council and local groups.

In line with the long-term objective of encouraging scientific research, process-oriented monitoring could be undertaken by local educational institutions or consultants with the assistance of Council.

A significant problem with assessing processes for this study has been the lack of long-term data on a range of matters including algal characteristics, stratification and nutrient loads and in-lake nutrient concentrations, to establish long-term trends and seasonal patterns. Subject to funding constraints long-term monitoring should be undertaken.

Compliance Monitoring

- The monitoring of faecal coliform bacteria within the lake should continue with analysis of the data on a site-by-site basis to compute annual and seasonal median values.

- Monitoring of algal cell counts in accordance with NCRACC standards should be continued.

Maintenance Monitoring

- Monitoring or observations for potential leaks from the sewerage system should be undertaken on a regular basis.

  Observations for sewer overflows should be made during storm events, so any sewer overflows can be identified and remedial action taken.

- Once a year a plan or inventory of vegetation and fauna in and around the lake and on the dune systems should be made, and areas of foreshore erosion and dune scour noted.

Process Monitoring

- Process-oriented monitoring can involve both one-off exercises and ongoing monitoring.

<u>One-Off exercises</u>

The relative magnitudes of groundwater nutrient loads and internal nutrient loading from bottom sediments need to be carefully assessed before any sediment remediation management strategies are considered. Such assessments may include:

- A study of the sediment/water interface including measuring of nutrient fluxes to and from the sediment.
- Monitoring of nutrient flux from macrophyte beds to the lake during a period of low water level.
- Measurement of a nutrient concentration profile in the lake bed sediments down to a depth of six metres.

To identify sources of faecal coliform bacteria during high concentration events a detailed monitoring program would need to be instigated and may include:

- Analysis of biomarkers in water samples to assess the proportion of human and animal contamination.

<u>Ongoing Monitoring</u>

Ongoing monitoring would improve the understanding of processes including the determination of more accurate water and nutrient budgets from direct measurements of inputs and outputs.

- One year of monitoring water quality of the lake to identify significant changes to the system. This would involve periodic sampling and also event-based sampling associated with rainfall events and algal blooms. Components of this monitoring program could include:

  * Continuous recording with a thermistor string to resolve development and breakdown of stratification;

  * Weekly and event sampling for nutrients and physico-chemical parameters by profiling at selected sampling locations; and

  * Weekly and event sampling for light penetration, water clarity and algal composition. The monitoring of algae should include both the existing "compliance monitoring" of "worst case" algal bloom and an integrated sample from the lake.

- One year of periodic and event monitoring of groundwater levels and quality from the western bore and the Gibbons Street town bore. The event could be a storm where rainfall exceeds 50 mm per day.

- Continuation of monitoring of rainfall and water levels with the continuous recorder.

- Installation of a weather station to monitor wind for the study of lake mixing processes and to assist in estimation of evaporation from the lake.

- Every two years conduct a usage survey involving traffic counts at selected peak and off-peak periods and a survey of social carrying capacity at a peak period.

Obviously, the amount of monitoring that can be undertaken is subject to funding. Accordingly, taking into account the elements of a monitoring program outlined above, priorities and scope should be established in the following phases of the estuary management process.

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