SEPTIC TANKS AND ADSORPTION FIELDS IN TASMANIA

- Matching Environmental Conditions with Operating Requirements

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Being a thesis submitted in part fulfilment of the requirements for the Degree of Master of Environmental Studies.

Centre for Environmental Studies
University of Tasmania
May 1979

CONTENTS

Page

ACKNOWLEDGEMENTS

I would like to thank many people for their assistance during the course of this study, in particular: Dr. R. Jones and Dr. R. Swain for their criticisms and guidance; Mr. P.E. Spratt for this project's inspiration and his advice throughout; the National Parks and Wildlife Service for authorisation to collect and remove samples from the Mt. Field National Park; the respective executives of the University Ski Club and the Oldina Ski Club for making their septic tanks and adsorption fields available for study; Mr. and Mrs. Crosswell for making the Camp Carlton wastewater treatment system available; and Mrs. N. Hickson and Mrs. V. Noar for the typing of the manuscript.

ABSTRACT

Septic tanks and soil adsorption fields are a commonly used wastewater treatment system in unsewered areas. The biological processes on which they rely were considered in detail and their operating requirements established along with the assumptions underlying the design of the treatment system. The principal regions in which septic tanks and adsorption fields are used in Tasmania were also established and the environmental conditions in these areas were compared with the operating and design conditions of septic tank and adsorption field systems. From this the suitability of septic tank wastewater treatment in the particular areas of use was predicted. In highland areas septic tank and adsorption field systems were considered to be unsuitable for wastewater treatment whilst in lowland areas their suitability is dependent upon site characteristics. No region of septic tank and adsorption field use in Tasmania was considered to be completely suitable for this form of wastewater treatment.

The environmental conditions of two dissimilar sites, Mt. Mawson and Carlton, were characterised and the performance of septic tank and adsorption field systems under them assessed. The behaviour of the treatment systems was consistent with the predictions made earlier.

Within this study several deficiencies in septic tank and adsorption field design and operation, both in Tasmania generally and specifically at the two study sites, were highlighted. Remedial action was suggested where appropriate.

CHAPTER 1

INTRODUCTION

1.1 Background

Man by his nature is a waste maker. The natural metabolic processes of a 70 kg adult produce about 120 grams of solid waste and 1.4 litres of liquid waste daily (Altman and Dittmer 1974) These contain not only high levels of undecomposed organic material, which on release to the surrounding environment can exert heavy loads on the systems dissolved oxygen, but also the agents of several serious diseases, such as typhoid fever, paratyphoid, cholera, dysentry, poliomyelitis and infectious hepatitis (Ehlers and Steel 1965). Human waste is not only unpleasant aesthetically but dangerous hygenically. Some form of treatment and effective disposal of it is clearly required.

Traditionally man has relied upon the natural degradation processes within the surrounding environment to decompose his wastes and render them harmless. Soil disposal has long been the recommended method of treatment. For example, in the Old Testament (Deut. xxii v 12-13) it is stated that: "Thou shalt have a place also whither thou shalt go forth abroad: And thou shalt have a paddle upon thy weapon: and it shall be, when thou whilt ease thyself abroad, thou shalt dig therewith, and shall turn back and cover that which cometh from thee." Such a method of disposal is quite effective, provided the receiving system is not over-loaded.

This is precisely what happened in the early 1800's when the industrial revolution brought more and more people to the cities. The soil in many areas became saturated with human wastes and ground water was often little more than undiluted percolation from cesspits (Sidwick and Murray 1976a). Not surprisingly, then, during this period diseases, such as typhoid, cholera and dysentry, were rife. By the mid 1800's, through the development of reticulated water systems and the efforts of sanitary reformers, like Edwin Chadwick, wastes were no longer left on-site but removed to the nearest waterway. The incidence of disease down stream of the waste discharge and the eutrophication of these rivers led to the appointment in 1898 of a Royal Commission on sewage disposal. In its 17 years of deliberation it produced ten reports which laid the foundations for present day wastewater treatment technology in the U.K. and much of the world. The first report showed that "artificial" treatment was an alternative to land disposal, the third report recommended that matters relating to wastewater treatment be administered by regional or national authorities, the fifth report laid down guidelines for sewage treatment units and the eighth report established effluent discharge standards which are still in force today: maximum five day oxygen demand (BOD_5) 20 mg/l, minimum suspended solids 30 mg/l (Sidwick and Murray 1976b). Other reports of the Royal Commission were concerned with local matters, a literature review or the summary.

In the U.S. wastewater treatment technology developed along different lines, although the basic need for wastewater treatment was demonstrated similarly. In the 1880's-1890's the rising death rate from typhoid in areas that took their water from streams into which upstream cities discharged their sewerage and the establishment of the typhoid-sewerage link highlighted the need for wastewater treatment (Tarr and McMichael 1977). However, the limitations of treatment technology at the time and the cost of treating the high outflow from combined wastewater and storm water sewers (most of the U.S. cities had opted for combined sewers rather than separate sewers) restricted this option. Instead many municipalities opted for filtration of the contaminated water: a less expensive but more cost-effective way of reducing the incidence of typhoid. However, the highly polluted nature of waterways receiving sewerage eventually lead to water pollution laws and the widespread adoption of wastewater treatment.

Since the early 1900's, community wastewater treatment has become a well established and researched branch of engineering practice. In comparison, however, the development of wastewater treatment technology for isolated dwellings and communities remote from reticulation schemes has been slow. The most common form of wastewater treatment in these areas is by way of septic tanks and adsorption fields (STAF),which were developed around the 1880's (Sidwick and Murray 1976a). In this system wastewater is retained long enough for the solids to settle to the tank bottom where they undergo anaerobic digestion to methane and carbon dioxide. The supernatant liquid, which still contains much of the organic material and all of the enteric microorganisms, is percolated through the surrounding soil where microbes oxidise it. Following modifications arising from initial "teething" troubles, such as gas buildup and tank explosion (due to lack of ventilation) no further consideration was given to the design of septic tanks until 1946 when the U.S. Public Health Service (USPHS) began a series of studies on household wastewater disposal. The results of these studies were correlated with practical operating experience from areas where septic tanks were commonly used (rural USA) (Kiker 1956) and published as the *Manual of Septic Tank Practice* (USPHS 1958). This report contained not only recommendations for the operation of septic tanks but also their design. Consequently, implicit within this design were the environmental conditions of rural USA and the assumption that septic tanks would be used in areas which have similar conditions. The only substantial work since this relating to septic tank and adsorption field design and operation was that by the Sanitary Engineering Research Laboratory at the University of California on the mechanism and prevention of failure in adsorption fields. Several reports were released from this program, e.g. McGauhey and Winneberger (1967), suggesting guidelines for improving the design and adapting the system to the soil. Although some consideration has been given to alternatives to septic tanks and/or adsorption fields (Dea 1975; Magdoff, Bouma and Keeney 1974; Magdoff *et al.* 1974; Bouma *et al.* 1975) no consideration has been given to septic tank design since the USPHS study in 1958.

In Australia, the official recommendations for the operation of STAF systems, e.g. DHV* (1975) and EPA* (1975a), and the Australian Standards for their design and operation, SAA* (1976), although based on operating experience and research in Australia, closely parallel those of the USPHS. The areas in which STAF systems have their greatest use in Australia, rural New South Wales and Victoria, have conditions similar to those in rural USA. In Tasmania, the Department of Health Services (the authority responsible administering wastewater disposal in unsewered areas of Tasmania) closely follows the recommendations of the Department of Health in Victoria. Yet the environmental conditions of Tasmania may differ markedly from those of the principal septic tank areas in Victoria, or New South Wales. The conditions under which STAFs operate in Tasmania may, therefore, differ from their implicit design conditions and, consequently, their efficiency may be less than optimum. This

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*EPA is the abbreviation for the Environmental Protection Authority.
DHV is the abbreviation for the Department of Health in Victoria.
SAA is the abbreviation for the Standards Association of Australia.

is witnessed by the situation at Ben Lomond, a ski resort in the north-east of the state, when in September 1978 the possibility of raw septic effluent entering domestic water supplies was reported (*Examiner* 16 September 1978).

1.2 Aim and Objectives

Although the requirements for effective operation of large scale community treatment plants are well known, little consideration has been given to small scale operations, such as septic tanks and adsorption fields. Yet, the processes by which the septic tank and the adsorption field operate are essentially the same as those commonly used in fully engineered treatment works. If the operating requirements for septic tanks and adsorption fields were laid down problems such as those at Ben Lomond could be avoided. The purpose of this study is to collect such information, assemble it into a meaningful package and to assess the suitability of septic tanks for wastewater treatment in Tasmania. Towards this aim the following specific objectives are directed.

1. To establish the optimum and design operating requirements for septic tanks and associated adsorption fields.
2. To establish the principal regions where STAF wastewater treatment systems are used in Tasmania.
3. To establish the environmental conditions pertinent to STAF operation in each STAF region.
4. To compare the environmental conditions pertinent to STAF operation in the principal STAF regions with the optimum and design operating requirements of STAF systems.
5. To predict the suitability of STAF wastewater treatment systems for the particular areas of Tasmania in which they are commonly used.
6. To characterise the environmental conditions pertinent to

STAF operation at two dissimilar sites, the University Ski Club (USC) on Mt. Mawson and Camp Carlton at Carlton, and to evaluate the performance of STAF systems at these sites.

7. To assess the suitability of official recommendations in Tasmania relating to septic tanks and adsorption fields.

1.3 Report Structure

The above objectives are addressed in the three main chapters of this report. Chapter 2 reviews the literature on wastewater treatment and establishes the principles of septic tank and adsorption field operation. These are considered in detail to provide the basis of the operating requirements and the design criteria of septic tanks treating all domestic wastewaters; that is, combined bathroom, kitchen, laundry and toilet wastewaters; or toilet wastewaters only. In chapter 3 the likely distribution of STAF systems in Tasmania is considered and the principal regions of STAF operation established. The environmental conditions pertinent to STAF operation in these areas are also established. These are compared with design requirements established in Chapter 2 and the suitability of STAF wastewater treatment systems for the particular areas assessed. Chapter 4 presents data from field studies conducted at two dissimilar sites, Mt. Mawson and Carlton. The pertinent environmental conditions in each area are characterised and the performance of STAF systems under them assessed. Chapter 5 considers conclusions drawn from this study and implications arising from them. It highlights several deficiencies in STAF design and operation and suggests appropriate remedial action.

CHAPTER 2

PRINCIPLES OF SEPTIC TANK AND ADSORPTION FIELD OPERATION

2.1 Introduction

In areas remote from reticulated water schemes, domestic wastewater; that is, toilet wastes or combined bathroom, kitchen laundry and toilet wastes; is commonly treated in septic tanks. In these, solids are settled from the raw wastewater to form a sludge which then undergoes anaerobic digestion, eventually, to methane, carbon dioxide and solid residue. The supernatant liquid, which still contains many organic compounds and microorganisms, is given further treatment commonly in a soil adsorption field. Both the primary (septic tank) and secondary (adsorption field) treatments involve biological processess which have precise operating requirements. The organisms involved in these processes, their treatment mechanisms and their operating requirements are considered below. From those operating and design criteria for septic tanks are developed. The structure of the bacteria populations however, will vary depending on the wastewater composition. The likely composition of domestic wastewater is, therefore, also considered.

2.2 Wastewater Composition

The characterisation of domestic wastewater has been attempted by several authors including Heukelekian and Balmat (1959); Hunter and Heukelekian (1965); Painter and Viney (1959) and Painter, Viney and Bywaters (1961). These studies have been conducted in the U.S. and the U.K. on wastewater collected from sewer systems (sewage), which contains kitchen, bathroom and laundry wastes as well as toilet wastes. Recently domestic wastewater has been characterised according to source (Ligman, Hutzler and Boyle 1974; Siegrist, Witt and Boyle 1976). The characteristics reported by Siegrist, Witt and Boyle (1976) are given in Table 2.1. No comparable studies on wastewater composition, in general or by source, have been reported in Australia.

TABLE 2.1

Mean Composition of Domestic Wastewater

(adapted from Siegrist, Witt and Boyle 1976)

Characteristic*	Toilet Wastewater (mg/l)	All Wastewater+ (mg/l)
BOD_5 unfiltered	470	440
BOD_5 filtered	265	260
TOC unfiltered	360	290
TOC filtered	190	190
Total Solids	1200	950
TVS	850	580
TSS	600	400
TVSS	490	270
Total Nitrogen	175	64
Ammonia Nitrogen	56	16
Nitrate Nitrogen	1.0	0.7
Total Phosphorus	26	30
Orthophosphate P	13	9.7
Temperature (^{o}C)	18.9	27.3
Flow (l/capital day)	34.8	131

*BOD_5 = five day biochemical oxygen demand

TOC = total organic carbon

TVS = total volatile solids

TSS = total suspended solids

TVSS = total volatile suspended solids

+combined bathroom, kitchen (excluding garbage grinder), laundry and toilet wastewaters

The constituents of the organic fraction of domestic wastewater have been determined by several authors. Those reported by Hunter and Heukelekian (1965) for U.S. sewerage are given in Table 2.2. From these it can be seen that the principal components of the settleable fraction of wastewater, the fraction treated in septic tanks (see Section 2.3),are lipids and carbohydrates. Care must be taken in extrapolating precise details of these characteristics to Australia, including Tasmania, however, since significant differences in the wastewater between the two countries can occur. For example, the toilet flush volumes are different. Ligman, Hutzler and Boyle (1974) and Siegrist, Witt and Boyle (1976) reported flush volumes of 16 litres in rural and 19 litres in suburban Wisconsin whilst Heeps (1977) gave flush volumes of 3.5 litres (14l/capita/day) in unsewered and 11 litres (45l/capita/day) in sewered Melbourne. In spite of this, the total domestic wastewater flow into septic tanks in the two areas (Wisconsin and Melbourne) is similar, Siegrist, Witt and Boyle, (1976) reported the mean flow to be 131 l/capita/day whilst Heeps (1977) gave it to be 126 and 133 l/capita/day (average 130 l/capita/day).

2.3 Primary Treatment

Septic tanks are essentially primary treatment facilities only. Their principal function is to retain wastewater long enough for solids to settle. The sludge so formed is anaerobically digested to methane and carbon diodixe. The design criteria for septic tanks, their settling mechanisms and their digestion mechanisms are considered below. The optimum and design conditions are also considered.

TABLE 2.2

Composition and Size Distribution of Organic Material in Domestic U.S. Wastewater in Winter/Spring and Autumn/Spring.

(from Hunter and Heukelekian 1965)

Component	Composition (mg/l)			
	Settleable*	Supra-Colloidal*	Colloidal*	Soluble*
Lipids (fats and grease)	11.70 - 11.25	9.57 - 8.65	5.55 - 6.06	-
Detergents	0.08 - 0.11	0.13 - 0.14	0.09 - 0.10	3.94 - 4.02
Sugars and Tannins	4.62 - 4.93	1.83 - 2.01	0.70 - 1.40	9.48 - 10.74
Amino Acids	8.59 - 12.41	12.26 - 12.84	4.76 - 5.37	9.01 - 9.05
Carbohydrates and Lignin	18.05 - 27.75	10.60 - 9.31	6.09 - 5.83	-
Total Organic Carbon	43.01 - 56.34	35.02 - 32.05	18.41 - 17.35	68.74 - 85.29
Volatile Solids	52.25 - 63.89	41.29 - 36.86	18.41 - 17.35	72.19 - 87.86

*Rudolphs and Balmat (1952) defined settleable solids as particles greater than 100 μm in diameter, supra-colloidal solids as 1 - 100 μm, colloids as 0.001 - 1 μm and solubles as less than 0.001 μm.

2.3.1 Septic Tank Design

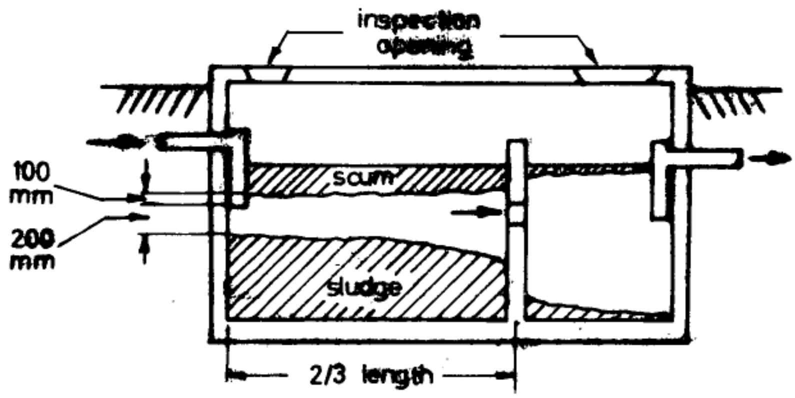
The design of septic tanks in Tasmania, and elsewhere in Australia, is laid down by the Standards Association of Australia (SAA 1976) and is based upon operating experience and research in their major areas of use (New South Wales and Victoria) (see Figure 2.1). Conditions in these areas are similar to those of rural U.S.A., which septic tanks were originally designed for. The design of septic tanks in Australia is, consequently, similar to the U.S. design.

As stated above the principal function of a septic tank is to retain wastewater long enough for solids to settle. The minimum retention time is considered to be 24 hours (Barnes and Wilson 1975). The volume of the tank must be such, then, to accommodate at least one day's wastewater flow with allowance made for adequate sludge storage. Provision must also be made to prevent turbulent flow and carry-over of sludge solids into the secondary treatment (see later). The minimum tank volume recommended for treatment of all waste wastewater (kitchen, laundry and bathroom wastes as well as toilet wastes) in the U.S. is 2850 litres (Kiker 1956; Cotteral and Norris 1969). In Australia the comparable recommendation is 2500 litres (SAA 1976) or 3000 litres (DHV 1975). No recommendation is given in the U.S. for toilet wastes alone. In Australia, however, for toilet wastes only 1600 litre (SAA 1976) or 1750 litre tanks (DHV 1975) are recommended for a "five person" dwelling with a further 50 litres for each additional occupant. The tank itself is recommended to be a two compartment design in which the capacity of the first compartment is to be 2/3 of the total capacity (Kiker 1956; Cotteral and Norris 1969; SAA 1976; DHV 1975). The first chamber is to settle the solids and the second chamber is to prevent any solids carry-over.

In septic tanks the digestion rate is usually slower than the solids deposition rate and sludge accumulates. The average sludge accumulation rate, over two years, in three septic tanks in southern Ontario (Canada) was estimated to be 200 litres/person/ year and was shown to be dependant upon wastewater strength and retention time (Brandes 1978). When sludge has reached to within 200 mm, and/or floatable scum within 100mm, of the bottom of the inlet desludging is recommended (DHV 1975). This corresponds to a sludge volume of 55% of the liquid volume. U.S. regulations recommend desludging when sludge volume reaches 50% of the total liquid volume or 63% of the first chamber volume (Brandes 1978).

FIGURE 2.1

A Typical Two Compartment Septic Tank
(from DHV 1975)



2.3.2 Sedimentation

In septic tanks 40 - 70% of the suspended solids may be removed by settling (Imhoff, Muller and Thistlethwayte 1971). These particles, principally lipids and carbohydrates (see Table 2.2 earlier), settle as discrete entities at a constant velocity governed only by the size, shape and density of the particle and the viscosity and density of the liquid (Eckenfelder and O'Connor 1965). For small particles, settling occurs under laminar flow conditions and the settling velocity is controlled principally by the liquids viscosity. This, in turn, is influenced by temperature. With larger particles, however, their settling velocities are higher and the process becomes more turbulent. Inertia forces controlled by particle diameter and specific gravity then become the dominating incluence and temperature assumes diminishing importance (Eckenfelder and O'Connor 1965).

The suspended solids encountered in domestic wastewater are usually of the flocculant type, however (Eckenfelder and O'Connor 1965); that is, particles or regions which rapidly settle and coalesce with particles or regions of lower settling velocity (Camp 1953). The efficiency of separation in flocculation is a function of both settling velocity and the time allowed for flocculation; that is, the retention time in the tank (Eckenfelder and O'Connor 1965). This, in turn, is influenced by septic tank volume and wastewater flow rate. The retention time for design purposes in septic tanks is taken to be greater than 24 hours (Barnes and Wilson 1976). This gives a flow rate, for a maximum sludge volume of 55% of the tank volume (see Section 2.3.1) of 450 litre/day/m^3 of tank capacity.

2.3.3 Anaerobic Digestion

Despite widespread use of septic tanks and the process of anaerobic digestion the microbiology and biochemistry involved is poorly understood. Detailed reviews of the current understanding of the process have been conducted by Toerien and Hattingh (1969); Kotze, Theil and Hattingh (1969) and Wolfe (1971). These are summarised below.

In an environment depleted of freely available oxygen, the carbonaceous matter of the settled sludge is digested to methane and carbon dioxide. This is believed to occur via two phases; firstly, a non-methanogenic phase and secondly, a methanogenic phase, each of which is associated with a different population of micro-organisms. In the first stage, complex molecules such as proteins, carbohydrates and lipids are converted to simple organic acids through the action of mainly obligate anaerobes (Kotze *et al.* 1968). In the methanogenic phase, products of the non-methanogenic organisms are converted to methane and carbon dioxide by a group of strict obligate anaerobic bacteria. (Toerien and Hattingh 1969).

(a) Non-methanogenic Microorganisms and Mechanisms

Bacteria. The bacteria of the non-methanogenic phase are known to be predominantly obligate anaerobes (Kotze *et al.* 1968) and include a wide range of groups, from chemolithotrophs to chemo-organotrophs and photo-organotrophs (Toerien and Hattingh 1969). Toerien (1970) reported the following genera of micro-aerophiles (microbes needing little oxygen) and obligate anaerobes isolated from anaerobic digesters: *Cornybacterium, Lactobacillus, Ramiebacterium, Actinomyces, Bifidobacterium, Eubacterium, Clostridium, Bacteroides, Sphaerophorus* or *Fusobacterium, Vibrio* or *Sprillium, Peptococcus, Veillonella* and an unknown crescent shaped bacterium. Several species of aerobic or facultative anaerobic bacteria have also been isolated from digesters. These, however, are believed to play only a minor role in the digestion process (Kotze *et al.* 1968; Thiel *et al.* 1968; Toerien 1970).

Fungi. Fungi have also been observed in digestion sludge. The principal genera from which species have been isolated are shown in Table 2.3. Cooke (1965) considered that fungi were participating in the digestion to the extent of obtaining growth nutrients. Toerien and Hattingh (1969), however, consider their role to be insignificant.

Protozoa. Several protozoa have been found in digesters but not in large numbers. Approximately 18 genera including the flagellates (*Trepomonas, Tetramitus* and *Trigomonas*) amoebae (*Vahlkampfia* and *Hartmonella*) and ciliates (*Metopus, Trimyena* and *Saprodium*) have been observed (Lackey 1949). The role of protozoa in the digestion is probably insignificant (Toerien and Hattingh 1969).

Non-methogenic bacteria degrade the complex organic molecules of wastewater sludge into simple substrates which can be utilized by

TABLE 2.3

Genera of Fungi Detected in Digesting or Drying Sludges

(from Toerien and Hattingh 1969)

Phycomycetes

Mucor
Rhizopus
Syncephalastrum
Zygorhynchus

Ascomycetes

Allescheria
Ascophanus
Eurotium
Pseudoplea
Satoria
Aspergillus
Subbaromyces
Talaromyces
Thielavia

Fungi Imperfecti

Acremonium
Aspergillus

Fungi Imperfecti (cont)

Pencillium
Cephalosporium
Geotrichum
Gliochadium
Paecilomyces
Scopulariopsis
Sepedonium
Spicaria
Trichoderma
Trichothecium
Alternaria
Cladosporium
Margarinomyces
Memnoniella
Humicola
Phialophora
Pularia
Stachybotrys
Epicoccum
Fusarium
Myrothecium

the methanogenic bacteria. The first step in this process is extracellular enzymatic hydrolysis of the compled organic molecules. Many of the enzymes required for this, such as the cellobiases, proteases and amylases, have been identified in digesters (Thiel and Hattingh 1967; Kotze *et al.* 1968) whilst others, like cellulases and lipases, have been postulated (Toerien and Hattingh 1969). Following hydrolysis, the reaction products are metabolised intracellularly.

Lipids. Lipids are hydrolysed enzymatically to a mixture of fatty acids and glycerol according to the general reaction below.

$$\begin{array}{lcccc} CH_3COOR_1 & & CH_3OH & & R_1COOH \\ | & & | & & \\ CH_2COOR_2 & \xrightarrow{\text{lipase}} & CH_2OH & + & R_2COOH \\ | & & | & & \\ CH_3COOR_3 & & CH_3OH & & R_3COOH \\ \text{lipid} & & \text{glycerol} & & \text{fatty acids} \end{array}$$

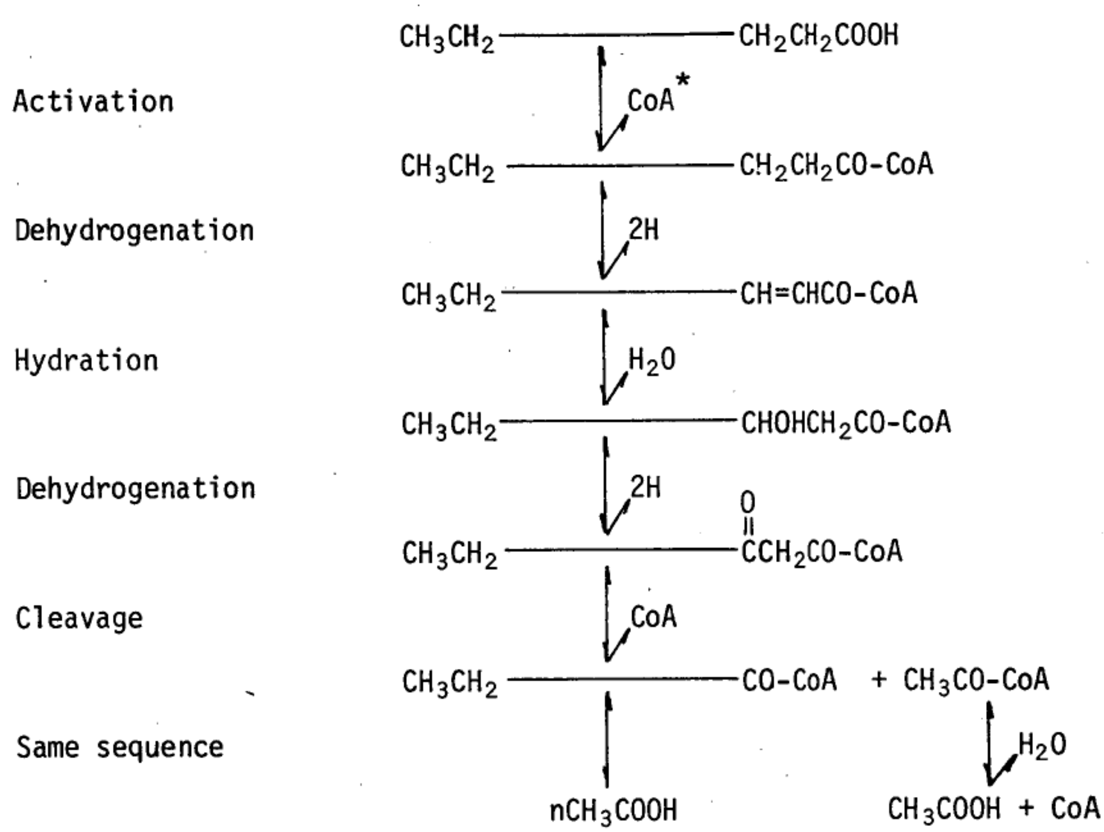
Following this the medium to long chain fatty acids are degraded by β oxidation (see Figure 2.2 below) to acetic acid (for even numbered carbon chains) or acetic and propionic acids (for odd numbered carbon chains) (Kotze, Thiel and Hattingh 1969). Little variation in this scheme exists between different saturated fatty acids, other than a different catalysing enzyme being required for different chain lengths. Separate activating enzymes are required for C_{2-3}, C_{4-13} and C_{14-20} chains (Novak and Carlson 1970). The glycerol produced by the initial hydrolysis is degraded through the glycolysis route (see Figure 2.3 later) to volatile fatty acids (VFA) or alcohols (Toerien and Kotze 1970).

The exact pathway of the degradation of unsaturated fatty acids has not been fully established (Novak and Carlson 1970). Evidence suggests, however, that the unsaturated chain is first hydrogenated and then degraded by a β oxidation (Heukelekian and Mueller 1958).

FIGURE 2.2

β Oxidation of Long Chain Fatty Acids

(from Novak and Carlson 1970)



*Co-A = co-enzyme A

<u>Carbohydrates</u>. The carbohydrates present in wastewater are a diverse group consisting principally of cellulose, starch, pectin and hemicellulose. Each of these is a condensation product of at least ten glucosidically linked sugar residues. These are catabolised (degraded) by extracellular splitting of the glycosidic link to produce a disaccharide (usually) then hydrolysis of the dimer to a monosaccharide. Enzymes involved in this sequence include cellulase C_1 and C_x, Cellobiase, β-glucosidase, α and β amylase, protopectinase, polygalacturonase, pectase, xylase and xylobiase (Higgins and Burns 1975). Of these the presence of cellobiases and the amylase group has been established in digesters

and that of the cellulase has been postulated (Kotze *et al.* 1968; Toerien and Hattingh 1969). Following the disaccharide hydrolysis the monosaccharides are metabolised intercellularly along the glycolytic pathway, the tricarboxylic acid cycle, the glyoxylic acid cycle and the pentose phosphate shunt (Hattingh *et al.* 1967; Kotze *et al.* 1968; Thiel *et al.* 1968) (see Figure 2.3). The pentose phosphate shunt, however, has been found to be active only with substrates high in cellulose (Kotze *et al.* 1968).

Proteins. Protein catabolism begins with the extracellular action of the protease group of enzymes. The amino acids produced are then degraded intracellularly by several different mechanisms depending on the type of amino acid and organism involved. Bacteria known to be proteolytic are the obligate anaerobes *Clostridium, Micrococcus, Diplococcus* and *Fusobacterium nucleatum* (Kotze, Theil and Hattingh 1969). Other obligate anaerobic *Bacteriaceae* and the facultative anaerobe *Escherichia coli* may also be able to break down amino acids. The general processes involved in amino acid metabolism, according to Kotze, Thiel and Hattingh (1969). are:

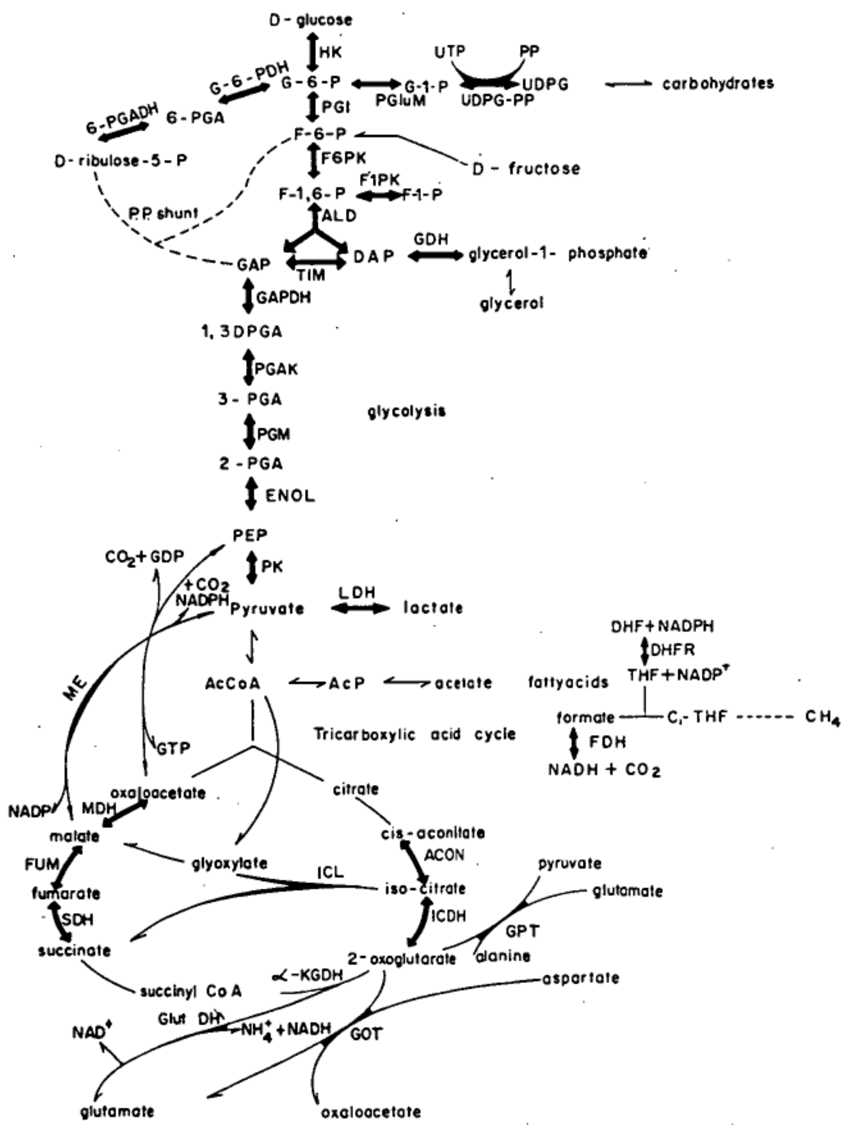
(a) Transamination, in which amino acids are converted to α keto acids by the action of the enzymes glutamateoxaloactetate transaminase (GOT) or glutamate-pyruvate transaminase (GPT). These reactions link amino acid degradation with carbohydrate catabolism, by providing pyruvate as well as intermediates of the tricarboxylic acid cycle.

(b) Transamination followed by deamination with nicotinamide adenine diphosphotase (NAD) according to the following general reaction.

<u>FIGURE 2.3</u>

The Interdependence of Intracellular Enzyme Systems in Anaerobic Digestion.

(from Kotze 1967)



Abbreviations:

Substrates: ADP = adenosine diphosphate; ATP = adenosine triphosphate; DAP = dihydroxy acetone phosphate; DHF = dihydrofolic acid; EDTA = ethylenediaminotetra-acetic acid; F-1-P = fructose-1-phosphate; F-6-P = fructose-6-phosphate; F-1,6-P_2 = fructose-1,6-diphosphate; GAP = D-glyceraldehyde 3-phosphate; G-1-P = glucose-1-phosphate; G-6-P = glucose-6-phosphate; NAD^+ = nicotinamide adenine dinucleotide (oxidized); NADH = nicotinamide adenine dinucleotide (reduced); $NADP^+$ = nicotinamide adenine dinucleotide phosphate (oxidized); NADPH = nicotinamide adenine dinucleotide phosphate (reduced); NH_4 OAc = ammonium acetate; OA = oxaloacetic acid; PP = pyrophosphate; P_i = inorganic phosphate; PEP = phosphoenol pyruvate; 2-PGA = 2-phosphoglycerate; 3-PGA = 3-phosphoglycerate; 1,3-DPGA = 1,3-diphosphoglycerate; 6-PGA = 6-phosphogluconic acid; THF = tetrahydrofolic acid; *tris* = *tris* (hydroxymethyl)-aminomethane or 2-amino-2-(hydroxymethyl) propane-1,3-diol; UDPG = uridine diphosphate glucose.

Enzymes: ACON = aconitase; ALD = aldolase; DHF-R = dihydrofolic reductase; ENOL = enolase; F-1-PK = fructose-1-phosphate kinase; F-6-PK = fructose-6-phosphate kinase; FDH = formic dehydrogenase; FUM = fumarase; GAPDH = glyceraldehyde-3-phosphate dehydrogenase; G-6-PDH = glucose-6-phosphate dehydrogenase; GDH= glycerol-1-phosphate dehydrogenase; GlutDH = glutamic dehydrogenase; GOT = glutamate-oxaloacetate transaminase; GPT = glutamate-pyruvate transaminase; GR = glyoxylate reductase; HK = hexokinase; ICDH = isocitric dehydrogenase; ICL = isocitric lyase; α-KGDH = α-ketoglutarate dehydrogenase; LDH = lactate dehydrogenase; MDH = malate dehydrogenase; ME = malic enzyme; PGK = phosphoglycerate kinase; PGluM = phosphoglucomutase; PGI = phosphoglucose isomerase; PGM = phosphoglycerate mutase; PK = pyruvate kinase; 6-PGADH = 6-phosphogluconic acid dehydrogenase; SDH = succinic dehydrogenase; TIM = triose phosphate dehydrogenase; UDPG-PP = uridine diphosphateglucose pyrophosphorylase.

amino acid + NAD + $H_2O \longrightarrow \alpha$ keto acid + NADH + H^+ + NH_3

This reaction is actually a two reaction sequence, the second reaction being catalysed by the enzyme glutamate dehydrogenase (GlutDH) (Thiel *et al.* 1968). A product of the second step, α ketoglutaric acid, is also part of the tricarboxylic acid cycle in carbohydrate metabolism.

(c) Strickland Reaction. Several clostrida are capable of degrading acids in what is known as the Strickland Reaction, a coupled oxidation - reduction reaction, For example,

alanine + 2 glycine + $2H_2 \longrightarrow 3NH_3 + 3CH_3COOH + CO_3$

Heterocyclic nitrogen compounds, the degradation products of RNA, DNA and certain enzymes, can be produced by several *Clostridium* spp., *Micrococcus* spp. and *Streptococcus allantoiccus* along similar pathways to those above (Kotze, Thiel and Hattingh 1969).

The enzymatic pathways so far considered are closely interrelated and interdependent. This is illustrated by Figure 2.3

The main end products of the catabolism of the lipids, carbohydrates and protein of wastewater are saturated fatty acids, carbon dioxide and ammonia (Toerien and Hattingh 1969). The acids formed are predominantly acetic acid with some propionic acid. Lesser amounts of formic, butyric, lactic and valeric acids may also be formed. Toerien and Hattingh (1969) postulate that hydrogen is a major end product also. They further suggest that an intermediate population of bacteria capable of catabolising propionate, valerate, butyrate, caproate and alcohols other than methanol (minor end products of some degradations) is present. Methanogenic bacteria are not thought capable of utilizing substrates other than formate, formaldehyde, acetate, methanol and carbon dioxide (Toerien and

Hattingh 1969; Wolfe 1971).

(b) Methanogenic microorganisms and mechanisms

The bacteria and mechanisms of the methanogenic phase are poorly understood (Wolfe 1971). However, methanogenic organisms isolated from digesting sludge include the genera *Methanobacterium, Methanoccus, Methanosarcina* and *Methanospirillum*. *Methanobacterium omelianski* has recently been shown to be a symbiotic association of *Methanobacterium* strain M.o.H. and a previously unreported gram negative, motile, anaerobic rod capable of oxidizing ethanol to acetate (Wolfe 1971). All of the above bacteria are strict obligate anaerobes.

The basic substrates for methanogenesis are formate, formaldehyde, acetate, methanol and carbon dioxide (Toerien and Hattingh 1969; Wolfe 1971) and co-factors like tetrahydrofolic acid (THF), co-enzyme A (Kotze, Thiel and Hattingh 1969), co-enzyme M and adenosine triphosphate (ATP) (Wolfe 1971). Cheeseman, Tomms-Wood and Wolfe (1972) reported the presence of another factor, F_{420}, associated with key enzymes in the hydrogen metabolism of *Methanobacterium* strain M.o.H. The precise role of these factors in methane formation, however, is not clear. Barker (1967) proposed a scheme for the formation of methane from methanol, serine or acetate which Kotze, Thiel and Hattingh (1969), after reviewing the data, considered justified. This is shown in Figure 2.4.

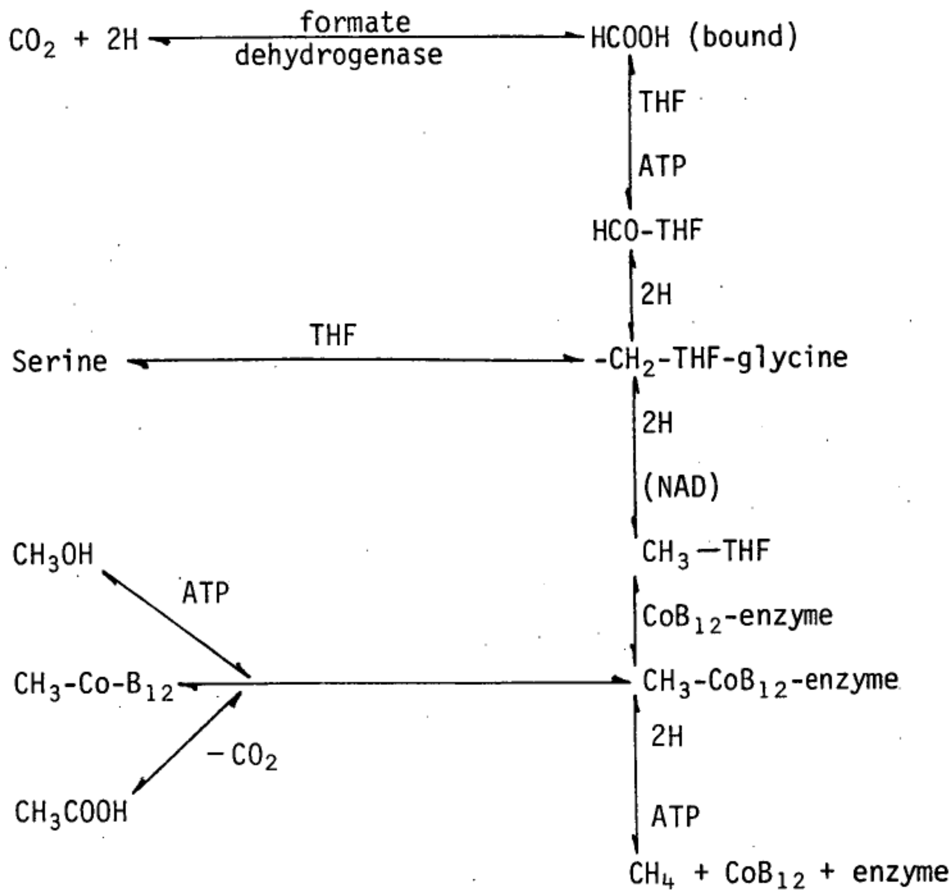
(c) Digestion conditions

The satisfactory digestion of an organic substrate is influenced by the conditions under which it is to occur. These may include temperature, pH, alkalinity, volatile fatty acids concentration, loading rate and digestion time and are considered below. The factors of pH, alkalinity and volatile fatty acids are intimately

FIGURE 2.4

Proposed Reaction Sequence for Methane Production from Carbon Dioxide, Methanol, Serine or Acetate.

(from Kotze, Thiel and Hattingh 1969)



related and are considered collectively.

Temperature. The general temperature range for bacterial life is - 10°C to 90°C (Rheinheimer 1974). This may be arbitarily subdivided into three sections depending on the requirements of the specific organisms (see Table 2.5). The distinctions between each of these groups, however, is not clear and many organisms may adapt to survive in a higher or lower temperature range. Their growth rates however, would be expected to be slower than at their optimum temperature (Friedman and Schroeder 1972).

The influence of temperature upon anaerobic digestion was believed to have been established early. Fair and Moore (1934),

TABLE 2.4

Minimum, Maximum and Optimum Temperature Ranges for Bacterial Life (adapted from Rheinheimer 1974)

Bacteria Group	Temperature (^{o}C)		
	Minimum	Maximum	Optimum
Psychrophilic	-10	20	10
Mesophilic	10	40	30
Thermophilic	25	75	50

reporting several authors, concluded that the digestion efficiency measured according to the gas production at $t^{o}C$ relative to that at $35^{o}C$, 96% at $30^{o}C$ to 37% at $15^{o}C$, and 10% at $5^{o}C$. The optimum temperature for digestion was considered to be $35^{o}C$ (Golueke 1958) or $37^{o}C$ (Kotze, Thiel and Hattingh 1969). The temperature response of organisms was considered to conform to the Arrehenius relationship for the temperature dependence of chemical reactions, modified in terms of bacterial growth rate; $K_T = K_{20}\Theta^{(T - 20)}$ where K_T is the growth rate at temperature T, K_{20} the growth rate at $20^{o}C$ and Θ a constant called the temperature coefficient (Fair and Moore 1934; Novak 1974). Recent work has shown that the applicability of this relationship is limited. The growth rate of an organism is also dependent upon the substrate concentration and, therefore Θ is not a constant (Novak 1974). As intracellular methanogenic reactions are the rate limiting steps in digestion (Lawrence and McCarty 1969; Ghosh and Pohland 1974) the production of methane is also substrate concentration dependent. The initial enzymatic hydrolyses, however, being extracellular, are substrate independent and may be expected to follow the Arrhenius relationship (Novak 1974): in this case, $k = Ae^{-E/RT}$ where k is the reaction rate, A the frequency factor, E the energy of activation, R the gas constant and T the absolute temperature. The studies reported by Fair and Moore (1934), and by subsequent authors, were mainly conducted on sludges adapted for mesophilic conditions. The applicability of the results for temperatures outside the optimum range of the sludge is consequently questionable. The only study conducted on septic tank digestion at low temperatures, and with a sludge adapted to cold temperatures (Hindin, Green and Dunstan 1962) reported digestion efficiencies (as % BOD removed) of 27.0% at 15.0^{o}C, 23.7% at 4.4^{o}C and 24.6% at 0.7^{o}C. The theoretical maximum digestion efficiency (as % BOD removed), if complete digestion of the settled solids is assumed, is 40 - 70%. The digestion efficiencies of Hindin, Green and Dunstan (1962), then, represent less than 68%, 59% and 62% respectively, of the theoretical maximum efficiency. In these digestions only the first one, the digestion at 15^{o}C, produced CO_2 and CH_4; the other two produced mainly CO_2 with a small amount of N_2.

Even within the "normal" temperature range few studies on the influence of temperature on septic tank digestion have been conducted; most studies have concentrated on anaerobic digestions of the sort used in large wastewater treatment works where temperature control is possible. The optimum temperature for mesophilic bacteria, the most likely sort of bacteria to be encountered in septic tanks in "normal" conditions, in large scale digesters has been reported as 35^{o}C - 37^{o}C.

Although temperatures of this magnitude may occur in air in areas where septic tanks find their principal use they are uncommon in water. Water held in a shallow tank, such as a toilet cistern, tends to assume the average air temperature (Bayly and Williams 1973), which in a house usually is within the range 15-20^{o}C. For example, the temperature of toilet wastewater reported by Siegrist, Witt and Boyle (1976) was 18.9^{o}C. If the temperature behaviour of large scale digesters is considered applicable to septic tanks those handling only toilet wastewater rarely, if ever, operate at their optimum temperature. Even through the addition of hot water, as in all wastewater treatment, this temperature is unlikely to be attained. The temperature of all wastewater in north-central U.S.A. (Wisconsin) was calculated from the data of Siegrist, Witt and Boyle (1976) to be 27.3^{o}C (see Table 2.1). Viraraghavan (1974), however found that in southern Canada the maximum temperature within a septic tank treating all wastes was 21.5^{o}C. The minimum temperature recorded in the same septic tank was 16.0^{o}C. The range of temperatures likely to be found in septic tanks, therefore, is considered to be 15^{o}C - 30^{o}C.

Temperature stability has been shown to be also important to digestion efficiency. Golueke (1958) and Brown and Kinchusky (1965) demonstrated that a rapid change in digestion temperature of only 4^{o}C (36^{o}C to 40^{o}C) can result in an acid accumulation sufficient to endanger the digestion process. This is for temperatures stable before and after the change. Short term fluctuations in the reaction liquor temperature, even changes of 10 - 20^{o}C for some hours, do not affect digestion performance once the initial temperature has been restored, although during the period of reduced temperature the digestion will be retarded (Speece and Kem 1970). Temperature changes over a period of time long enough for bacterial acclimation to occur, which at 15^{o}C is about 2 weeks (Benedict and Carlson 1973), do not affect the digestion performance. In septic tank operation sudden changes in the reaction liquor temperature are not likely to occur. To change the temperature within the smallest septic tank, a 1600 litre tank, from (say) 15^{o}C to 19^{o}C would require the input of 26.8 megajoules of energy; that is, about 80 litres of boiling water. Changes in the tank liquor temperature are more likely to result from season factors which occur over a period of time sufficient for bacterial adaption.

pH, Volatile Fatty Acids and Alkalinity. The fluids of a living cell have a pH of around 7 (Kotze, Theil and Hattingh 1969). However, many species of bacteria are able to survive external pH's up to 9. This is because the cell wall is relatively impermeable to H^+ and OH^- ions (Kotze and Hattingh 1969). Non-ionic species, however, can penetrate the wall more readily. At extreme pH's, weak acids and bases are undissociated and are able to penetrate the cell wall and alter the internal pH of the cell. Consequently weak acids and bases at pH's below 6.0 and above 9.0 are toxic to many bacteria, but around neutrality they are relatively harmless (Kotze, Thiel and Hattingh 1969).

The pH of a digestion has long been recognised as an important parameter in its characterisation. It is a measure of the interplay between the buffering capacity of the system and the concentrations of fatty acids and ammonia. A well operating digestion process should have a pH of 6.0 - 7.5, a free fatty acid concentration of less than 2000 - 3000 mg/l, as acetic acid (Kotze, Thiel and Hattingh 1969) and an ammonia concentration of less than 1250 mg/l (Albertson 1961; McCarty and McKinney 1961). Below the fatty acid or ammonia limits, that is, in the optimum pH range, the fatty acids and ammonia are almost completely ionised and behave as strong acids and bases respectively. The buffering capacity of these compounds under these conditions is negligible. The pH of the system is controlled by the alkalinity, the ionic equilibrium between various species of CO_2 in solution (Capri and Marais 1975). In the pH range 6.0 - 7.5 the controlling equilibrium would be

$$H_2CO_3 \longrightarrow H^+ + HCO_3^-$$

The other dissociation equilibrium,

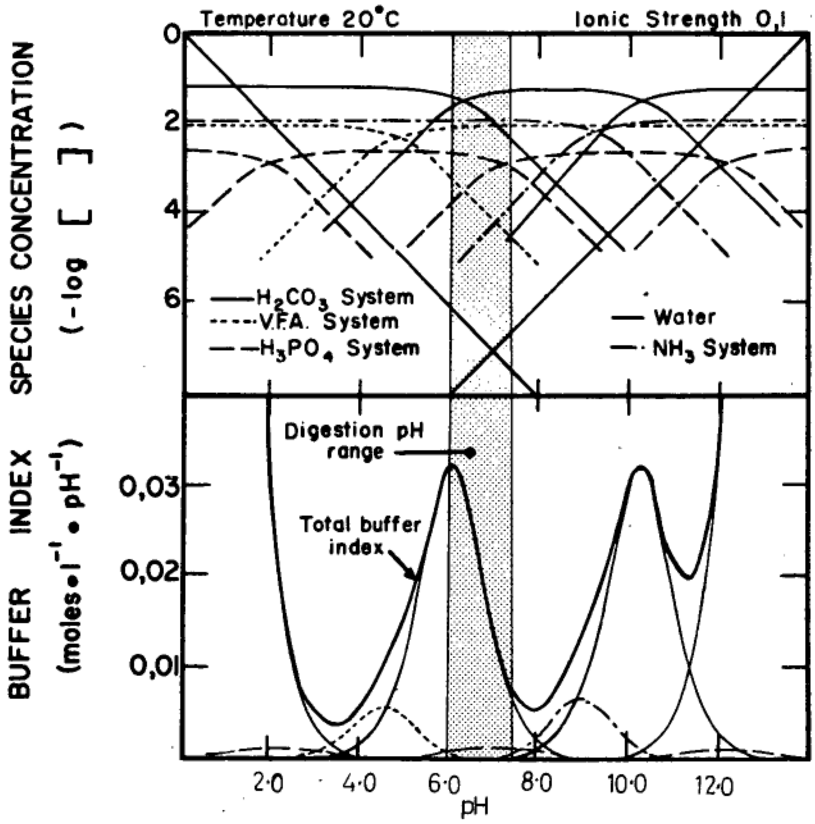
$$HCO_3^- \longrightarrow H^+ + CO_3^{2-}$$

would buffer the system around pH 8.3 - 10.5 (Lijklema 1969). Between these two pH ranges, the buffering capacity of the digestion liquor is low. The influence of other compounds likely to be in the liquor, e.g. H_3PO_4 is negligible (Capri and Marais 1975). The interplay between the above pH influences is illustrated in Figure 2.5; although derived for spent wine waste digestion, the principles are considered to be applicable to domestic wastewater digestion.

FIGURE 2.5

Relative Significance of the Weak Acid/Base Systems in Anaerobic Digestion.

(from Capri and Marais 1975)



$[H_2CO_3]$ = 57.5 mmole.1^{-1} $[VFA]$ = 10.0 mmole.1^{-1}

$[H_3PO_4]$ = 2.5 mmole.1^{-1} $[NH_3]$ = 11.6 mmole.1^{-1}

An alternative measure of the two competing pH influences, volatile fatty acids (VFA) and alkalinity, is given by the VFA/alkalinity ratio. If this should fall below 0.8, the buffering capacity of the bicarbonate equilibrium is endangered and digestion unbalance is indicated (Kotze, Thiel and Hattingh 1969). The buffering capacity of the bicarbonate system is also influenced by the dissolved CO_2 concentration which, in a well operating digestion, is at saturation. Any perturbation, then, which will generate unsaturated conditions, such as shock doses of carbonate or strong base, will produce high pHs and endanger the digestion (Capri and Marais 1975). The digestion may also be endangered by the input of water with a pH < 6.0. This may lower the digestion pH sufficiently for the weak acids to assume some toxicity. Fortunately, the pH of most natural waters is in the 6-9 range. The only waters likely to exceed it are from peat bogs or unusual geological formations, such as overflow from Mt. Ruapehu in New Zealand (whose crater lake pH is 0.9) producing a pH of 2.5 in the Shangaeku River 30 km downstream (Bayly and Williams 1973). These waters do not find common useage in septic tanks.

If for some reason, the pH of the digestion is disturbed the equilibrium may be restored by dosing with bicarbonate (Capri and Marais 1975), although, sodium carbonate, calcium carbonate or calcium hydroxide are commonly used (Imhoff, Muller and Thistlethwayte 1971). In fact, EPA* in Victoria (EPA 1975a, p.11) recommend that "if excessive odours arise from the tank ... indicating acid digestion conditions (Imhoff, Muller and Thistlethwayte 1971)... flush a handful of lime into it daily until odours cease".

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*EPA is the abbreviation used for the Environment Protection Authority.

Other Toxic Substances. As well as volatile fatty acids and ammonia, above certain concentrations, being toxic to anaerobic digestion the common cations Na^+, K^+, Ca^{2+} and Mg^{2+} may also be digestion toxins. McCarty and McKinney (1961) showed that above certain concentrations these cations can inhibit or halt a digestion. At lesser concentrations, however, they may actually stimulate the process. Several of these cations also have an antagonistic effect upon the influence of another cation; that is, reduce their digestion inhibition. Sodium and potassium are very effective at this, 300 mg/l of K^+ will reduce the inhibitory effect of 7000 mg/l Na^+ by 80%, but calcium and magnesium are less effective (McCarty 1964). The stimulatory and inhibitory concentrations of these cations, given in order of decreasing toxicity at equivalent concentrations to methanogenic bacteria (McCarty and McKinney 1961), is shown in Table 2.5. From this, some justification of the common practice of using lime for volatile fatty acid and pH adjustment can be seen. Calcium is of lower toxicity and is only sparingly soluble, which means that excess calcium will precipitate from the digestion liquor. Anion concentrations apparently have little effect upon the digestion.

TABLE 2.5

Stimulatory and Inhibitory Concentrations of Common Cations (from McCarty 1964)

Cation	Concentration (mg/l)		
	Stimulatory	Moderately Inhibitory	Strongly Inhibitory
Na^+	100 - 200	3500 - 5500	8000
K^+	200 - 400	2500 - 4500	12000
Ca^{2+}	100 - 200	2500 - 4500	8000
Mg^{2+}	75 - 150	1000 - 1500	3000

In natural waters the inhibitory cation concentrations shown above are unlikely to be reached. Even in "hard" bore water, whose principal cations are Ca^{2+} and Mg^{2+}, concentrations rarely exceed 500-600 mg/l. The only natural water that could threaten a digestion through cation inhibition is sea water, which has average Na^{+}, K^{+}, Ca^{2+} and Mg^{2+} concentrations of 10810, 390, 410 and 1300 mg/l respectively (Bayly and Williams 1973). Therefore, septic tank operation is unlikely to be affected by cation poisoning unless sea water or bore water contaminated appreciably with sea water is used.

Loading Rate and Solids Retention Time. The rate at which substrate is supplied to the organisms will affect the degree of decomposition and the stability of the digestion. Mueller *et al.* (1959) showed that in a mature digestion operating at 37°C the digestion activity, which includes VFA production, increased with loading up until a loading rate of 1.6 kg total volatile solids (TVS)/day/m^3 of digester capacity. In septic tanks only about 50% of the incoming total volatile solids are settled and added to the digestion. Therefore, the maximum loading rate in septic tanks treating only toilet wastes, which have a TVS level of 2110 mg/l (Table 2.1 adjusted for different flow rates), would be 1520 l/day/m^3. This rate is for septic tank operation at 35-37°C when the digestion is operating at its maximum efficiency. However, at the usual operating temperature of toilet waste septic tanks (around 20°C) the digestion efficiency is only 52% of the optimum efficiency (Fair and Moore 1934). The maximum loading rate of toilet wastewater at 20°C is, therefore, 790 l/day/m^3. For septic tanks that treat all wastes, which have a TVS level of 580 mg/l (Table 2.1), the maximum loading rate at 35-37°C is 5520 l/day/m^3. At temperatures likely in all waste digestion (around 30°C), though, the digestion efficiency is 96% of the optimum (Fair and Moore 1934) and the maximum loading rate is 4880 l/day/m^3. Loading at this rate, or the above one for toilet waste, however, would be in violation of the liquid retention time (24 hours) and the sludge storage capacity (55% of total capacity) design criteria. In properly managed septic tanks the maximum loading rate, after allowing for sludge storage, is 450 l/day/m^3.

The maximum loading rate for an immature digestion system, such as a septic tank starting up after a long period of disuse, would probably be less than that calculated above. The growth and metabolism of the methanogenic bacteria community is slower than that of the non-methanogenic community; that is, digestion rate controlling (Lawrence and McCarty 1969; Ghosh and Pohland 1974). In an immature community these bacteria would be poorly established and probably unable to tolerate a sudden increase in the acid concentration. A sudden load could, then, precipitate digestion failure through VFA accumulation. Cassell and Sawyer (1959) indicated that such an accumulation on starting digesters with a sudden load may be averted by dosing with lime.

Lawrence and McCarty (1969) reported that digestion completeness was also related to the solids retention time, which, in turn, is dependent upon the substrate concentration. Dague, McKinney and Pfeffer (1970) investigated this further and showed that the critical solids retention time was equivalent to the regeneration time of the slowest growing member of the methanogenic community. With a solids retention time less than this wash-out of these organisms and incomplete digestion would result. The minimum solids retention time they suggested for domestic wastewater sludge was 10 days. Hindin and Dunstan (1960), however, suggested a critical solid retention time of 30 days. As septic tanks, under ideal conditions, have a solids retention time of 4 - 10 years, depending on the tank volume (DHV 1975; EPA 1975a) inadequate digestion in this regard is unlikely to be a problem.

(d) Digestion Conditions and Septic Tank Use

Septic tanks are primarily settling chambers whose performance is governed by the liquid retention time which, in turn, is controlled by the flow rate. For design purposes the liquid retention time is taken to be 24 hours. This means that the design flow rate, allowing 55% of the tank volume for sludge storage (see Section 2.2.1), is 450 $l/day/m^3$ of tank capacity.

The optimum operating temperature for anaerobic digestion, which is the treatment mechanism of septic tanks, have been shown to be around 35^{o}C for mesophilic bacteria (the most common type of bacteria in septic tanks) or 10^{o}C for psychrophilic bacteria (the bacteria adjusted to low temperatures). Within the temperature range of these bacteria deviations from their optimum result in reduced growth rates and digestion efficiencies. Thus, septic tank operation at the temperature in which they are most likely to be found, 15-30^{o}C, will be less than optimum. Fair and Moore (1934) reported digestion efficiencies between 37% and 96% for this range. Between 15^{o}C with a sludge adapted for psychrophilic (cold) conditions, as against one adapted for mesophilic (warm) conditions, digestion efficiencies less than 68% of the theoretical maximum, but with no methane production, have been obtained (Hindin, Green and Dunstan 1962). Temperature instability also affects anaerobic digestion. In septic tanks, however, sudden changes of the magnitude required are considered unlikely to occur.

Anaerobic digestion is also sensitive to variations in the VFA/alkalinity ratio. Should this fall below 0.8 digestion inbalance and ultimate failure through VFA accumulation is indicated. The level of VFA at which this occurs is around 2000-3000 mg/l, which corresponds to a pH of 6.0 (Kotze, Thiel and Hattingh 1969). Ammonia, in concentrations of greater than 1250 mg/l, which corresponds to a pH of 7.5, is also inhibitory to digestion completeness (Albertson 1961; McCarty and McKinney 1961). Furthermore, at this pH the buffering capacity of the H_2CO_3/HCO_3^- equilibirum, the principal pH controlling equilibrium, is low (Capri and Marais 1975) and the digestion is vulnerable to factors which may adversely affect pH, such as shock doses of carbonate or strong bases. These alter the solubility equilibrium of CO_2, reducing the concentration of H_2CO_3 in the buffering equilibrium, and produce high pHs. At pHs above 7.5 and below 6.0 weak acids and bases are undissociated and can enter bacterial cell walls with ease. Once inside they may change the internal pH and poison the cell (Kotze, Thiel and Hattingh 1969). The cations Na^+, K^+, Ca^{2+} and Mg^{2+} above concentrations of 1000 - 3500 mg/l, depending on the cation, are also toxic to digestion bacteria (McCarty 1964). At concentrations below 150 - 400 mg/l, which are the levels likely to be encountered in rain or surface water commonly used in septic tanks, they may be stimulatory. In bore water cation levels are generally less than 1000 mg/l but for particular sites, particularly those with a sea water component, it may be higher. Water of this nature may inhibit septic tank digestion and caution is advised in its use.

The wastewater loading rate was also shown to affect septic tank digestion. Loading over a rate of 1.6 kg TVS/day/m^3 of digester capacity produced failure in a laboratory digester operating at 37^oC through VFA accumulation (Mueller *et al.* 1959). The maximum loading rate, then for toilet wastewater, which has a TVS concentration of around 2110 mg/l, in septic tanks, which only settle about 50% of the volatile solids and which usually operate at temperatures around 20°C, is 790 l/day/m^3 The maximum loading rate for treatment of all waste, which has a TVS level of 580 mg/l and a temperature of less than 30°C, is 4880 l/day/m^3. Both the above loading rates, however, can only be achieved if the liquid retention time and sludge storage criteria are violated. These arbitary design conditions have a maximum loading rate of 450 l/day/m^3.

The only operational characteristic actively considered in the installation is tank capacity, which means liquid retention time and digestion loading rate: put in a tank big enough to give a liquid retention time of greater than 24 hours, which means a loading rate of less than 450 l/day/m^3 of tank capacity, and the rest will take care of itself. The tank is, therefore, based on the assumption of optimum or near optimum operation. For this assumption to be valid the environmental conditions in which the tank is to operate must approximate, at least, the conditions shown in Table 2.6. As already suggested digestion temperature frequently does not do this.

TABLE 2.6

Optimum and Design Requirements for Septic Tank Operation

Requirement	Optimum*	Design+
Tank characteristics		
- liquid retention time		24 hours
- sludge storage volume		55% of tank capacity
Water characteristics		
- temperature	35 - 37°C	15 - 30°C
- pH	6.0 - 7.5	6.0 - 7.5
- cation level	< 150 - 400 mg/l	< 1000 - 3500 mg/l
Loading Rate		
- toilet waste	< 1520 l/day/m^3	< 450 l/day/m^3
- all waste	< 5520 l/day/m^3	< 450 l/day/m^3

*at 35 - 37°C

+at 20°C (toilet waste) or 30°C (all waste)

2.4 Secondary Treatment

The supernatant liquid from a septic tank contains between 30 - 60% of the suspended solids in raw wastewater and all of the enteric microorganisms. Further treatment of this is clearly necessary. Several may be used but the most common one is soil adsorption. In this, the septic tank effluent is percolated through a specially constructed adsorption field where naturally occurring microorganisms use the entrained organic particles and bacteria as food. This process occurs in the presence of freely available oxygen (O_2); that is, aerobically; in contrast to those in the septic tank which are anaerobic.

2.4.1 Adsorption Field Design

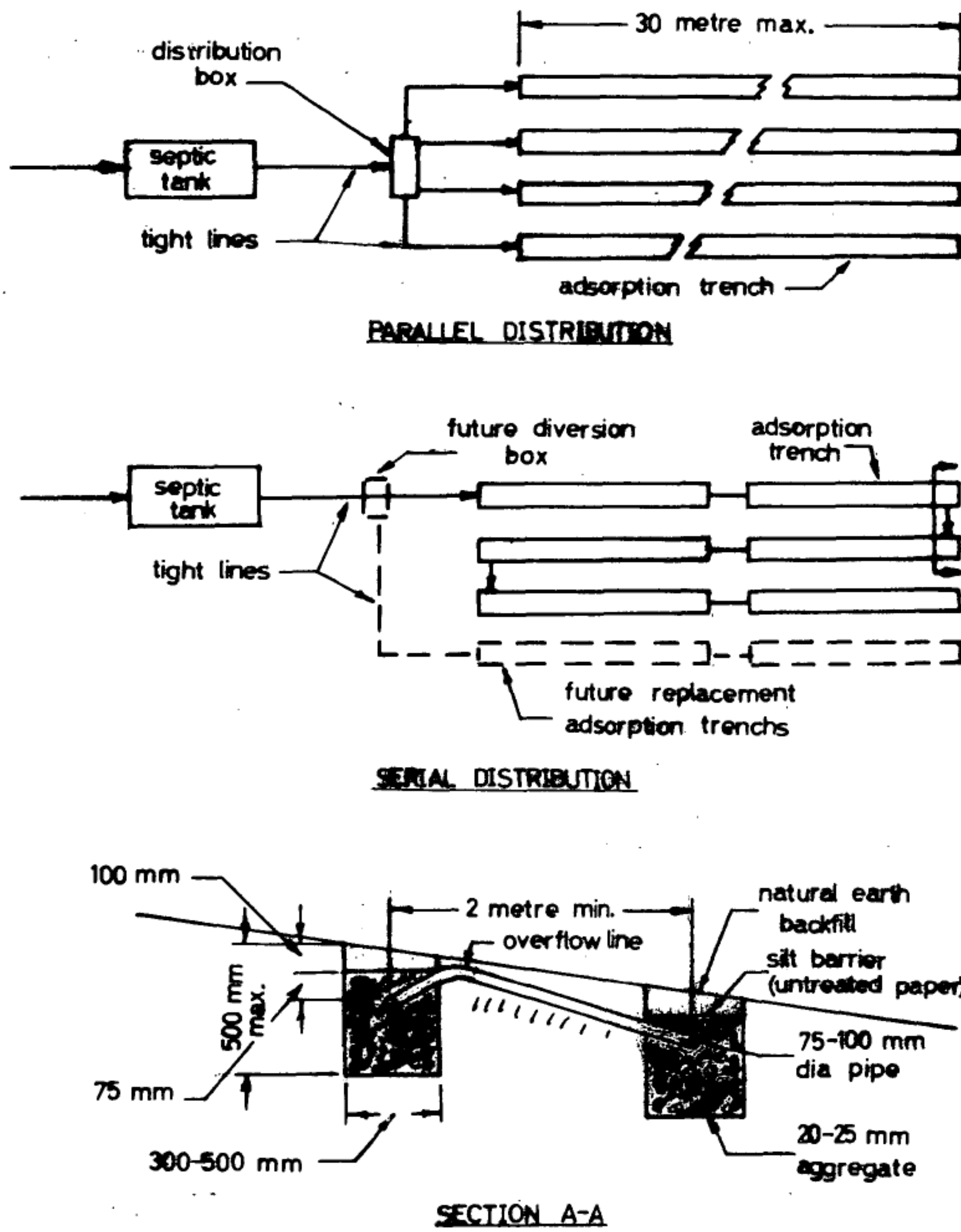
Soil adsorption fields in Australia were designed for use in the areas with the greatest population, New South Wales and Victoria and are based upon operating experience and research in these areas. The conditions of New South Wales and Victoria, particularly the soil temperatures, soil adsorption and relief, are generally similar to those of the main areas of adsorption field use in the U.S. Consequently, the U.S. and Australian designs for adsorption fields are also alike.

Septic tank adsorption fields consist of one or more trenches of 20 - 25 mm aggregate less than 500 mm below the soil surface (DHV 1975). Where more than one trench is used they may be connected in series or in parallel, with laterals up to 30 metres long spaced at least 2 metres apart (DHV 1975). These are the present day requirements for adsorption fields. Older installations may be undisturbed local soil. As fields are prone to clogging (see later) sufficient area must be provided for alternative trenches and this is naturally influenced by relief; the bigger the slope, the bigger the area required. The recommendations of the

FIGURE 2.6

Adsorption Trench Design and Layout

(from DHV 1975)



EPA in Victoria (EPA 1975a) are given in Table 2.7.

TABLE 2.7

Recommended Minimum Adsorption Field Area in Relation to Slope (from EPA 1975a)

Slope (%)	Minimum Area (hectares)
0 - 5	0.4
5 - 10	0.5
10 - 15	0.6
15 - 20	0.8
above 20	not recommended

The layout of an adsorption field is shown in Figure 2.6. Such an arrangement is considered suitable for soils with percolation rates greater than 25 mm/hour (DHV 1975). An alternative to trenches occasionally used is the adsorption tank. This is a vessel with regular spaces along its sides, so that liquid may pass through, placed well into the ground. Adsorption can then occur evenly over a broad soil face minimising clogging (see later).

The percolation rate of an adsorption field soil is determined by a technique known as the Auger Hole Percolation Test. In this, a hole of specific dimensions is filled with water to a set depth and the time required for it to be adsorbed is measured. This is an empirical estimation of a soil's permeability, a property determined by the soils grain size, texture (% clay, silt and sand), porosity (% void space), perviousness (size of void space), infiltration capacity (rate at which water passes the soil-water interface), capillary capacity, depth and thickness of soil horizons, depth and degree of soil saturation, relief and vegetation cover (McGauhey and Winneberger 1964; Healy and Laak 1973; Daniels, Gamble and Nelson 1967; Huddleston and Olson 1967; Schwartz and Bendixen 1970). The method is inherently inaccurate, particularly in fine grained soils, and estimates are greatly influenced by the size and shape of the percolation hole (Healy and Laak 1973). In spite of this the recommended minimum percolation rate of soil for use as an adsorption field is 25 mm/hour (DHV 1975). Moreover, this rate is based upon North American experience and may not be applicable to Australian soils, particularly with their higher clay content which probably necessitates a higher rate (EPA 1975b)

2.4.2. Aerobic Oxidation

In soil adsorption, the septic tank effluent is added to a specially designed soakage trench and allowed to percolate into the surrounding soil. The soil acts jointly as a filter entrapping the suspended solids of the wastewater and as a support for an active biomass which feeds upon the suspended organics. The soil micro-organisms oxidise the organic material to carbon dioxide, water and inorganic salts. In contrast to the anaerobic processes of the septic tank the processes involved in soil adsorption are aerobic and require abundant free oxygen.

The understanding of microbial ecology in soil and soil adsorption fields is poor. The purification mechanisms, however, are a little better understood in sand filtration, a similar process. Several studies have been conducted on the ecology of these (Calaway, Carroll and Long 1952; Calaway 1957; Brink 1967). These studies will be used as guides to the likely ecology of the soil surrounding adsorption trenches.

(a) Adsorption Field Community and Ecology

Soil as a habitat supports a wide variety of microorganisms which includes bacteria, actinomycetes, fungi, algae and protozoa

(Alexander 1961). The precise structure of the community varies with soil type and local environment but the most common organisms are members of the bacteriae and actinomycetes microflora. The predominant genera of bacteria are *Pseudomonas*, *Arthobacter*, *Clostridium*, *Achromobacter*, *Bacillus*, *Micrococcus* and *Flavobacterium* with *Streptomyces* and *Norcardia* being the major actinomycetes (Alexander 1961). The most common microfauna are flagellate, rhizopod and ciliate protozoa (Alexander 1961).

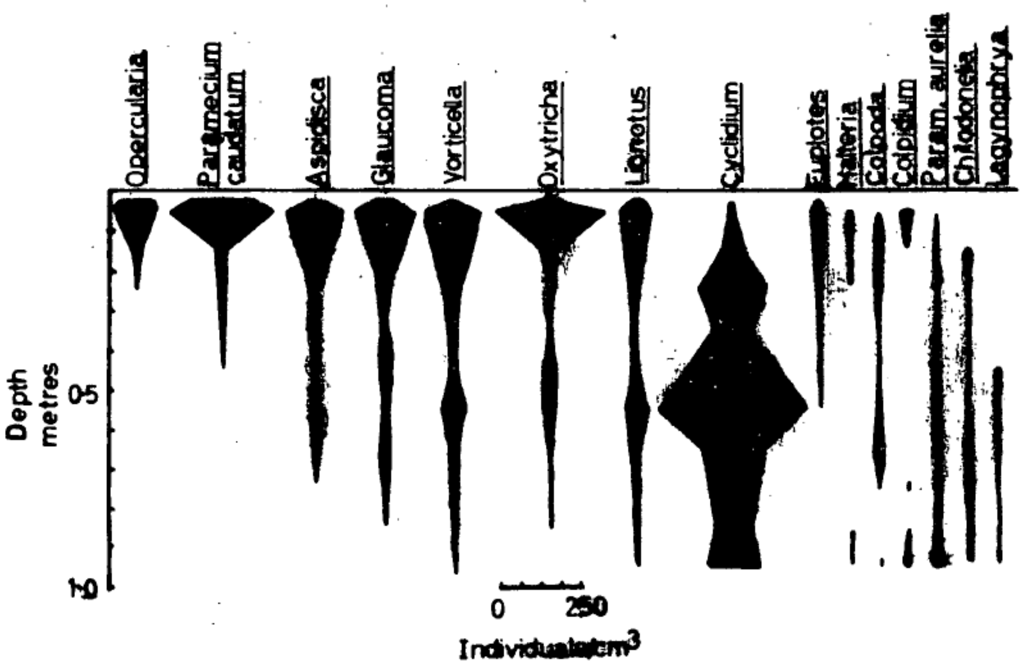
Few studies have been carried out on the microbiology of soil adsorption fields. However, the microflora and fauna reported for sand beds receiving settled wastewater is similar to the soil populations described above. Fourteen genera of heterotrophs including *Bacillus*, *Flavobacterium*, *Norcardia*, *Streptomyces*, *Actinomyces* and *Alicaligenes* have been isolated from various levels in sand filters (Calaway, Carroll and Long 1952). Of these *Bacillus* and *Flavobacterium* were the most abundant. In the upper 300 mm of sand, however, the most abundant organisms were zoogloea bacteria such as *Zoogloea ramigera* (Calaway, Carroll and Long 1952). Curtis (1969) noted that *Sphaerotilus natans* may also be present in the zoogloeal mass. In the deeper portion of sand filters the autotrophs *Nitrosomonas* and *Nitrobacter* have been observed (Brink 1967; Pike 1975). These two genera also occur in soil.

Aside from the above organisms a diverse fauna of protozoa, rotifers, nematodes, arachnids and insects may also be found in sand filters (Brink 1967). Of these, the greatest diversity belongs to the protozoans. Some 218 species of protozoa, distributed amongst several classes: Phytomastigophorea, 35 species; Zoomastigophorea, 30 species; Rhizopodea, 31 species; Actinopodea, 7 species; and Ciliatea, 116 speices: have been reported in filters (Curds 1975). The distribution of some of the more common ciliates in a sand filter is shown in Figure 2.7.

FIGURE 2.7

Typical Distribution of Common Ciliates in a Sand Filter

(from Brink 1967)



The precise roles of the organisms observed in sand filters in the treatment process are not clear. The genus *Zoogloea* was originally described as being non-proteolytic and unable to ferment carbohydrates but very active in their oxidative utilization. Recent evidence has shown, that *Zoogloea* possesses urease, catalase, an oxidase reaction and a nitrate reduction capacity but not a carbohydrate fermentation one (Curtis 1969). *Sphaerotilus natans*, on the other hand, a species known to form a zoogloeal mass, can readily degrade most simple carbohydrates (Curtis 1969). It has been shown that 65% of the principal heterotrophic bacteria of sand filters can peptonize protein, 78% can hydrolyse amino acids and 57% are able to decompose at least two different carbohydrates (Calaway, Carroll and Long 1952). Brink (1967) supported this by showing that in sand filters organic oxidation principally occurred in the upper part of the filters where the conditions were favourable to heterotrophic bacteria.

Little work has been conducted on the role of protozoa in biological filters. However, the similarity between the protozoan populations in aerobic filtration and activated sludge allows parallels to be drawn (Curds 1975). Within activated sludge it has been shown that ciliated protozoa, the most common type of protozoa in activated sludge (and biological filtration), predate on dispersed growths of bacteria and thereby clarify the effluent (Curds, Cockburn and Vandyke 1968; Curds and Fey 1969). Other protozoa such as flagellates and amoebae are also known to feed on bacteria and probably play a similar role (Curds 1975).

The role other fauna play in the purification process is principally that of predation. Schiemer (1975) suggested that nematode predating of the bacterial population had a stimulating effect on growth rates. Solbe (1975) considered that annelid worms may assist filtration by film and microorganism grazing and the formation of water soluble aggregates. Calaway (1957), however, considered their contribution to be the metabolic conversion of insoluble forms of humus like material found in the filters into a more porous form. The role of rotifers is grazing dispersed, flocculated bacteria too large for the protozoa to handle (Doohan 1975).

Macro fauna such as insects and arachnids have been given predatory roles in percolation filters (Learner 1975; Baker 1975). These are not considered to be of great importance in soil adsorption.

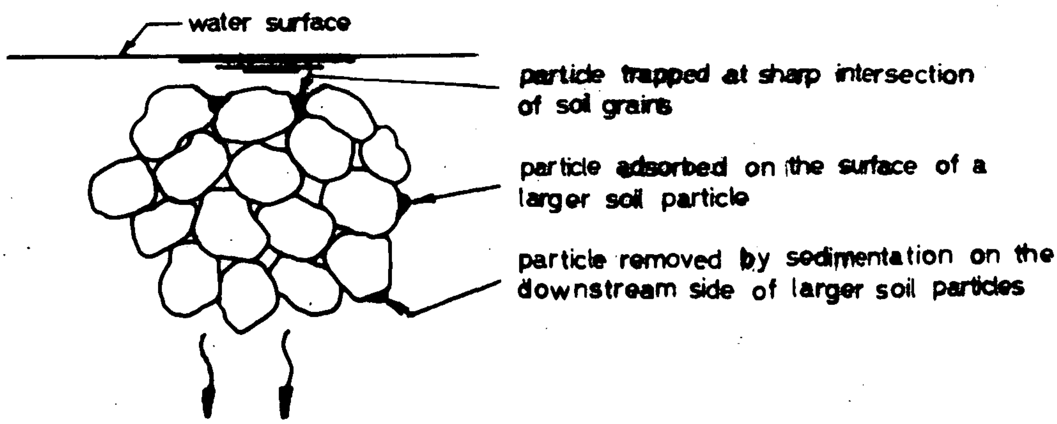
(b) Adsorption Mechanism

Part of the purification mechanism of an adsorption field is physical filtration. Suspended particles particularly the colloids, can be removed from the wastewater by three separate mechanisms. They may be trapped in grain intersections, attracted to the grain surface by electrostatic forces or deposited on to the grains (McGauhey and Winneberger 1967). These mechanisms are illustrated in Figure 2.8 below. On the particles so collected the organisms given earlier develop and enhance the filtration capacity of the soil.

FIGURE 2.8

Removal of Particles from Water Through a Soil System

(from McGauhey and Winneberger 1967)



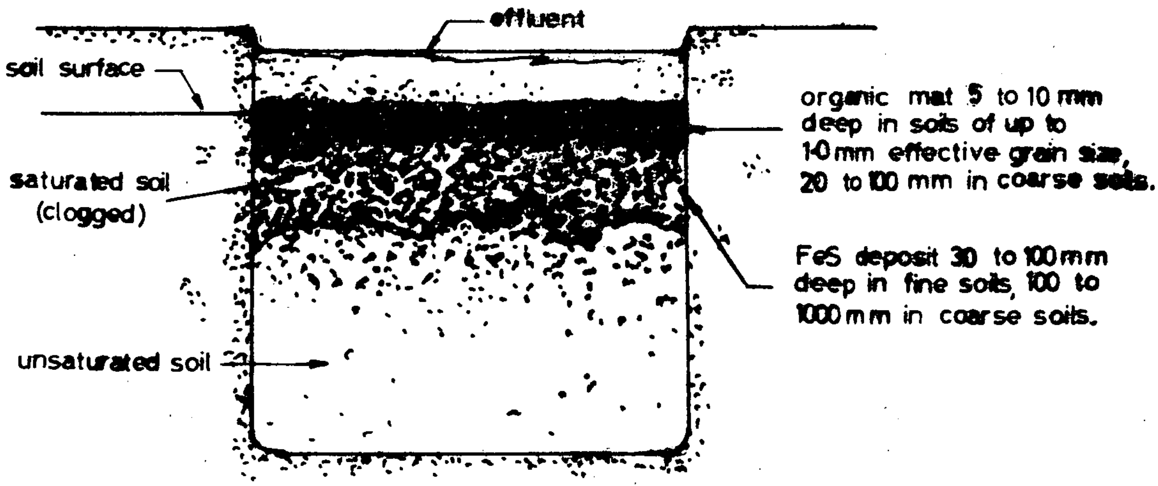
(c) Adsorption Conditions

Several factors are known to reduce soil percolation and adsorption capacity, all through the development of anaerobic conditions and the clogging of the soil. The principal factor affecting an adsorption field is that of continual use. As wastewater percolates through the soil, air is displaced and hypoxic conditions are generated. As a result, ferrous sulphide precipitates and blocks the soil pores (McGauhey and Winnberger 1967). This process occurs throughout the trench depth but is particularly noticeable in the trench bottom where water may stagnate for a time. As the ponded water accumulates the ferrous sulphide clogging will continue, gradually working its way up the trench wall. Concurrent with this, a matt of filamentous organisms such as *Zoogloea* forms in the top 100 mm of soil on the organic particles retained by filtration (McGauhey and Winneberger 1967). As the matt develops it becomes itself a filter medium retaining smaller and smaller particles. The nett effect of these two influences, particularly the latter (McGauhey and Winneberger 1967; De Vries 1972), is eventual clogging of the soil (see Figure 2.9). The life of an adsorption trench may be prolonged, by periodic restoration of aerobic conditions through resting (McGauhey and Winneberger 1967). In practice, however, this is difficult to achieve and consequently the average life of an adsorption trench receiving septic tank effluent has been estimated to be less than 10 years (Cotteral and Norris 1969). Clayton (1974), however, states that with proper design and adequate maintenance lives of up to 30 years are possible.

FIGURE 2.9

Elements of Clogging Zone in Organic Loaded Soil

(from McGauhey and Winneberger 1967)



Anaerobic conditions in an adsorption field are known to be enhanced by the degree of saturation of the soil; that is, the water table depth. Through capillary and surface tension phenomena filtrate may remain suspended in the filter (McGauhey and Winneberger 1964). Inundation of the adsorption field may produce the same effect and a minimum water table depth of 1.0 metre below the trench (1.5 metre below ground level) is recommended (Schwartz and Bendixen 1970; Bouma 1975; EPA 1975a). Another factor known to enhance anaerobiasis is overloading; that is, application of primary effluent at a rate greater than that with which the soil and microorganisms can cope. Ponding is the clear result. DHV (1975) recommend application rates of 25 - 150 $l/day/m^2$ of trench area, depending on the soil percolation rate, but Robeck *et al.* (1964), suggested a maximum rate of 11 $l/day/m^2$ and McGauhey and Winneberger (1967) considered that for continuous application a loading rate of only 0.9 $l/day/m^2$ was the wiser, "most conservative", figure. Temperature may also affect the adsorption capacity of the soil. De Vries (1972) showed that at 4^oC loading at a rate of 200 $l/day/m^2$ caused soil clogging after 10 days as against 240 days at 20^oC. Robeck *et al.*(1964) and Schwartz and Bendixen (1970), however, reported that low temperature causes soil clogging only with immature biological systems. Although uncertainty exists as to the nature of the temperature influence it would be reasonable to expect it to follow a similar pattern as septic tank operation: the lower the temperature the lower the biological process efficiency. The implicit design temperature range is, then, expected to be similar to that of septic tanks less (say) 5^oC for cooling (15 - 25^oC). Yet, in several situations where septic tanks may be used, such as mountain areas during winter, this range will not be attained. This is because surface soil temperature tends to assume the average air temperature at that time (Bureau of Meteorology, personal communication). Only in adsorption fields handling effluent from a septic tank receiving all wastes; that is, kitchen, laundry, bathroom and toilet wastes; is such a range possible. For example, Viraraghavan (1974) found that the hot water in such wastes maintained the temperature at an adsorption field in Canada at around 3°C whilst air temperature was below zero (the average air temperature from December to March at 1000 hours was -5.3°C).

A final factor known to influence trench clogging is construction methods. These include soil compaction by heavy loads (ponded water or construction equipment), smearing of soil surfaces by excavation equipment, migration of fines from rainfall or vibration of dry soil during construction and washdown of fines perched on larger particles (McGauhey and Winneberger 1967).

Consideration of the above, and other factors led McGauhey and Winneberger (1967) to recommend a number of operational criteria. These are given below.

Criteria 1: Continuous inundation of the infiltration surface must be avoided.

Criteria 2: Aerobic conditions should be maintained in the soil.

Criteria 3: Initially the infiltration surface should be typical of an internal plane of the undisturbed soil.

Criteria 4: The entire infiltration surface should be loaded uniformly and simultaneously to minimize creeping failure.

Criteria 5: There should be no abrupt change in particle size between the trench fill material (rock) and soil at the infiltration surface to prevent loss of infiltration area.

Criteria 6: The amount of suspended solids in the septic tank effluent should be a minimum.

Criteria 7: The leaching system should provide a maximum of sidewall surface per unit volume of effluent and a minimum of bottom area to minimize creeping failure (walls clog slower than the bottom).

Boumer (1975), however, disagrees with the final criteria believing that shallow trench systems are preferable particularly in areas with a continuous or seasonly high water table. This is because puddling and smearing is more likely with deep trenches and deep trenches can fill with water, giving high hydraulic heads, which seem to cause severe bottom clogging.

All of the above considers factors causing loss of soil adsorption capacity. In sandy soils with very high percolation rates, this is unlikely. In fact the reverse, inadequate treatment through too rapid movement through the field, is possible. Schaub and Sorber (1977) reported that enteroviruses and a tracer viruses (caliphage f_2) were detectable after 183 metres of travel through unconsolidated silty sand and gravel. EPA in Victoria (EPA 1975a) makes no recommendation on the maximum percolation but advises that proposed adsorption field sites in such soils be assessed in relation to their proximity to surface and ground water. For example, adsorption fields adjacent to shallow poorly flushed lakes are prohibited.

(d) Adsorption Conditions and Adsorption Field Use

As shown previously several factors are known to influence adsorption trench and field performance and life. These include "creeping failure", water table depth, loading rate, soil temperature, soil percolation and shoddy trench construction. All of these factors eventually lead to anaerobic conditions and the blocking of soil pores. Another factor influencing trench and field performance is slope. The greater the slope the faster water will move through the field and the less treatment it will receive. Therefore, a greater field area is required the bigger the slope.

The basic design of adsorption trenches and fields is based on experience, and research, of systems operating under usual habitation conditions; that is, moderate to warm temperatures, adsorbant, unsaturated soil and moderate slope. The frequent non-ideality of many of these conditions, however, has been recognised in the appropriate regulations. No adsorption fields are to be constructed in areas with a slope greater than 20% (1 in 5), a water table less than 1.5 metres from the surface, or a soil percolation less than 25 mm/hour. Where adsorption fields can be constructed their area is to be between 0.4 and 0.8 ha, depending on the slope, with sufficient area for an alternative field when the first one fails, and their loading rates are to be less than 150 l/day/m^2 of trench area, the actual amount depending on the soil percolation (DHV 1975; EPA 1975a). Furthermore, government inspection maintains a watchful eye on the observance of these regulations and on construction standards. The only factor whose deviation from ideality is not recognised is soil temperature. This could be an important influence in the operation of intermittently used adsorption fields in rough conditions, such as at ski fields.

2.5 Operational Requirements of Septic Tanks and Adsorption Fields

In the foregoing sections is has been shown that septic tanks and adsorption fields have specific requirements for efficient operation. These are shown in Table 2.8 along with the likely conditions under which they were designed to operate.

TABLE 2.8

Operational Requirements of Septic Tanks and Adsorption Fields

Requirement	Optimum+	Design^{X}
Tank characteristics		
- liquid retention time		24 hours*
- sludge storage volume		55% of tank capacity*
Water Characteristics		
- temperature	35 - 37°C	15 - 30°C
- pH	6.0 - 7.5	6.0 - 7.5
- cation level	< 150 - 400 mg/l	< 1000 - 3500 mg/l
Loading Rate		
- toilet waste septic tanks	< 1520 l/day/m^3	< 450 l/day/m^3
- all waste septic tanks	< 5520 l/day/m^3	< 450 l/day/m^3
- adsorption field		25 - 150 l/day/m^2*
Area		0.4 - 0.8 hectares*
Slope		< 20%*
Soil Characteristics		
- percolation rate		> 25 mm/hour*
- water table depth		> 1.5 metres*
- temperature		15 - 25°C

*DHV (1975) and EPA (1975a) recommendations

+at 35 - 37°C

^{X}at 20°C (toilet waste), 30°C (all waste) or 25°C (adsorption field).

In the Table above three large discrepencies between the optimum and design conditions are apparent. These are water temperature, water cation concentrations and the septic loading rates. In the every-day useage of septic tanks the optimum temperatures are considered unlikely to be attained, even if hot water is added to the tank, and 30°C is believed to be a reasonable estimate of the upper limit of septic tank digestion temperatures. As temperature and efficiency are intimately related, this means that septic tank digestion efficiency and consequently the loading rate will be less than optimum. Even allowing for this, the design loading rate is much less than the theoretical maximum loading rate at both optimum or usual temperatures. It is given by arbitary liquid retention time and sludge storage requirements not the digestion performance.

The difference between the optimum and design cation requirements, conversely, is a reflection of the generous safety margin in the digestion operation. Although the optimum cation concentrations for digestion are less than 150 - 400 mg/l, depending on the cation, the digestion can tolerate concentrations of up to 1000 - 3500 mg/l before inhibition is apparent. The only natural waters whose cation levels are likely to exceed these limits are sea water and bore water heavily contaminated with sea water. The cation levels of water commonly used in septic tanks are not likely to even approach the above limits. Similarly, although water pH is critical to septic tank digestion; pHs outside the range 6.0 - 7.5 can result in digestion failure; the pH of natural waters is unlikely to exceed operational range. The remaining requirements of Table 2.8 are design specifications based on operating experience, although the water table depth specification has been supported by research.

CHAPTER 3

TASMANIAN CONDITIONS IN RELATION TO SEPTIC TANK AND ADSORPTION FIELD (STAF) DESIGN CRITERIA

3.1 Introduction

In the previous chapter it was established that septic tanks are designed to operate under conditions which approximate their optimum conditions; that is, warm temperatures and neutral waters with moderate to low cation concentrations. Similarly, adsorption fields are designed on the premise that operation is to be under ideal conditions; warm temperatures, and adsorbant soil with low water tables. In areas where septic tanks and associated adsorption fields (STAF) may be used in Tasmania these conditions may not be met. The likely distribution of STAF systems in Tasmania and the conditions in which they may be required to operate are considered in the following sections. The relationship of these conditions to the system's design criteria are also considered.

3.2 Characteristics of STAF Operating Areas in Tasmania

3.2.1. Distribution

In comparison to other states of Australia the population of Tasmania is distinctive in its relative decentralisation. The population distribution is not dominated by one central metropolis but is focussed on two cities (Hobart and Launceston) and several smaller towns. The June 1976 national census estimated that 32% of Tasmania's 407,360 people lived in Hobart, 16% in Launceston, 27% in other urban areas and 25% in rural locations (ABS* 1977a). This means that at least 25% of the population cannot make use of common municipal services such as community wastewater treatment.

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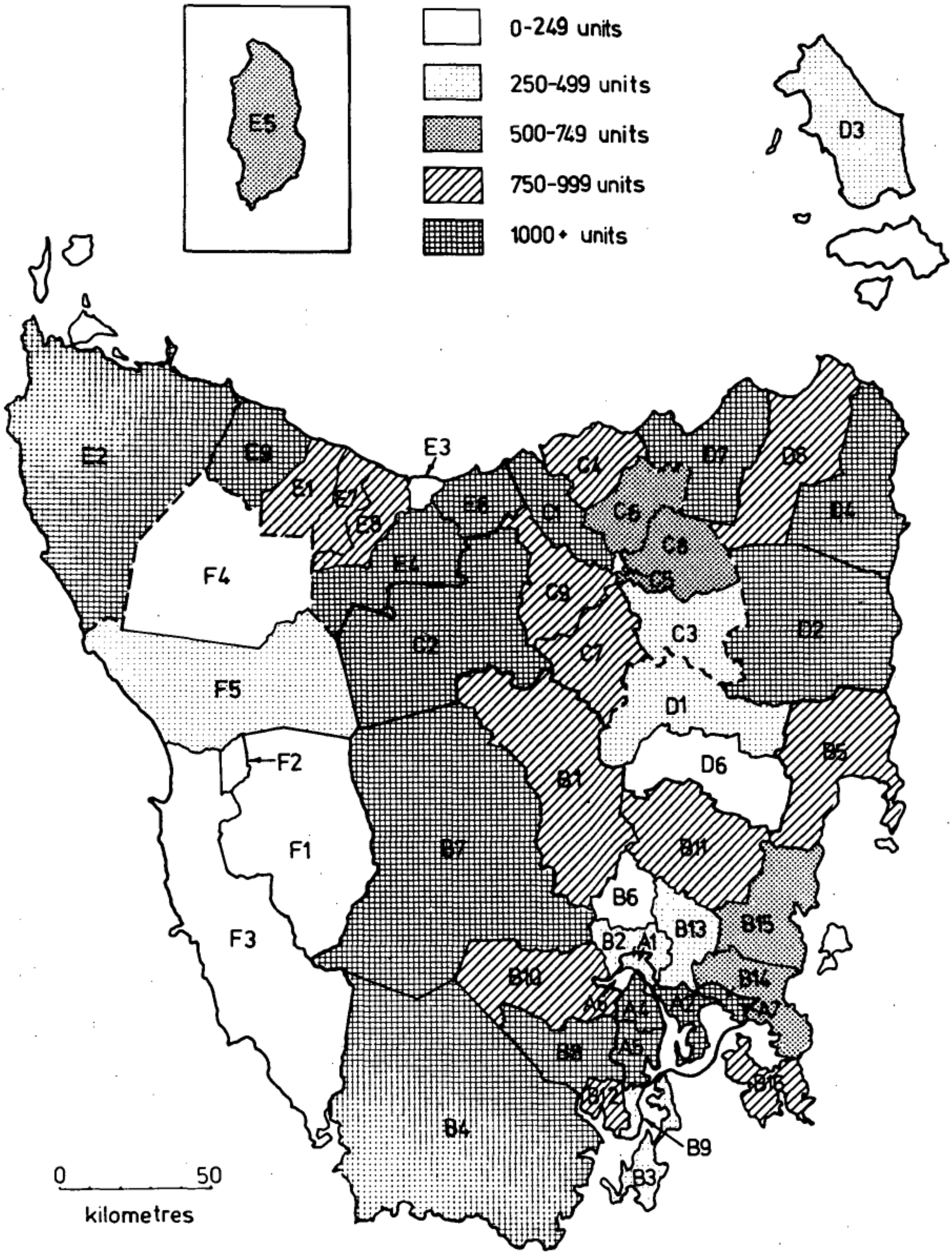
*ABS is the abbreviation for the Australian Bureau of Statistics.

FIGURE 3.1

Estimated Distribution of STAF Units by Local Government Area



Key to Local Government Areas in Figure 3.1

HOBART DIVISION

A1 Brighton A

A2 Clarence

A4 Glenorchy
Hobart

A5 Kingborough A

A6 New Norfolk A

A7 Sorell A

SOUTHERN DIVISION

B1 Bothwell

B2 Brighton B

B3 Bruny

B4 Esperance

B5 Glamorgan

B6 Green Ponds

B7 Hamilton

B8 Huon

B9 Kingborough B

B10 New Norfolk B

B11 Oatlands

B12 Port Cygnet

B13 Richmond

B14 Sorell B

B15 Spring Bay

B16 Tasman

NORTHERN DIVISION

Tamar Subdivision

C1 Beaconsfield

C2 Deloraine

C3 Evandale

C4 George Town

C5 Launceston

C6 Lilydale

C7 Longford

C8 St. Leonards

C9 Westbury

Northern Eastern Subdivision

D1 Campbell Town

D2 Fingal

D3 Flinders

D4 Portland

D5 Ringarooma

D6 Ross

D7 Scottsdale

MERSEY - LYELL DIVISION

Northern Western Subdivision

E1 Burnie

E2 Circular Head

E3 Devonport

E4 Kentish

E5 King Island

E6 Latrobe

E7 Penguin

E8 Ulverstone

E9 Wynyard

Western Subdivision

F1 Gormanston

F2 Queenstown

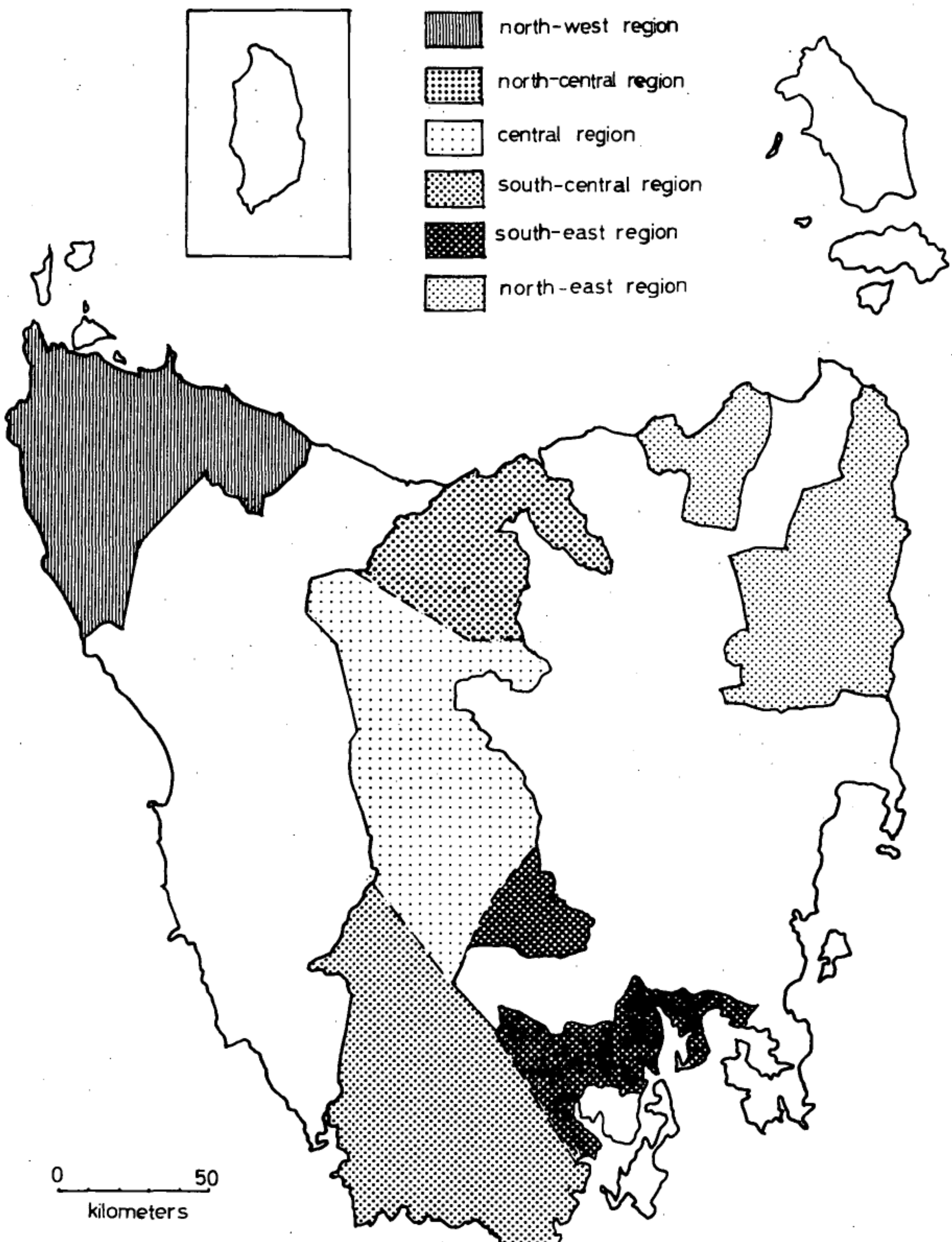
F3 Strahan

F4 Waratah

F5 Zeehan

FIGURE 3.2

Principal Regions of STAF Operation



In areas not serviced by sewers and community treatment schemes wastewater is commonly disposed of by using STAF units. The total number of dwellings in Tasmania not serviced by municipal sewers (total number of dwellings less dwellings connected to sewers), based on 1976 census figures, updated to 30 June 1977, and municipal records (ABS 1978) is estimated to be 42,264. This is assuming that the number of sewer connections equals the number of sewered dwellings; that is, that there are no dwellings with shared connections or multiple connections. If each of the above unsewered dwellings is assumed to be connected to a STAF treatment system (a reasonable assumption seeing that Section 557 of the Local Government Act (Parliament of Tasmania 1962) and Section 300 of the Building Regulations (Parliament of Tasmania 1965) prohibit (in towns) or discourage (in areas outside towns) wastewater treatment by means other than public sewer systems or septic tanks) the number of septic tanks in Tasmania is approximately 42,264. The estimated distribution of these according to local government area is shown in Figure 3.1.

From Figure 3.1 six specific regions of operation can be derived (see Figure 3.2 opposite).

A. The municipalities of Circular Head (E2) and Wynyard (E9) in the north-west of Tasmania.

B. The municipalities of Latrobe (E6), Kentish (E4), Beaconsfield (C1), Deloraine (C2), Hamilton (B7) Esperance (B4), Huon (B8), Kingborough A (A5), Hobart/Glenorchy (A4), Clarence (A2) and Sorell A (A7) down through central Tasmania. This region may be subdivided along topographical lines (see Section 3.2.2 later) into: (i) the northern subregion comprising Beaconsfield (C1), 3/4 of Kentish (E4), Latrobe (E6) and about 2/3 of Deloraine (C2) municipalities; (ii) the central subregion comprising 1/3 of the Deloraine (C2), 1/4 of the Kentish (E4) and 2/3 of the Hamilton (B7) municipalities; (iii) the south-central subregion comprising the south-eastern corner (about 1/6) of the Hamilton (B7) and 7/8 of the Esperance (B4) municipalities; and (iv) the south-eastern subregion comprising 1/6 of the Hamilton (B7), 1/8 of the Esperance (B4) municipalities along with the local government areas of Huon (B8), Kingborough A (A5), Hobart and Glenorchy (A4), Clarence (A2) and Sorell A (A7).

C. The municipalities of Scottsdale (D7), Portland (D4) and Fingal (D2) in the north-east of the state.

Four of the above areas, the north-west the north-central, the north-east and the south-east, are principally agricultural areas of dispersed populations, although some urban areas are located within them. The central and south-central regions, however, are harsh mountainous country unsuited for permanent habitation. Nevertheless, small isolated settlements, such as Tarraleah (a HEC+ town) and Port Davey (a mining settlement), do occur in these regions and they frequently operate STAF treatment systems (R. Freeman,* personal communication).

3.2.2 Relief

Tasmania is a mountainous island; only a small portion of it lies close to sea level and extensive lowland plains are uncommon. The only inland plain is that between Launceston and Tunbridge, some 90 kilometres to the south-east. This plain is bordered on the south-west by the Great Western Tiers, whose peaks rise to over 1300 metres, and on the north-east by Mts. Arthur, Barrow and Ben Lomond. To the west, north-west and south of the Great Western Tiers

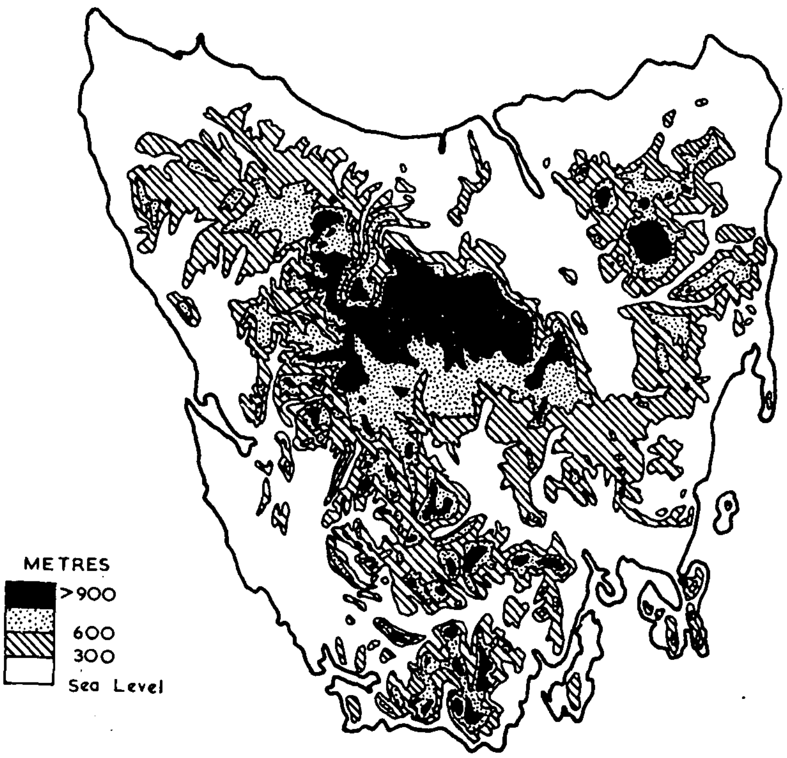
+HEC is the abbreviation for the Hydro Electric Commission in Tasmania.
*Chief Health Inspector in the Tasmanian Department of Health, the administering authority on matters relating to septic tanks in Tasmania.

several ranges of mountains, with peaks up to 1600 metres high, extend from less than 40 kilometres inland in the north-west to about 10 kilometres from the south coast. Bordering the highlands, and extending in many areas to the coast, are hills up to 300 metres high. These are the principal areas of habitation. The general relief of Tasmania is illustrated in Figure 3.3.

FIGURE 3.3

General Relief of Tasmania

(adapted from Davies 1965)



STAF operation is directly influenced by relief, through the area required for soil adsorption, and indirectly through its influence on other factors such as precipitation, temperature and soil type. Four of the principal STAF operating areas, the north-west, the north-central, the north-east and the south-east, have a moderate relief with elevations generally less than 300 metres.

Adsorption field area requirements and operation here is unlikely to be adversely affected except for individual sites. The remaining STAF regions, central and south-central Tasmania, have elevations of over 300 metres with many points being over 900 metres. Mt. Ossa, the highest mountain in Tasmania at 1617 metres, is located in the central region. The general relief in these areas, therefore, is likely to be severe and adsorption field operation restricted. These highlands, being located in the path of the prevailing westerly and northwesterly winds, are also likely to influence climatic factors, such as precipitation, dramatically.

3.2.3. Precipitation

(a) Rainfall and Evaporation

Tasmania's location between latitudes 39°30'S and 43°30'S on the northern edge of the "roaring forties", a westerly airstream, and its mountainous relief strongly influence the amount, distribution and reliability of the state's rainfall. The ranges in the west, act as barriers to the moisture laden westerlies and precipitate heavy rain over most of the year. The average annual rainfall in this region ranges from 1300 mm to 1500 mm on the coast to 3600 mm at Lake Margaret (Bureau of Meteorology 1978). Ranges in the north-east of the state similarly precipitate moisture carried by winds off the Tasman Sea. Here the average annual rainfall rises from 900 mm on the coast to 1750 mm in the highland areas (Bureau of Meteorology 1978). Inland from the western and north-eastern ranges average annual rainfalls decrease markedly and distinct areas of rain shadow occur. Parts of the Midlands, situated between the Ben Lomond massif and the Great Western Tiers, receive less than 500 mm of rain annually (Bureau of Meteorology 1978). Further south, in the lee of the Central Plateau, a similar rain shadow

FIGURE 3.4

Mean Annual Rainfall Distribution

(from Bureau of Meteorology 1978)

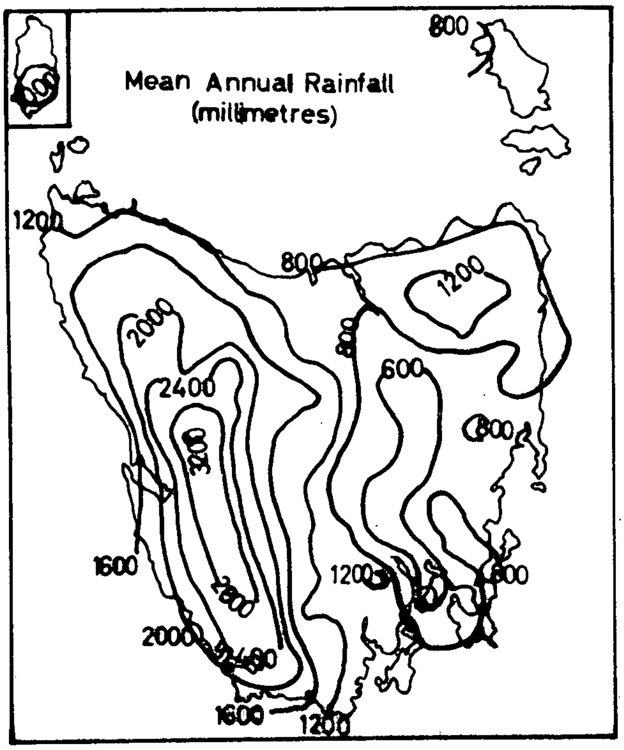
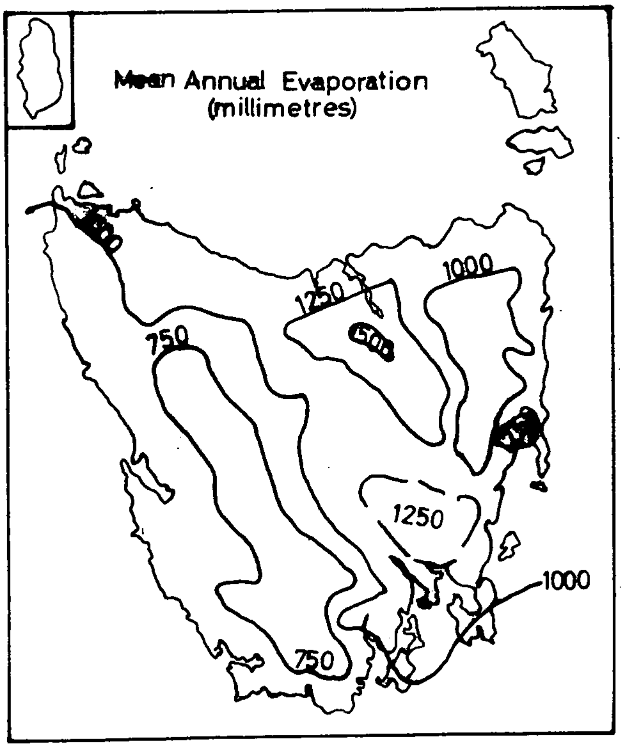


FIGURE 3.5

Mean Annual Evaporation Distribution

(from Bureau of Meteorology 1978)



is apparent, although annual averages are slightly higher. The mean annual distribution of rainfall over Tasmania is illustrated in Figure 3.4.

The mean annual evaporation is similarly affected by relief. In the central, southern and north-eastern highlands rainfall exceeds evaporation and a nett surface runoff occurs. In midland and south-eastern areas the situation is reversed with evaporation exceeding rainfall. Rainfall in these areas is also less reliable than in the highlands. Langford (1965) gave the percentage mean deviation from average rainfall in eastern, south-eastern and midlands areas as 16 - 20% compared to 10 - 14% in the west and highlands. The mean annual evaporation over Tasmania is illustrated in Figure 3.5.

Comparing Figures 3.4 and 3.5 it can be seen that the driest areas of the state are in the midlands, eastern and northern Tasmania. These correspond to the north-central, the south-east and parts of the north-east and north-west STAF regions. No difficulties in relation to soil saturation are expected in these areas. The remaining regions; the highland areas of the north-west, the central the south-central, and the north east regions, are areas where rainfall exceeds evaporation and a nett runoff occurs. On sites of low relief saturated soils and poor adsorption may be expected. However, with artificial drainage the water table may be lowered sufficiently to prevent adsorption field failure (Reneau 1978). The surface water may also be utilized to dilute the septic tank effluent to such an extent that further treatment is not necessary. This is the treatment method in use at Waldheim Chalet in the Cradle Mt. - Lake St. Clair National Park on the north-western corner of the central STAF region.

(b) Snowfall

In highland areas throughout the year, but particularly during the months of July and August, snow showers may occur. They also occur occasionally in southern lowland areas but falls are generally light and do not lie for long. Above about 650 metres, however, heavy snow falls are common (Langford 1965). Although there is no permanent snow line, snow may lie on high peaks until mid September - October and on sheltered crags until December and beyond. Thus, the only STAF regions where snow may accumulate and lie for any length of time are the central, the south-central and highland areas of the north-east regions. In the remaining regions snow does not occur or is present for only short periods. The influence of snow cover on STAF operation is ambiguous, for although the temperatures required for snow to fall are not consistent with STAF requirements, the presence of snow, through its insulating and temperature attenuating capabilities, mitigates this somewhat. The most profound influence of snow, however, may be that on thawing; considerable quantities of water are released to saturate the soil, or dilute the septic tank effluent.

3.2.4 Water Characteristics

In Chapter 2 it was shown that several water characteristics were important to septic tank operation. These include temperature, pH and cation concentration. With a variety of water sources, including rain water, ground water and local stream water, used in unsewered areas variation in these characteristics may be expected. These are considered below.

(a) Temperature

A large number of factors operate in determining water temperature. These include depth and surface area of container (cistern or tank), length of time in the container (particularly the cistern where equilibrium with the ambient air temperature inside the house is possible), depth of the aquifer and time underground, the presence of lakes or impoundments along a stream's course, the origin of the water (e.g., springs, lakes, runoff, snow and ice thaw), shading, protection from the wind and altitude (Bayly and Williams 1973). The variations in these factors are such that generalisations regarding the water temperature of each water source within each STAF region are difficult. However, it may be said that surface water (and cistern water) will approach ambient air temperatures but be less variable; that is approximate the mean monthly or seasonal temperatures. This conclusion is supported by Table 3.1 which compares the average annual temperature ranges of several streams in each STAF region with the average annual air temperature range for the same region. The derivations fo for each of these regional averages are given in Appendices A and B. Spring and ground water are more constant and generally slightly lower (for non thermal waters) than the corresponding surface water (Bayly and Williams 1973). The average monthly and annual air temperatures may, then, be regarded as approximations to the maximum monthly and annual water temperatures for a particular region where such data are not available.

From Table 3.1 it can be seen that the temperature range of surface water throughout Tasmania is fairly uniform around 5 - 17^{o}C (assuming that the water temperature in the south-central region shows a similar relationship to air temperature as in the other regions). Comparison of the water temperature range with the design temperature range (15 - 30^{o}C) indicates that only in their upper/ lower reaches do these ranges overlap. As surface water temperatures follow average air temperatures (with a lag time of around one

TABLE 3.1

Average Annual Temperature Range of
Surface Water and Air in each STAF Region

Region	Average Annual Temperature Range °C	
	Water*	Air+
North-west	6 - 17	9 - 17
North-central	6 - 17	8 - 17
North-east	6 - 17	9 - 19
South-east	5 - 16	7 - 16
South-central	(5 - 11)	7 - 15
Central	5 - 16	3 - 13

*Unpublished data from the Rivers and Water Supply Commission and the Hydro-Electric Commission (see Appendix A). Parentheses indicate averages for less than 6 bodies of water.

+Unpublished data from the Bureau of Meteorology (see Appendix B).

one month) the maximum water temperatures would probably occur during December to March. In the remainder of the year the water temperatures would be less than 15°C. In fact, for five months (May - October) in the south-central region and for eight months (April - November) in the central region the water temperatures are likely to be less than 10°C (see Appendix B). At these temperatures a psycrophilic bacterial community, rather than a mesophilic one, would become established in the digestion and its operating efficiency would be low (less than 60% of the optimum efficiency). In the northern and south-eastern regions the water temperatures are likely to be less than 15°C for eight or nine months (April to December/January) and less than 10°C for three months (June to August). In Tasmania, then, the design operating temperatures for septic tanks receiving only toilet wastes are apparently attained only in the summer months. An input of energy, as hot water, would appear necessary to reach the design requirements and to improve the process efficiency. To retain this extra energy the tank would have to be constructed of an insulating material. Furthermore, its capacity would have to be larger to accommodate the addition water. The Standards Association of Australia (SAA 1976) recommend a 60% increase in capacity when hot wastewater, as well as toilet wastewater, is added to septic tanks.

(b) pH

Rain in Tasmania is derived from winds of recent maritime origin which, although their principal direction may vary depending on the area, have very little of their trajectory over areas that may adversely affect the rain's pH. Consequently, the pH of the rain water is expected to be around neutrality and be controlled by the H_2CO_3/HCO_3^- equilibrium; that is, in the 6.0 - 8.0 range. This is very similar to the pH range required for anaerobic digestion (it is the same buffering mechanism) and no difficulty is anticipated in using this water in septic tanks. Only in specific areas downwind of industrial estates, such as the Clarence municipality in the south-east region, would deviations from the above pH range be likely. Experience in Europe, particularly in the Scandanavian countries, has shown that acidic rain water is common in this type of situation. Water of this nature may represent a threat to the septic tank digestion process and should not be used.

In contrast to rain water the pH of ground water is quite variable from mildly acidic (*c.* pH 5) to mildly alkaline (*c.* pH 9) depending on its geological origin. Water from Precambrian,

Cambrian, Permian and upper Triassic sediments and Tertiary rocks is neutral to moderately alkaline with appreciable concentrations of HCO_3^- and CO_3^{2-} ions whilst water from lower Triassic sediments is moderately acidic (Guilline 1959: Leaman 1967, 1971). In these latter waters the HCO_3^- and CO_3^{2-} concentrations are low to negligible. As the pH of this water may be less than the septic tank digestion limit caution should be used in using ground water in septic tanks in the south-east region where lower Triassic sediments are common (Banks 1965). In the north-east, the north-central and the north-west regions however, the base rocks produce neutral to alkaline waters whilst those in the south-central and central regions either do not contain ground water or do not influence its pH. The principal influence on water pH in these regions is surface peat (see below).

In areas where surface water is plentiful, such as in the north-west and the highlands, this may be used instead of rain or ground water in septic tanks. In a comprehensive survey of surface water throughout Tasmania, Buckney and Tyler (1973) reported that pH was generally in the 6.0 - 8.0 range. Recent (since June 1974) stream monitoring by the Rivers and Water Supply Commission support this conclusion (see Appendix A). The only exception to it occurs in the south-west and west of Tasmania, which corresponds to the south-central STAF region. Here the surface water pH is commonly in the pH 4.0 - 6.0 range (Appendix A; Buckney and Tyler 1973). This is characteristic of waters that drain peat bogs and heaths from which humic acids may be dissolved. In the central region and highland areas of the north-east region peaty conditions also occur, although not as commonly as in the south-central region. At specific points, then, surface water in these regions may also be quite acidic. As the pH of water draining peat areas is outside the range required for septic tank digestion (pH 6.0 - 7.5) caution should be exercised in the use of these waters in septic tanks.

The pH of water for septic tank use in Tasmania, be it rain, ground or surface water, has been shown to generally be within the design range of septic tanks, pH 6.0 - 7.5. Little difficulty with these waters, in relation to pH control, should be experienced in septic tanks. Only where the pH of the water is in excess of the digestion range are problems considered likely. Regions where this type of water may be found include the south-east region, in areas downwind of industrial estates (acid rain water) or on lower Triassic sediments (acid ground water), and in the central and south-central regions and highland areas of the north-east region on peaty soil (acid surface water). Caution with the use of these waters in septic tanks is recommended.

(c) Cation Concentrations

The cation concentration of water for septic tank use is expected to vary from slight with rain water to moderately high with ground water. The only ion sources rain water is likely to contact are those of recent maritime origin, such as sea spray. The ionic concentrations of rain water, then, should show sea water proportions ($Na^+ > Mg^{2+} > Ca^{2+} > K^+ : Cl^- > HCO_3^- > SO_4^{2-}$) but with levels dependant upon the proximity of the coast. These are not expected to be of concern in septic tank operation. Surface water has been shown to have the same general ionic proportions (Buckney and Tyler 1973). Superimposed over this, however, is the influence of local rocks. In the eastern and northern STAF regions where easily weathered sedimentary rocks are common their influence is likely to be significant in terms of water chemistry but insignificant in terms of septic tank operation. For example, the highest concentrations reported by Buckney and Tyler (1973) for surface waters in the northern and eastern STAF regions were 0.5 mg Na^{+}/l, 0.34 mg Mg^{2+}/l and 0.35 mg Ca^{2+}/l. These are well below the tolerance limits for septic tank operation. Similarly, in the central and south-central STAF regions where rocks are either of a resistant alumino-silicate nature or protected from surface waters by layers of peat their impact on septic tank performance is slight.

The cation concentrations in ground water are also likely to reflect their geological origin. Several authors (Gulline 1959; Leaman 1967; 1971; Nye 1921, 1922, 1924, 1926) have reported that the dominant ions in ground water from Quaternary and Precambrian sediments are Ca^{2+} and $CO_3{}^{2-}$; from Tertiary, Permian and Cambrian sediments Na^{+}, Cl^{-} and HCO_3^{-}; and from Triassic sediments Na^{+} and Cl^{-}. The concentrations of these ions, even within the same rock type, are strongly influenced by the area's rainfall. The north-west region, with its high rainfall generally has more dilute waters than the drier wouth-east region. For example, Gulline (1959) reported that water from Triassic sediments in the north-west region had a Na^{+} concentration of 194.2 mg/l whilst Leaman (1971) reported Na^{+} levels from similar water in the south-east region of up to 954.0 mg/l. This does not imply, however, that ground water in the north-west is better or worse than ground water in the drier areas. Natural variation even within the same rock type in the same area may explain much of the difference. Leaman (1971) also reported Na^{+} levels in waters from Triassic sediments in the south-east region as low as 14.0 mg/l. In spite of this Na^{+} concentrations in ground water may be quite high, particularly ground water from Triassic sediments. However, they are still well below the limits given for septic tank digestion in Chapter 2. Similarly, other cations, such as Ca^{2+}, Mg^{2+} and K^{+}, are below their respective concentration limits. Ground water from the above rocks then, is not anticipated to present any cation poisoning problems in septic tank operation.

In coastal areas on unconsolidated coastal sands, which frequently contain large quantities of potable water (Cromer and Sloane 1976), the principal influence on water quality is the sea. These sands are quite permeable and sea water seepage into the aquifer in areas close to the coast may be expected. For example, Cromer and Sloane (1976) showed that at Seven Mile Beach the total dissolved solids, of which about 80% was Na^+ and Cl^-, of the ground water increased from 800 mg/l (640 mg Na^+/l) 700 metres from the coast to 3300 mg/l (2640 mg Na^+/l) 300 metres inland. Although this sodium level is below that shown in Chapter 2 to be necessary for digestion inhibition the potential for higher concentrations closer to the coast, particularly if heavy loads are placed upon the aquifer (thereby allowing more sea water to enter), is apparent. Caution in using this water for waste transport in septic tanks, particularly if close to the coast, is therefore advised. Each bore should be accompanied by a water analysis to determine its suitability for domestic, including STAF, use.

Unconsolidated coastal sands such as those considered above occur in areas along the north-west, north-central, north-east and south-east coasts (W.C. Cromer, personal communication). In fact, the communities of Currie (King Island), Greens Beach (Municipality of Beaconsfield in the north-central STAF region) and Lewisham - Dodges Ferry - Carlton (Municipality of Sorell in the south-east STAF region) rely heavily on water from such sands for domestic purposes (W.C. Cromer, personal communication). This is a potentially dangerous situation in areas such as the Dodges Ferry district where the population has trebled in the last ten years (Dobson and Williams 1978) placing heavy loads on the aquifer. The only regions in which ground water quality is not considered a potential threat in some areas to septic tank operation are the south-central and central regions. Here the rocks are generally not considered to be the water bearing type. Surface springs, however, do occur and these have been considered along with surface water earlier. In all STAF regions the cation levels of rain and surface water are not considered to present a hazard to septic tank operation.

3.2.5 Soil Characteristics

(a) Type and Percolation

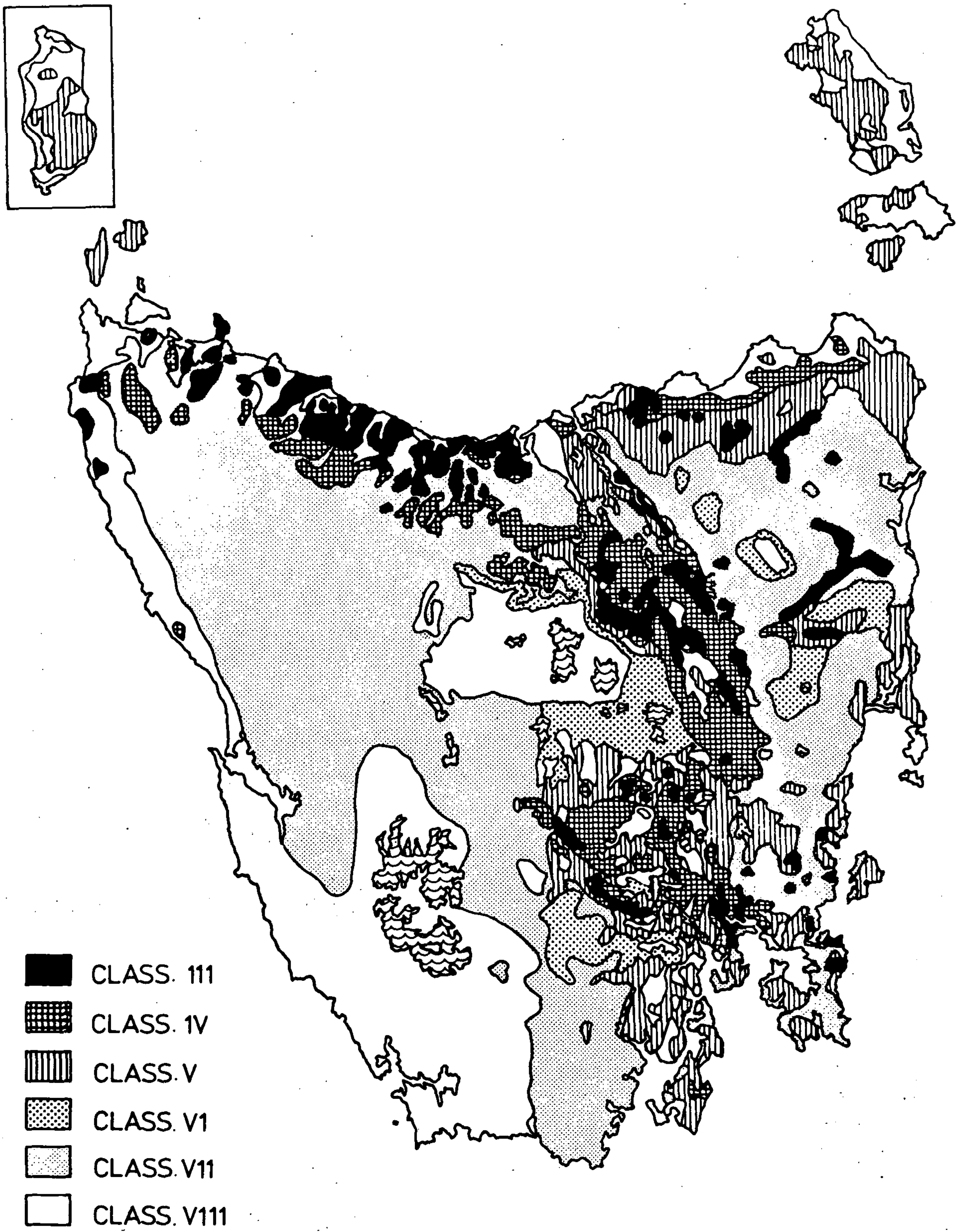
Detailed knowledge of the soils in Tasmania is limited. Little more than one fifth of the state has been covered by soil surveys (Nicholls and Dimmock 1965). However, in any one climatic zone soil types largely follow the underlying geology and geological maps may be used if soil maps are not available. The usefulness of a soil is influenced also by climate and relief. A map ranking the agricultural value of the soils in Tasmania, compiled by the Tasmanian State Strategy Plan (TSSP 1976) based on a soil map of Tasmania (Nicholls and Dimmock 1965) and a scheme developed by the Ministry of Works in New Zealand to consider the influence of climate and relief, is shown in Figure 3.6. In this the soils of Tasmania are ranked from III to VIII; no soils received the top rankings, I and II.

One of the factors which influences the agricultural value of a soil is its hydraulic capacity and conductivity; that is, the amount of water a soil holds and the rate at which water passes through the soil. For example, swampy soils, which frequently contain much organic matter and have a high fertility, are of less agricultural value than soils of lower fertility. Similarly, soils of very

FIGURE 3.6

Estimated Agricultural Capability of Tasmanian Soils

(from TSSP 1976)



high permeability are of less value than soils of lower permeability. Part of the assessment of the suitability of a soil for use as an adsorption field is also based on its hydraulic capacity and conductivity (see Sections 2.4.1 and 2.4.2). Parallels may, therefore, be drawn, to some extent, between the agricultural capability of a soil and its adsorption field capability. This is not to imply, however, that assessment of the agricultural capability of a particular site can be substituted for percolation measurements. From Figure 3.6, then, an indication of the general suitability of Tasmania's soils for adsorption field use can be gained.

It is apparent that most of Tasmania's soils are of classes VII and VIII, the poorest classes, which generally correspond to Alpine Humus Soils, with or without Moor Peats, Yellow Podzolic Soils and Grey Brown Podzolic Soils (Nicholls and Dimmock 1965). These soils contain up to 60 - 70% of clay (Stace *et al.* 1972), often with a clayey horizon close to the soil surface, and they are found frequently associated with poorly weathered dolerite above about 600 metres. In soils of this nature liquid would percolate down until the clay horizon and travel horizontally along the soil-clay interface. As this is frequently close to the ground surface considerable distance would be required before adequate treatment could be effected. During this untreated septic tank effluent would be close to the soil surface presenting an obvious health hazard. Furthermore, in areas of low relief, effluent would lie around the outlet or trench, giving rise to anaerobic conditions.

In coastal areas class VII and VIII soils correspond to Ground-water Podzols, Podzols, Calcareous Coastal Sand and Terra Rossa Soils (Nicholls and Dimmock 1965). Soils such as these are very sandy and porous and caution must be used in the siting of adsorption fields in relation to ground and surface waters, lest these become contaminated with bacteria and nutrients. The EPA in Victoria (EPA 1975a) recommends, for example, that adsorption fields be prohibited in sandy soils adjacent to shallow, poorly flushed, lakes. Although Briton (1975) indicated that 60 metres of soil was sufficient to remove most pathogens from wastewater, Schaub and Sorber (1977) have shown that in unconsolidated silty sand and gravel, enteroviruses may still be detected 183 metres from their source. The better classes of soil in Tasmania, Classes III, IV, V, and VI, which correspond to the Krasnozems, Brown Earths, Black Earths, Prairie Soils, lowland Yellow Podzolics Soils and Lateritic Podzolic Soils (Nicholls and Dimmock 1965), are found only along the northern coast, the Fingal Valley in the north-east and down through the midlands.

Four of the six STAF regions, the north-west, the north-central, the north-east and the south-east, have soils of varying quality ranging from class III to class VIII. No general conclusions regarding the suitability of soils in these regions for adsorption field use, other than that it is site specific, can, therefore, be made. The north-west and the north-east regions, however, contain a sizeable proportion of class VII and VIII soils, the inland members of which probably represent the high clay content, and consequently low permeability, alpine soils whilst those on the coast the high permeability sands. The remaining areas, the central and south-central regions, have soils predominantely of classes VII and VIII. Because of their high clay content these soils are considered unsuitable, or at best marginally suitable, for use in adsorption fields.

(b) Temperature

Temperature is expected to influence adsorption field operation in a similar manner to septic tank operation; that is, the lower the temperature, the lower the treatment efficiency. In lowland areas the temperature within surface layers of soil are expected to approach the average monthly/seasonal air temperatures. The average monthly air temperature ranges in the north-west, north-central, north-east and south-east regions are 9.4 - 16.6°C, 7.4 - 16.8°C, 9.0 - 18.8°C and 7.4 - 16.4°C respectively and the implicit temperature range of adsorption fields (15 - 25°C) is attained only during December (north-east region only), January, February and March. During June, July and August the average monthly air temperatures, and consequently the soil temperatures, in the above regions are between 5 - 10°C. Little biological activity in the adsorption field can, therefore, be expected at this time.

The highland south-central, central and parts of the north-east regions, however, are expected to have surface soil temperatures less than the average monthly air temperature. In fact, during winter and spring when snow may lie on the ground for some time the soil temperatures are likely to be around 0°C. Even after the snow has melted soil temperatures are not expected to rise above 15°C, which is the average maximum February (the warmest month) air temperature for the south-central STAF region. These temperatures are not considered sufficient to maintain a satisfactory bacterial process in the adsorption field. If, however, the septic tank effluent contained appreciable amounts of warm water, as would effluent from a septic tank receiving kitchen, bathroom and laundry wastes as well as those from the toilet, the temperature in the adsorption field may be high enough for oxidation to commence/continue. For example, the mean monthly temperature range at a depth of 1.1 metres in adsorption field treating all wastes was shown by Viraraghavan (1979) to be 3.4 - 15.8°C whilst the corresponding air temperature range was - 6.6°C to 23.7°C and the snow cover up to 0.5 metres.

3.3 Tasmanian Conditions and STAF Operating Requirements

Six regions have been suggested as the principal areas of STAF use in Tasmania. These are the north-west, the north-central, the north-east, the south-east, the south-central and the central districts. The environmental conditions of each area in relation to STAF use have been considered and compared to those of STAF design. The compatibility of the regional conditions with the design requirements is summarised in Table 3.2.

TABLE 3.2

Summary of Compatibility of Regional Conditions in Tasmania and STAF Design Requirements

Conditions	Region					
	NW	NC	NE	SE	SC	C
Relief	-	-	-	-	x	x
Rainfall and Evaporation	-	+	-	+	-	-
Snow Cover		-			-	-
Water Characteristics						
- temperature	*	*	*	*	*	*
- pH	+	+	-	-	-	-
- cation level	-	-	-	-	+	+
Soil Characteristics						
- percolation	-	-	-	-	x	x
- temperature	*	*	*	*	x	x

NW = North-west region
NC = North-central region
NE = North-east region
SE = South-east region
SC = South-central region
C = Central region

+ = compatible
x = incompatible
- = compatibility dependant upon site
* = compatibility dependant upon time

Perusal of Table 3.2 shows that no region has conditions completely compatible with STAF design. Only at specific sites during specific times in four regions is complete compatibility possible. It is notable also that no one single condition has complete compatibility. Relief determines the area required for adsorption fields and slopes greater than 20% (1 in 5), such as are very common in the central and south-central regions, are not recommended for adsorption fields. In other regions slope is a site specific phenomenon.

Rainfall and evaporation, through their influence on soil saturation, also affect adsorption field performance. Only in the north-central and the south-east regions and lowland areas of the north-west and north-east regions does evaporation exceed rainfall. Saturated soils are not considered likely in these areas. In the remaining areas, which correspond to the regions above 600 metres, a nett runoff occurs and soils in positions with moderate to low relief and drainage may well become saturated. In areas of better drainage, and unimpeded surface flow this runoff may dilute septic tank effluent to such an extent that further treatment is no longer necessary. Snow cover has an ambiguous effect of STAF operation; the temperatures required for snow are low but its presence stabilizes them. Furthermore, although snow may saturate adsorption field soils on thawing, the same phenomenon may also dilute the septic tank effluent. The effect of this, which is restricted to the central, south-central and parts of the north-east regions where snow may lie for some time, is, therefore, very site specific.

Conversely, the influence of temperature, specifically water temperature, is the same in all regions. Surface water temperatures in Tasmania are compatible with septic tank design only during the summer months. Even then they are only just within the range. This is the most fundamental inconsistency in septic tank design and operation in Tasmania, for it means that even under the best conditions septic tanks will not be operating at their design efficiency. Water pH, on the other hand, is one of the more compatible factors with septic tank design in Tasmania. In the lowland northern regions the factors affecting water pH are slight or favourable and no difficulty regarding these in septic tanks is anticipated. In the south-east region, however, rain and ground water from specific areas as well as surface water in the south-central, central and north-eastern highlands may be quite acidic. Caution is, therefore, advised in using these waters in septic tanks. Other types of water in these three regions are compatible with the pH requirements of septic tank digestions.

Another water quality parameter important to septic tank operation is the Na^{+}, Mg^{2+}, Ca^{2+} and K^{+} concentrations. This condition is the only one the south-central and central regions are generally compatible with. Rain and surface water here experience no contaminating cationic influences and the bed rocks of these regions are commonly stable alumino-silicates that do not contain ground water. In the other regions, unconsolidated coastal sands, from which several communities derive their domestic water, frequently occur. In areas close to the coast water from these sands may become contaminated with sea water, particularly if the aquifer is heavily loaded. This is because the sands are extremely permeable. In fact, they are so permeable, that ground or surface water may also become contaminated with poorly treated septic tank effluent. Adsorption fields should not be installed in highly porous soils such as these where ground and surface water are in close proximity. Soils derived from dolerite, particularly those above about 600 metres, have a high clay content and are also considered unsuitable for use in adsorption fields. The only soils considered suitable are the class III to VI soils found in inland areas of the north-west, north-central, north-east and south-east regions.

Soil temperatures also affect adsorption field performance. In alpine areas, such as the central, south-central and parts of the north-east regions, the soil temperatures may be around $0^{o}C$ for several months and are not considered compatible with adsorption field requirements. In the remaining regions, however, the soil temperature is generally adequate to maintain biological activity in all months except June, July and August.

As stated earlier no region shows total compatibility with STAF requirements at all times and in all places. Furthermore, no one factor, is totally compatible with all design criteria in all regions. Thus, it would seem that STAF systems are not well suited to Tasmanian conditions, particularly those conditions characteristic of the highland areas.

CHAPTER 4

CHARACTERISTICS OF SELECTED STUDY SITES

4.1 Introduction

In the previous chapter the environmental characteristics of the principal STAF areas were considered in relation to STAF design requirements. These were shown to be compatible with STAF design only in specific areas at specific times. No one characteristic was consistent with the design precepts in all regions. Similarly, no region was consistent with all aspects of design. Arising from this several operational difficulties were predicted for each STAF area.

The operational conditions and performance of septic tanks in two dissimilar areas, Mt. Mawson and Carlton, were investigated with regard to these predictions. Mt. Mawson is an alpine ski area within the Mt. Field National Park on the boundary of the New Norfolk and Hamilton minicipalities; that is, on the south-east edge of the Central STAF region. The specific facility studied here was that of the University Ski Club (USC). Carlton, on the other hand, is a coastal community within the Sorell minicipality; that is, in the eastern portion of the south-east STAF region. The treatment facility investigated here was at Camp Carlton, a holiday camp for children.

4.2 University Ski Club (USC) on Mt. Mawson

Mt Mawson is a popular ski area, some 90 kilometres west north-west of Hobart, within the Mt. Field National Park (see Figure 4.1).

During winter, particularly on weekends, many people utilise the facilities here and the ski slopes can be quite crowded. Most of the visitors are members of ski clubs and, after enjoying a day's

FIGURE 4.1

Location of Mt. Mawson

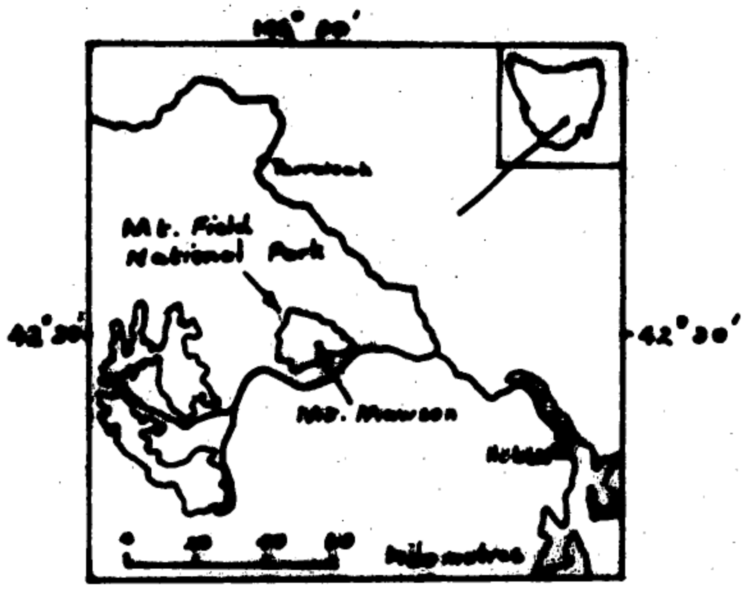
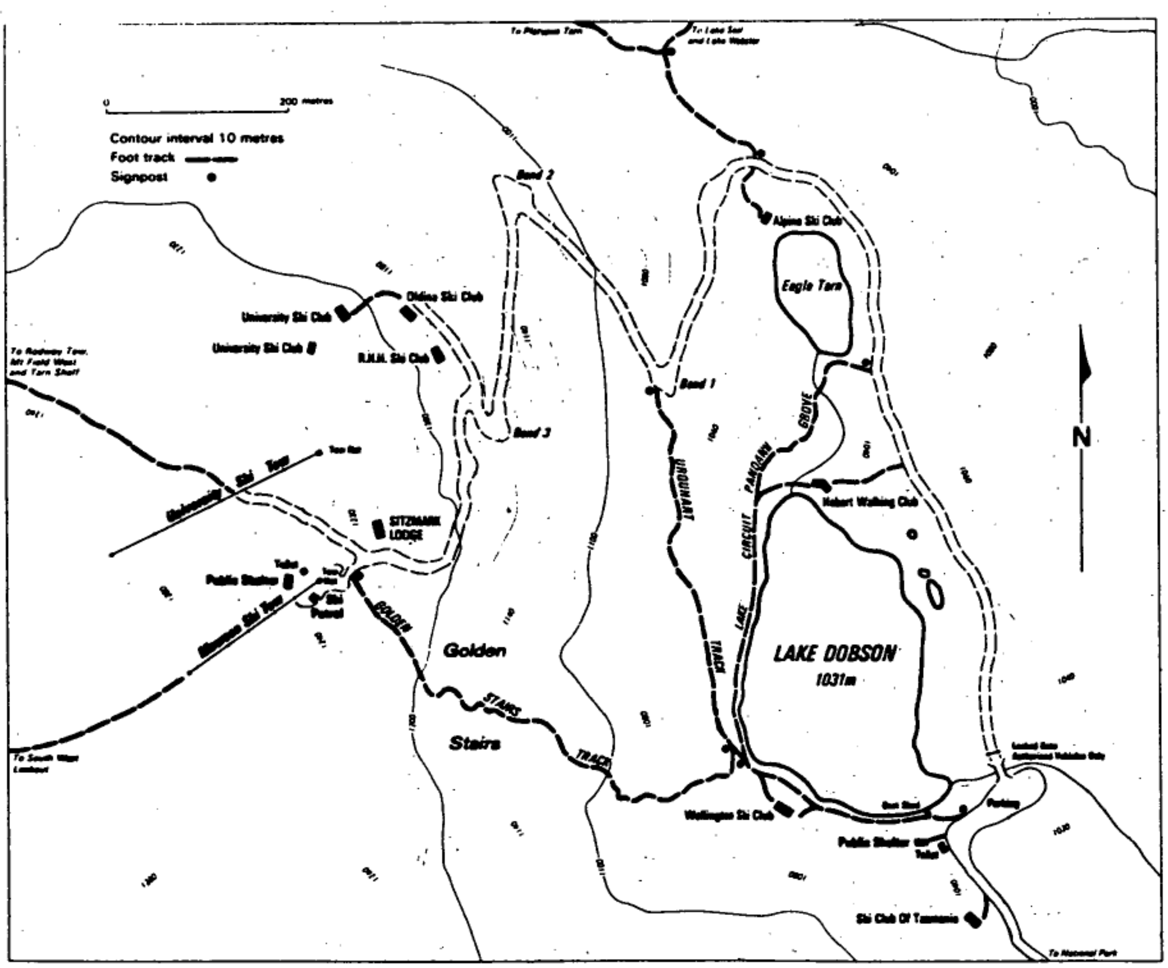


FIGURE 4.2

Location of Ski Club Houses on Mt. Mawson

(from Lands Department 1976)



skiing stay overnight in one of the nearby club houses (see Figure 4.2). No public accommodation is available on the ski slopes. The accommodation capacity of each club house, the type of wastewater treatment employed and the source of domestic water is shown in Table 4.1. Day visitors to the area are relatively uncommon. The walk from the car park is strenuous, climbing 200 metres in about 800 metres, and all but enthusiasts are discouraged.

TABLE 4.1

Accommodation Facilities on Mt. Mawson

(modified from GHD* 1976)

Establishment	Nominal Sleeping Capacity+	Water Supply	Wastewater Treatment
Alpine Ski Club	10	roof water	deep pit
Hobart Walking Club	26	roof water	pit
Oldina Ski Club	18	roof water	STAF
Royal Hobart Hospital Ski Club	30	roof water	STAF
Ski Club of Tasmania	16	spring water	STAF
Sitzmark Lodge	5	roof water	STAF
University Ski Club	30	spring water	STAF
Wellington Ski Club	48	stream water	STAF

+ The actual accommodation capacity of each establishment may be greater because several clubs have benches in their living areas which can be converted to beds.

4.2.1 Site Details

The operational conditions and characteristics of one of the above wastewater treatment systems, that of the USC, were studied from July to mid September. For comparison purposes some

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* GHD is the abbreviation for Gutteridge, Haskins and Davey Pty. Ltd.

<u>PLATE 1</u>

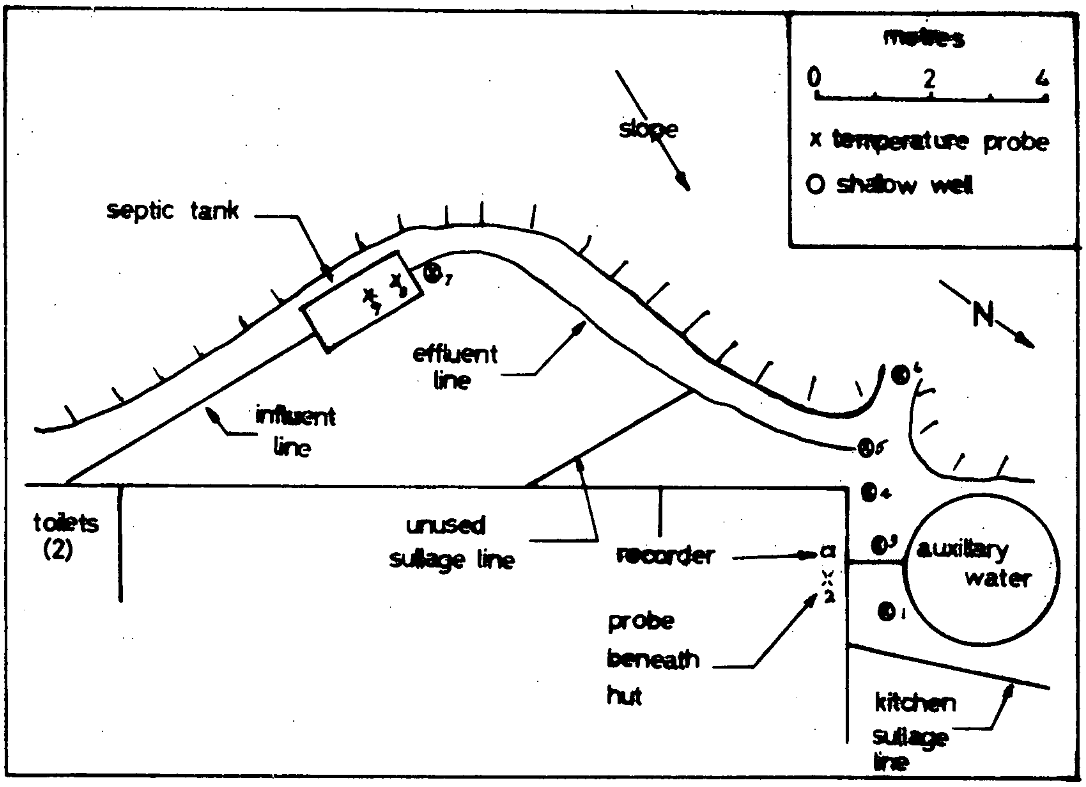
USC water supply tanks looking west from the adsorption field on the north-west side of the club building.

operational conditions of the Oldina Ski Club (OSC) facility were also determined. The USC's main building is located some 300 metres north of the main ski slope in an area of alpine health bordering a low open *Eucalyptus coccifera* forest. The elevation of the site is 1210 metres above sea level. About 30 metres away to the south-west the USC also has a storage hut. The septic tank of the USC is a toilet waste only facility situated on levelled ground on the south-western side of the building about 4 metres from the building. The adsorption field is about 8 metres away beside the north-west (kitchen) wall. This represents a potential health hazard with wastewater, which may contain the agents of several serious diseases, being so close to an area of food preparation. Sullage from the kitchen passes through the adsorption field about 3.5 metres from the septic tank effluent pipe outlet. An unused sullage line joins the effluent pipe about two thirds of the way along its length. The slope of the area is north to north-west; that is, from the septic tank towards the hut. This represents another potential health hazard, should the tank or the sewers overflow. The falls of both the effluent and influent pipes are minimal, only a few centimetres in 8 metres, and are considered inadequate to maintain a self-cleansing flow, particularly in the influent line where fats may settle from suspension during low temperatures. Immediately behind the septic tank the terrain rises abruptly 2 - 2½ metres onto an area of dolerite talus which rises a further 10 metres to a crest about 25 metres away. The USC's main water supply tanks are located on the ridge (see Plate 1).

Approximately 60 metres east of the USC hut is the Oldina Ski Club (OSC) hut which also has a STAF treatment system. The septic tank is located on the north-east side of the building, approximately 3 metres from the building wall, and its effluent

FIGURE 4.3

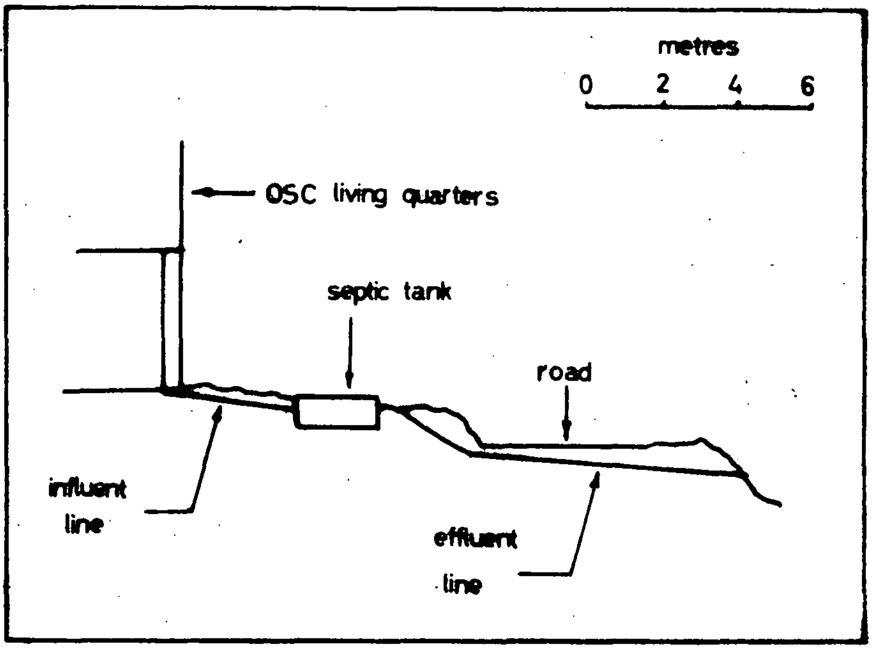
The USC STAF System Showing Characterisation Points



drains away from the but underneath a nearby road and down a "scree" slope (see Figure 4.4). No connections are made into this effluent line. The fall from the tank to the effluent pipe outlet is about 2 metres in 10 metres and from the toilet to the tank 4 metres in 3. The building is a two storey construction with the first floor being used for accommodation and the ground floor for storage. The toilet facilities are located on the first floor.

FIGURE 4.4

Sectional View of OSC STAF System



4.2.2 Occupancy and Wastewater Load

The USC is one of the more popular clubs on Mt. Mawson. During the past ski season many people made use of its facilities, principally over weekends from Friday night to Sunday afternoon. The number of people recorded as staying in the USC hut overnight is shown in Table 4.2. The estimated amount of wastewater generated, based on 4 flushes per person per day (one flush was assumed to occur elsewhere) (Heeps 1977) at a determined flush volume of 3.5 litres, is also included. During the University's August vacation, 11 August to 3 September, and for five days thereafter the hut was occupied continuously. The calculated wastewater production for this period was about 410 litres/day. Prior to this the wastewater production would have been about 440 litres/day for two days or 880 litres/weekend. Wastewater flow after 8 - 9 September was not considered. On the following weekend the septic tank became blocked with solids and wastes from this date on were deposited in the "scree" outside. A solids build up and blockage also occurred on 4 August but this was cleared on 19 August. Yet, prior to this, on 29 July, the sludge depth had been measured at 250 mm. The capacity of the tank receiving the wastewater was estimated to be 1600 litres; that is, a "5 person" tank according to the design specification in Australian Standard No. 1546 (SAA 1976). The capacity required for toilet wastes only however, assuming a 24 hour liquid retention time (Barnes and Wilson 1976) and allowing 1350 litres for liquid and sludge storage (SAA 1976) is 1800 litres; that is a "9 person" tank. This is on the assumption that the digestion will be operating satisfactorily under the conditions of the area. At the temperatures likely to be encountered in the area the digestion efficiency would be about 60% of the maximum efficiency. Based on this rate and the determined wastewater flow the septic tank capacity would need to be 2300 litres; that is, a "19 person" tank.

The OSC septic tank received about 31% smaller loading than the USC septic tank. The average occupancy rate over the same period was 21 persons/day with a calculated wastewater flow of 290 litres/day (see Table 4.3). The tank accepting this is a "15 person" tank (J. Moon, OSC President, personal communication); that is, a tank of 2050 litres (SAA 1976) which is 31% larger than the USC septic tank. Allowing 1350 litres for liquid and sludge storage the calculated retention time of the wastewater would be about 62 hours. During the week 26 August to 3 September the hut was continuously occupied and about 430 litres of wastewater would have been produced a day. At this loading rate the liquid retention time would be 42 hours.

TABLE 4.2

Overnight Occupancy and Estimated Wastewater Flow at USC Hut

Day	Number of Occupants	Estimated Wastewater Flow (litres/day)
7 - 8 July	26	360
14 - 18 July	39	550
21 - 22 July	34	480
28 - 29 July	25	350
4 - 5 August	33	460
11 - 12 August	27	380
13 - 17 August	23	320
18 - 19 August	36	500
20 - 24 August	25	350
25 - 26 August	17	240
27 - 31 August	10	140
1 - 2 September	32	450
3 - 7 September	60	840
8 - 9 September	36	500
Average (persons/day)	30	420

TABLE 4.3

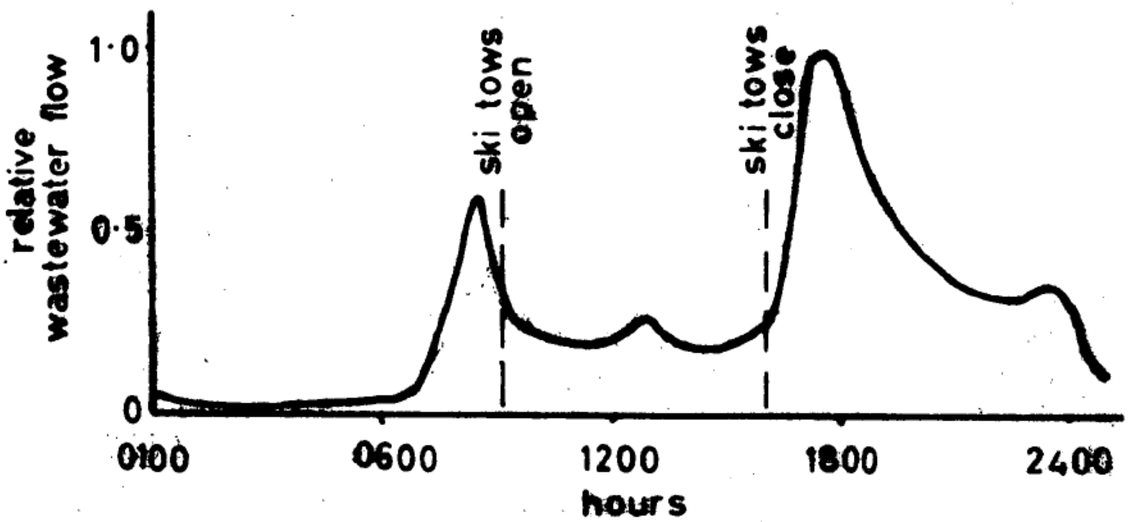
Overnight Occupancy of OSC Hut and Estimated Wastewater Flow

Date	Number of Occupants	Estimated Wastewater Flow (litres/day)
7 - 8 July	24	340
14 - 15 July	17	240
21 - 22 July	12	170
4 - 5 August	29	410
11 - 12 August	30	280
18 - 19 August	24	340
26 - 31 August	31	430
1 - 3 September	31	430
6 September	13	180
15 - 16 September	8	110
22 September	7	98
Average (persons/day)	21	290

The wastewater flow during winter on Mt. Mawson would occur principally in the evening when the skiers returned from their day's exercise. A minor peak would occur in the morning between 0700 and 0900 but would rapidly drop after 0900 when the ski tows opened. The flow would remain low until 1200 - 1300 when some skiers return for lunch. The major flow peak would occur after 1600, when the ski tows close, and remain substantial throughout the evening until around midnight when another small peak would occur. Very little wastewater would be generated from this time until about 0700 the next day. A schematic diagram of the predicted flow pattern is given in Figure 4.5

FIGURE 4.5

Schematic Diagram of Predicted Wastewater Flow on Mt.Mawson



4.2.3 Temperature

One of the factors shown in Chapter 2 to strongly influence septic tank digestion and adsorption field operation was temperature; the lower the temperature, the lower the biological treatment activity. Consequently, temperatures were monitored at several locations in and around the USC STAF facility (see Figure 4.3 earlier) with thermistors and a Grant model D automatic temperature recorder. Two temperature probes were placed in the septic tank itself, one approximately 50 mm from the bottom in the first chamber and the other approximately 150 mm from the liquid surface in the second chamber, six probes were placed in and around the adsorption field and one probe underneath the hut. The probe beneath the hut was to measure ambient air temperature. This was the only position where the probe was sheltered from direct solar flux and at the same time protected from snow or ice accumulation. The temperature beneath the hut was not considered to be influenced by the activities within it because of its insulated floor. The 24 hour (0900 hours to 0900 hours) minimum, maximum and mean temperatures recorded by the air, septic tank and adsorption field probes are shown in Figures 4.6, 4.7 and 4.8. The temperatures recorded by the septic tank probes (probes 8 and 9) were consistently similar and are reported in combination. The temperatures recorded by three of the soil probes (probes 1, 4 and 6) were also quite similar and are reported similarly. The temperature responses of the other three probes (probes 3, 5 and 7), however, were intermittant and variable and have been ignored. A full log of temperature recordings for probes 1, 2, 4, 6, 8 and 9 is given in Appendix C.

FIGURE 4.6

Daily Mean Air Temperatures (line) and range (bar)

Recorded by Probe 2 from 1 July to 24 August

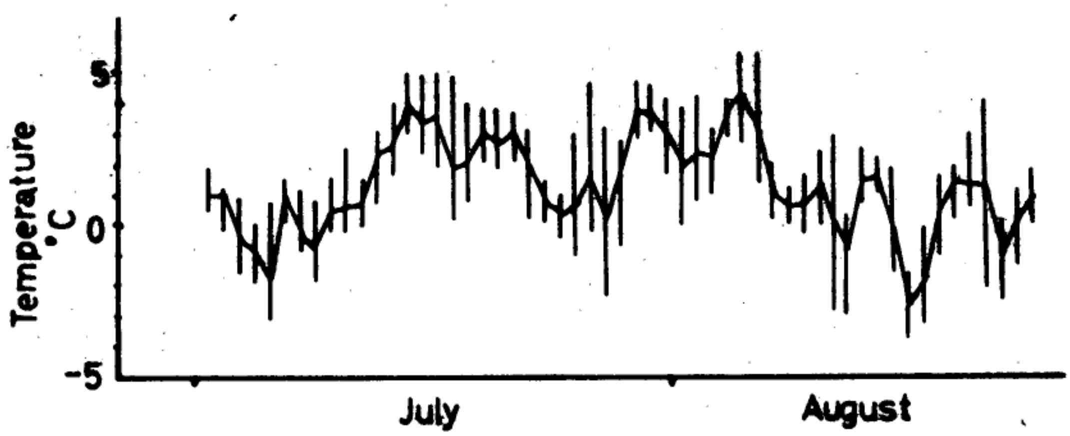
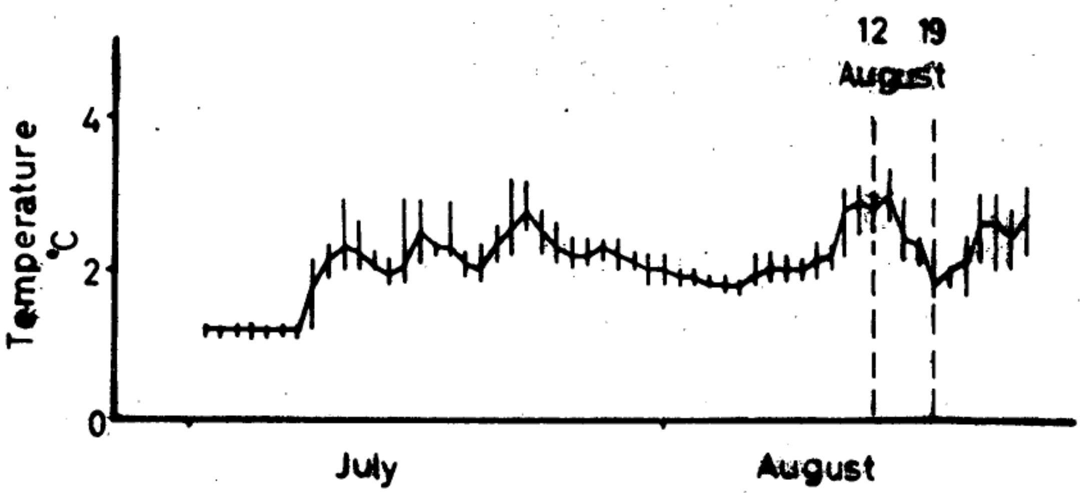


FIGURE 4.7

Daily Mean Temperatures (line) and Range (bar) Recorded by

Probes 8 and 9 in the USC Septic Tank from 1 July to 24 August



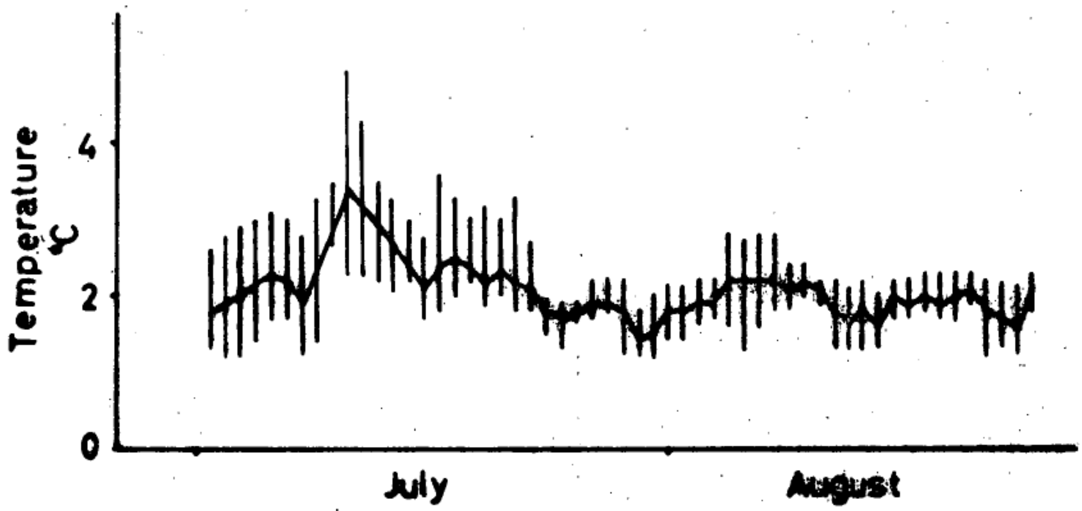
Temperatures recorded inside the USC septic tank during July and August lay between $1^{\circ}C$ and $3^{\circ}C$ (See Figure 4.7). At these temperatures the degree of solids digestion would be considerably reduced. In Chapter 2 it was shown that at less than $4.4^{\circ}C$ septic tank efficiency was about 60% of the optimum efficiency. The general stability of the temperatures in the septic tank is also noteworthy, particularly when compared with ambient air temperatures (Figure 4.6). During July and August ambient air temperature had little effect on the septic tank temperature. A greater influence on temperature is believed to be that of the snow cover. The evenness of the tank temperatures, less than $2^{\circ}C$ variation over the entire study period, is considered to be due to the insulating capability of covering snow (see (b) ~~later~~ below).

Clearly evident in Figure 4.7 is the commencement of hut occupation, Friday 7 July. Prior to this date the temperature of the tank was constant at $1.2^{\circ}C$. During the following weekend, however, the input of wastewater to the tank had increased its temperature to $2.3^{\circ}C$. After peaking on Sunday the temperature dropped until on Thursday it reached $1.9^{\circ}C$. A fresh input of wastewater on Friday night and the weekend increased the temperature to a new high, $2.5^{\circ}C$, repeating the above cycle. This pattern was continued until the weekend of 22-23 July, after which the temperature stabilised at around $2.0^{\circ}C$. This date also marks a change in the source of domestic water. Prior to this the pipes from the supply tanks (see Plate 3) were frozen and "emergency" water derived from roof run-off was used instead. On the afternoon of 23 July the supply lines were unblocked and spring water from the supply tanks was piped to the hut. This water was subsequently used for all domestic purposes including toilet flushing. In the previous situation less water was used per flush, since it had to be carried to the toilet by hand, than in the latter and a warmer wastewater (less water and, therefore, less cooling of the excreta) would result. Hence the temperature increase on each of the first three weekends. Following these increases the next temperature change occurred on 12 August. This corresponded to the beginning of the University August vacation and a period of continuous hut occupation until 3 September (see Section 4.2.1). The drop in temperature from 15-18 August may be attributed to a back-up of solids in the septic tank on 12 August and the subsequent blocking of the influent line. The line was cleared on 19 August, although flow was still restricted, and further wastewater was added producing another temperature gain. The high solids content of the septic tank eventually gave another sewer blockage on 9 September.

FIGURE 4.8

Daily Mean Soil Temperatures (line) and Range (bar)

Recorded by Probes 1, 3 and 5 from 1 July to 24 August

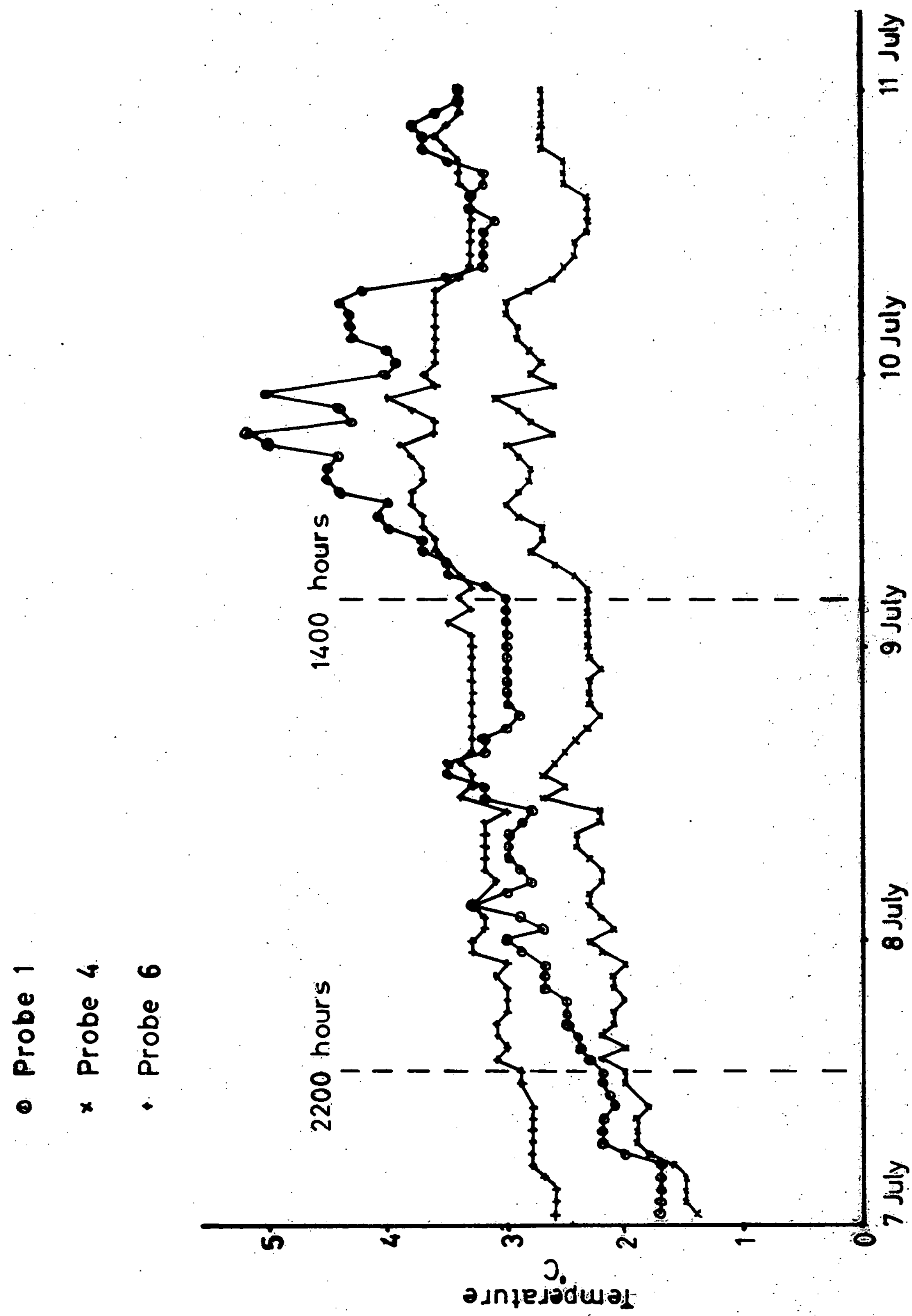


The temperatures in the adsorption field were fairly constant over the entire study period, varying between 1.4°C and 2.5°C. If the adsorption field was in constant use these temperatures, and the degree of biological activity they generate, would probably have been low enough for anaerobiosis and soil clogging to occur,

FIGURE 4.9

Hourly Soil Temperatures Recorded by

Probes 1, 4 and 6 from 7 - 11 July



particularly in early July when the biological system would be immature. The field, however, was not in constant use. Consequently. aerobic conditions, should they have been lost through low temperature, would have had time to re-establish. This is assuming that other factors, such as water table depth, permit aerobic conditions. The general evenness of the recorded temperatures is also notable. This is believed to be due to the insulating ability of the field's snow cover (see Section 4.2.4)

An exception to this general temperature stability, however, is apparent for the weekend 7 - 11 July, the first weekend of hut occupation. The relatively large temperature increase was due to the influence of two human actions both affecting mainly probe 1. The first action followed the evening meal on 7 July at about 2200 hours. Hot water from dish cleaning was released down the kitchen sullage which was about 1 metre away from probe 1 (see Figure 4.3). The heat adsorbed by the pipe during this was radiated back throughout the night warming probe No. 1. The other action occurred on the afternoon of 9 July. The sample points, 1, 4 and 6, which each had temperature probes close by, were blocked with snow and ice. These obstructions were removed manually (surface obstruction) or by the application of warm water (deep obstruction). The influence of these two actions may be seen in Figure 4.9. Figure 4.9 also shows clearly the difference in the temperatures recorded by probes at points 4 and 6. This is the result of probe 6 being placed deeper than probe 4 and thus receiving greater insulation from the cooling of the snow and ground water. By 17 July, however, the temperatures recorded by both probes were quite similar. Ground water probably had reached probe 6 by then. After 17 July further variations around the daily mean were the result of higher temperatures recorded by probe 1. As these coincided with

<u>PLATES 2 and 3</u>

Snow cover of the USC septic tank and adsorption field showing sample points 1, 3, 4, 6 and 7. Sample point 5 is obscured by a tree on the right of Plate 2.

PLATE 3

PLATE 2

weekends the above explanation (radiation from the sullage line) is the most probable.

4.2.4 Snow cover

The presence of snow in the area not only affects the temperature *per se* but also its stability. The ability of snow to act as a heat source/sink attenuating any temperature variations is well known and has already been referred to. As both of these influences, temperature and temperature stability, are important to STAF operation the snow depth within the USC STAF system was monitored.

Throughout the study period considerable snow covered both the USC septic tank and its adsorption field. The extent of this may be seen in Plates 2 and 3. The actual depth of snow recorded over the tank and in the adsorption field is shown in Table 4.4. The depth of snow covering the OSC septic tank is also shown. Much more snow was recorded on the USC septic tank than in its adsorption field or on the OSC septic tank. The position of the USC tank, on the weather side of the building in an artificial "gully" between the hut and a small ridge, was ideal for snow accumulation. The positions of the adsorption field and the OSC septic tank, however, were less susceptible.

TABLE 4.4

Depth of Snow Covering the USC and OSC STAF Systems

Date	Depth of Snow Cover (mm)			
	Tank		Field	
	USC	OSC	USC	OSC
8 July	1300	N.D.	150	N.D.
22 July	1450	N.D.	200	N.D.
29 July	300	N.D.	30	N.D.
12 August	1750	N.D.	200	N.D.
19 August	1800	400	200	N.D.
2 September	1200	200	180	N.D.
16 September	500	80*	120*	N.D.
23 September	-	-	-	-

*patchy

N.D. = Not Determined

4.2.5 Water characteristics

Wastewater treatment using biological methods is sensitive to a number of water characteristics which include pH, sodium concentration and organic particle loading. These are considered below. Two measures of the effectiveness of the soil treatment, *E. coli* counts and nutrient (NH_3, NO_2^-, NO_3^-) levels, are also considered.

(a) pH

The pH of water samples taken from six sample wells in and around the USC adsorption field (see Figure 4.3), the USC septic tank and the toilet cistern was determined with a Townson Portable Pollution Monitor and a combined hydrogen - reference (calomel) electrode. Initially determinations were performed in the field but later were conducted in the laboratory. In the latter part of

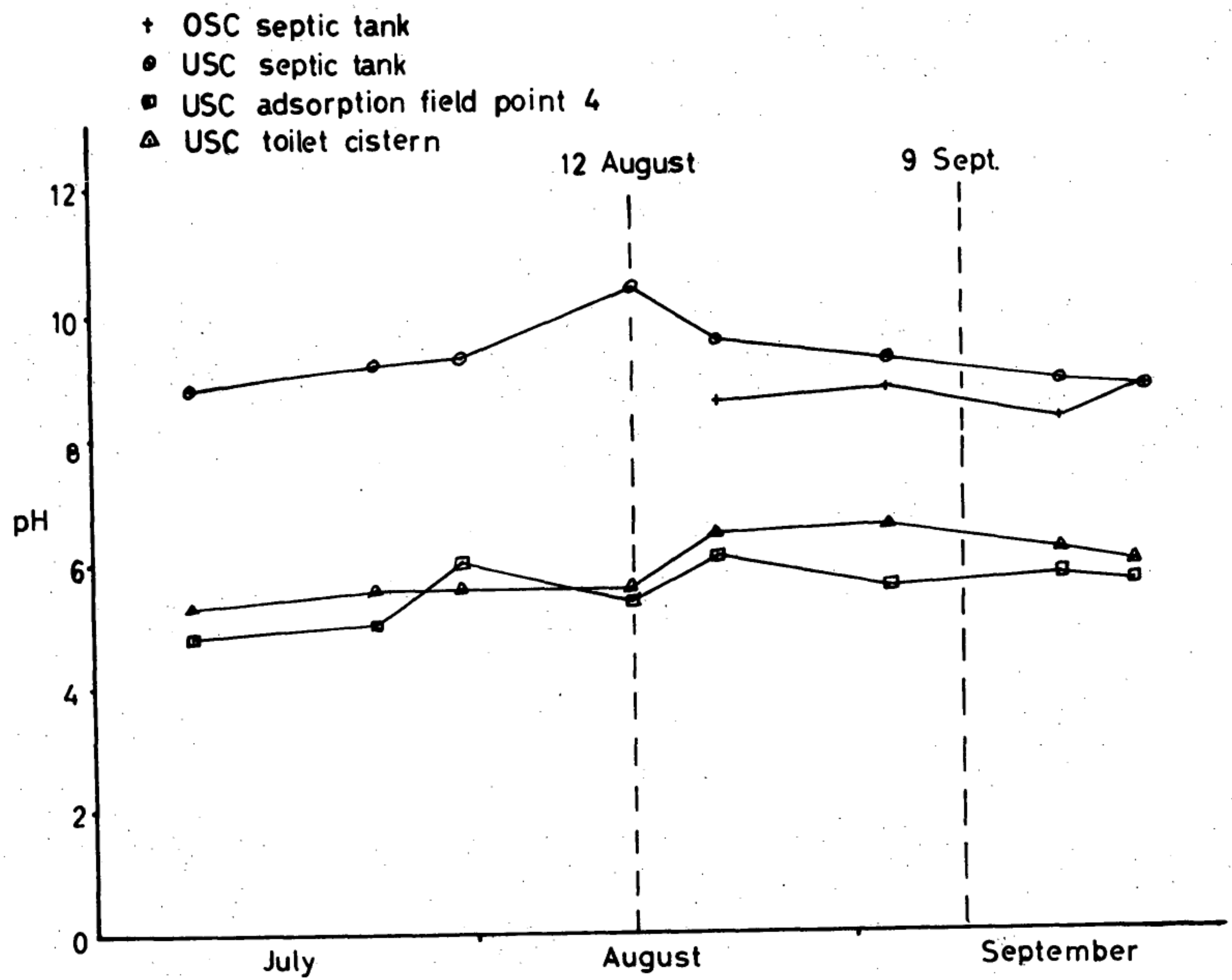


FIGURE 4.10

pH within the USC and OSC STAF systems

the study period the pH of samples from the OSC septic tank was also determined. The pH of the samples taken is shown in Table 4.5 and illustrated in Figure 4.10.

TABLE 4.5

pH Values of Water Samples Taken During the Study Period

Sample Date	pH								
	Point 1	Point 2	Point 3	Point 4	Point 5	Point 6	USC Cistern	USC Tank	OSC Tank
8 July	N.D.	N.D.	N.D.	4.8	N.D.	N.D.	5.3	8.8	N.D.
22 July	6.1	5.5	7.2+	5.0	7.2+	N.D.	5.6	9.2	N.D.
29 July	5.6	6.1	6.6+	6.0	6.0	6.2	5.6	9.3	N.D.
12 August	5.5	5.2	5.3	5.4	5.6	N.D.	5.6	10.4	N.D.
19 August	5.7	N.D.	5.9	6.1	I.S.	N.D.	6.5	8.6	8.6
2 September	5.5	5.5	5.6	5.6	5.6	5.6	6.6	9.3	8.8
16 September	6.7	5.2	5.6	5.8	5.7	5.7	6.2	8.9	8.3
23 September	5.5	N.D.	5.3	5.7	5.3	5.2	6.0	8.8	8.8

N.D. = Not Determined

+ probably rain water

In Table 4.5 and Figure 4.10 it can be seen that the pH values of the cistern water and the adsorption field water were very similar. Some modification of the pH of this water in the septic tank, however, was expected. The cistern water, after 23 July when the pipes were cleared of ice, was spring water stored in tanks on the ridge behind the hut (see Plate 1). These frequently overflowed spilling water down through the adsorption field. The spring water, and the over-flow water, after passing through or over soil with a high degree of humified vegetable material (see Section 4.2.5) would dissolve small quantities of organic acids, such as humic acid and tannins, resulting in a low pH. The pHs reported above, then, would appear to be from samples of this water rather than water that had been through a septic tank.

In contrast to the cistern and adsorption field water the septic tank water was quite alkaline. From July to mid September the pH of the USC septic tank was between 8.8 and 10.4 (see Figure 4.10 and Table 4.6). At these pHs the weak acids and bases of the digestion are toxic to many digestion bacteria and considerable "die off", along with digestion failure, may be expected. During the latter portion of this same period the pH of the OSC septic tank was fairly constant in the range 8.3 to 8.8. The usual pH to expect in anaerobic digestion is 6.0 - 7.5 (Capri and Marais 1975). The pH of the OSC septic tank can be explained by the fact that lime was added to it at the start of the ski season in July (J. Moon, personal communication). Cassell and Sawyer (1959) showed that this would prevent an acid inbalance in a digestion under heavy load, as in a septic tank after a long period of disuse. The pH of the USC septic tank, however, is not as readily explained; officially no lime had been added to it. Yet, the pH rose from 8.8 on 8 July to 10.4 on 12 August. Following this it dropped rapidly to 9.6 and then steadily over about one month to 8.8. The period of maximum pH corresponds to the start of the period of greatest load, 12 August to 9 September (see Section 4.2.1), and just prior to a major solids back-up flow restriction. The obstruction was cleared on 19 August but flow into the tank was limited. The steady decline of the pH corresponds to this period. After 9 September no further use was made of the tank; it was completely full of solids.

(b) Sodium Concentration

Enquiries as to the possible cause of the unexpectedly high pH in the USC septic tank (see above) indicated that in early July about 20 ml of a commercial product called "Drano" had been added.

to the system. This was to clear the influent line of supposed grease blockages, arising from its small "fall". Twenty ml of this product, which is 54.2% NaOH, diluted to 1600 litres (the tank capacity) represents an OH^- ion concentration of 0.169 mm moles/l. This is equivalent to a pH of 10.2. The addition of "Draino", then, may explain the high pH. To test this hypothesis the concentration of the corresponding ion, Na^+, was determined. For comparison, the sodium concentration of the OSC septic tank was also determined. The analyses were conducted on triplicate samples using an EEL mark II flame photometer, with a sodium filter, calibrated against 0.01 M NaCl by standard addition. This method is considered sensitive to Na^+ concentrations down to 0.03 mg/l at ± 1% accuracy (Willard, Merritt and Dean 1965). The sodium concentrations of the USC and the OSC septic tanks are shown in Table 4.6 along with the corresponding pH values.

TABLE 4.6

Sodium Concentration and pH of USC and OSC Septic Tanks

Date	Sodium Concentration (mg/l) USC	OSC	Corresponding pH USC	OSC
2 September	840	265	9.3	8.8
16 September	480	210	8.9	8.3
23 September	160	56	8.8	8.8
Range*	23 - 349		6.0 - 7.5	

*GHD (1977); Capri and Marais (1975)

The sodium ions added in the "Draino" (389 mg/l of tank liquor) plus those already present (up to 349 mg/l) (GHD 1977) give a total sodium concentration similar to that determined for 2 September. The sodium levels within the tank, therefore, support the hypothesis that "Drano" caused the high pH values observed.

(c) Volatile Suspended Solids and Biochemical Oxygen Demand

Organic loading of the adsorption field was assessed directly, by determining the volatile suspended solids (VSS) concentration of the septic tank effluent, and indirectly, by determining its biochemical oxygen demand. These determinations were also conducted on samples collected from points in and around the adsorption field. In the VSS determination the mass loss of Satorius SM 134 fiberglass filter discs through which water samples had been passed was assessed following ignition at 550°C for 30 minutes. Every fourth filter disc in the pack was reserved for blank determination. The VSS levels of each sample are shown in Table 4.7.

TABLE 4.7

Volatile Suspended Solids in Water Samples from the USC STAF System

Date	Volatile Suspended Solids (mg/l)							
	USC Cistern	USC S. tank	USC 1	USC 3	USC 4	USC 5	USC 6	USC 7
2 September	-	309	-	-	-	-	-	98
16 September	-	168	-	-	-	-	-	13
23 September	25	215	93	ND	40	64	18	59

ND = not determined

The VSS levels of the septic tank were as expected, falling within the ranges given in GHD (1977), e.g. 100 - 350 mg/l. The VSS concentration of USC 7, the sample point close to the septic tank outlet, however, was unexpected, particularly in view of the VSS concentrations at the other points. No conclusions, however, can be drawn from this as points 1, 3, 4, 5 and 6 were all in the path of the overflow from the main water supply tanks (see Section (a) earlier) and the VSS of the effluent may have been diluted beyond detection. In fact, this is more than likely considering the high sludge level of the tank and the possibility of solids carry-over. Furthermore, the VSS concentrations of USC 7 are similar to those for 23 September which are considered to represent undiluted background levels for by this time ground water flow had ceased and the septic tank was no longer in use (see Section 4.2.2).

BOD_5 was determined according to the procedure given in *Standard Methods* (APHA 1976) in duplicate using a seeded dilutant and a Townson Portable Pollution Monitor, fitted with a Titron dissolved oxygen electrode. The BOD_5 levels determined are reported in Table 4.8.

TABLE 4.8

Five Day Biochemical Oxygen Demand of USC STAF Samples

Date	Five Day Biochemical Oxygen Demand (mg/l)							
	USC Cistern	USC S. tank	USC 1	USC 3	USC 4	USC 5	USC 6	USC 7
22 July	ND	720	2.8	3.9	1.0	3.2	1.0	ND
31 July	ND	540	7.1	9.2	7.3	59	7.4	ND
12 August	-	1750	47	57	70	50	43	65
19 August	-	3300	40	ND	36	40	ND	ND
2 September	-	3180	ND	ND	180	160	110	170
16 September	-	810	31	71	21	-	39	26
23 September	-	1540	19	ND	54	34	12	17

ND = not determined

The very high BOD_5 for the USC tank on 19 August and 2 September corresponded to when the tank was extremely full of loose, partly disintegrated solids (which is characteristic of sludges over pH 9.5 (Lijklema 1971)) making obtaining a liquid sample without considerable entrained solids very difficult. The reason for the high BODs of samples 4, 5, 6 and 7 on 2 September is not known. No VSS were detected in these samples (see Table 4.7). The low oxygen demand for the remaining samples is an indication either that very few organic solids entered the adsorption field or, more likely, that the septic tank effluent was diluted by surface waters (see (a) earlier). Usually septic tank effluents have BOD_5 levels between 93 and 166 mg/l (Barnes and Wilson 1976).

(d) Faecal Coliforms

As septic tank effluent passes through the adsorption field organismsin the soil predate upon bacteria contained within the effluent. These bacteria may include pathogenic species. The level of *E. coli* in the adsorption field water is commonly used as an indicator of the effectiveness of the soil treatment. Samples of water taken from the six sample points (see Figure 4.3) and from the septic tank were passed through a 0.45 μm membrane filter and incubated on MacConkey agar at 37°C for 24 hours. Colonies of likely faecal coli were confirmed by sub-culture in EC broth at 45°C for 24 hours according to *Standard Methods* (APHA 1976). The numbers of faecal coli determined for each sample are reported in Table 4.9. Very few coli were detected in any of the samples from the septic tank or the adsorption field. Yet, the expected range of faecal coliforms/100 ml in septic tank effluent is 4.1×10^3 - 5.2×10^6 (Viravaghavan 1978). In the septic tank the low faecal coli numbers are believed to be the result of the high pH. Parhad and Rao (1974) showed that *E. coli* was eliminated from wastewaters whose pH was above 9.4. In the adsorption field, however, the low faecal coli count may also be explained by dilution with surface water (see (a) earlier). The low VSS and BOD_5 values for adsorption field samples given earlier support this.

TABLE 4.9

Faecal Coliforms in Water Samples from the USC STAF System

Date	Faecal Coliforms (No./100 ml)							
	USC cistern	USC S.tank	USC 1	USC 3	USC 4	USC 5	USC 6	USC 7
22 July	ND	6000	-	-	-	-	-	ND
29 July	ND	4000	60	10	20	20	10	50
12 August	ND	-	-	-	-	-	-	ND
29 August	-	-	10	-	-	-	-	-
2 September	-	-	-	-	-	-	-	-
16 September	-	-	-	-	-	-	-	10
23 September	-	435	25	-	-	20	-	-

ND = not determined

(e) Nitrogen Nutrients

Septic tank effluent on entry into the adsorption field is a highly ammoniacal liquid. On passage through the field the nitrifying bacteria, *Nitrosomonas* and *Nitrobacter*, oxidize the ammonium salts of the septic effluent progressively to nitrite and nitrate salts. Test for each of these forms of nitrogen, using semi-quantitative Merckoquant test strips, were performed on each of the samples taken from the adsorption field and from the septic tank. In none of the samples from the adsorption field were NH_3, NO_2^- or NO_3^- detected. This is believed to be the result of dilution by surface water (see (a) earlier). In the septic tank, however, nitrogen was detected, principally in the ammonia form (see Table 4.10). This was expected for the nitrifying bacteria are aerobes and occur in the anaerobic environment of the septic tank, if at all, only at the liquid-air interface where some oxygen dissolution may occur. The levels detected fall within the range of NH_3-N values reported by Viraraghvan and Warnock (1973), 6.3 - 226.6 mg/l, and approximate those of Brandes (1978), 8.7 - 160 mg/l.

TABLE 4.10

Date	Nitrogen Concentration (mg/l)		
	NH_3 - N	NO_2 - N	NO_3 - N
19 August	60	-	-
2 September	100	-	-
16 September	200	5	30
23 September	20	-	-

4.2.6 Soil Type and Percolation

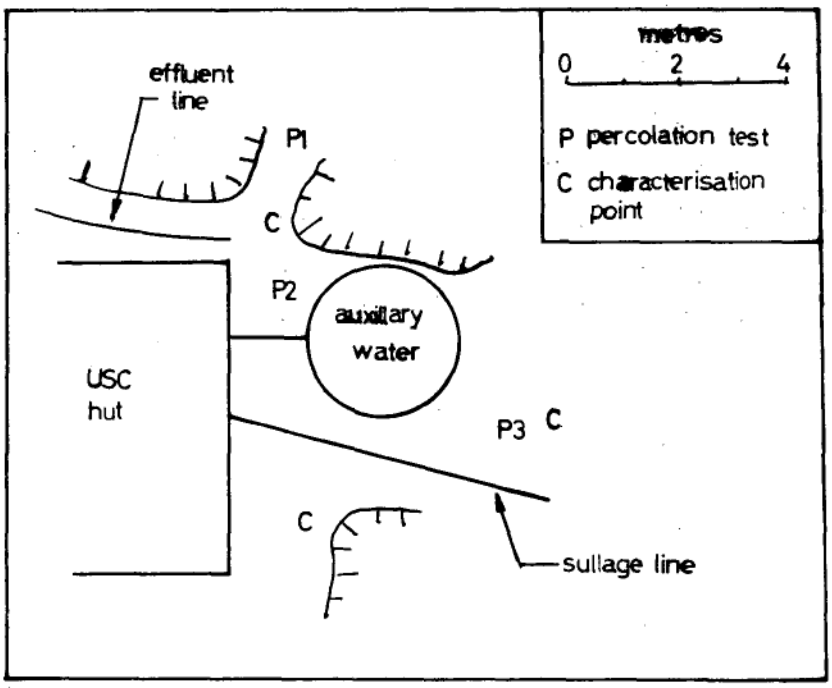
Observations of the soil within the USC adsorption field were made at the three points in and around the adsorption field shown in Figure 4.11. Reference was made to Munsell (1954) colour charts, the recognition key of Northcote (1971) and the moisture description of Butler 1955. The soil was skeletal with many outcrops and unweathered boulders of dolerite occurring. The first 300 - 400 mm of soil was a black (5YR 2/1), fibrous, moist - wet peat. Beneath this was a strong brown (7.5 YR 5/6, 5/8), medium textured, gritty, moist clayey B horizon of more than 1 metre depth. The boundary between these horizons was abrupt to occasionally diffuse. The pH of composite peat and B horizon samples, measured in water at 1:5 dilution by glass electrode according to *Methods of Soil Analysis* (ASA* 1965) was 5.2 and 5.4 respectively. The soil around the USC hut was considered to be of the Alpine Humus group. This was confirmed by comparison with a

*ASA is the abbreviation of the American Society of Agronomy description of Alpine Humus soil for a site on Mt. Wellington, given in Stace *et al.* (1972), similar in altitude (1090 metres compared with 1200 metres), aspect (north-east), parent rock (Jurasic dolerite) and soil profile to the USC site on Mt. Mawson.

FIGURE 4.11

Soil Characterisation and Percolation Test

Points in and around the USC Adsorption Field



Soil percolation tests were conducted at three points in and around the USC adsorption field (see Figure 4.11). These were performed according to the auger method given in EPA (1975a) where the drop in water level in at least three separate holes of 300 mm diameter and 300 mm depth is measured over 30 minutes following soaking for 24 hours. The results of this, shown in Table 4.11, indicate that the drainage of points P1 and P2 is quite restricted in comparison to that of point P3. The high percolation rate at point P3, located about 3 metres west of the adsorption field, may be because insufficient time for soil slaking (the absorption of water and swelling of soil particles) had been allowed. The percolation rates of the other two test points, both of which were in the adsorption field and whose soil should not require preliminary soaking, were as expected, low and only marginally greater thus the recommended minimum percolation rate (25 mm/hour). This rate, however, is based upon North American experience and it may not be applicable to Australian, particularly Tasmanian, soils with their higher clay contents; it may need to be higher (EPA 1975b).

TABLE 4.11

Soil Percolation at Three Points in and around the USC Adsorption Field

Point	Percolation Rate (mm/hour)
P1	40
P2	80
P3	200
min.*	25

*recommended minimum percolation rate of EPA (1975a, 1975b)

As stated earlier (Section 4.2.4 (a)) the USC's main water supply tanks frequently overflowed inundating the adsorption field. Consequently, the adsorption field soil soon became saturated. The ground water depths through the study period are shown in Table 4.12. On several occasions this water was actually flowing and sufficient oxygen may have been brought into the system to maintain its aerobic nature. Furthermore, the dilution of the septic tank effluent by this water would reduce the oxygen demand on the soil (see 4.2.5c).

TABLE 4.12

Ground Water Depth in the USC Adsorption Field

Date	Groundwater Depth (mm)
8 July	-
22 July	50
29 July	surface, flowing
12 August	surface, flowing
19 August	surface
2 September	surface, flowing
16 September	surface, flowing
23 September	200 to 500

4.2.7 USC STAF Operation

The entire USC STAF system was inadeuqately designed and operated. The septic tank was situated where the gradient throughout the entire system was minimal and where it represents a potential health hazard should the tank overflow. The siting of the adsorption field, beside the kitchen windows, also represents a potential health hazard. Furthermore, the septic tank was much too small to accommodate the load imposed. The tank in use was a "5 person" tank; that is, a toilet waste only tank of 1600 litres; whilst a "9 person" tank of 1800 litres is recommended for the load (SAA 1976). These recommendations are based on the assumption that the digestion will occur at between 15-30^oC. From July to mid August, however, the temperatures within the USC septic tank were between 1^oC and 3^oC. At these temperatures the rate and efficiency of the solids digestion would be about 60% of the optimum rate and efficiency (see Section 2.3.3 (d)). Calculations based on this rate show that a "19 person" tank of 2300 litres is more appropriate.

Even taking the reduced digestion rate at low temperatures into account solids accumulated in the USC septic tank remarkably rapidly. At the pH of the tank liquid, 8.8 - 10.4, this is hardly surprising; few bacteria, including digestion bacteria, can survive pHs this high (see Section 2.3.3 (d)). A small volume (20 ml) of 54.2% NaOH was flushed into the septic tank to clear the influent line of grease buildup, resulting from the lines low "fall". The amount used, however, was demonstrated to be sufficient to explain the pH and sodium concentrations observed. The sudden dose of OH^- ions would have generated unsaturated CO_2 conditions by converting all dissolved CO_2 to ${CO_2}^{3-}$ ions, thereby upsetting the H_2CO_3/HCO_3^- and $HCO_3^-/{CO_3}^{2-}$ equilibria which control the digestion pH. Following this the pH controlling influence would be the OH^- concentration. The addition of NaOH to the tank occurred in early July, when the tank temperatures were around 2.5^{0}C. At this temperature and at the new pH, biological activity in the tank would be negligible with no CO_2 being generated to restore the previous equilibria. The only mechanism whereby the previous dissolved CO_2 concentrations could be reestablished, partially at least, was by dissolution of atmospheric CO_2. This mechanism is slow, hence the slow decline of pH after 19 August, and gives a CO_2 concentration less than that at saturation. The principal buffering mechanism cannot be restored unless the digestion is restarted (which cannot occur because of the high pH) or HCO_3^- is added to the digestion liquor. The amount of base required to produce such a catastrophic impact on the digestion as that which occurred at the USC is small, particularly if the digestion is operating at a pH where its buffering capacity is low; for example, between pH 7.5 and 8.5. The pH of the USC septic tank at the start of loading and prior to the input of the NaOH was slightly above this range at pH 8.8. The buffering capacity of the tank liquor, then, would be expected to be small.

In the adsorption field conditions were similarly unsuited for its proper operation. With ground temperatures around 2^{o}C little biological activity would be expected. This, and the sudden loading on 8 July of a very immature system after a long period of disuse, would have generated anaerobic conditions, clogging the soil, (see Section 2.2.3 (c)) but for the five days of rest following (the hut on most occasions was occupied only on the weekends). The acidic nature of the soil and the high to very high water table would have assisted in generating these anaerobic conditions. The ground water, however, probably prevented such a circumstance from happening. No evidence, in the form of BOD, VSS, NH_3-N, NO_2^--N, NO_3^--N and Coliform levels of septic tank effluent, was apparent. This could only be because the effluent was diluted by the ground water to such an extent that the above factors were below their detection limits.

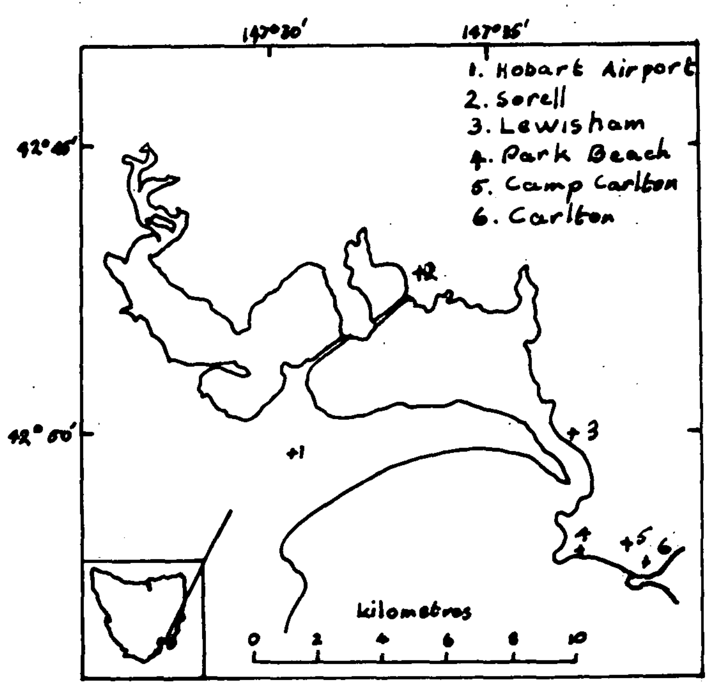
In summary, then, the USC STAF system was poorly planned and it was used in conditions that were far removed from the original design criteria. The septic tank was inappropriately sited, overloaded and operating at a very low efficiency (because of the low temperatures) until NaOH was added when it ceased to operate at all. The adsorption field was also inappropriately sited and would have fared little better than the septic tank, probably becoming clogged by mid season, save for the fortuitous overflow of water tanks on the ridge above, and the dilution that this produced in the septic tank effluent. The general influence of the areas environmental conditions on the operation of the STAF system were as predicted in Chapter 3; that is, that temperature would be important in septic tank operation, that soil temperature, and degree of saturation would be determinant factors in adsorption field operation and that surface dilution may be an alternative form of secondary treatment. The influence of the pH of the water used in flushing or the soil percolation rate was not apparent in the USC STAF system. In other circumstances; that is, no NaOH and no surface water; however, they may well be important.

4.3 Camp Carlton at Carlton

Carlton is the south-eastern hamlet within a small coastal community, population 442 (ABS 1977b), comprising Lewisham, Dodges Ferry, Park Beach and Carlton and is situated about 35 kilometres east of Hobart (see Figure 4.12). Approximately 0.5 kilometres north-west of Carlton is a holiday camp, Camp Carlton, run by Mr. and Mrs. W. Crosswell (formerly the YMCA) for children in the school holidays. During school term excursions and sundry trips may also be accommodated.

FIGURE 4.12

Location of Camp Carlton



4.3.1 Site Details

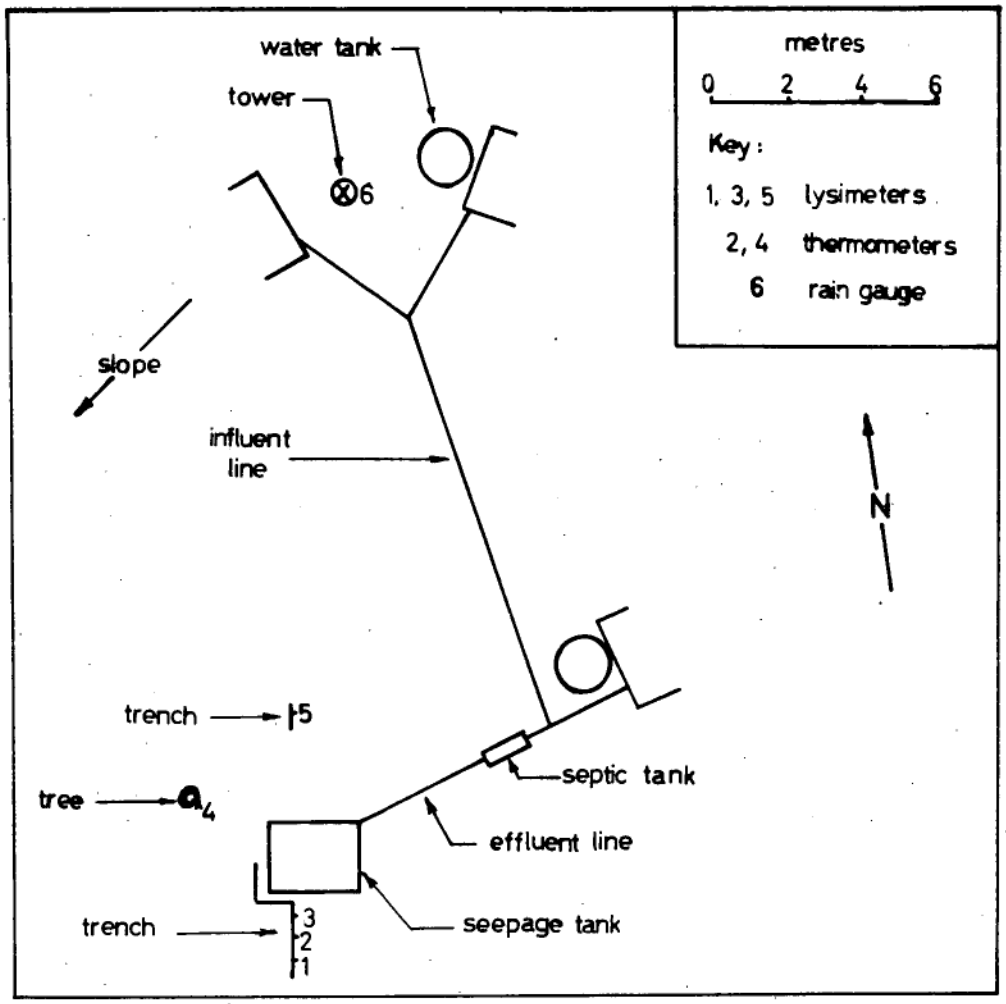
The Camp itself consists of three separate dormitories, each with sleeping facilities for 24 people, located around a central mess hall. Several small huts are scattered around the Camp grounds and these may also be used for accommodation if necessary. Each dormitory is serviced by a toilet block that is connected to a central septic tank and seepage tank, instead of septic tank and adsorption trench, (see Figure 4.13). No other wastewaters are added to the treatment system. The fall from the nearest dormitory to the septic tank is about 1 metre in 10 whilst that from the furthest dormitory is about 2 metres in 15. In areas not built on or used for other purposes, such as sporting fields, the land is covered in an open forest of *Eucalyptus viminalis* and *E. amygdalina*. This vegetation and the *Pteridium esculentum* understorey is shown in Plate 4. This also shows the gentle nature of the Camp's relief; it is 900 metres inland but only 20 metres above sea level (Lands Department 1973).

PLATE 4

General Surroundings of the Camp Carlton Septic Tank (arrowed foreground) and Seepage Tank (arrowed background)

FIGURE 4.13

The Camp Carlton STAF System Showing Characterisation Points



4.3.2 Occupancy and Wastewater Load

Camp Carlton is a holiday camp for children during school holidays. Consequently, from 10 August to 5 September it was occupied continuously. The numbers staying at the camp during this period are shown in Table 4.13 along with the estimated daily wastewater flow. This is based on 5 flushes/person/day, assuming no other toilet system was used (Heeps 1977), at a determined flush volume of 3.4 litres/flush

The recommended capacity of a septic tank for the Camp, based on a maximum occupancy of 72 people (24 beds/dormitory x 3)

TABLE 4.13

Occupancy and Estimated Wastewater Flow at Camp Carlton

Period	Number of Occupants	Estimated Wastewater Flow (liters/day)
10 - 15 August	96	1630
15 - 16 August	60	1020
16 - 18 August	83	1410
19 - 22 August	44	750
23 - 25 August	36	610
26 - 31 August	56	950
1 - 5 September	63	1070
Average (persons/day)	65	1110

dormitories) is 4950 litres (SAA 1976). The capacity of the septic tank in use at Camp Carlton, according to Health Department records, is 8400 litres which meant that the wastewater liquid retention time for the above flow was greater than 100 hours, assuming a maximum sludge volume of 55% of the tank volume (see Section 2.3.1). The septic tank, then, was operating well within its capacity. The capacity of the seepage tank receiving the septic tank effluent was estimated to be 24000 litres. This was adequate to accommodate almost the entire load of 25560 litres. The level of wastewater in the tank, however, was never observed to be more than 1 metre below the tank surface; that is, about 750 mm below ground level. The seepage rate of the surrounding soil, under a 1 metre "head", must have approximated the tank input rate.

4.3.3. Temperature

Air temperatures were recorded at Camp Carlton from mid August to mid September using a Zeal Minimum and Maximum thermometer placed in a shaded position about 2 metres north-west of the

PLATE 5

Position of Ambient air Thermometer photographed from the seepage tank looking north west

seepage tank (see Figure 4.13 and Plate 5). The temperatures recorded from mid August to mid September are shown in Table 4.14 along with temperatures for the same period at Hobart airport 11 kilometers north-west of Camp Carlton. A close similarity is apparent between these and the Camp Carlton readings (see Figure 4.14). This supports personal communication from the Bureau of Meteorology that the temperature regime of the airport was representative of that at Camp Carlton. The minimum, maximum and mean three hourly temperatures for the 24 hours to 0900 recorded at the airport are shown in Figure 4.15. Full details of the airport temperature data are given in Appendix D.

TABLE 4.14

Minimum, Maximum and Noon Air Temperatures at Camp Carlton and Hobart Airport

Date	Temperature (°C)					
	Camp Carlton			Hobart Airport		
	Min.	Max.	Noon*	Min.	Max.	Noon*
18-19 August	1	13	11	6	13	11
24-25 August	4	12	10	6	12	10
1- 2 September	1	18	14	7	16	14
3- 4 September	7	18	14	8	16	13
4- 5 September	9	19	14	9	14	16
5- 6 September	8	18	18	8	16	16
16-17 September	1	20	14	5	14	13

*Noon reading for the following 24 hour period.

FIGURE 4.14

Air Temperature at Camp Carlton and Hobart Airport

During August and September

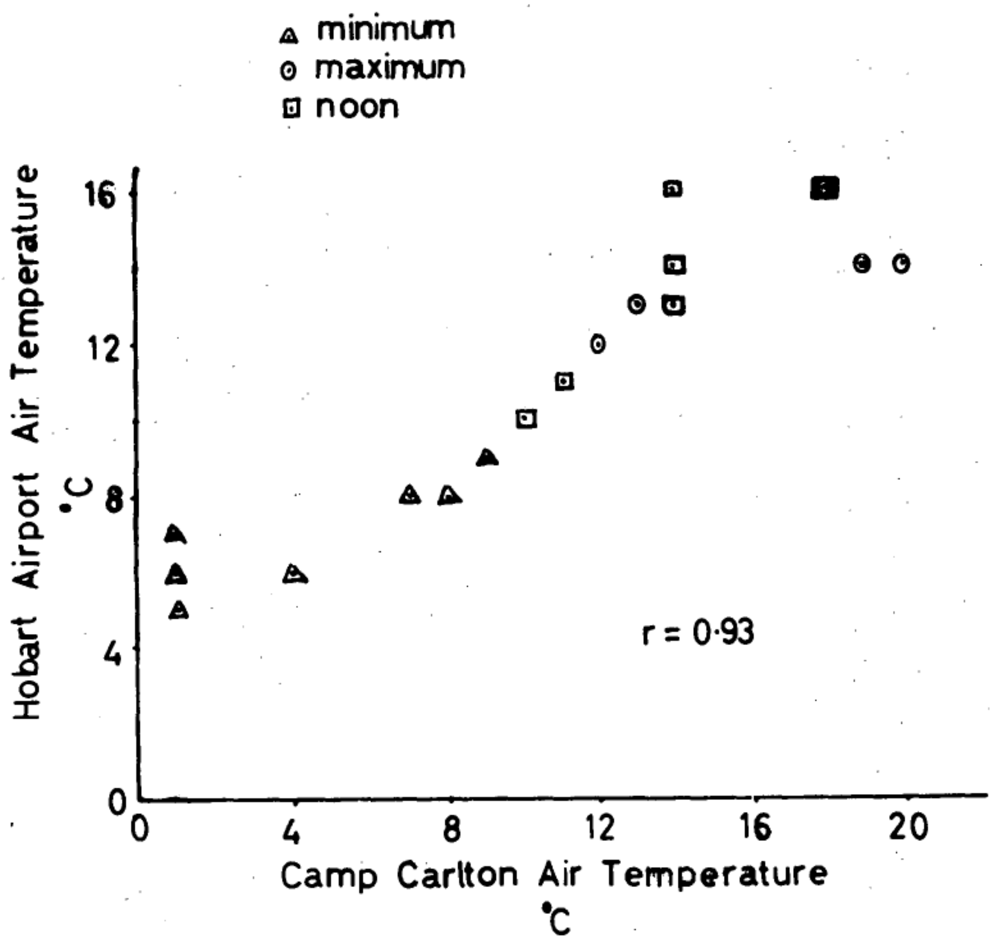
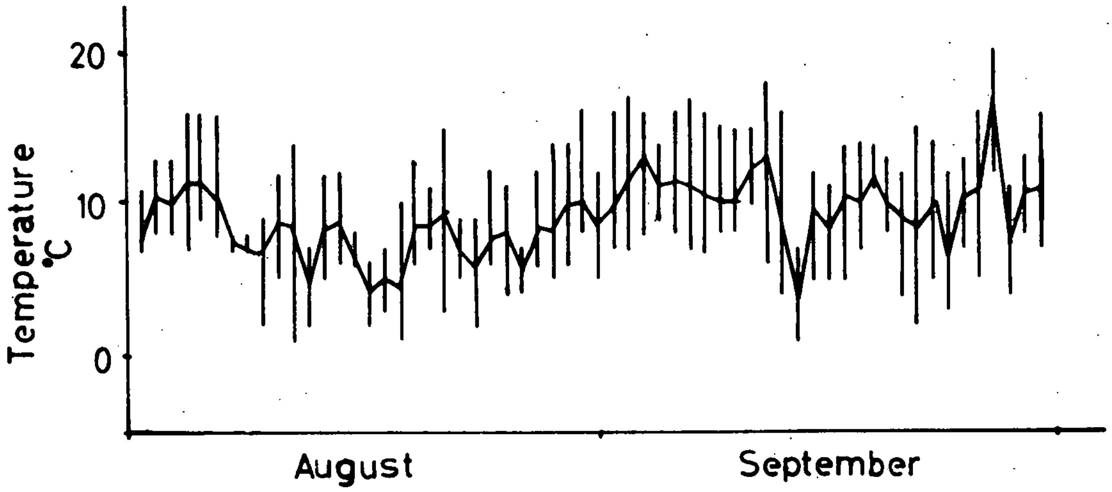


FIGURE 4.15

Mean Three Hourly Temperatures (line) and Range (bar) at Hobart Airport During August and September



The air temperature of the area during the study period was fairly mild with the mean being between 4°C and 13°C and the maximum diurnal variation ± 6.5°C. This stability reflects the influence of the nearby sea. By absorption and desorption of heat the sea moderates temperature extremes (Langford 1965) and only after prolonged periods of northerly winds is this influence over-ridden.

Spot checks on the temperature within the septic tank were also made and these all fell between 8.0°C and 9.7°C. This is within the temperature range of ground water in nearby areas (Leaman 1971) and is considered to reflect the influence of ambient air temperature. At these temperatures the bacterial population in the septic tank sludge would probably be quite mixed with psychrophilic bacteria, whose optimum temperature is around 10°C, becoming dominant over residual mesophilic bacteria from warmer periods. The efficiency of the digestion would consequently be around 60% of the maximum efficiency. In later months the air and water temperatures are expected to be higher and a more mesophilic bacterial population, with a corresponding increase in digestion efficiency, would be expected to develop in response. Generally throughout the year the temperatures at Camp Carlton are considered sufficient to maintain a satisfactory digestion, albeit at somewhat reduced efficiencies.

From mid August to mid September soil temperatures were also measured at Camp Carlton. A Zeal Maximum and Minimum thermometer was placed about 200 mm into the soil between lysimeters 2 and 3 in the main trench 1.25 metres below ground level. The readings taken are reported in Table 4.15. A similarity between these and the air temperatures in the previous Table (4.14) is apparent. This was probably due to ineffectual repacking of the soil after a reading, leaving air in contact with the thermometer bulb. Soil temperatures do not show variations such as those recorded. Never-the-less soil temperatures are related to air temperatures. The mean soil temperature, over five years, at 200 mm below the surface for January in Hobart is 17°C whilst the mean air temperature at the same time (0900 hours) is 16.5°C. During July the same temperatures are 6.4°C and 6.7°C respectively (Bureau of Meteorology, personal communication). In the Hobart area, then, a close correspondence between average surface soil temperature and air temperature is apparent. At greater depths a time lag in this relationship is expected. If this holds for Camp Carlton, and there is no apparent reason why it should not, the soil temperatures at Camp Carlton are considered adequate to maintain a viable treatment population.

PLATE 6

Position of Rainfall Gauge at Camp Carlton

Note water tank in foreground.

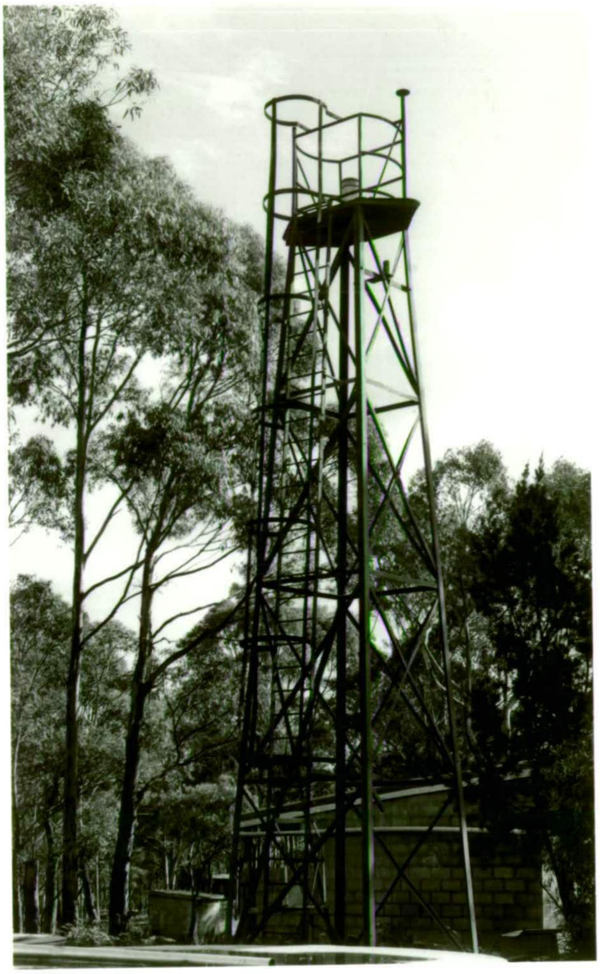


TABLE 4.15

Minimum, Maximum and Noon Soil Temperature at Camp Carlton.

Date	Soil Temperature (°C) Minimum	Maximum	Noon*
18 - 19 August	6	11	10
24 - 25 August	5	12	9
1 - 2 September	8	16	11
3 - 4 September	8	17	10
4 - 5 September	Trench Flooded		
5 - 6 September	(see Section 4.3.4)		
16 - 17 September			

*Noon for the following 24 hours.

4.3.4 Rainfall

Rainfall at Camp Carlton was measured with a 200 mm capacity gauge of standard design (Commonwealth Bureau of Meteorology 1942) placed atop of a 13 metre tower (see Figure 4.13 and Plate 6). This represented the only unobstructed but accessible position at the Camp. In spite of this the readings were suspected to be strongly influenced by spray from a nearby water tank (see foreground of Plate 6). According to the Camp operator, Mr. W. Crosswell, some of the readings were unreasonably high. This was confirmed by comparison with readings taken by the Bureau of Meteorology at Park Beach, 1.5 kilometres west of Camp Carlton. As the rainfall regime here is not believed to be significantly different from that at Camp Carlton (Bureau of Meteorology, personal communication) the Park Beach readings are reported instead in Table 4.16. These show that August had a slightly higher than average rainfall but that September was relatively dry. The quantities of rain recorded are not considered sufficient to affect the adsorption field at Camp Carlton, particularly in view of its sandy nature (see Section 4.3.6).

TABLE 4.16

Park Beach Rainfall for August and September

(Bureau of Meteorology)

Date*	Rainfall (mm) Recorded	Average+
6 - 7 August	19	
7 - 8 August	14	
8 - 9 August	20	
9 - 10 August	3	
10 - 11 August	0.2	
15 - 16 August	2	
16 - 17 August	0.8	
22 - 23 August	4	
25 - 26 August	6	
Total August	69	53
11 - 12 September	2	
12 - 13 September	5	
13 - 14 September	3	
26 - 27 September	0.2	
27 - 28 September	2	
Total September	12.2	42

*for the 24 hours to 0900.

+based on 16 years of records.

4.3.5 Water Characteristics

(a) Bore Water

The toilets of Camp Carlton are operated by water obtained from a nearby shallow bore. Water depth in this varies from 7 to 17 metres depending on the extent of recent pumping and aquifer pressure variations (Cromer 1977). The characteristics of this water have been determined by the Department of Mines, Hobart, and are reported in Table 4.17. The water is saline, hard and mildly acidic. These characteristics, however, are within the operational limits of septic tank digestion and are not expected to disturb the process.

TABLE 4.17

Chemical Composition of Camp Carlton Bore Water

(Department of Mines Hobart, Analysis No. 750745)

Characteristic	Concentration (mg/l*)
CO_3^{2-}	-
HCO_3^-	28
Cl^-	960
SO_4^{2-}	83
SiO_2	45
Ca^{2+}	30
Mg^{2+}	120
Fe^{3+}	< 0.1
Al^{3+}	< 0.2
K^+	1.0
Na^+	460
Total dissolved solids	1790
Permanent hardness	550
Temporary hardness	23
Alkalinity	23
pH	6.2

*except pH

PLATE 7

Photograph of Lysimeter used to

collect ground water samples

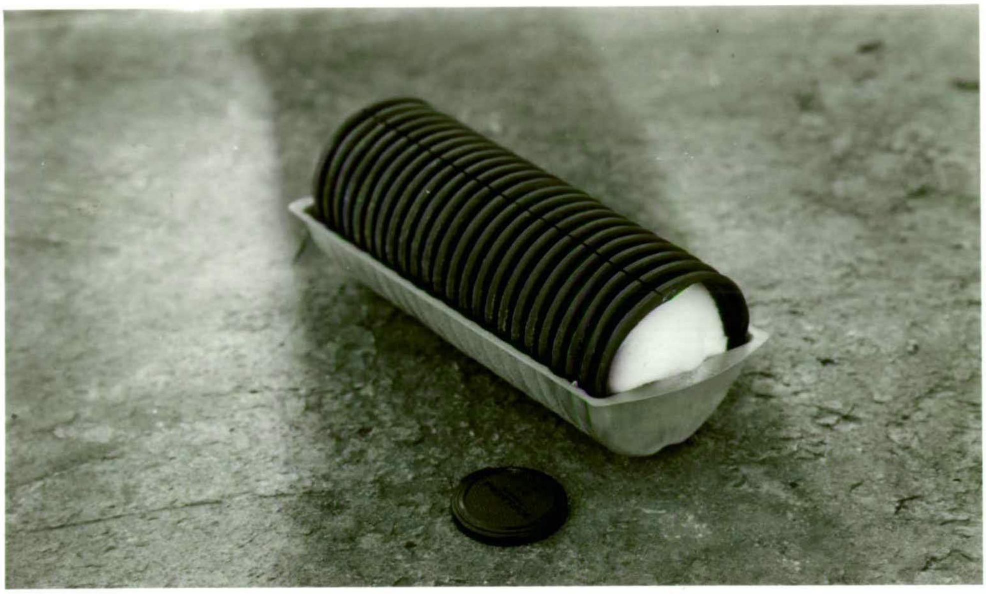


PLATE 8

Exploded view of Lysimeter

(b) Adsorption Field Water

Lysimeters following the design of Viraraghavan (1974) (see Plates 7 and 8) were installed approximately 1.3 metres below ground level 0.6 and 0.9 metres downslope of Camp Carlton's seepage tank (see Figure 4.13). A further lysimeter was installed at the same depth 3 metres upslope. From these samples of adsorption field water were to be collected but, owing to the very porous nature of the soil (see Section 4.3.5), this was not possible. Furthermore, on 4 - 5 September, following blockage of the septic tank influent lines by local vandals (two full rolls of toilet paper were flushed down a bowl) a "blow out" in the 0.3 metres of soil between the seepage tank and the observation trench occurred and the trench filled with septic tank effluent. This resulted from the large volumes, approximately 4500 litres, of high pressure water used to clear the blockage. No attempts were made to collect lysimeter samples after this date. Samples were collected from the seepage tank, however, and characterised according to pH, Na^+, BOD_5, NH_3, NO_2^-, NO_3^- and faecal coliform concentrations. The results of these determinations are given in Table 4.18. The methods employed have already been described.

The BOD_5 concentrations reported in Table 4.18 are notable in that they indicate that a considerable proportion of organic solids was present in each sample; that is, carried over from the septic tank. The usual BOD_5 concentrations for septic tank effluent are 93 - 166 mg/l (Barnes and Wilson 1976). A solids carry over such as this not only threatens the adsorption field, through the development of anaerobic conditions and the clogging of soil pores, but indicates a need for tank desludging. This need was confirmed in December when a solids back-up occurred blocking the influent lines and preventing any further inputs. Apparently the tank had not been

TABLE 4.18

Characteristics of Septic Tank Effluent at Camp Carlton

Date	Characteristic Concentration (mg/l*)						
	pH	Na^+	BOD_5	NH_3	NO_2^-	NO_3^-	F. coliforms (No./100 ml)
19 August	8.8	630	2600	100	-	-	TNTC+
25 August	8.4	560	3700	200	-	-	10000
2 September	8.6	670	4500	100	-	-	20000
5 September	8.2	630	3700	200	-	-	22000
16 September	8.3	840	2500	100	10x	-	15000

*except faecal coliform counts (No./100 ml) and pH

+TNTC = too numerous to count

xfor liquid from the flooded trench.

desludged for sometime; not within the experience (3 years) of the camp operator, Mr. Crosswell, at least. The remaining characteristics, with the exception of pH, are as expected; the faecal coliform counts are within the range given by Viraraghavan (1978), 4.1×10^3 - 5.2×10^6 /100 ml, and the sodium levels, over the above that of the bore water, agree with those reported by others, e.g. Painter (1971). The pH values reported in Table 4.16 are unusual in that they approximate those determined for the OSC tank (Section 4.2.4 (a)), yet the Camp Carlton tank had not been limed (W. Crosswell, personal communication). This, and the trend of the pH in the USC tank towards the same range, indicates that the pH control mechanism in septic tanks may not be as described earlier (Section 2.3.3 (d)). Further study is recommended to confirm this and to elucidate the pH control mechanism.

4.3.6 Soil Type and Percolation

Soils of the Sorell - Carlton - Copping area have been described by Loveday (1957) and revised, for the Dodges Ferry - Carlton area, by Hurburgh (1973). The soils of Camp Carlton were described as being a Podzol or Ground Water Podzol with Podzolic Soil on Cover Sands (PSC). Loveday (1957) described these types of soils as deep sands with a dark grey surface of coarse organic material and a bleached subsurface over a sandy B horizon. Cromer (1974, 1977) showed that on neighbouring properties to Camp Carlton these sands were at least 4 metres thick and lay over a basement of Parmeer non-marine sandstone or mudstone. Stace *et al.* (1972) gave these soils as acidic in all horizons. The pH and colour of the soil around the seepage tank at Camp Carlton is reported in Table 4.19. pH was determined according to *Methods of Soil Analysis* (ASA 1965) in water at 1:5 dilution. Colour was assessed from Munsell (1954) colour charts.

TABLE 4.19

Soil Characteristics at Camp Carlton

Sample Depth mm	pH	Colour
250	5.6	yellowish brown 10YR 5/4
750	5.2	brown 10YR 4/3
1500	4.7	dark brown 10YR 3/3

The percolation rate of the soil around the seepage tank was also assessed, using the auger method described in EPA (1975a). Holes were dug, two 0.75 metres below ground level and one 1.5 metres below ground level, in the positions shown in Figure 4.16. These depths were selected to represent the soil - adsorption field interface (0.75 metres) (see Section 4.3.2) and mid adsorption field (1.5 metres). The percolation rates at these points are reported in Table 4.20 following

FIGURE 4.16

Position of Percolation Rate Assessment Holes

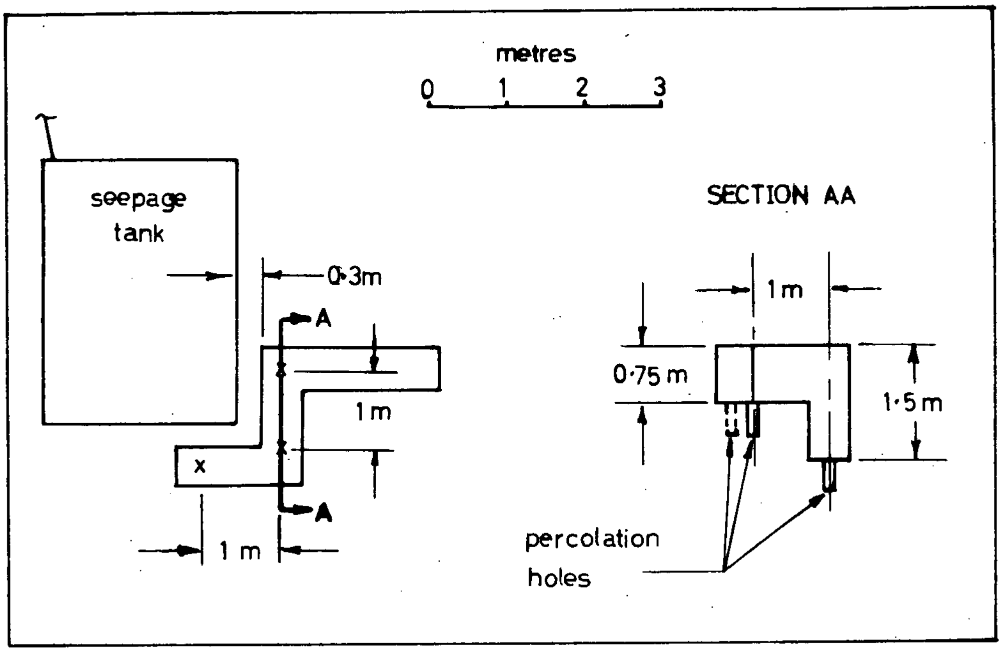


TABLE 4.20

Percolation Rate of Soil in the Camp Carlton Adsorption Field

Assessment point	Depth (m)	Percolation rate (mm/hour)
1	1.5	2480
2	0.75	4150
3	0.75	4150
min.*		25

*recommended minimum percolation rate given in EPA (1975a, 1975b).

The percolation rates in Table 4.20 are high, two orders of magnitude greater than the recommended minimum rate. In unconsolidated coastal sands such as these the distance required to effect adequate treatment of the effluent may be considerable. Schaub and Sorber

(1977) reported that in unconsolidated silty sand and gravel wastewater enteroviruses and a tracer virus (coliphage f2) were detected 183 metres from the wastewater input. At Camp Carlton the unconsolidated sands extend to the water table, which may be no more than 17 metres below ground level. A possibility of this water becoming contaminated with septic tank effluent, then, is apparent.

4.3.7 Camp Carlton STAF Operation

During the study period the environmental conditions at Camp Carlton were shown to be generally compatible with STAF design and operation. The wastewater load was moderate and within the tanks capacity to accept. The organic load on the adsorption field, however, was considered to be quite high. This indicated that the tank was in need of desludging and that adequate maintenance checks had not been maintained. The mean ambient air temperature was cool to mild, ranging from 4°C to 13°C and fairly stable with a maximum diurnal variation of only ± 6.5°C. Similarly, the temperatures of the Camp's ground water, the water used for toilet flushing, were stable at around 8 - 9.5°C. At these temperatures a mixed population of psychrophilic and mesophilic bacteria would become established in the septic tank sludge and the digestion efficiency would be lower than optimum (around 60%). At higher temperatures the bacterial population would change to a more mesophilic one, with corresponding higher efficiencies. The septic tank digestion at Camp Carlton was never considered to be threatened through low temperature, although its efficiency was probably reduced. Similarly, the ground temperature was considered to represent no threat to the adsorption process. The rainfall at Camp Carlton was also considered to be of little influence on adsorption field operation. The daily and monthly totals during August and September were moderate to low and the soil of the area is quite sandy. Saturation of the adsorption field soil was, therefore, considered unlikely. Ground water chemistry was similarly shown to be of small concern to septic tank operation. Although its pH was low (6.2) and its magnesium and sodium ion concentrations high (120 mg/l) and 460 mg/l respectively) the levels of these characteristics were within the digestion tolerance limits.

The only environmental factor shown to be of concern at Camp Carlton was that of soil percolation. The percolation rate of the soil was so high that a danger of ground and surface water becoming contaminated with septic tank effluent was felt to exist. This is supported by the observations of Dobson and Williams (1978) who reported that faecal coliform levels in surface waters at Dodges Ferry following heavy rain were greater than 10^6/100 ml; these are the magnitudes expected in raw septic tank effluent. Considerable caution must, therefore, be exercised in the siting of adsorption fields relative to ground and surface waters in this area. As the Lewisham - Dodges Ferry - Carlton district relies heavily on ground water for domestic purposes an investigation into the fate of septic tank effluent in this area and its effect upon surrounding waters is urgently required.

The influence of the above environmental conditions upon STAF operation were as predicted in Chapter 3 for areas on unconsolidated coastal sands; that is, that the cation levels and soil percolation rates will be high (with the latter being the limiting factor) whilst the other factors are of little concern.

CHAPTER 5

CONCLUSIONS AND IMPLICATIONS

5.1 Introduction

Septic tanks and associated assorption fields are a wastewater treatment system widely used by individual households where community treatment schemes are not available. Their design and operation is based upon practical experience and research in the usual areas of STAF use. Implicit in their design, therefore, are several assumptions relating to operating conditions in these areas. In Tasmania, however, the environmental conditions in which septic tanks operate may be different from these design assumptions. If this is so treatment inefficiencies are to be expected. This study was undertaken to establish the operating requirements and design assumptions of septic tanks, to compare these with the prevailing conditions in which they are used in Tasmania and to report on any likely operational difficulties. The specific objectives of the study and the conclusions made appropriate to them are reported below. The implications of each conclusion are also given. These highlight deficiencies in the design and operation of STAF systems generally in Tasmania or specifically in the two study areas. They also suggest appropriate remedial action which is itemised in the following section.

5.2 Conclusions and Implications

5.2.1 STAF Requirements

(a) Objective

To establish the optimum and design operating requirements of septic tanks and associated adsorption fields.

(b) Conclusion

The optimum operating conditions for anaerobic digestion, which is the treatment mechanism of septic tanks, were shown to be temperatures of 35 - 37°C, pH of 6.0 - 7.5 and cation concentrations of less than 450 mg/l. The implicit design conditions for septic tanks, however, were considered to be temperatures of 15 - 30°C, pH of 6.0 - 7.5 and cation concentrations of less than 1000 - 3500 mg/l, depending on the cation. In the adsorption field the determinant variables were considered to be soil percolation (less than 25 mm/hour), water table depth (greater than 1.5 metres) and soil temperatures (15 - 25°C).

(c) Implications

The implicit requirements of pH and cation concentration in septic tank design are either the same as the optimum requirements of anaerobic digestion (pH) or within the limits where no adverse effects are expected (cation concentration). The temperature range of septic tank design, however, is 5 - 20°C below the optimum temperature for anaerobic digestion. Consequently, only in the very upper limits of this range (which are attainable only through the treatment of wastes containing hot water) does septic tank efficiency approach the optimum.

The operating requirements for adsorption fields, are laid down in appropriate official recommendations. However, soil temperature, which is one factor believed to be important to adsorption field operation, is not considered. In fact, the literature on this aspect of adsorption field operation is sparse. Soil microorganisms, are expected to behave in a manner similar to the septic tank microorganisms, with respect to temperature. Consequently, temperature range of the adsorption field design is expected to be similar to that of the septic tank design. Research is needed. to substantiate these hypotheses.

5.2.2 Principal Regions of STAF Operation in Tasmania

(a) Objective

To establish the principal regions where STAF wastewater treatment systems are used in Tasmania.

(b) Conclusion

The principal areas of septic tank and adsorption field use in Tasmania were shown to be the north-west, north-central, north-east, south-east, south-central and the central regions.

(c) Implications

The areas of STAF use were established by subtracting the number of sewer connections in each local government area from the number of private dwellings in each area. The number of unsewered dwellings so estimated was assumed to equal the number of STAF units in the particular area; that is, that no other form of wastewater disposal, such as pan services, was available. It was also assumed that the number of sewer connections reported contained no non-residential connections, no multiple connections and no shared connections. Local government areas with estimates of over 1000 STAF units were considered to be the principal STAF areas. These were grouped according to proximity and local characteristics into six regions of STAF operation.

5.2.3 Environmental Conditions Pertinent to STAF Operation in Each STAF Region

(a) Objective

To establish the environmental conditions pertinent to STAF operation in each STAF region.

(b) Conclusions

The conditions pertinent to STAF operation in each STAF region are given below.

(i) Relief

In the central and south-central regions the elevation of the land is generally above 300 metres. In the remaining STAF regions, however, the elevation is generally less than 300 metres.

(ii) Rainfall and Evaporation

Rainfall exceeds evaporation, giving a nett surface runoff in the central, south-central and parts of the north-west and north-east regions. In the remaining regions, or parts thereof, rainfall equals or is less than evaporation.

(iii) Snow Cover

In areas above 650 metres, which includes much of the central and south-central and parts of the north-east regions, snow may accumulate and lie for some time.

(iv) Water Temperature

Water temperature in all STAF regions lies within the range 5 - 17^{o}C. In fact, for eight or nine months (April to December) in the central region, five months (May to October) in the south-central region and for three months (June to August) in the remaining regions it is less than 10^{o}C.

(v) Water pH

Rain water throughout Tasmania generally has a pH of between 6.0 - 8.0. In parts of the south-east region, however, it may fall below this. The pH range of ground water is similar to that of rain water in all regions but the south-east, where at specific sites it may be around pH 5.0. The pH range of surface water in all regions, but the south-central, the central and parts of the north-east where it may be between 4.0 - 6.0, is 6.0 to 8.0.

(vi) Water Cation Concentrations

The concentrations of sodium, calcium, magnesium and potassium ions in rain and surface water is expected to be low (less than 1.0 mg/l). In ground water the concentrations of these ions are generally moderate with the sodium concentration being, for exmaple, up to 1000 mg/l. Close to the coast, as in parts of the north-west, north-central, north-east and south-east regions, the salinity level of the ground water may be high and sodium concentrations of around 3300 mg/l may occur.

(vii) Soil Type and Percolation

The soil type and percolation within the north-west, north-central, north-east and south-east regions varies considerably and is specific to each site. For example, some coastal soils may have a very high percolation rate whilst the soils further inland may have a low rate. In the central and south-central regions the soils generally have a low percolation rate.

(vii) Soil Temperature

The soil temperature in the north-west, north-central, lowland north-east and south-east regions varies between 7^{o}C and 19^{o}C. It is above 15^{o}C only during December (north-east region only), January, February and March and below 10^{o}C during June, July and August. In the central, south-central and highland north-east regions the soil temperature is between 0^{o}C and 15^{o}C and is not expected to rise much above 0^{o}C, particularly where snow may accumulate, during winter and spring.

(c) Implications

The data upon which some of the above estimates of environmental conditions are based are unfortunately somewhat tenuous. This includes the data for the estimates of water temperature, particularly in the south-central region, soil type and percolation and soil temperature. Sufficient information was available, however, to indicate a possible trend within the water temperature figures. The remaining two sets of predictions, those relating to the soil type and percolation and soil temperature, are based upon hypotheses that adsorption field capability can be extrapolated from agricultural capability; and that a thermodynamic equilibrium exists between the surface layers of soil and the air above. Owing to the lack of time and resources these hypotheses have not been tested. The remaining estimates, those concerning relief, rainfall and evaporation, snow cover, water pH and water cation concentration, are based upon actual surveys and on-going monitoring programs.

5.2.4 Compatibility of Environmental Conditions in STAF Regions with STAF Requirements

(a) Objective

To compare the environmental conditions pertinent to STAF operation in the principal STAF Regions with the optimum and design operating requirements of STAF systems.

(c) Conclusions

Each variable was considered individually. The conclusions drawn are presented accordingly.

(i) Relief

In the central and south-central regions the relief of the area was considered incompatible with STAF operation. In the other STAF regions the compatibility is dependant upon the characteristics of the particular site.

(ii) Rainfall and Evaporation

In the north-central and the south-east regions rainfall and evaporation was considered compatible with STAF useage. In the remaining regions the compatibility is dependant upon the characteristics of the particular site.

(iii) Snow Cover

Snow cover is likely to occur only in the highland areas, the central, south-central and parts of the north-east regions. Its compatibility with STAF requirements is ambiguous and depends upon the specific location of the STAF unit.

(iv) Water Temperature

In all regions of STAF operation the water temperature is within the temperature design range of STAF systems only during the summer months.

(v) Water pH

The pH of rain and ground water at specific sites in the south-east region and surface water in the central, south-central and highland areas of the north-east region may be lower than the pH requirements of septic tank digestion. Other waters in each of these regions have a pH within the range required for septic tank operation. The pH of all waters in the north-west and north-central regions fall within the design range.

(vi) Water Cation Concentration

The Na^{+}, Ca^{2+}, Mg^{2+} and K^{+} concentrations of all waters in the central and south-central regions are considered compatible with STAF requirements. In the other regions the cation concentrations of rain and surface water are also considered consistent with STAF operation. In specific areas, particularly those on unconsolidated coastal sands near the coast, the Na^{+} concentration of the ground water may be incompatible with septic tank digestion. In other areas, however, no difficulty with the ground water cation concentrations are expected.

(vii) Soil Type and Percolation

In the central and south-central regions the clay content of the soils is considered sufficient to restrict percolation and to render the soils unsuitable for use in adsorption fields. In the remaining regions soil percolation may vary from site to site. In coastal areas, particularly those on sands, it may be very high whilst in other areas it may be low.

(viii) Soil Temperature

The soil temperature in the central, south-central and highland areas of the north-east regions may be around $0^{o}C$ for some time and are considered incompatible with adsorption field operation. In the remaining regions soil temperature is adequate for biological activity; that is, adsorption field operation; in all months but June, July and August.

(c) Implications

(i) Relief

The main influence of relief is not upon the STAF system itself, other than in influencing the area required for adequate adsorption, but upon other factors which effect the system. For example, the high relief of the central, south-central and parts of the north-east region encourages high rainfall and snowfall, low evaporation and low temperatures in these areas whilst at the same time giving low rainfall in the northern and eastern areas.

(ii) Rainfall, Evaporation and Snow Cover

In areas where rainfall exceeds evaporation a nett surface runoff occurs which may be used as an alternative from of secondary treatment. This applies also to the water released on the melting of accumulated snow. If the volume of water, or its flow, is sufficient the septic tank effluent may be diluted to such an extent that further treatment is not necessary. Septic tank effluent at Waldheim in the Cardle Mt. - Lake St. Clair National Park on the north-western corner of the central STAF region is treated in this manner. Surface dilution, however, is not a complete treatment (the contaminants are not removed, only dispersed) and it is contingent upon the amount of water available. In the summer months, when water flow is low, adequate dilution may not be effected. Personal communication with officers of the National Parks and Wildlife Service indicates that such a situation may occur at Waldheim. During December, January and February, which is also the period of heaviest park use, die-back of nutrient sensitive vegetation adjacent to the receiving waters has been observed. Surface dilution is really only a viable alternative secondary treatment mechanism in areas that experience the greatest population load during times of greatest water flow, e.g. ski resorts.

In areas where evaporation exceeds rainfall, evapo-transpiration beds may also form an alternative to adsorption fields. In these, the septic tank effluent is distributed over the impermeable base of an area of porous material upon which vegetation with a high transpiration rate, such as cereals and clover, is growing. The adsorption and transpiration of the plants combined with the evaporation of the sun effectively dispose of the wastewater while having it confined in a definite area.

(iii) Water Temperature

In septic tanks where no extra energy was added to the system; that is, in those treating only toilet wastes; the digestion temperature would rarely reach the design range. Solids would, therefore, accumulate at a rate faster than indicated in the literature and desludging would be required at more frequent intervals. As the sludge accumulation rate depends on the operating characteristics of the particular tank the sludge depth within it should be checked annually. The householder may find the task onerous, though, and neglect to do it. However, if checking the sludge depth, and recommending its removal when necessary, were to become one of the responsibilities of the septic tank authorising authority (the Department of Health Services in Tasmania) such a difficulty would be avoided and treatment failure through solids carry-over averted, or controlled at least.

In septic tanks that treat all domestic wastewaters sufficient energy is added to the system to maintain the digestion temperature within the design range and desludging is not required as frequently as in toilet waste septic tanks. Wherever practical, these should be the only type of septic tanks installed. The capacity of the tank, however, must be increased by about 60% to accommodate the extra wastewater. The recommended minimum capacity for septic tanks treating only toilet wastewater is 1600 litres whilst that for tanks accepting all domestic wastewaters (excluding that from garbage grinders) is 2500 litres. The tank would need to be constructed of a material with a low heat conductivity so as to prevent loss of heat. Although concrete, the most common construction material at the moment has this property other materials, such as fibreglass, may be superior. Before fibreglass tanks could be accepted for general use, however, the impact (if any) of resin monomers, leached from the solid matrix, upon the treatment organisms would need to be evaluated.

(iv) Water pH

As the pH of rain, ground or surface water in specific areas of the north-east, south-east, south-central and central regions may be below the pH range of septic tank digestion these waters should not be used in septic tanks. Where their use is unavoidable the pH of the digestion would need to be closely watched, and adjusted when necessary. For this narrow range pH papers and lime or sodium bicarbonate would be suitable. However, where the salinity of the water used in flushing the toilet is high, lime would be a more preferable alternative. There should be no other chemicals used in a septic tank, including strong acids or alkalies. Despite the narrow pH requirements of anaerobic digestion the pH in three separate septic tanks, each receiving water of different pH, was around 8.5 Two of these tanks, one of which had been limed, were operating satisfactorily. A different pH control mechanism may be operating in septic tanks than that established for large scale anaerobic digesters. Further research is needed to confirm these observations and to elucidate the pH control mechanism.

(v) Water Cation Concentration

The cation, particularly Na^+, concentration of ground water from unconsolidated sands is strongly influenced by the proximity of the bore to the coast. These sands are very porous and the closer they are to the sea the greater the amount of sea water that can enter the aquifer and the further it can penetrate. As the cation concentrations of sea water are in excess of the digestion tolerance the use of contaminated ground water in septic tanks represents a potential hazard to their operation. Such a circumstance is a distinct possibility in the Carlton - Dodges Ferry - Lewisham area which relies heavily on ground water from unconsolidated coastal sands for domestic purposes. Here the population, and the aquifer load (?), has undergone rapid development in recent times, trebling since 1966.

(vi) Soil Type and Percolation

The high clay content and frequent shallow clay horizons of much of Tasmania's soil result in restricted soil drainage and effectively reduce the area for soil treatment. Effluent will percolate down through the soil until a barrier, such as a clay horizon, is reached and from thence forth travel horizontally along the soil - barrier interface. As this in many cases is only a few centimetres deep septic tank effluent may remain close to the surface representing an obvious health hazard. Furthermore, in areas of low relief the effluent may lie around the adsorption trench or the effluent line outlet, generating ponded soil and anaerobic conditions. Even though these soils may have a percolation rate greater than the recommended minimum (25 mm/hour) their high clay content may render them unsuitable for use in adsorption fields. This percolation rate is based on experience with North American soils which have a lower clay content than Tasmanian, or other Australian, soils. Research is needed to establish the minimum, percolation rate in the local context.

In sandy coastal soils the percolation may be the other extreme; too high. Effluent may travel through these soils at such a rate that effective treatment is not possible in less than (say) 200 metres. As ground and surface waters are frequently much closer than this bacterial and nutrient contamination of these waters is clearly possible. As several coastal communities rely on ground water from unconsolidated sands for domestic purposes research is urgently needed to establish the distance of travel, the degree of treatment received and the ultimate destination of septic tank effluent in these soils. Where the soil is unsuitable for use in adsorption fields alternative secondary treatment schemes should be considered. These could be surface dilution in areas where precipitation exceeds evaporation and where a nett surface run-off occurs, or evapotranspiration beds where precipitation is less than evaporation.

(vii) Soil Temperature

The temperatures within adsorption fields treating toilet waste effluent are considered to be below those of adsorption field design during winter in lowland areas and during much of the time in highland areas. In adsorption fields treating all waste, however, sufficient energy may be added to maintain the temperature at or near the design range continuously in lowland areas. In highland areas this range would be attained only during the summer months. However, sufficient energy may be added to support a low level of biological activity throughout the remainder of the year. If such was the case the adsorption field would have to be very well drained, lest it become saturated from melting snow that would otherwise accumulate on it.

5.2.5 Suitability of STAF Wastewater Treatment for the STAF Regions

(a) Objective

To predict the suitability of STAF wastewater treatment systems for the particular areas of Tasmania in which they are commonly used.

(b) Conclusions

STAF wastewater treatment systems are not considered suitable for use in alpine conditions. They should be used in such situations only as a last resort when alternative treatment schemes are not practical. In other regions in which they are used STAF systems are considered acceptable provided sufficient caution is used in selecting their operational environment.

(c) Implications

The only really suitable form of wastewater treatment in alpine conditions is in community treatment plants with at least secondary treatment capabilities, e.g. primary settling coupled with anaerobic digestion of the solids and activated sludge (say) secondary treatment of the supernatant liquor. Although STAF systems on the surface provide the same degree of treatment (primary and secondary) their operation cannot be readily controlled. On the other hand, the operating conditions within a treatment plant can be controlled, and modified if necessary. At ski resorts on the mainland and overseas all wastewater is treated in such plants. Any development which is likely to attract people to the mountains, particularly if they are likely to be concentrated in a small area, should include a community wastewater treatment facility. Where septic tanks already exist and community treatment schemes are not practical, such as at isolated huts, positive incentive should be given to encourage upgrading these tanks along the lines discussed within this report.

In other areas of Tasmania STAF systems are considered suitable for use in wastewater treatment only at specific times or in specific places. This means that some thought should be given to the water, soil and general site characteristics before the systems are installed.

5.2.6 STAF Conditions and Operation at the USC and Camp Carlton

(a) Objective

To characterise the environmental conditions pertinent to STAF operation at two dissimilar sites, the University Ski Club

(USC) on Mt. Mawson and Camp Carlton at Carlton, and to evaluate the performance of STAF systems at these sites.

(b) Conclusions

(i) USC

The USC STAF system was found to be inappropriately positioned. This, through the low gradient of the influent line, caused a grease blockage and led to the addition of sodium hydroxide which, in turn, produced digestion failure. At the same time the system was grossly overloaded and the septic tank quickly filled with loosly packed solids, making further use of the system impossible. Throughout the study period the adsorption field was also inoperative. The soil temperature was considered too low for biological activity and the soil itself was saturated with surface water. This surface water, however, diluted the septic tank effluent sufficiently to make further treatment unnecessary.

(ii) Camp Carlton

The environmental conditions pertinent to STAF operation at Camp Carlton were generally found to be within the limits of STAF design. Water and soil temperatures were considered adequate for treatment, the wastewater load was within the systems operating capacity, and the water pH and cation concentrations were within the tolerance limits of septic tank digestion. The only factors not consistent with STAF design were the organic load on the soil and the soil percolation; both of these were considered to be too high.

(c) Implications

(i) USC

The most fundamental point to arise from this study is that in alpine areas no short cuts should be taken with wastewater treatment. The biological processes have precise operating requirements which can only be achieved in these situations by careful engineering in community treatment plants. This is the practice at ski resorts on the mainland and overseas. Such a facility could be operated jointly by the ski clubs and businesses on the mountain or, preferably, by the National Parks and Wildlife Service and it would need to be constructed below Lake Dobson. Above Lake Dobson no large building site is available as the terrain is basically unstabilised dolerite talus subject to movement. Furthermore, no suitable repository for the treated wastewater exists. Even if this wastewater was spread over the slopes to be diluted by the melting snow the effluent would eventually end up in Lake Dobson. This is a relatively small lake and an input of nutrients, such as that from a wastewater treatment plant, could seriously effect it.

Despite the only suitable site for a wastewater treatment plant being below Lake Dobson most of the ski clubs are over it. Therefore, either an extensive sewer system is required or the club houses should be moved to near the treatment plant. As the building sites on Mt. Mawson are leased from the National Parks and Wildlife Service on a short term basis (most can be cancelled at three months notice) little difficulty should be experienced in persuading the clubs to relocate given sufficient incentive. As the cost involved in building new club houses and constructing a treatment plant are not going to encourage the transfer such an incentive could be a government subsidy if the transfer is made within (say) 5 years. In the meantime a "freeze" on all development (club or otherwise) should be adopted and some encouragement to upgrade the existing STAF systems and to have them desludged annually (at least) should be forthcoming. The above subsidy could be on the condition that these steps were taken prior to the transfer.

One STAF system at Mt. Mawson that urgently needs upgrading is that of the USC. The first requirement is to relocate the entire STAF system. In its present location it not only does not operate effectively but represents a serious hazard to the health of the club members. Due to the lack of experienced professional advice in the installation of the STAF system the septic tank was placed in a position where the gradient of the influent and effluent lines is minimal. The low gradient of the influent line produced a grease blockage which, in turn, led to the addition of a small amount of "Drano". Although this product is recommended for use in septic tanks its high porportion (54.2%) of NaOH effectively poisoned the digestion and the tank quickly filled with solids. If this had overflowed from the tank the fall of the area would have taken the wastewater back underneath the main living area of the hut. A similar health hazard would have occurred in the adsorption field, which runs alongside the kitchen wall, but for the action of surface water. This diluted the septic tank effluent to such an extent that further treatment was no longer necessary.

Any new site chosen for the USC STAF system should be such that:

(a) the gradient throughout the system is sufficient to generate a self-cleansing flow;

(b) the fall of the land is away from the hut;

(c) the adsorption field is placed away from the hut;

(d) snow and ground water cannot accumulate unduly over or around the septic tank or adsorption field;

(e) advantage can be taken of surface water for secondary treatment.

Such a site may be on the north-east (lee) side of the hut.

The septic tank itself also needs to be replaced. The unit in use at the moment is a second hand "5 person" tank of 1600 litres. The minimum capacity required for the load, if only toilet wastewater is to be treated, is a "19 person" tank (2300 litres). However, if all household wastewaters are to be treated the tank capacity, based on a 60% digestion efficiency and the wastewater flow suggested by the Australian Standards Association (130 litres/ person/day), would need to be 4360 litres. A smaller capacity, however, may be more realistic for the volume of wastewater generated at the hut is unlikely to be 130 litres/person/day; the laundry and bathroom activities are minimal. The actual rate of water use at the USC hut would need to be determined to give the appropriate septic tank capacity for treatment of all wastewater.

The treatment of all household wastewater, may not be practical in the USC STAF system. If a wastewater flow of 670 litres/day (the average wastewater flow from the toilets given in Table 4.2 plus a 60% allowance of 250 litres/day for other wastewaters) is assumed each day's flow would be diluted by about 15% in a 4360 litre tank. The nett temperature increment, which is an overestimate for the volume of warm wastewater is unlikely to be 250 litres/day, would be only 3 - 4°C. Over two days, then, the temperature in the tank would change from 2°C to 10°C. During the following five days of disuse (the USC is usually occupied only on the weekends) this gain is lost to the surrounging environment and the tank liquor would assume the ambient temperature. The nett increase in the digestion temperature, and the consequential increase in biological activity, is, therefore, likely to be small and the cost - effectiveness of adding warm wastewater to the digestion marginal (at the best). Still a polluting liquid that would otherwise be released untreated is given some degree of conditioning.

The water used in the new STAF system may be either roof water or surface (spring) water. If roof water is used few worries regarding the pH of the digestion are to be expected. If surface water is used, however, its acid nature may cause the digestion pH to fall below 6.0. The pH of the digestion should, therefore, be monitored and adjusted, with bicarbonate or lime, when necessary. A similar situation; that is, acid conditions; may occur at the start of the ski season when a sudden wastewater load would be added to a biological community immature after a long period of disuse. This may be avoided, however, if bicarbonate or lime is added to the tank prior to the load imposition. These should be the only chemicals used in the septic tank. Other chemicals, such as strong acids and alkalies should not be used in any circumstances, including pH adjustment.

In spite of the above, limeing an immature digestion does not activate it; it only eliminates one of the inhibiting factors. At the likely operating temperatures on Mt. Mawson, and with an intermittant load, some time would be required for a viable bacterial community to develop. Some mechanism(s) need to be developed that will reduce this time lag and rapidly activate a bacterial community that will operate at low temperatures. A commercial product, "Actizyme", claims to be able to do this in "normal" conditions. However, this product is a preparation of protease, amylase, cellulase and lipase enzymes along with *Bacillus subtillus* spores (to promote enzyme production) which participate only in the initial stages of the digestion (the extracellular) hydrolyses). The rates of these reactions are strongly influenced by temperature. At low temperatures, then, little reaction would be expected. Furthermore, the enzymes of "Actizyme" can assist only in the production of volatile fatty acids (VFA) and not in the conversion of these to methane and carbon dioxide. In an immature digestion, where the methanogenic populations would be the least developed of the community, the use of "Actizyme" may actually promote VFA accumulation and digestion failure.

(ii) Camp Carlton

The implications which arise from the study of the STAF system at Camp Carlton are basically twofold. Firstly, it was evident from the organic solids in the septic tank effluent that the tank had not been desludged for some time and that the sludge level in the tank was excessive. This was confirmed shortly after the study was completed when a solids back-up in the influent line occurred. The depth of the sludge should be measured annually and appropriate action (desludging) taken if the level approaches or exceeds 55% of the tank depth.

The other implications arising from the Camp Carlton study are concerned with the soil percolation. At the percolation rates observed wastewater would require a considerable distance of soil to affect adequate treatment. Yet, ground water in the Carlton area is no more than 17 metres below the surface and little change in the soil structure is expected in this depth. A considerable danger of ground water becoming contaminated with septic tank effluent is, therefore, believed to exist. In spite of this the Carlton - Dodges Ferry - Lewisham community relies heavily on ground water for domestic purposes. Research is urgently needed to establish the fate of septic tank effluent in this area.

The population of the Carlton - Dodges Ferry - Lewisham area is rapidly expanding and changing from basically a recreation population to a residential one. The demand on the ground water supplies is, therefore, likely to increase, along with the amount of wastewater contamination. A community treatment scheme is clearly needed. For this a reticulated water scheme is usually required. However, as the introduction of reticulated water to an area effectively doubles its rainfall and as the soils are not only unconsolidated but unstable in many parts erosion problems may follow. The water table and the salinity of the ground water, which are already both quite high, may also increase and lead to areas of soil sterility. The latter implication, salt poisoning, is considered unlikely, however.

An alternative form of wastewater treatment, other than STAF systems and community treatment schemes for areas, such as Camp Carlton, where evaporation exceeds rainfall would be septic tanks coupled to evapo-transpiration beds (see Section 5.2.4 c(ii)). The principal advantage of this system is that wastewater is treated and disposed of whilst being held in a confined area where the surrounding environment is under little or no risk of contamination from untreated or partly treated effluent. Consideration should be given to combining future septic tank installations in areas such as the Carlton - Dodges Ferry - Lewisham district with evapo-transpiration beds rather than adsorption fields.

5.2.7 Suitability of Official Recommendations in Tasmania Relating to STAF operation

(a) Objective

To assess the suitability of official recommendations in Tasmania relating to septic tanks and adsorption fields.

(b) Conclusions

No official recommendations relating to septic tanks and adsorption fields exist in Tasmania. All actions in this regard are guided by the recommendations of the Victorian Department of Health and the Victorian Environmental Protection Authority.

(c) Implications

The Victorian recommendations used for guidance on matters relating to STAF systems in Tasmania are concerned mainly with adsorption fields. The only considerations they contain relevant to septic tanks are on tank capacity and desludging interval. The unwritten assumptions within these recomemndations are that the optimum conditions for adsorption fields are equivalent to those for septic tanks and that adsorption fields are the only part of the system likely to go awry. This study, however, has shown that the operating requirements of septic tanks are not the same as those of adsorption fields and that septic tanks can also operate ineffectively. It has also been shown that the recommendations on septic tank capacity and desludging interval are not appropriate for some areas of Tasmania. A set of recommendations relating to STAF requirements, their operation and their siting in Tasmania are clearly needed.

5.3 Action Required

In the preceeding discussions several inadequacies in STAF design and operation, generally throughout Tasmania or specifically at the two study sites, were referred to. The need for further research into specific areas of STAF operation was also highlighted. The action required arising from these points is given below. The background to each recommendation has already been given and shall not be repeated, other than to give an appropriate reference.

5.3.1 STAF Design

The following suggestions, bar the final two, for design modification of STAF systems arise from Sections 5.2.4c subsections (iii), (vii) and (viii). The final two recommendations are derived from Sections 5.2.5c and 5.2.6c.

(a) All new septic tank installations should treat all household wastewaters wherever practical.

(b) The capacities of septic tanks should be consistent with the above recommendation.

(c) Septic tanks should be constructed of a material with a low heat conductivity, such as fibreglass.

(d) In areas where the soils are unsuitable for use in adsorption fields and where a nett surface runoff occurs during the time of greatest wastewater load surface dilution should be used as an alternative form of treatment for septic tank effluent.

(e) In areas such as that above the adsorption field should also be well drained.

(f) In areas where the soils are unsuitable for use in adsorption fields and where evaporation exceeds precipitation evapo-transpiration beds should be used instead of adsorption fields for the treatment of septic tank effluent.

(g) In alpine areas wastewater treatment should be conducted in community treatment plants where ever possible.

(h) In alpine areas,in the time lag before community treatment plants are established or where they are impractical, positive incentive should be given to the operators of STAF systems to make appropriate modifications to them.

5.3.2 STAF Operation

The recommendations given below for modifications to STAF operating procedures arise from the discussion in Sections 5.2.4c(iii), 5.2.4c (iv) and 5.2.7c.

(a) The depth of sludge within septic tanks should be checked regularly (annually at least) and removed when necessary. The Department of Health Services, or its representatives, should be responsible for checking the sludge depth whilst the householder should, on receipt of appropriate advice from the above Department, be responsible for removing the sludge.

(b) In areas where the pH of the water used in flushing the toilet may inhibit the septic tank digestion the pH of the tank liquor should be monitored and adjusted when necessary with lime or sodium bicarbonate. Sodium bicarbonate should not be used where the flushing water has a high salinity.

(c) Official recommendations relating to the operating requirement of septic tanks and adsorption fields and their siting in Tasmania should be drawn up and promulgated. These recommendations should stipulate that:

(i) septic tanks are to treat all household wastewaters and that facilities treating only toilet wastes will not be approved unless in special circumstances;

(ii) septic tanks are to be installed in alpine areas only where community treatment plants are impractical;

(iii) the capacities of septic tanks are to be consistent with the recommendations of the Australian Standards Association, unless it is to be used above 600 metres or where the average air temperature does not rise above 15^{o}C, when the recommended sludge storage capacity is to be increased by 40%;

(iv) the sludge within the septic tank is to be removed annually in areas above 600 metres or where the average air temperatures does not exceed 15^{o}C. In lowland areas where this temperature is regularly exceeded the sludge depth is to be checked annually by an appointed authority;

(v) where water whose pH is less than 6.0 is used in the STAF system regular checks on the digestion pH are to be made and adjusted with lime or sodium bicarbonate if outside the pH range 6.0 - 7.5; and

(vi) sodium bicarbonate is not to be used for pH adjustment where the water used in the STAF system is highly saline.

These recommendations should also consider adsorption field requirements, along the lines of the recommendations of the Victorian Department of Health or the Victorian Environmental Protection Authority, but including:

(i) restriction on the use of adsorption fields within a distance, to be determined on-site, of surface or ground water where the surrounding soil has a high percolation rate; and

(ii) the provision that adsorption fields in areas of high precipitation be well drained.

5.3.3 USC STAF System

All the following suggestions for further action arise from Section 5.2.6c subsection (i).

(a) The gradient within the system should be sufficient to generate a self-cleansing flow.

(c) Provision should be made in the construction of the adsorption field for the use of surface water as an alternative form of secondary treatment in winter.

(d) All domestic wastewater, include toilet, kitchen and bathroom wastewater, should be added to the septic tank.

(e) The rate of water use in the hut should be determined.

(f) The capacity of the septic tank installed should be appropriate to the rate of water use determined above plus a 40% allowance for cold weather operation.

(g) Lime or sodium bicarbonate should be added to the septic tank at the start of the ski season.

(h) The pH of the septic tank digestion should be monitored and adjusted with lime or sodium bicarbonate when necessary.

(i) The depth of the accumulated sludge in the septic tank should also be monitored.

(j) The accumulated sludge in the septic tank should be removed annually and adequately disposed of.

5.3.4 Camp Carlton STAF System

The action requirements for the Camp Carlton STAF system given below derive from the discussion in Section 5.2.6c (ii).

(a) The sludge level within the septic tank should be checked annually.

(b) Consideration should be given to replacing the existing adsorption field with an evapo-transpiration bed.

5.3.5 Further Research

Several recommendations for further research may be made arising from the Implications discussed in Section 5.2.

(a) The influence (if any) of fibreglass resin monomers, leached from the resin matrix, upon the digestion microorganisms should be determined.

(b) The usual operating pH of septic tanks should be established and the mechanism(s) controlling this elucidated.

(c) A mechanism of rapidly activating bacterial communities in septic tanks at low temperatures should be developed.

(d) The influence of soil temperature on the activity of microorganisms in soil adsorption fields and treatment efficiency should be investigated.

(e) The minimum percolation rate for effective wastewater treatment in adsorption fields should be established for Tasmanian, and other Australian, soils.

(f) The distance required for effective treatment of septic tank effluent in unconsolidated coastal sands, and similar porous soils, should be determined.

(g) The fate of septic tank effluent in several communities on unconsolidated coastal sands should be investigated.

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APPENDIX A

Mean annual temperature and pH ranges of streams within the principal STAF Regions (based on unpublished data from the Rivers and Water Supply Commission and the Hydro Electric Commission).

Stream	Average Annual Temperature Range+ (°C) Min.	Max.	Mean Annual pH Range+ Min.	Max.
North-west Region				
Arthur River	5.0	14.5	6.03	7.35
Black River	4.2	17.5	5.20	6.83
Cam River	6.8	17.7	6.56	7.28
Camp River	6.1	14.8	6.62	7.34
Duck River	8.0	17.4	6.63	8.01
Elliot Research Weir*	4.0	15.0	6.60	7.2
Flowerdale River	5.6	16.0	6.35	7.14
Inglis River	6.0	16.3	6.54	7.09
Montagu River				
- at Montagu	7.0	17.2	6.36	7.87
- at Togari	5.8	20.0	4.79	7.53
Seabrook Creek	5.6	16.1	6.78	7.91
Regional Average	5.8	16.6	6.22	7.41
North-central Region				
Anderson Creek	6.8	15.4	6.39	7.29
Franklin River	4.4	15.8	6.44	7.28
Meander River	3.7	15.2	6.33	7.55
Mersey River				
- at Latrobe	7.0x	21.7x	6.93x	8.13x
- below Arm River	6.7x	18.1x	5.77x	6.43x
Rubicon River	5.0	15.6	6.93	7.75
Supply River	6.8	15.6	6.79	7.98
Western Creek	3.5	16.5	6.45	7.31
Regional Average	6.2	16.8	6.51	7.47
North-east Region				
George River	6.0	15.8	6.33	7.29
Great Forester River	5.8	16.2	6.09	7.19
Great Mussell Roe River	7.5	17.5	5.78	6.72
River Brid	6.4	16.5	6.22	7.07
Scamander River	6.0	19.3	6.63	7.29
Tomahawk River	6.8	16.0	5.58	6.37
Regional Average	6.4	16.9	6.11	7.00

Stream	Average Annual Temperature Range[+] (°C)		Mean Annual pH Range[+]	
	Min.	Max.	Min.	Max.
<u>South-east Region</u>				
Browns River	6.2	15.4	6.85	7.56
Carlton River	6.2	15.8	7.10	7.88
Clyde River	6.8[x]	15.6[x]	-	-
Derwent River	6.5	16.8	6.71	7.77
Esperance River	4.8	13.8	6.10	7.17
Hamilton Weir*	1.0	19.0	7.48	8.49
Iron Creek	5.2	16.2	7.29	7.97
Mountain River	5.0	16.2	6.73	7.69
North West Bay River	6.2	17.0	7.66	7.81
Ouse River	6.2[+]	18.2[+]	6.90[+]	7.45[+]
Peak Rivulet	4.3	12.3	5.98	7.09
Orielton Rivulet	7.5	17.2	7.69	8.31
Rileys Creek*	4.0	14.0	6.05	7.77
Snug River	5.8	17.2	5.91	7.25
Regional Average	5.4	16.0	6.81	7.71
<u>South-central Region</u>				
Arcadian Creek	4.8[x]	9.6[x]	-	-
Davey River	7.7	14.5	5.39	5.93
Huon River	3.0	9.2	6.64	7.67
Regional Average	5.2	11.1	6.02	6.80

Stream	Average Annual Temperature Range+ (°C) Min.	Max.	Mean Annual pH Range+ Min.	Max.
Central Region				
Black Bobs Rivulet	3.1	13.8	6.6	8.0
Bronte Flume	5.6	18.1	6.4	6.9
Fischer River	2.0+	16.1+	5.76+	6.71+
Florentine River	6.0	15.3	-	-
Lake King William	5.1	18.0	-	-
Little Fischer River	4.2	12.7	6.7	7.2
Tarraleah No. 1. Canal	5.7	15.0	6.3	6.6
Wayatinah Pond	5.3	16.9	6.7	6.8
Regional Average	4.6	15.7	6.41	7.0

+ based on unpublished data from the Rivers and Water Supply Commission.

x based on unpublished data from the Hydro Electric Commission

* for 1978 only

APPENDIX B

Mean monthly minimum and maximum air temperatures for stations within the principal STAF regions of Tasmania (based on unpublished data from the Bureau of Meteorology).

Station	Years of records	J	F	M	A	M	J	J	A	S	O	N	D	Range
		Mean Monthly Air Temperature (°C)												
<u>North-west Region</u>														
Marrawah	29													
-minimum		11.0	11.8	10.9	9.5	8.1	6.7	6.1	6.0	6.7	7.6	8.6	10.0	6.0 - 11.8
-maximum		19.2	19.5	18.2	15.9	13.7	12.2	11.5	11.9	12.9	14.2	15.3	17.1	11.5 - 19.5
Smithton	16													
-minimum		11.4	12.2	10.8	9.1	7.1	5.7	5.1	5.5	6.3	7.2	8.7	10.1	5.1 - 12.2
-maximum		20.9	21.7	20.1	17.6	15.2	13.5	12.7	13.1	14.3	16.1	17.5	19.1	12.7 - 21.7
Wynyard	17													
-minimum		11.3	12.0	10.3	7.8	5.5	4.4	3.7	4.3	5.1	6.4	8.1	9.8	3.7 - 12.0
-maximum		21.0	21.5	20.0	17.6	14.6	13.1	12.4	12.8	14.1	16.1	17.7	19.3	12.4 - 21.5
Stanley	18													
-minimum		12.7	13.0	11.9	10.2	8.2	7.0	6.1	6.2	7.1	8.1	9.5	10.9	6.1 - 13.0
-maximum		21.0	21.1	19.7	17.5	14.9	13.3	12.4	12.8	14.2	15.8	17.6	19.2	12.4 - 21.1
Regional														
-minimum		11.6	12.2	11.0	9.2	7.2	6.0	5.2	5.5	6.3	7.3	8.7	10.2	5.2 - 12.2
-maximum		20.5	21.0	19.5	17.2	14.6	13.0	13.6	14.0	13.9	15.6	17.0	18.9	13.0 - 21.0
-average		16.1	16.6	15.2	13.2	10.9	9.5	9.4	9.8	10.1	11.4	12.9	14.6	9.4 - 16.6

Station	Years of records	Mean Monthly Air Temperature (°C)												
		J	F	M	A	M	J	J	A	S	O	N	D	Range
<u>North-central Region</u>														
Deloraine	7													
-minimum		9.7	10.2	8.2	5.6	3.2	1.0	0.8	1.9	3.2	4.6	7.0	8.5	0.8 - 10.2
-maximum		22.7	23.7	21.0	17.8	14.2	11.9	11.1	11.9	13.9	16.5	18.3	20.6	11.1 - 23.7
Geroge Town	9													
-minimum		12.2	12.8	11.0	8.9	6.5	4.5	4.2	4.6	5.6	7.0	9.2	10.5	4.2 - 12.8
-maximum		22.0	22.9	21.1	18.2	15.2	12.9	12.6	13.1	14.1	16.1	18.3	19.7	12.6 - 22.9
Low Head	83													
-minimum		12.7	13.1	12.1	10.2	8.2	6.5	5.9	6.3	7.3	8.5	10.0	11.6	5.9 - 13.1
-maximum		20.0	20.6	19.2	16.8	14.3	12.3	11.7	12.2	13.2	14.7	16.6	18.5	11.7 - 20.6
Sheffield	13													
-minimum		9.5	10.1	8.5	6.3	4.0	2.5	2.2	2.8	3.7	4.9	6.7	8.3	2.2 - 10.1
-maximum		20.7	21.7	19.3	16.1	13.2	11.0	10.4	11.1	12.8	15.2	16.8	18.8	10.4 - 21.7
Regional														
-minimum		11.1	11.5	10.0	7.8	5.5	3.6	3.3	3.9	5.0	6.2	8.2	9.7	3.3 - 11.5
-maximum		21.3	22.2	20.2	17.2	14.2	12.0	11.4	12.1	14.7	15.6	19.6	19.4	11.4 - 22.2
-average		16.2	16.8	15.1	12.5	9.8	7.8	7.4	8.0	9.8	10.9	13.9	14.6	7.4 - 16.8

Station	Years of Records	Mean Monthly Air Temperature (°C) J	F	M	A	M	J	J	A	S	O	N	D	Range
<u>North-east region</u>														
Bicheno	9													
-minimum		12.3	13.1	12.0	10.5	8.5	6.7	6.1	6.5	7.3	8.4	9.8	11.1	6.1 - 13.1
-maximum		20.6	21.7	20.6	19.2	16.1	14.3	13.9	14.3	16.0	17.5	18.2	19.6	13.9 - 21.7
Bridport	9													
-minimum		12.2	12.5	10.7	9.0	7.1	4.8	3.5	4.8	5.8	7.5	9.7	11.0	3.5 - 12.5
-maximum		21.8	22.8	21.4	18.7	15.0	14.0	13.2	13.7	14.7	16.6	18.5	19.9	13.2 - 22.8
Eddystone Point	68													
-minimum		12.8	13.6	12.8	10.9	9.1	7.5	6.7	6.8	7.7	8.8	10.1	11.7	6.7 - 13.6
-maximum		20.4	20.7	19.7	17.5	15.2	13.2	12.7	13.2	14.4	15.9	17.4	19.0	12.7 - 20.7
Scottsdale	24													
-minimum		10.5	11.1	9.7	7.3	5.2	3.6	2.8	3.5	4.2	5.8	7.2	9.0	2.8 - 11.1
-maximum		22.0	22.2	20.3	17.2	14.1	12.1	11.4	12.1	13.7	15.9	17.6	19.6	11.4 - 22.2
Regional														
-minimum		12.0	12.6	11.3	9.4	7.5	5.6	5.3	5.4	6.2	7.6	9.2	10.7	5.3 - 12.6
-maximum		21.2	25.0	20.5	18.2	15.1	13.4	12.8	13.3	14.7	16.5	17.9	19.5	12.8 - 20.5
-average		16.6	18.8	15.9	14.7	13.2	9.5	9.0	9.4	10.5	12.0	13.6	15.1	9.0 - 18.8

Station	Years of Records	J	F	M	A	M	J	J	A	S	O	N	D	Range
		Mean Monthly Air Temperature (°C)												
<u>South-east Region</u>														
Geeveston	7													
-minimum		9.5	9.5	8.8	6.7	4.5	2.6	1.3	1.8	4.2	5.3	6.9	9.1	1.3 - 9.5
-maximum		22.1	22.5	20.7	17.6	14.3	12.0	11.7	12.6	14.3	16.2	17.7	19.8	11.7 - 22.5
Grove	26													
-minimum		9.2	9.5	7.9	6.8	4.1	2.4	2.0	2.3	3.7	5.4	6.8	8.6	2.0 - 9.5
-maximum		22.4	22.3	20.4	17.5	14.1	11.9	11.5	12.6	14.6	16.6	18.0	20.1	11.5 - 22.4
Hobart	94													
-minimum		11.6	11.8	10.6	8.7	6.7	5.1	4.4	5.0	6.2	7.5	9.0	10.5	4.4 - 11.8
-maximum		21.4	21.5	20.0	17.1	14.2	11.8	11.4	12.8	14.9	16.7	18.4	20.1	11.4 - 21.5
Hobart Airport	30													
-minimum		11.5	11.5	10.4	8.2	6.1	4.2	3.6	3.8	5.4	6.9	8.5	10.2	3.6 - 11.5
-maximum		22.3	21.7	20.8	17.6	14.4	12.5	12.0	12.7	15.1	16.9	18.3	20.3	12.0 - 22.3
Risdon	54													
-minimim		11.6	11.9	11.3	9.0	7.0	4.9	4.3	4.8	6.0	7.7	6.1	10.7	4.3 - 11.9
-maximum		21.9	21.7	20.4	17.3	14.3	11.5	11.6	12.9	15.1	16.9	18.5	20.1	11.5 - 21.9
Regional														
-minimum		10.7	10.8	9.8	7.9	5.7	3.8	3.1	3.5	5.1	6.6	7.5	9.8	3.1 - 10.8
-maximum		22.0	21.9	20.5	17.4	14.3	11.9	11.6	12.7	14.8	16.7	18.2	20.1	11.6 - 22.0
-average		16.4	16.4	15.1	12.7	10.0	7.9	7.4	8.1	10.0	11.6	12.8	14.9	7.4 - 16.4

Station	Years of Records	Mean Monthly Air Temperature (°C)												
		J	F	M	A	M	J	J	A	S	O	N	D	Range
<u>South-central Region</u>														
Hastings	20													
-minimum		9.6	9.8	8.7	7.3	5.0	3.5	2.8	2.9	3.8	6.0	6.8	8.2	2.8 - 9.8
-maximum		20.6	19.6	19.2	16.7	13.4	11.9	10.7	12.3	13.7	16.5	17.0	18.9	10.7 - 20.6
Port Davey	3 - 5													
-minimum		9.1	9.9	8.8	7.9	6.7	5.4	4.7	5.2	5.4	6.1	7.5	7.8	4.7 - 9.9
-maximum		19.1	20.1	17.9	15.8	13.4	12.2	11.9	12.6	14.4	15.7	16.1	19.3	11.9 - 20.1
Strathgordon	7													
-minimum		9.6	10.2	8.7	6.9	5.1	3.6	3.0	2.9	4.3	5.3	6.7	8.2	2.9 - 10.2
-maximum		20.2	21.0	17.9	14.4	11.5	9.2	9.0	9.7	11.2	13.3	15.4	17.2	9.0 - 21.0
Regional														
-minimum		9.4	10.0	8.7	7.4	5.6	4.2	3.5	3.7	4.5	5.8	7.0	8.1	3.5 - 10.0
-maximum		20.0	20.2	18.3	15.6	12.8	11.1	10.5	11.5	14.6	15.2	16.2	18.5	10.5 - 20.2
-average		14.7	15.1	13.5	11.5	9.2	7.6	7.0	7.6	9.6	10.5	11.6	13.3	7.0 - 15.1

Station	Years of Records	J	F	M	A	M	J	J	A	S	O	N	D	Range
		Mean Monthly Air Temperature (°C)												
<u>Central Region</u>														
Bronte Park	25													
-minimum		7.0	7.0	5.5	3.8	2.1	0.7	0.0	0.2	1.4	2.9	4.1	5.8	0.0 - 7.0
-maximum		20.4	20.4	18.1	14.2	10.6	8.7	7.8	8.7	11.2	13.8	15.3	17.7	7.8 - 20.4
Butlers Gorge	33													
-minimum		6.3	6.4	5.2	3.2	1.7	0.2	-0.4	-0.2	0.8	2.4	3.9	5.4	-0.4 - 6.4
-maximum		19.1	18.8	16.5	12.9	9.7	7.6	6.9	7.7	10.1	12.3	14.1	16.6	6.9 - 19.1
Cradle Valley	50													
-minimum		5.2	5.9	4.6	3.1	1.5	-0.2	-0.2	-0.5	0.3	1.5	2.6	4.1	-0.5 - 5.9
-maximum		16.6	17.0	14.5	10.9	7.9	4.9	4.6	4.9	7.5	10.5	12.8	15.1	4.6 - 17.0
Lake St. Clair	25													
-minimum		7.2	7.6	6.1	4.4	2.5	1.1	0.3	0.5	1.3	3.0	4.4	6.1	0.3 - 7.6
-maximum		18.5	18.8	16.1	12.5	9.3	7.4	6.5	7.5	9.4	11.9	13.4	15.9	6.5 - 18.8
Regional														
-minimum		6.4	6.7	5.4	3.6	2.0	0.4	-0.1	0.0	1.0	2.4	3.8	5.4	-0.1 - 6.7
-maximum		18.6	18.8	16.3	12.6	9.4	7.2	6.5	7.2	9.6	12.7	14.8	17.7	6.5 - 18.8
-average		12.5	12.7	10.8	8.1	5.7	3.8	3.2	3.6	5.3	7.6	9.3	11.5	3.2 - 12.7

APPENDIX C

Hourly temperature recordings around the University Ski Club (USC) Hut, Mt Mawson, from 1 July to 23 September 1978.

Date: 2-3 July 1978 Site: USC, Mt Mawson

Time	Temperature °C					
	Probe 1	Probe 2	Probe 4	Probe 6	Probe 8	Probe 9
1500	1.3	1.4	1.3	1.7	1.2	1.2
1600	2.0	1.9	1.3	1.7	1.2	1.2
1700	2.0	1.5	1.3	1.8	1.1	1.1
1800	2.0	1.5	1.3	1.8	1.2	1.2
1900	2.0	1.4	1.3	1.9	1.1	1.1
2000	2.0	1.0	1.3	2.0	1.2	1.2
2100	2.0	1.0	1.2	2.0	1.1	1.1
2200	2.0	0.8	1.3	2.1	1.2	1.2
2300	2.0	0.6	1.3	2.1	1.2	1.2
2400	2.0	0.6	1.3	2.2	1.2	1.2
0100	2.0	0.6	1.3	2.2	1.2	1.2
0200	2.0	0.7	1.2	2.3	1.2	1.2
0300	2.0	0.8	1.2	2.3	1.2	1.2
0400	2.0	0.8	1.2	2.3	1.2	1.2
0500	2.0	0.8	1.2	2.4	1.2	1.2
0600	2.0	0.9	1.3	2.4	1.2	1.2
0700	2.0	0.9	1.2	2.4	1.2	1.2
0800	2.0	0.8	1.3	2.5	1.2	1.2
0900	2.0	0 9	1.3	2.6	1.2	1.2

Date: 3-4 July 1978 Site: USC, Mt Mawson

Time	Temperature °C					
	Probe 1	Probe 2	Probe 4	Probe 6	Probe 8	Probe 9
1000	2.0	0.8	1.3	2.4	1.2	1.2
1100	2.0	1.1	1.3	2.7	1.2	1.2
1200	2.0	1.0	1.3	2.7	1.2	1.2
1300	2.0	1.1	1.3	2.8	1.2	1.2
1400	2.0	1.1	1.3	2.8	1.2	1.2
1500	2.0	1.0	1.2	2.8	1.2	1.2
1600	2.0	1.1	1.3	2.8	1.2	1.2
1700	2.0	1.0	1.2	2.7	1.2	1.2
1800	2.0	0.9	1.2	2.7	1.2	1.2
1900	1.9	0.9	1.2	2.7	1.2	1.2
2000	1.9	0.8	1.2	2.7	1.2	1.2
2100	1.9	0.4	1.2	2.7	1.2	1.2
2200	1.8	0.3	1.2	2.7	1.2	1.2
2300	1.8	0.2	1.2	2.7	1.2	1.2
2400	1.9	0.0	1.2	2.7	1.1	1.1
0100	1.9	0.0	1.2	2.8	1.2	1.2
0200	1.9	-0.1	1.2	2.7	1.2	1.2
0300	1.9	-0.2	1.2	2.8	1.2	1.2
0400	1.9	0.0	1.2	2.8	1.2	1.2
0500	1.9	0.0	1.2	2.8	1.2	1.2
0600	1.9	0.1	1.2	2.8	1.2	1.2
0700	1.9	0.2	1.2	2.8	1.2	1.2
0800	1.9	0.0	1.2	2.8	1.2	1.2
0900	1.9	0.0	1.2	2.8	1.2	1.2

Date: 4-5 July 1978 Site: USC, Mt Mawson

Time	Temperature °C					
	Probe 1	Probe 2	Probe 4	Probe 6	Probe 8	Probe 9
1000	1.9	0.0	1.2	2.9	1.2	1.2
1100	1.9	0.3	1.2	2.9	1.2	1.2
1200	1.9	0.2	1.2	2.9	1.2	1.2
1300	1.9	0.2	1.2	2.9	1.2	1.2
1400	1.9	-0.1	1.2	2.9	1.2	1.2
1500	1.9	-0.2	1.2	2.9	1.2	1.2
1600	1.9	-0.8	1.2	2.9	1.2	1.2
1700	1.9	-1.2	1.2	2.9	1.2	1.2
1800	1.9	-1.0	1.2	2.9	1.2	1.2
1900	1.9	-1.1	1.2	2.9	1.2	1.2
2000	1.9	-1.2	1.2	2.9	1.2	1.2
2100	1.9	-1.2	1.2	2.9	1.2	1.2
2200	1.9	-1.6	1.2	2.9	1.2	1.2
2300	2.0	-1.2	1.2	2.9	1.2	1.2
2400	2.0	-1.2	1.2	2.9	1.2	1.2
0100	2.0	-1.0	1.4	2.9	1.2	1.2
0200	2.0	-1.0	1.4	2.9	1.2	1.2
0300	2.0	-0.5	1.4	2.9	1.2	1.2
0400	2.0	-0.3	1.4	2.9	1.2	1.2
0500	2.0	0.0	1.4	2.9	1.2	1.2
0600	2.0	0.2	1.4	2.9	1.2	1.2
0700	2.0	0.4	1.4	2.9	1.2	1.2
0800	2.0	0.4	1.4	2.9	1.2	1.2
0900	2.0	0.7	1.4	2.9	1.2	1.2

Date: 5-6 July 1978 Site: USC, Mt Mawson

Time	Temperature °C					
	Probe 1	Probe 2	Probe 4	Probe 6	Probe 8	Probe 9
1000	2.0	0.9	1.4	2.9	1.2	1.2
1100	2.0	0.9	1.4	2.9	1.2	1.2
1200	2.0	0.4	1.4	2.9	1.2	1.2
1300	2.0	-0.6	1.4	2.9	1.2	1.2
1400	2.0	-1.0	1.4	2.9	1.2	1.2
1500	2.0	-1.2	1.4	2.9	1.2	1.2
1600	2.0	-1.2	1.4	2.9	1.2	1.2
1700	2.0	-1.8	1.4	3.0	1.2	1.2
1800	2.0	-1.6	1.4	3.0	1.2	1.2
1900	2.0	-1.2	1.4	3.0	1.2	1.2
2000	2.0	-1.2	1.4	3.0	1.2	1.2
2100	2.0	-1.0	1.4	3.0	1.2	1.2
2200	2.0	-1.0	1.4	3.0	1.2	1.2
2300	2.0	-0.9	1.4	3.0	1.2	1.2
2400	2.0	-0.8	1.4	3.0	1.2	1.2
0100	2.0	-1.0	1.5	2.9	1.2	1.2
0200	2.0	-1.2	1.6	2.9	1.2	1.2
0300	2.0	-1.1	1.7	2.9	1.2	1.2
0400	2.0	-1.2	1.7	3.0	1.2	1.2
0500	2.0	-1.0	1.7	3.0	1.2	1.2
0600	2.0	-1.0	1.7	3.0	1.2	1.2
0700	2.0	-0.9	1.6	3.0	1.2	1.2
0800	2.0	-0.9	1.6	3.0	1.2	1.2
0900	2.0	-1.3	1.6	3.0	1.2	1.2

Date: 6-7 July 1978 Site: USC, Mt Mawson

Time	Temperature °C					
	Probe 1	Probe 2	Probe 4	Probe 6	Probe 8	Probe 9
1000	2.0	-1.2	1.7	3.0	1.2	1.2
1100	2.0	-1.1	1.7	3.0	1.2	1.2
1200	2.0	-1.4	1.7	3.0	1.2	1.2
1300	2.0	-2.1	1.7	3.0	1.2	1.2
1400	2.0	-2.5	1.8	3.0	1.2	1.2
1500	2.0	-2.2	1.8	3.0	1.2	1.2
1600	2.0	-2.8	1.8	3.0	1.2	1.2
1700	2.0	-2.9	1.7	3.0	1.2	1.2
1800	2.0	-2.9	1.7	3.0	1.2	1.2
1900	2.0	-3.0	1.8	3.0	1.2	1.2
2000	2.1	-2.9	1.8	3.0	1.2	1.2
2100	2.1	-3.1	1.9	3.0	1.2	1.2
2200	2.1	-2.9	1.8	3.0	1.2	1.2
2300	2.1	-2.8	1.9	3.0	1.2	1.2
2400	2.1	-2.6	1.9	3.0	1.2	1.2
0100	2.2	-2.4	1.8	3.0	1.2	1.2
0200	2.2	-1.9	1.8	3.1	1.2	1.2
0300	2.2	-1.7	1.8	3.1	1.2	1.2
0400	2.2	-1.2	1.8	3.4	1.2	1.2
0500	2.2	-1.1	1.8	3.1	1.2	1.2
0600	2.2	-0.6	1.8	3.1	1.2	1.2
0700	2.2	-0.3	1.8	3.1	1.2	1.2
0800	2.2	0.0	1.8	3.1	1.2	1.2
0900	2.1	0.7	1.8	3.0	1.2	1.2

Date: 7-8 July 1978 Site: USC, Mt Mawson

Time	Temperature °C					
	Probe 1	Probe 2	Probe 4	Probe 6	Probe 8	Probe 9
1000	2.1	1.1	1.8	3.0	1.2	1.2
1100	2.0	1.1	1.8	3.0	1.2	1.2
1200	2.0	1.5	1.8	3.0	1.2	1.2
1300	2.0	1.4	1.8	3.0	1.2	1.2
1400	2.0	1.5	1.8	3.0	1.2	1.2
1500	2.0	1.2	1.8	3.0	1.2	1.2
1600	2.0	1.0	1.8	3.0	1.2	1.2
1700	2.0	0.9	1.8	3.0	1.2	1.2
1800	2.0	0.9	1.8	3.0	1.2	1.2
1900	2.0	1.0	1.8	3.0	1.2	1.2
2000	2.0	1.0	1.8	3.0	1.2	1.2
2100	2.0	1.0	1.8	3.0	1.2	1.2
2200	2.0	1.0	1.8	3.0	1.2	1.2
2300	2.0	0.9	1.8	3.0	1.2	1.2
2400	1.8	0.9	1.8	3.0	1.2	1.2
0100	1.8	0.9	1.7	3.0	1.2	1.2
0200	1.8	0.8	1.7	2.9	1.2	1.2
0300	1.8	0.7	1.7	2.9	1.2	1.2
0400	1.8	0.5	1.7	2.9	1.2	1.2
0500	1.8	0.8	1.7	2.9	1.2	1.2
0600	1.8	0.4	1.7	2.9	1.2	1.2
0700	1.8	0.2	1.7	2.9	1.2	1.2
0800	1.8	0.4	1.7	2.9	1.2	1.2
0900	1.8	0.7	1.7	2.8	1.2	1.2

Date: 8-9 July 1978 Site: USC, Mt Mawson

Time	Temperature °C					
	Probe 1	Probe 2	Probe 4	Probe 6	Probe 8	Probe 9
1000	1.8	0.9	1.6	2.8	1.2	1.2
1100	1.8	1.1	1.6	2.8	1.2	1.2
1200	1.8	0.8	1.6	2.8	1.2	1.2
1300	1.8	0.9	1.6	2.8	1.2	1.2
1400	1.7	0.4	1.4	2.8	1.2	1.2
1500	1.5	0.3	1.4	2.8	1.2	1.2
1600	1.6	0.2	1.3	2.8	1.2	1.2
1700	1.6	0.1	1.3	2.7	1.2	1.2
1800	1.6	-0.1	1.3	2.6	1.2	1.2
1900	1.6	-0.3	1.5	2.6	1.2	1.2
2000	1.5	-0.6	1.5	2.5	1.2	1.2
2100	1.5	-0.5	1.5	2.5	1.2	1.2
2200	1.5	-0.3	1.5	2.5	1.2	1.2
2300	1.5	-0.2	1.5	2.5	1.2	1.2
2400	1.5	-0.6	1.5	2.5	1.2	1.2
0100	1.5	-0.5	1.4	2.6	1.2	1.2
0200	1.6	-0.2	1.4	2.6	1.2	1.2
0300	1.7	-0.4	1.4	2.6	1.2	1.2
0400	1.8	-0.3	1.4	2.6	1.2	1.2
0500	1.8	-0.7	1.4	2.6	1.2	1.2
0600	1.8	-0.9	1.4	2.6	1.2	1.2
0700	1.8	-0.8	1.4	2.6	1.2	1.2
0800	1.8	-0.9	1.4	2.6	1.2	1.2
0900	1.8	-0.9	1.4	2.6	1.2	1.2

Date: 9-10 July 1978 Site: USC, Mt Mawson

Time	Temperature °C					
	Probe 1	Probe 2	Probe 4	Probe 6	Probe 8	Probe 9
1000	1.9	-0.7	1.4	2.6	1.2	1.2
1100	1.9	-0.6	1.5	2.6	1.2	1.2
1200	1.9	-0.2	1.5	2.6	1.2	1.2
1300	1.9	0.8	1.5	2.7	1.2	1.2
1400	1.9	0.3	1.6	2.8	1.4	1.4
1500	2.0	0.5	1.8	2.8	1.6	1.6
1600	2.2	0.0	1.9	2.8	1.7	1.7
1700	2.2	-0.9	1.9	2.8	1.7	1.7
1800	2.2	-1.0	1.9	2.8	1.7	1.7
1900	2.1	-1.4	1.8	2.8	1.8	1.8
2000	-	-	-	-	-	-
2100	2.2	-1.2	2.0	2.9	1.8	1.8
2200	2.2	-1.8	2.0	2.9	1.8	1.8
2300	2.3	-1.2	2.2	3.1	1.9	1.9
2400	2.4	-1.5	2.0	3.0	1.9	1.9
0100	2.4	-1.5	2.2	3.1	1.9	1.9
0200	2.5	-1.4	2.1	3.1	1.9	1.9
0300	2.5	-1.5	2.1	3.0	1.9	1.9
0400	2.5	-1.2	2.0	3.0	1.9	1.9
0500	2.7	-1.4	2.1	3.0	1.9	1.9
0600	2.7	-1.0	2.1	3.1	1.9	1.9
0700	2.7	-1.0	2.0	3.0	1.9	1.9
0800	2.9	-0.3	2.2	3.3	2.1	2.1
0900	3.0	0.0	2.3	3.3	2.1	2.1

Date: 10-11 July 1978　　　　Site: USC, Mt Mawson

Time	Temperature °C					
	Probe 1	Probe 2	Probe 4	Probe 6	Probe 8	Probe 9
1000	2.7	-0.7	2.1	3.2	2.0	2.0
1100	2.9	-0.2	2.2	3.2	2.0	2.0
1200	3.3	0.3	2.3	3.3	2.0	2.0
1300	3.0	0.0	2.3	3.2	2.0	2.0
1400	2.8	0.1	2.2	3.1	2.0	2.0
1500	2.9	0.3	2.2	3.2	2.0	2.0
1600	3.0	0.4	2.3	3.2	2.0	2.0
1700	3.0	0.4	2.4	3.2	2.0	2.0
1800	3.0	0.7	2.4	3.2	2.0	2.0
1900	2.9	0.8	2.2	3.2	2.0	2.0
2000	2.8	0.9	2.2	3.0	1.9	1.9
2100	3.2	1.2	2.6	3.4	2.2	2.2
2200	3.2	1.5	2.5	3.3	2.1	2.1
2300	3.5	1.1	2.7	3.3	2.1	2.1
2400	3.5	1.0	2.6	3.4	2.3	2.3
0100	3.2	1.0	2.5	3.3	2.2	2.2
0200	3.2	0.8	2.4	3.3	2.0	2.0
0300	3.0	0.7	2.3	3.3	2.0	2.0
0400	2.9	0.5	2.2	3.3	2.0	2.0
0500	3.0	0.4	2.3	3.3	2.0	2.0
0600	3.0	0.2	2.3	3.3	2.0	2.0
0700	3.0	0.2	2.3	3.3	2.0	2.0
0800	3.0	0.0	2.2	3.3	2.0	2.0
0900	3.0	0.0	2.3	3.3	2.0	2.0

Date: 11-12 July 1978 Site: USC, Mt Mawson

Time	Temperature °C					
	Probe 1	Probe 2	Probe 4	Probe 6	Probe 8	Probe 9
1000	3.0	0.2	2.3	3.3	2.0	2.0
1100	3.0	0.4	2.3	3.3	2.0	2.0
1200	3.0	0.7	2.3	3.5	2.0	2.0
1300	3.0	0.4	2.3	3.3	2.0	2.0
1400	3.0	0.2	2.3	3.4	2.0	2.0
1500	3.2	-0.2	2.3	3.3	2.0	2.0
1600	3.5	0.0	2.4	3.4	2.2	2.2
1700	3.5	0.2	2.6	3.5	2.3	2.3
1800	3.7	0.3	2.8	3.6	2.3	2.3
1900	3.7	0.3	2.7	3.6	2.3	2.3
2000	4.0	0.5	2.7	3.7	2.2	2.2
2100	4.1	0.5	2.9	3.7	2.5	2.5
2200	4.0	0.3	3.0	3.8	2.4	2.4
2300	4.4	1.3	2.9	3.8	2.3	2.3
2400	4.5	1.8	2.8	3.7	2.3	2.3
0100	4.5	1.5	2.8	3.7	2.3	2.3
0200	4.4	2.0	2.9	3.8	2.3	2.3
0300	5.0	2.5	3.0	3.9	2.7	2.6
0400	5.2	0.0	2.6	3.6	2.3	2.3
0500	4.3	0.8	2.8	3.6	2.3	2.3
0600	4.4	0.6	2.9	3.7	2.3	2.3
0700	5.0	0.0	3.1	4.0	2.9	2.9
0800	2.8	0.0	2.6	3.6	2.5	2.5
0900	4.0	0.8	2.8	3.7	2.6	2.4

Date: 12-13 July 1978 Site: USC, Mt Mawson

Time	Temperature °C					
	Probe 1	Probe 2	Probe 4	Probe 6	Probe 8	Probe 9
1000	3.9	0.6	2.7	3.6	2.2	2.2
1100	4.0	0.8	2.8	3.6	2.3	2.6
1200	4.3	1.0	2.9	3.6	2.4	2.4
1300	4.3	1.2	2.9	3.6	2.4	2.4
1400	4.3	1.2	3.0	3.6	2.4	2.4
1500	4.4	1.5	3.0	3.6	2.4	2.4
1600	4.2	1.0	2.8	3.6	2.4	2.4
1700	3.5	0.8	2.6	3.4	2.0	2.0
1800	3.2	0.2	2.5	3.3	2.0	2.0
1900	3.2	0.2	2.4	3.3	2.0	2.0
2000	3.2	0.0	2.4	3.3	2.0	2.0
2100	3.2	0.0	2.3	3.3	2.0	2.0
2200	3.1	0.0	2.3	3.3	2.0	2.0
2300	3.3	0.3	2.3	3.3	2.0	2.0
2400	3.3	0.2	2.3	3.3	2.0	2.0
0100	3.2	0.2	2.5	3.4	2.1	2.1
0200	3.2	0.3	2.5	3.4	2.1	2.1
0300	3.5	1.0	2.5	3.4	2.1	2.1
0400	3.7	1.2	2.7	3.6	2.1	2.1
0500	3.7	1.1	2.7	3.6	2.1	2.1
0600	3.8	1.1	2.7	3.5	2.1	2.1
0700	3.6	1.0	2.7	3.4	2.1	2.1
0800	3.4	0.8	2.7	3.4	2.1	2.1
0900	3.4	0.8	2.7	3.4	2.1	2.1

Date: 13-14 July 1978 Site: USC, Mt Mawson

Time	Temperature °C					
	Probe 1	Probe 2	Probe 4	Probe 6	Probe 8	Probe 9
1000	3.5	0.8	2.7	3.4	2.1	2.1
1100	3.2	0.7	2.7	3.4	2.1	2.1
1200	3.1	0.8	2.7	3.4	2.1	2.1
1300	3.2	2.0	2.9	3.4	2.2	2.1
1400	3.2	2.0	2.7	3.4	2.1	2.1
1500	3.2	2.3	2.7	3.4	2.1	2.1
1600	3.1	3.0	2.6	3.4	2.1	2.1
1700	3.0	2.9	2.5	3.4	2.0	2.0
1800	3.0	3.0	2.4	3.2	2.0	2.0
1900	3.0	3.1	2.3	3.2	2.0	2.0
2000	2.8	3.0	2.3	3.2	2.0	2.0
2100	2.7	3.0	2.2	3.0	2.0	2.0
2200	2.7	3.0	2.3	3.0	2.0	2.0
2300	2.8	3.0	2.3	3.0	2.0	2.0
2400	2.8	3.0	2.3	3.0	2.0	2.0
0100	2.7	2.5	2.3	3.0	2.0	2.0
0200	-	-	-	-	-	-
0300	-	-	-	-	-	-
0400	2.8	2.0	2.3	3.1	2.0	2.0
0500	3.0	2.2	2.5	3.2	2.1	2.1
0600	2.8	2.2	2.3	3.1	2.0	2.0
0700	3.0	2.0	2.6	3.3	2.1	2.1
0800	3.0	1.8	2.5	3.1	2.0	2.0
0900	3.0	2.0	2.4	3.1	2.0	2.0

Date: 14-15 July 1978 Site: USC, Mt Mawson

Time	Temperature °C					
	Probe 1	Probe 2	Probe 4	Probe 6	Probe 8	Probe 9
1000	2.9	2.0	2.4	3.1	2.0	2.0
1100	2.9	1.7	2.3	3.1	2.0	2.0
1200	3.0	2.3	2.3	3.2	2.0	2.0
1300	3.0	2.5	2.5	3.2	2.0	2.0
1400	3.0	3.0	2.5	3.2	2.0	2.0
1500	3.0	3.2	2.7	3.3	2.1	2.1
1600	3.0	4.0	2.6	3.3	2.1	2.1
1700	2.9	2.3	2.4	3.2	2.0	2.0
1800	2.8	2.2	2.2	3.2	1.9	1.9
1900	2.5	2.2	2.2	3.2	1.9	1.9
2000	2.6	2.2	2.2	3.2	1.9	1.9
2100	2.8	2.2	2.3	3.2	2.0	2.0
2200	-	-	-	-	-	-
2300	-	-	-	-	-	-
2400	2.4	2.2	2.2	3.1	1.9	1.9
0100	2.5	3.0	2.2	3.0	1.9	1.8
0200	2.5	2.8	2.2	3.0	1.8	1.8
0300	2.3	2.4	2.1	3.0	1.8	1.8
0400	2.3	2.2	2.1	3.0	1.8	1.8
0500	2.4	2.4	1.1	3.0	1.8	1.8
0600	2.3	2.7	2.2	3.0	1.8	1.8
0700	2.4	3.0	2.1	3.0	1.8	1.8
0800	2.4	3.0	2.1	3.0	1.8	1.8
0900	2.4	2.9	2.1	3.0	1.8	1.8

Date: 15-16 July 1978 Site: USC, Mt Mawson

Time	Temperature °C					
	Probe 1	Probe 2	Probe 4	Probe 6	Probe 8	Probe 9
1000	2.6	3.1	2.2	3.0	1.8	1.8
1100	2.7	3.3	2.2	3.0	1.8	1.8
1200	2.6	3.8	2.2	3.0	1.8	1.8
1300	2.5	4.0	2.2	3.0	1.8	1.8
1400	2.5	3.7	2.1	3.0	1.8	1.8
1500	2.5	3.8	2.1	3.0	1.8	1.8
1600	2.4	3.4	2.1	3.0	1.8	1.8
1700	2.4	3.5	2.1	3.0	1.8	1.8
1800	2.4	3.8	-	3.0	1.8	1.8
1900	2.5	3.9	2.2	3.0	2.2	2.2
2000	2.3	3.9	2.1	3.0	2.0	2.2
2100	2.2	3.9	2.1	2.8	2.0	2.0
2200	2.2	4.0	2.0	2.7	2.1	2.1
2300	2.2	4.0	2.0	2.7	2.1	2.1
2400	-	-	-	-	-	-
0100	2.3	4.2	2.2	2.0	2.5	2.5
0200	2.5	4.2	2.3	2.1	2.5	2.5
0300	2.8	4.3	2.3	2.3	2.9	2.9
0400	2.8	4.7	2.2	2.2	2.7	2.7
0500	2.4	4.3	2.1	2.1	2.3	2.3
0600	2.4	4.5	2.1	2.1	2.2	2.2
0700	2.5	4.6	2.1	2.1	2.3	2.3
0800	3.0	5.0	2.1	2.1	2.3	2.3
0900	2.4	5.0	2.0	2.0	2.1	2.1

Date: 16-17 July 1978 Site: USC, Mt Mawson

Time	Temperature °C					
	Probe 1	Probe 2	Probe 4	Probe 6	Probe 8	Probe 9
1000	2.5	4.9	2.0	2.0	2.1	2.1
1100	2.4	4.2	2.1	2.1	2.2	2.1
1200	2.4	3.7	2.0	2.0	2.1	2.1
1300	2.5	3.8	2.0	2.0	2.2	2.2
1400	2.5	3.7	2.0	2.0	2.4	2.4
1500	2.3	3.3	2.0	1.9	2.9	2.9
1600	2.3	3.0	1.9	1.9	2.9	2.9
1700	2.3	2.9	1.9	1.9	2.9	2.9
1800	-	-	-	-	-	-
1900	2.2	3.5	1.9	1.9	2.9	2.9
2000	-	-	-	-	-	-
2100	2.2	3.4	1.8	1.8	2.9	2.9
2200	2.2	3.4	1.9	1.8	2.9	2.9
2300	2.3	3.9	1.9	1.9	2.8	2.8
2400	2.2	2.9	1.8	1.8	2.7	2.7
0100	2.2	2.8	1.8	1.7	2.3	2.3
0200	2.2	2.8	1.8	1.8	2.3	2.3
0300	2.2	3.4	1.8	1.8	2.3	2.3
0400	2.2	3.0	1.8	1.8	2.3	2.3
0500	2.3	2.7	1.8	1.8	2.3	2.3
0600	2.3	2.3	1.8	1.8	2.3	2.3
0700	2.3	2.8	1.8	1.8	2.3	2.3
0800	2.3	3.0	1.8	1.8	2.3	2.3
0900	2.3	3.2	2.0	2.0	2.3	2.3

Date: 16-17 July 1978

Site: USC, Mt Mawson

Time	Temperature °C					
	Probe 1	Probe 2	Probe 4	Probe 6	Probe 8	Probe 9
1000	2.6	3.2	2.1	2.1	2.3	2.3
1100	2.7	3.2	2.1	2.1	2.3	2.3
1200	2.5	3.3	2.1	2.1	2.3	2.3
1300	2.8	3.0	2.1	2.1	2.3	2.3
1400	2.8	3.0	2.1	2.1	2.3	2.3
1500	2.8	3.3	2.1	2.1	2.3	2.3
1600	-	-	-	-	-	-
1700	2.7	4.2	2.2	2.2	2.3	2.3
1800	3.0	4.8	2.7	2.7	2.3	2.3
1900	3.0	3.7	2.2	2.2	2.3	2.3
2000	3.0	3.2	2.1	2.1	2.3	2.3
2100	3.0	2.8	2.1	2.1	2.3	2.3
2200	3.0	2.1	2.4	2.1	2.3	2.3
2300	3.2	2.0	2.2	2.2	2.3	2.3
2400	3.6	2.1	2.7	2.7	2.3	2.3
0100	2.3	3.0	1.9	1.8	2.2	2.2
0200	2.4	3.2	1.9	2.1	2.3	2.3
0300	2.6	3.2	2.1	2.0	2.3	2.3
0400	2.7	3.2	2.2	2.1	2.3	2.3
0500	2.5	3.3	2.1	2.1	2.2	2.2
0600	2.6	3.0	2.1	2.0	2.2	2.2
0700	2.7	3.0	2.1	2.0	2.2	2.2
0800	2.7	3.3	2.2	2.0	2.2	2.2
0900	-	-	-	-	-	-

Date: 17-18 July 1978 Site: USC, Mt Mawson

Time	Temperature °C					
	Probe 1	Probe 2	Probe 4	Probe 6	Probe 8	Probe 9
1000	2.7	4.3	2.2	2.2	2.4	2.4
1100	3.0	4.8	2.8	2.4	2.6	2.6
1200	3.0	3.7	2.2	2.3	2.6	2.6
1300	3.0	3.2	2.2	2.1	2.3	2.2
1400	2.9	2.8	2.2	2.1	2.3	2.3
1500	2.7	2.2	2.1	2.0	2.2	2.2
1600	2.9	2.1	2.3	2.2	2.3	2.3
1700	3.3	2.1	2.8	2.7	2.4	2.4
1800	3.2	1.8	2.3	2.2	2.3	2.3
1900	2.8	1.0	2.2	2.1	2.2	2.2
2000	2.8	0.7	2.2	2.0	2.2	2.2
2100	3.2	0.9	2.4	2.2	2.3	2.3
2200	3.0	0.8	2.3	2.2	2.2	2.2
2300	3.0	0.7	2.3	2.1	2.2	2.2
2400	3.0	0.6	2.3	2.2	2.2	2.2
0100	3.2	0.7	2.4	2.2	2.3	2.3
0200	3.2	1.6	2.6	2.3	2.3	2.3
0300	3.2	0.8	2.4	2.2	2.3	2.3
0400	3.0	0.4	2.4	2.3	2.2	2.2
0500	3.2	0.3	2.4	2.3	2.3	2.3
0600	3.2	0.7	2.4	2.3	2.3	2.3
0700	3.2	1.2	2.6	2.3	2.3	2.3
0800	3.2	1.8	2.6	2.3	2.3	2.3
0900	-	-	-	-	-	-

Date: 18-19 July 1978 Site: USC, Mt Mawson

Time	Temperature °C					
	Probe 1	Probe 2	Probe 4	Probe 6	Probe 8	Probe 9
1000	-	-	-	-	-	-
1100	3.0	4.0	2.3	2.3	2.2	2.2
1200	-	-	-	-	-	-
1300	2.3	2.4	2.2	2.2	2.1	2.1
1400	2.7	2.3	2.2	2.2	2.1	2.1
1500	2.8	2.0	2.3	2.3	2.1	2.1
1600	2.8	1.2	2.3	2.3	2.1	2.1
1700	2.6	1.3	2.2	2.3	2.0	2.0
1800	-	-	-	-	-	-
1900	2.8	1.2	2.3	2.3	2.1	2.1
2000	2.6	1.1	2.3	2.3	2.1	2.1
2100	2.7	1.2	2.4	2.3	2.1	2.1
2200	2.6	0.7	2.2	2.3	2.1	2.1
2300	2.7	1.0	2.3	2.2	2.1	2.1
2400	2.6	0.8	2.2	2.2	2.1	2.1
0100	2.6	1.3	2.2	2.2	2.0	2.0
0200	2.7	1.0	2.6	2.3	2.0	2.0
0300	2.7	1.7	2.7	3.0	1.8	2.0
0400	-	3.0	2.4	3.4	2.1	2.0
0500	2.6	3.0	2.3	2.4	2.1	2.0
0600	2.6	3.2	2.3	2.4	2.0	2.0
0700	2.5	3.7	2.2	2.3	1.9	1.9
0800	2.7	3.7	2.4	2.6	2.2	2.1
0900	2.6	3.7	2.3	2.4	2.1	2.1

Date: 19-20 July 1978 Site: USC, Mt Mawson

Time	Temperature °C					
	Probe 1	Probe 2	Probe 4	Probe 6	Probe 8	Probe 9
1000	2.7	3.7	2.3	2.4	2.2	2.1
1100	-	-	-	-	-	-
1200	2.9	3.7	2.2	2.2	1.9	1.9
1300	2.8	3.7	2.2	2.3	2.0	2.0
1400	-	-	-	-	-	-
1500	2.8	3.8	2.5	2.3	2.3	2.3
1600	2.4	3.4	2.2	2.2	2.2	2.2
1700	-	-	-	-	-	-
1800	2.3	3.2	2.3	2.2	2.0	2.0
1900	3.2	3.1	2.2	2.1	2.0	2.0
2000	2.6	3.1	2.2	2.0	2.0	2.0
2100	2.7	3.4	2.2	2.0	2.0	2.0
2200	-	-	-	-	-	-
2300	2.3	2.6	2.1	2.0	2.0	2.0
2400	-	-	-	-	-	-
0100	2.2	3.2	2.1	2.0	2.0	2.0
0200	2.2	2.8	2.1	2.0	1.9	1.9
0300	2.3	2.2	2.1	2.1	1.9	1.9
0400	2.3	2.5	2.1	2.1	2.0	2.0
0500	2.3	2.3	2.1	2.1	2.0	2.0
0600	2.3	2.5	2.1	2.1	2.0	2.0
0700	2.3	2.7	2.1	2.1	2.0	2.0
0800	2.3	2.8	2.2	2.2	2.0	2.0
0900	2.3	2.9	2.1	2.2	2.2	2.2

Date: 20-21 July 1978 Site: USC, Mt Mawson

Time	Temperature °C					
	Probe 1	Probe 2	Probe 4	Probe 6	Probe 8	Probe 9
1000	2.3	3.0	2.1	2.2	2.2	2.2
1100	2.3	3.3	2.1	2.1	2.1	2.1
1200	2.2	3.6	2.1	2.1	2.1	2.1
1300	2.2	3.6	2.0	2.1	2.1	2.1
1400	2.2	3.6	2.0	2.1	2.2	2.2
1500	2.2	3.8	2.1	2.2	2.2	2.2
1600	2.2	3.8	2.3	2.2	2.3	2.3
1700	2.7	3.6	2.2	2.2	2.3	2.3
1800	-	-	-	-	-	-
1900	-	-	-	-	-	-
2000	2.9	3.1	2.5	2.3	2.5	2.5
2100	2.4	2.2	2.2	2.1	2.3	2.3
2200	2.3	1.8	2.1	2.0	2.2	2.2
2300	2.5	2.0	2.2	2.2	2.3	2.3
2400	2.5	2.1	2.3	2.2	2.3	2.3
0100	2.5	2.0	2.3	2.2	2.3	2.3
0200	2.5	2.2	2.2	2.2	2.2	2.2
0300	2.5	2.2	2.2	2.1	2.2	2.2
0400	2.4	2.0	2.2	2.1	2.2	2.2
0500	2.5	1.9	2.2	2.1	2.3	2.3
0600	2.5	1.7	2.2	2.3	2.3	2.3
0700	-	-	-	-	-	-
0800	-	-	-	-	-	-
0900	2.8	1.7	2.3	2.3	2.6	2.6

Date: 21-22 July 1978 Site: USC, Mt Mawson

Time	Temperature °C					
	Probe 1	Probe 2	Probe 4	Probe 6	Probe 8	Probe 9
1000	-	-	-	-	-	-
1100	2.8	2.4	2.4	2.6	2.2	2.2
1200	-	-	-	-	-	-
1300	2.5	3.3	2.2	2.2	2.2	2.2
1400	-	-	-	-	-	-
1500	2.8	3.3	2.5	2.3	2.6	2.7
1600	2.4	3.3	2.2	3.0	2.6	2.7
1700	2.6	3.2	2.2	2.3	2.4	2.4
1800	2.4	3.2	2.1	2.2	2.2	2.2
1900	3.3	4.0	2.7	2.7	2.7	2.7
2000	2.6	4.0	2.2	2.4	2.5	2.5
2100	3.0	3.8	2.5	2.5	2.6	2.6
2200	2.2	3.8	2.1	2.2	2.4	2.4
2300	2.5	3.7	2.2	2.3	2.7	2.7
2400	-	-	-	-	-	-
0100	2.4	4.7	2.4	2.6	2.7	2.8
0200	2.2	3.6	2.0	2.2	2.5	2.5
0300	2.4	3.7	2.2	2.4	3.2	3.3
0400	-	3.6	2.0	2.1	2.8	2.9
0500	2.3	2.8	2.0	2.0	2.9	2.9
0600	2.3	2.9	2.0	1.9	2.3	2.3
0700	2.3	2.3	1.9	1.8	2.3	2.3
0800	2.3	2.2	1.9	1.8	2.3	2.3
0900	2.3	2.2	1.9	1.9	2.2	2.2

Date: 22-23 July 1978 Site: USC, Mt Mawson

Time	Temperature °C Probe 1	Probe 2	Probe 4	Probe 6	Probe 8	Probe 9
1000	2.2	2.3	1.9	1.9	2.7	2.7
1100	2.2	2.8	1.9	1.9	2.6	2.6
1200	2.2	4.2	1.9	1.8	2.5	2.5
1300	2.3	3.3	1.9	1.8	2.6	2.6
1400	2.2	2.8	1.9	1.8	2.7	2.7
1500	2.2	2.2	1.9	1.8	2.6	2.6
1600	2.2	1.9	1.9	1.9	2.8	2.8
1700	-	-	-	-	-	-
1800	2.3	1.8	2.0	1.8	2.8	2.8
1900	2.4	2.1	2.3	2.0	3.2	3.2
2000	2.4	1.8	2.2	2.0	3.0	3.0
2100	2.3	1.7	2.0	1.8	2.8	2.8
2200	2.3	1.5	2.1	1.8	2.8	2.8
2300	2.3	1.4	2.1	1.8	2.8	2.8
2400	2.3	1.5	2.1	1.9	2.9	2.9
0100	2.4	1.2	2.1	2.0	2.9	2.9
0200	2.3	1.1	2.0	2.0	2.9	2.9
0300	2.1	0.2	1.8	1.7	2.5	2.5
0400	2.3	1.0	2.6	2.1	2.9	2.7
0500	2.4	0.4	2.1	1.9	2.7	2.7
0600	2.4	0.5	2.1	2.0	2.7	2.7
0700	2.4	0.6	2.2	2.1	2.8	2.8
0800	2.6	0.9	2.2	2.1	2.8	2.8
0900	2.6	1.3	2.2	2.0	2.8	2.8

Date: 23-24 July 1978 Site: USC, Mt Mawson

Time	Temperature °C					
	Probe 1	Probe 2	Probe 4	Probe 6	Probe 8	Probe 9
1000	1.9	1.0	1.8	1.7	2.2	2.2
1100	1.8	1.2	1.8	1.7	2.2	2.8
1200	1.8	1.3	1.8	1.7	2.2	2.8
1300	1.8	1.4	1.8	1.7	2.2	2.8
1400	1.6	1.2	1.7	1.7	2.2	2.7
1500	1.7	1.3	1.7	1.7	2.4	2.5
1600	1.7	0.8	1.7	1.7	2.7	2.6
1700	1.7	0.8	1.8	1.7	2.6	2.7
1800	1.8	1.0	1.8	1.8	2.8	2.8
1900	1.8	1.0	1.8	1.8	-	2.8
2000	1.8	0.3	1.8	1.8	2.3	2.7
2100	1.8	0.7	1.8	1.8	2.3	2.7
2200	1.8	0.6	1.8	1.8	2.3	2.7
2300	1.8	0.7	1.8	1.8	2.3	2.7
2400	1.8	0.7	1.8	1.8	2.3	2.7
0100	1.8	0.7	1.7	1.8	2.3	2.7
0200	1.8	0.3	1.7	1.8	2.2	2.7
0300	1.8	0.6	1.7	1.8	2.2	2.7
0400	1.8	0.2	1.8	1.8	2.2	2.7
0500	1.8	0.3	1.8	1.6	2.2	2.7
0600	1.8	0.5	1.8	1.5	2.2	2.7
0700	1.4	0.2	1.8	1.5	2.2	2.7
0800	1.9	0.6	1.7	1.5	2.2	2.6
0900	1.9	1.0	1.7	1.5	2.2	2.6

Date: 24-25 July 1978 Site: USC, Mt Mawson

Time	Temperature °C					
	Probe 1	Probe 2	Probe 4	Probe 6	Probe 8	Probe 9
1000	1.9	0.8	1.7	1.5	2.2	2.6
1100	1.9	0.6	1.7	1.5	2.2	2.6
1200	1.9	0.1	1.6	1.5	2.2	2.6
1300	1.9	-0.1	1.6	1.4	2.2	2.6
1400	1.9	-0.1	1.6	1.4	2.1	2.6
1500	1.9	0.2	1.6	1.4	2.1	-
1600	1.9	0.1	1.6	1.4	2.1	2.6
1700	1.9	0.3	1.7	1.4	2.2	2.6
1800	1.9	0.2	1.7	1.4	2.2	2.6
1900	1.8	-0.1	1.7	1.4	2.2	2.6
2000	1.8	-0.3	1.7	1.4	2.1	2.6
2100	1.8	-0.2	1.7	1.4	2.1	2.5
2200	1.9	-0.2	1.7	1.4	2.1	2.5
2300	1.9	0.4	1.7	1.4	2.1	2.5
2400	1.8	0.8	1.7	1.4	2.1	2.4
0100	1.8	0.8	1.7	1.3	2.1	2.4
0200	1.8	0.9	1.7	1.4	2.1	2.4
0300	1.8	0.7	1.7	1.5	2.1	2.4
0400	1.8	0.6	1.7	1.5	2.1	2.4
0500	1.8	0.4	1.7	1.6	2.1	2.4
0600	1.8	0.0	1.7	1.6	2.1	2.4
0700	1.9	-0.3	1.7	1.6	2.1	2.4
0800	1.9	-0.7	1.8	1.7	2.1	2.4
0900	1.9	-0.2	1.8	1.7	2.1	2.4

Date: 25-26 July 1978 Site: USC, Mt Mawson

Time	Temperature °C					
	Probe 1	Probe 2	Probe 4	Probe 6	Probe 8	Probe 9
1000	1.9	0.1	1.8	1.7	2.1	2.4
1100	1.8	0.3	1.7	1.7	2.1	2.4
1200	1.8	1.3	1.7	1.7	2.1	2.4
1300	1.8	2.6	1.7	1.7	2.1	2.3
1400	1.8	3.0	1.7	1.7	2.1	2.3
1500	1.8	2.8	1.7	1.7	2.1	2.3
1600	1.8	1.6	1.7	1.7	2.1	2.3
1700	1.8	0.8	1.7	1.7	2.1	2.3
1800	1.8	0.7	1.7	1.7	2.0	2.3
1900	1.8	0.4	1.7	1.7	2.0	2.3
2000	1.8	0.7	1.7	1.7	2.0	2.3
2100	1.8	0.3	1.7	1.8	2.0	2.3
2200	1.8	0.2	1.7	1.8	2.0	2.3
2300	1.8	-0.4	1.7	1.8	2.0	2.3
2400	1.8	-0.4	1.7	1.8	2.0	2.3
0100	1.8	-0.8	1.7	1.8	2.1	2.3
0200	1.8	-1.0	1.7	1.8	2.1	2.3
0300	1.8	0.0	1.7	1.8	2.1	2.3
0400	1.8	0.3	1.7	1.8	2.1	2.3
0500	1.8	0.8	1.7	1.9	2.1	2.3
0600	1.8	0.8	1.8	1.9	2.2	2.3
0700	1.9	0.7	1.8	1.9	2.2	2.3
0800	1.9	0.8	1.8	1.9	2.2	2.3
0900	1.9	1.2	1.8	1.9	2.1	2.3

Date: 26-27 July 1978 Site: USC, Mt Mawson

Time	Temperature °C					
	Probe 1	Probe 2	Probe 4	Probe 6	Probe 8	Probe 9
1000	1.9	1.3	1.8	1.9	2.1	2.2
1100	1.9	2.8	1.8	1.9	2.1	2.2
1200	1.9	3.2	1.8	1.9	2.1	2.2
1300	1.8	4.6	1.8	1.9	2.1	2.2
1400	1.8	4.7	1.8	1.9	2.2	2.2
1500	1.8	3.2	1.8	1.9	2.2	2.2
1600	1.8	3.3	1.8	1.9	2.1	2.2
1700	1.8	2.5	1.8	1.9	2.1	2.3
1800	1.8	1.6	1.8	1.9	2.1	2.3
1900	1.8	1.7	1.8	1.9	2.1	2.3
2000	1.8	1.3	1.8	1.9	2.1	2.3
2100	1.8	1.1	1.8	1.9	2.1	2.3
2200	1.8	0.8	1.8	2.0	2.1	2.3
2300	1.8	0.8	1.8	2.0	2.2	2.3
2400	1.8	0.8	1.8	2.0	2.2	2.3
0100	1.8	0.7	1.7	1.9	2.2	2.2
0200	1.7	0.2	1.7	1.9	2.2	2.2
0300	1.7	0.3	1.7	1.9	2.2	2.2
0400	1.8	0.8	1.8	2.0	2.2	2.3
0500	1.8	0.5	1.8	2.0	2.2	2.4
0600	1.8	0.6	1.8	2.0	2.2	2.4
0700	1.8	0.4	1.8	2.0	2.2	2.4
0800	1.8	0.7	1.8	2.0	2.2	2.4
0900	1.8	1.2	1.8	2.0	2.2	2.4

Date: 27-28 July 1978 Site: USC, Mt Mawson

Time	Temperature °C					
	Probe 1	Probe 2	Probe 4	Probe 6	Probe 8	Probe 9
1000	1.8	1.9	1.8	2.0	2.2	2.4
1100	1.8	3.2	1.8	2.0	2.4	2.4
1200	1.8	2.8	1.8	2.0	2.3	2.4
1300	1.8	3.0	1.8	2.0	2.3	2.4
1400	1.8	2.6	1.8	2.0	2.3	2.4
1500	1.8	2.3	1.8	2.1	2.3	2.4
1600	1.8	2.3	1.8	2.1	2.3	2.4
1700	1.8	2.2	1.8	2.1	2.2	2.4
1800	1.8	1.8	1.8	2.1	2.2	2.4
1900	1.8	1.0	1.8	2.1	2.2	2.4
2000	1.8	0.8	1.8	2.1	2.2	2.4
2100	1.9	0.7	1.9	2.1	2.2	2.4
2200	1.9	-0.4	1.9	2.1	2.2	2.4
2300	1.9	-0.8	1.9	2.1	2.2	2.4
2400	1.9	-1.7	1.8	2.1	2.2	2.4
0100	1.8	-1.9	1.8	2.1	2.1	2.4
0200	1.8	-1.9	1.8	2.1	2.1	2.4
0300	1.9	-2.3	1.8	2.1	2.1	2.4
0400	1.9	-2.2	1.9	2.1	2.1	2.4
0500	1.9	-2.1	1.9	2.2	2.2	2.4
0600	2.0	-1.8	1.9	2.2	2.2	2.4
0700	2.0	-1.5	1.9	2.2	2.2	2.4
0800	2.0	-1.4	1.9	2.2	2.2	2.4
0900	2.0	-1.2	1.9	2.2	2.2	2.4

Date: 28-29 July 1978 Site: USC, Mt Mawson

Time	Temperature °C					
	Probe 1	Probe 2	Probe 4	Probe 6	Probe 8	Probe 9
1000	2.0	-0.6	1.9	2.2	2.2	2.4
1100	2.0	-0.3	1.9	2.2	2.2	2.4
1200	2.0	0.2	1.9	2.2	2.2	2.4
1300	2.0	0.8	1.9	2.2	2.2	2.4
1400	1.9	1.3	1.8	2.1	2.2	2.4
1500	1.9	1.8	1.8	2.1	2.1	2.4
1600	1.9	2.2	1.8	2.1	2.1	2.4
1700	1.9	2.1	1.8	2.1	2.1	2.3
1800	1.9	2.1	1.8	2.1	2.1	2.3
1900	1.9	2.3	1.8	2.1	2.1	2.3
2000	1.9	2.4	1.8	2.0	2.1	2.3
2100	1.9	2.5	1.8	2.0	2.1	2.3
2200	1.9	2.2	1.7	1.9	2.1	2.3
2300	1.8	2.3	1.7	1.8	2.1	2.2
2400	1.8	2.3	1.7	1.7	2.1	2.2
0100	1.8	2.4	1.6	1.6	2.1	2.3
0200	1.8	2.4	1.6	1.6	2.1	2.3
0300	1.8	2.3	1.6	1.5	2.1	2.3
0400	1.8	2.4	1.6	1.5	2.1	2.3
0500	1.9	2.3	1.5	1.3	2.1	2.3
0600	1.9	2.7	1.5	1.3	2.1	2.3
0700	1.9	2.5	1.5	1.2	2.1	2.3
0800	1.8	2.8	1.5	1.2	2.1	2.3
0900	1.8	2.6	1.5	1.2	2.0	2.2

Date: 29-30 July 1978 Site: USC, Mt Mawson

Time	Temperature °C					
	Probe 1	Probe 2	Probe 4	Probe 6	Probe 8	Probe 9
1000	1.8	2.8	1.5	1.2	2.0	2.2
1100	1.8	3.9	1.4	1.2	2.1	2.3
1200	1.8	3.9	1.4	1.2	2.1	2.3
1300	1.8	4.5	1.4	1.2	2.1	2.3
1400	1.7	4.5	1.4	1.2	2.0	2.2
1500	1.7	4.7	1.4	1.2	2.0	2.2
1600	1.7	4.4	1.4	1.2	2.0	2.2
1700	1.7	4.0	1.4	1.2	2.0	2.2
1800	1.7	3.8	1.4	1.2	2.0	2.2
1900	1.7	4.2	1.4	1.2	2.0	2.2
2000	1.7	3.7	1.4	1.2	2.0	2.2
2100	1.7	3.6	1.3	1.2	2.0	2.2
2200	1.7	3.5	1.3	1.2	2.0	2.2
2300	1.7	3.7	1.3	1.2	2.0	2.2
2400	1.7	3.7	1.3	1.2	2.0	2.2
0100	1.7	3.3	1.4	1.2	2.0	2.2
0200	1.7	3.5	1.4	1.2	2.0	2.2
0300	1.8	3.4	1.4	1.2	2.0	2.2
0400	1.8	3.6	1.4	1.2	2.0	2.2
0500	1.8	3.9	1.4	1.2	2.0	2.2
0600	1.8	3.7	1.4	1.2	2.0	2.2
0700	1.8	3.8	1.4	1.2	2.0	2.2
0800	1.8	3.9	1.4	1.2	2.0	2.2
0900	1.8	4.1	1.4	1.2	2.0	2.2

Date: 30-31 July 1978 Site: USC, Mt Mawson

Time	Temperature °C					
	Probe 1	Probe 2	Probe 4	Probe 6	Probe 8	Probe 9
1000	1.8	4.3	1.4	1.2	2.0	2.2
1100	1.8	4.2	1.4	1.2	2.0	2.2
1200	1.8	4.6	1.4	1.2	2.0	2.2
1300	1.8	4.4	1.4	1.2	2.0	2.2
1400	1.8	4.5	1.4	1.2	2.0	2.2
1500	1.8	4.8	1.4	1.2	2.0	2.2
1600	1.8	4.4	1.4	1.2	1.9	2.2
1700	1.8	4.7	1.4	1.2	1.9	2.2
1800	1.8	4.2	1.4	1.2	1.9	2.2
1900	1.8	3.8	1.4	1.2	1.8	2.1
2000	1.8	3.8	1.4	1.2	1.8	2.1
2100	1.8	3.7	1.5	1.2	1.8	2.1
2200	1.8	3.7	1.5	1.2	1.8	2.1
2300	1.8	3.5	1.5	1.2	1.8	2.1
2400	1.8	3.5	1.5	1.2	1.8	2.1
0100	1.8	3.2	1.4	1.2	1.8	2.1
0200	1.8	3.2	1.4	1.2	1.8	2.0
0300	1.8	3.3	1.4	1.2	1.8	2.0
0400	1.8	3.3	1.5	1.4	1.8	2.1
0500	1.9	3.7	1.7	1.4	1.9	2.1
0600	1.9	3.3	1.7	1.4	1.9	2.1
0700	2.0	3.7	1.7	1.4	1.9	2.1
0800	2.0	3.8	1.7	1.4	1.9	2.1
0900	2.0	3.9	1.7	1.4	1.9	2.1

Date: 31 July-1 August 1978 Site: USC, Mt Mawson

Time	Temperature °C					
	Probe 1	Probe 2	Probe 4	Probe 6	Probe 8	Probe 9
1000	2.0	3.8	1.7	1.4	1.9	1.9
1100	2.0	4.2	1.7	1.4	1.9	1.9
1200	2.0	4.1	1.7	1.4	1.9	1.9
1300	2.0	4.0	1.7	1.4	1.9	1.9
1400	2.0	3.9	1.7	1.4	1.9	1.9
1500	2.0	3.9	1.8	1.4	1.9	1.9
1600	2.0	3.7	1.8	1.4	2.0	1.9
1700	2.0	3.3	1.8	1.4	2.0	1.9
1800	2.0	3.1	1.8	1.4	2.0	1.9
1900	2.0	2.9	1.8	1.4	2.0	1.9
2000	2.0	2.8	1.8	1.4	2.0	1.9
2100	2.1	2.9	1.8	1.6	2.0	1.9
2200	2.1	2.8	1.8	1.6	2.0	1.9
2300	2.1	2.5	1.8	1.6	2.1	2.2
2400	2.1	2.6	1.8	1.6	2.1	2.2
0100	2.0	2.3	1.8	1.4	1.9	2.0
0200	2.0	2.2	1.8	1.4	1.9	2.0
0300	2.0	2.3	1.8	1.4	1.9	2.0
0400	2.0	2.1	1.8	1.6	1.9	2.0
0500	2.1	1.7	1.8	1.6	1.9	2.0
0600	2.1	1.8	1.8	1.6	2.0	2.1
0700	2.1	1.9	1.7	1.6	2.0	2.1
0800	2.1	2.1	1.7	1.6	1.9	2.0
0900	2.0	2.4	1.7	1.6	1.8	2.0

Date: 1-2 August 1978 Site: USC, Mt Mawson

Time	Temperature °C					
	Probe 1	Probe 2	Probe 4	Probe 6	Probe 8	Probe 9
1000	2.0	2.4	1.7	1.6	1.8	2.0
1100	2.0	3.0	1.7	1.6	1.8	2.0
1200	2.0	3.4	1.8	1.6	1.8	2.0
1300	2.0	3.9	1.8	1.6	1.8	1.9
1400	2.0	3.8	1.8	1.5	1.8	1.9
1500	2.0	3.3	1.8	1.4	1.8	1.9
1600	2.0	2.5	1.9	1.4	1.8	1.9
1700	2.0	2.3	1.9	1.4	1.9	1.9
1800	2.0	2.3	1.9	1.4	1.9	1.9
1900	2.0	2.3	1.9	1.4	1.9	1.9
2000	2.0	2.3	1.9	1.6	1.9	1.9
2100	2.0	2.0	1.9	1.5	1.9	1.9
2200	2.0	2.0	1.8	1.5	1.9	1.9
2300	2.0	2.0	1.8	1.5	1.8	1.9
2400	2.0	2.0	1.8	1.5	1.8	1.9
0100	2.0	0.1	1.8	1.4	1.8	1.9
0200	2.0	0.0	1.8	1.4	1.8	1.9
0300	2.0	0.2	1.8	1.5	1.8	1.9
0400	2.1	0.3	1.8	1.6	1.9	2.0
0500	2.1	0.3	1.8	1.6	1.9	2.0
0600	2.1	0.8	1.8	1.6	1.8	1.9
0700	2.1	0.9	1.8	1.6	1.8	1.9
0800	2.1	1.0	1.8	1.8	1.8	1.9
0900	2.1	1.8	1.9	1.7	1.8	1.9

Date: 2-3 August 1978 Site: USC, Mt Mawson

Time	Temperature °C					
	Probe 1	Probe 2	Probe 4	Probe 6	Probe 8	Probe 9
1000	2.1	2.7	1.9	1.7	1.8	1.9
1100	2.1	3.3	1.9	1.7	1.8	1.9
1200	2.0	2.9	1.9	1.7	1.8	1.8
1300	2.0	2.9	1.9	1.6	1.8	1.8
1400	2.0	4.3	1.9	1.6	1.8	1.8
1500	2.1	3.9	1.9	1.6	1.8	1.8
1600	2.1	3.4	2.0	1.6	1.8	1.8
1700	2.1	3.0	2.0	1.7	1.8	1.8
1800	2.1	3.1	2.0	1.7	1.8	1.8
1900	2.1	3.1	2.0	1.7	1.8	1.8
2000	2.2	3.0	2.0	1.7	1.9	1.9
2100	2.2	3.2	2.0	1.7	1.9	1.9
2200	2.2	3.1	2.0	1.7	1.9	1.9
2300	2.2	3.0	2.0	1.7	1.9	1.9
2400	2.2	3.2	2.0	1.7	1.9	1.9
0100	2.2	1.6	2.0	1.6	1.9	1.9
0200	2.2	1.4	2.0	1.6	1.9	1.9
0300	2.2	1.3	2.0	1.6	1.9	1.9
0400	2.2	1.2	2.0	1.6	1.9	1.9
0500	2.2	1.1	2.0	1.6	1.9	1.9
0600	2.2	0.9	2.0	1.7	2.0	2.0
0700	2.2	0.9	2.0	1.8	2.0	2.0
0800	2.2	1.0	2.0	1.8	1.9	1.9
0900	2.2	1.4	1.9	1.7	1.9	1.9

Date: 3-4 August 1978 Site: USC, Mt Mawson

Time	Temperature °C					
	Probe 1	Probe 2	Probe 4	Probe 6	Probe 8	Probe 9
1000	2.2	1.1	1.9	1.8	1.9	1.9
1100	2.1	1.7	1.9	1.8	1.9	1.9
1200	2.1	1.9	1.9	1.7	1.9	1.9
1300	2.1	3.1	1.9	1.7	1.8	1.8
1400	2.1	1.5	1.9	1.7	1.8	1.8
1500	2.0	2.1	1.9	1.7	1.8	1.8
1600	2.0	2.3	1.9	1.7	1.8	1.8
1700	2.0	2.2	1.9	1.7	1.8	1.8
1800	2.0	1.8	1.9	1.7	1.8	1.8
1900	2.0	1.8	1.8	1.7	1.8	1.8
2000	2.0	1.8	1.8	1.7	1.8	1.8
2100	2.0	1.9	1.8	1.7	1.8	1.8
2200	2.0	1.8	1.8	1.7	1.8	1.8
2300	2.0	2.3	1.8	1.7	1.8	1.8
2400	2.1	2.0	1.8	1.7	1.8	1.8
0100	2.0	2.0	1.8	1.7	1.8	1.8
0200	2.0	2.1	1.8	1.7	1.8	1.8
0300	2.0	2.6	1.8	1.7	1.8	1.8
0400	2.1	2.3	1.9	1.8	1.8	1.8
0500	2.1	2.4	1.9	1.8	1.8	1.8
0600	2.1	2.6	1.9	1.8	1.8	1.8
0700	2.1	2.7	1.9	1.7	1.8	1.8
0800	2.1	2.9	1.9	1.7	1.8	1.8
0900	2.1	3.0	1.9	1.7	1.8	1.8

Date: 4-5 August 1978 Site: USC, Mt Mawson

Time	Temperature °C					
	Probe 1	Probe 2	Probe 4	Probe 6	Probe 8	Probe 9
1000	2.1	3.2	2.0	1.7	1.8	1.8
1100	2.1	3.7	2.1	1.7	1.8	1.8
1200	2.1	4.9	2.2	1.7	1.8	1.8
1300	2.1	4.7	2.2	1.7	1.8	1.8
1400	2.2	4.7	2.4	1.7	1.8	1.8
1500	2.3	4.9	2.4	1.7	1.8	1.8
1600	2.4	5.0	2.4	1.6	1.8	1.8
1700	2.4	4.8	2.4	1.6	1.8	1.8
1800	2.4	4.2	2.4	1.6	1.8	1.8
1900	2.4	4.2	2.3	1.6	1.8	1.8
2000	2.4	4.1	2.2	1.6	1.8	1.8
2100	2.5	4.2	2.2	1.6	1.8	1.8
2200	2.5	3.8	2.2	1.6	1.8	1.8
2300	2.4	3.4	2.2	1.6	1.8	1.8
2400	2.4	3.1	2.2	1.6	1.8	1.8
0100	2.3	2.9	2.1	2.6	1.7	1.8
0200	2.4	3.0	2.1	2.7	1.7	1.8
0300	2.4	3.5	2.1	2.7	1.8	1.8
0400	2.4	3.4	2.1	2.7	1.8	1.8
0500	2.4	3.3	2.1	2.7	1.8	1.8
0600	2.4	3.6	2.1	2.7	1.8	1.8
0700	2.4	3.8	2.1	2.8	1.8	1.9
0800	2.4	3.6	2.1	2.7	1.9	1.9
0900	2.4	3.8	2.1	2.7	1.9	1.9

Date: 5-6 August 1978 Site: USC, Mt Mawson

Time	Temperature °C					
	Probe 1	Probe 2	Probe 4	Probe 6	Probe 8	Probe 9
1000	2.4	4.2	2.1	2.7	1.8	1.8
1100	2.2	4.6	2.1	2.6	1.8	1.8
1200	2.3	4.9	2.2	2.6	1.8	1.8
1300	2.4	5.7	2.3	2.6	1.8	1.8
1400	2.4	5.3	2.3	2.6	1.8	1.8
1500	2.4	5.0	2.3	2.6	1.8	1.8
1600	2.4	4.9	2.3	2.5	1.8	1.8
1700	2.4	4.6	2.2	2.4	1.8	1.8
1800	2.3	4.3	2.2	2.4	1.8	1.8
1900	2.3	4.2	2.2	2.4	1.8	1.8
2000	2.3	4.0	2.1	2.3	1.8	1.8
2100	2.3	4.0	2.1	2.3	1.8	1.8
2200	2.2	4.2	2.0	2.3	1.8	1.8
2300	2.2	4.0	2.0	2.3	1.8	1.8
2400	2.2	4.0	2.0	2.3	1.8	1.8
0100	2.2	3.9	2.0	1.3	1.8	1.7
0200	2.2	3.8	1.9	1.3	1.8	1.7
0300	2.2	3.7	1.9	1.3	1.8	1.8
0400	2.2	3.8	2.0	1.3	1.8	1.8
0500	2.2	3.9	2.0	1.3	1.8	1.8
0600	2.2	3.9	2.0	1.6	1.8	1.8
0700	2.3	3.9	2.0	1.6	1.8	1.8
0800	2.3	3.9	2.0	1.6	1.8	1.8
0900	2.3	4.2	2.0	1.6	1.8	1.8

Date: 6-7 August 1978 Site: USC, Mt Mawson

Time	Temperature °C					
	Probe 1	Probe 2	Probe 4	Probe 6	Probe 8	Probe 9
1000	2.3	4.2	2.1	1.6	1.8	1.8
1100	2.3	4.4	2.1	1.6	1.8	1.8
1200	2.3	4.4	2.2	1.6	1.8	1.8
1300	2.3	5.0	2.2	1.6	1.8	1.8
1400	2.3	5.7	2.2	1.6	1.8	1.8
1500	2.3	3.8	2.2	1.7	1.9	1.8
1600	-	-	-	-	-	-
1700	2.5	4.1	2.2	1.8	2.1	2.0
1800	2.5	4.1	2.2	1.8	2.1	2.0
1900	2.5	3.8	2.2	1.8	2.0	1.9
2000	2.5	3.4	2.2	1.8	2.0	1.9
2100	2.5	3.5	2.2	1.8	2.0	1.9
2200	2.5	3.6	2.2	1.9	2.0	1.9
2300	2.6	3.4	2.2	1.9	2.0	1.9
2400	2.6	3.4	2.2	1.9	2.0	1.9
0100	2.6	3.2	2.2	1.9	2.0	2.0
0200	2.6	3.2	2.2	1.9	2.0	2.0
0300	2.6	3.0	2.3	1.9	2.0	2.0
0400	2.7	2.9	2.3	2.0	2.1	2.1
0500	2.7	2.9	2.4	2.1	2.1	2.1
0600	2.7	2.2	2.4	2.1	2.1	2.1
0700	2.7	2.1	2.4	2.1	2.2	2.2
0800	2.8	1.9	2.4	2.1	2.2	2.2
0900	2.8	1.4	2.4	2.1	2.2	2.2

Date: 7-8 August 1978 Site: USC, Mt Mawson

Time	Temperature °C					
	Probe 1	Probe 2	Probe 4	Probe 6	Probe 8	Probe 9
1000	2.8	1.7	2.4	2.1	2.2	2.2
1100	2.8	1.8	2.3	2.1	2.2	2.2
1200	2.8	2.0	2.3	2.1	2.2	2.2
1300	2.8	2.0	2.3	2.1	2.1	2.1
1400	2.7	1.9	2.3	2.0	2.1	2.1
1500	2.7	1.7	2.2	2.1	2.1	2.1
1600	2.7	1.6	2.2	2.1	2.1	2.1
1700	2.7	1.3	2.2	2.1	2.1	2.1
1800	2.6	1.0	2.2	2.0	2.1	2.1
1900	2.6	0.9	2.2	2.0	2.0	2.0
2000	2.6	0.9	2.1	2.0	2.0	2.0
2100	2.6	0.8	2.1	2.0	2.0	2.0
2200	2.6	0.7	2.1	2.0	2.0	2.0
2300	2.4	0.7	2.0	1.9	1.9	1.9
2400	2.3	0.4	2.0	1.8	1.9	1.9
0100	2.2	0.6	1.9	1.8	1.9	1.9
0200	2.2	0.5	1.9	1.8	1.9	1.9
0300	2.2	0.4	1.9	1.8	1.9	1.9
0400	2.2	0.3	1.9	1.8	1.9	1.9
0500	2.2	0.3	1.9	1.8	1.9	1.9
0600	2.2	0.3	2.0	1.8	1.9	2.0
0700	2.2	0.3	2.0	1.8	1.9	2.0
0800	2.2	0.3	2.0	1.8	1.9	2.0
0900	2.2	0.3	2.0	1.8	1.9	1.9

Date: 8-9 August 1978 Site: USC, Mt Mawson

Time	Temperature °C					
	Probe 1	Probe 2	Probe 4	Probe 6	Probe 8	Probe 9
1000	2.2	0.4	2.0	1.8	1.9	1.9
1100	2.2	0.6	2.0	1.8	1.9	1.9
1200	2.2	0.7	2.0	1.8	1.9	1.9
1300	2.2	0.8	2.0	1.8	1.9	1.9
1400	2.2	0.8	2.0	1.8	1.9	1.9
1500	2.2	-	2.0	1.8	1.9	1.9
1600	2.2	0.7	2.1	1.8	1.9	1.9
1700	2.2	0.6	2.1	1.8	1.9	1.9
1800	2.2	0.3	2.1	1.8	1.9	1.9
1900	2.2	0.2	2.1	1.8	1.9	1.9
2000	2.2	0.1	2.1	1.8	1.9	2.0
2100	2.2	0.2	2.1	1.9	1.9	2.0
2200	2.2	0.3	2.1	1.9	1.9	2.0
2300	2.2	0.4	2.1	1.9	2.0	2.0
2400	2.2	0.6	2.2	1.9	2.0	2.0
0100	2.3	0.7	2.1	2.0	2.0	2.0
0200	2.3	0.7	2.1	1.9	2.0	2.0
0300	2.3	0.8	2.1	1.9	2.0	2.0
0400	2.3	0.8	2.1	2.0	2.0	2.0
0500	2.4	0.7	2.2	2.1	2.1	2.2
0600	2.4	0.8	2.2	2.1	2.1	2.2
0700	2.4	0.8	2.2	2.1	2.1	2.2
0800	2.4	1.1	2.2	2.1	2.1	2.2
0900	2.4	1.2	2.2	2.1	2.1	2.2

Date: 9-10 August 1978 Site: USC, Mt Mawson

Time	Temperature °C					
	Probe 1	Probe 2	Probe 4	Probe 6	Probe 8	Probe 9
1000	2.4	1.3	2.2	2.1	2.1	2.2
1100	2.4	1.4	2.2	2.1	2.1	2.2
1200	2.4	1.0	2.2	2.1	2.1	2.2
1300	2.4	1.4	2.2	2.1	2.1	2.1
1400	2.4	1.0	2.2	2.1	2.1	2.1
1500	2.4	0.9	2.2	2.1	2.1	2.1
1600	2.4	1.0	2.2	2.2	2.1	2.1
1700	2.4	1.2	2.2	2.2	2.1	2.1
1800	2.4	0.9	2.2	2.2	2.1	2.1
1900	2.4	0.3	2.2	2.2	2.1	2.1
2000	2.3	0.1	2.2	2.1	2.0	2.0
2100	2.3	-0.2	2.2	2.1	2.0	2.0
2200	2.3	-0.2	2.2	2.1	2.0	2.0
2300	2.3	0.0	2.1	2.1	2.0	2.0
2400	2.2	0.2	2.1	2.1	2.0	2.0
0100	2.3	0.4	2.1	2.0	1.9	1.9
0200	2.2	0.6	2.1	2.0	1.9	1.9
0300	2.2	0.8	2.1	2.0	1.9	1.9
0400	2.2	0.9	2.1	2.0	1.9	2.0
0500	2.2	0.9	2.1	2.1	1.9	2.0
0600	2.2	0.7	2.1	2.1	1.9	2.0
0700	2.2	0.6	2.1	2.1	1.9	2.0
0800	2.2	0.6	2.1	2.1	1.9	2.0
0900	2.2	0.4	2.1	2.1	1.9	2.0

Date: 10-11 August 1978 Site: USC, Mt Mawson

Time	Temperature °C					
	Probe 1	Probe 2	Probe 4	Probe 6	Probe 8	Probe 9
1000	2.2	0.8	2.1	2.1	1.9	2.0
1100	2.2	1.1	2.1	2.1	1.9	2.0
1200	2.2	1.3	2.1	2.1	1.9	2.0
1300	2.1	2.4	2.0	2.1	1.9	2.0
1400	2.1	2.3	2.0	2.1	1.9	2.0
1500	2.1	2.1	2.0	2.1	1.9	2.0
1600	2.1	1.9	2.0	2.1	1.9	2.0
1700	2.0	1.9	2.0	2.1	1.9	2.0
1800	2.0	1.9	2.0	2.1	2.1	2.0
1900	2.0	1.8	2.0	2.1	2.1	2.1
2000	2.0	1.9	2.0	2.1	2.1	2.1
2100	2.0	2.0	2.0	2.1	2.1	2.1
2200	2.0	1.8	2.0	2.0	2.1	2.1
2300	2.0	1.0	2.0	2.0	2.1	2.1
2400	2.0	0.6	2.0	1.9	2.1	2.1
0100	2.1	0.0	2.0	1.9	2.1	2.2
0200	2.1	0.2	2.1	1.9	2.1	2.2
0300	2.2	0.0	2.1	1.9	2.1	2.2
0400	2.2	0.1	2.1	1.9	2.1	2.3
0500	2.2	0.1	2.1	1.9	2.1	2.3
0600	2.2	0.4	2.1	2.0	2.1	2.3
0700	2.2	0.6	2.2	2.0	2.2	2.3
0800	2.2	0.8	2.2	2.0	2.2	2.3
0900	2.2	1.2	2.2	2.0	2.2	2.3

Date: 11-12 August 1978 Site: USC, Mt Mawson

Time	Temperature °C					
	Probe 1	Probe 2	Probe 4	Probe 6	Probe 8	Probe 9
1000	2.2	1.7	2.2	2.0	2.2	2.3
1100	2.2	2.1	2.2	1.9	2.2	2.3
1200	2.2	2.5	2.2	1.9	2.2	2.3
1300	2.2	2.7	2.2	1.9	2.2	2.2
1400	2.1	2.9	2.1	1.9	2.2	2.2
1500	2.1	2.8	2.1	1.9	2.2	2.2
1600	2.1	2.6	2.0	1.8	2.1	2.2
1700	2.1	2.3	2.0	1.8	2.1	2.2
1800	2.1	2.3	1.9	1.8	2.1	2.2
1900	2.1	1.9	1.9	1.8	2.1	2.2
2000	2.1	1.4	1.9	1.7	2.1	2.2
2100	2.1	0.8	1.8	1.6	2.1	2.2
2200	2.0	-0.4	1.8	1.4	2.0	2.1
2300	2.0	-1.0	1.8	1.3	2.0	2.1
2400	2.0	-1.2	1.8	1.3	2.0	2.1
0100	1.9	-1.4	1.7	1.3	2.1	2.1
0200	1.9	-1.6	1.7	1.3	2.2	2.1
0300	1.9	-2.2	1.7	1.3	2.3	2.1
0400	1.9	-2.6	1.7	1.3	2.3	2.2
0500	2.0	-2.4	1.8	1.3	2.3	2.2
0600	2.0	-2.6	1.8	1.3	2.2	2.2
0700	2.0	-2.4	1.8	1.3	2.2	2.2
0800	2.1	-2.8	1.8	1.3	2.2	2.3
0900	2.1	-2.4	1.8	1.3	2.2	2.3

Date: 12-13 August 1978 Site: USC, Mt Mawson

Time	Temperature °C					
	Probe 1	Probe 2	Probe 4	Probe 6	Probe 8	Probe 9
1000	2.1	-2.2	1.8	1.3	2.2	2.3
1100	2.1	-2.1	1.8	1.3	2.6	2.3
1200	1.9	-1.7	1.8	1.3	2.8	2.6
1300	1.9	-2.0	1.8	1.3	2.7	2.8
1400	1.9	-2.0	1.7	1.3	2.7	2.8
1500	1.9	-2.0	1.7	1.3	2.7	2.8
1600	1.9	-2.1	1.7	1.3	2.7	2.8
1700	1.9	-1.9	1.7	1.3	2.7	2.8
1800	1.9	-1.4	1.6	1.3	2.7	2.8
1900	1.9	-1.5	1.6	1.3	2.8	2.8
2000	1.9	-2.0	1.6	1.3	2.8	2.8
2100	1.9	-2.3	1.6	1.3	2.9	2.8
2200	1.9	-2.3	1.7	1.3	2.9	2.8
2300	1.9	-2.2	1.7	1.3	2.8	2.8
2400	1.9	-2.9	1.7	1.3	2.8	2.8
0100	1.9	-2.5	1.6	1.4	2.8	2.8
0200	2.0	-2.3	1.7	1.4	2.9	2.9
0300	2.0	-2.7	1.8	1.6	2.9	2.9
0400	2.1	-2.1	1.9	1.6	3.0	3.0
0500	2.1	-1.8	1.9	1.6	3.0	3.0
0600	2.1	-1.1	1.9	1.7	2.9	3.1
0700	2.1	-0.8	1.9	1.7	2.8	3.1
0800	2.2	-0.2	1.9	1.7	3.1	3.1
0900	2.2	0.3	2.0	1.8	-	3.0

Date: 13-14 August 1978 Site: USC, Mt Mawson

Time	Temperature °C					
	Probe 1	Probe 2	Probe 4	Probe 6	Probe 8	Probe 9
1000	2.2	1.2	2.0	1.8	3.1	3.0
1100	2.2	1.6	2.0	1.8	3.1	3.0
1200	2.2	2.5	2.0	1.8	3.1	3.0
1300	2.1	2.4	1.9	1.8	3.1	3.1
1400	2.1	2.3	1.9	1.8	3.1	3.2
1500	2.1	2.3	1.9	1.8	3.1	3.2
1600	2.1	2.2	1.9	1.8	3.1	3.2
1700	2.1	2.0	1.9	1.8	3.1	3.1
1800	2.1	1.9	1.9	1.8	3.1	3.1
1900	2.1	1.3	1.9	1.8	3.1	3.1
2000	2.1	1.2	1.9	1.8	3.1	3.1
2100	2.1	1.1	1.9	1.8	3.0	3.1
2200	2.0	1.1	1.9	1.7	3.0	3.1
2300	2.0	1.0	1.8	1.6	3.0	3.0
2400	2.0	1.2	1.8	1.4	3.0	3.0
0100	2.0	1.2	1.8	1.3	2.8	2.9
0200	1.9	1.2	1.7	1.3	2.7	2.9
0300	1.9	1.2	1.7	1.3	2.7	2.9
0400	1.9	1.2	1.6	1.3	2.7	2.8
0500	1.9	1.2	1.3	1.3	2.7	2.8
0600	1.9	1.2	1.3	1.3	2.6	2.8
0700	1.9	0.9	1.3	1.3	2.6	2.8
0800	1.9	1.3	1.3	1.3	2.6	2.8
0900	1.9	1.3	1.3	1.3	2.5	2.8

Date: 14-15 August 1978 Site: USC, Mt Mawson

Time	Temperature °C					
	Probe 1	Probe 2	Probe 4	Probe 6	Probe 8	Probe 9
1000	1.9	1.3	1.3	1.3	2.5	2.7
1100	1.9	1.7	1.3	1.3	2.5	2.7
1200	1.9	1.8	1.3	1.3	2.8	2.8
1300	1.9	1.6	1.3	1.3	2.8	2.8
1400	1.9	2.0	1.6	1.3	2.8	2.8
1500	1.9	1.9	1.6	1.3	2.8	2.8
1600	1.9	1.5	1.6	1.3	2.8	2.8
1700	1.8	1.6	1.6	1.3	2.7	2.8
1800	1.8	1.3	1.6	1.3	2.7	2.8
1900	1.8	1.2	1.6	1.3	2.7	2.8
2000	1.8	1.2	1.6	1.3	2.8	2.8
2100	1.8	1.2	1.6	1.3	2.8	2.8
2200	1.8	1.2	1.6	1.3	2.8	2.8
2300	1.8	1.1	1.6	1.3	2.8	2.8
2400	1.8	1.4	1.6	1.3	2.9	2.8
0100	1.8	1.3	1.5	1.3	2.9	2.8
0200	1.8	1.9	1.6	1.3	3.0	2.9
0300	1.9	2.2	1.7	1.3	3.0	3.0
0400	1.9	2.1	1.8	1.5	3.0	3.0
0500	1.9	2.0	1.8	1.5	2.9	3.0
0600	2.0	1.7	1.8	1.5	2.9	3.0
0700	2.0	1.6	1.8	1.5	2.9	3.0
0800	2.0	1.3	1.8	1.6	2.8	3.0
0900	2.0	1.3	1.9	1.7	2.8	3.0

Date: 15-16 August 1978 Site: USC, Mt Mawson

Time	Temperature °C					
	Probe 1	Probe 2	Probe 4	Probe 6	Probe 8	Probe 9
1000	2.0	1.8	1.9	1.7	2.8	3.0
1100	2.0	1.3	1.9	1.7	3.0	3.0
1200	2.0	1.4	1.9	1.7	3.0	3.0
1300	2.0	-0.2	1.9	1.7	3.0	3.0
1400	2.0	0.0	1.9	1.7	3.0	3.0
1500	2.1	-0.3	1.9	1.7	3.1	3.1
1600	2.1	-0.2	2.0	1.7	3.1	3.1
1700	2.1	-0.8	2.0	1.7	3.2	3.2
1800	2.1	-0.9	2.0	1.8	3.2	3.2
1900	2.1	-1.4	2.0	1.8	3.2	3.3
2000	2.2	-1.0	2.0	1.9	3.2	3.3
2100	2.2	-0.6	2.0	1.9	3.1	3.3
2200	2.2	-0.3	2.0	1.9	3.1	3.2
2300	2.2	0.0	2.0	1.9	3.1	3.2
2400	2.2	0.1	2.0	1.9	3.1	3.2
0100	2.1	0.3	2.0	1.8	2.8	3.0
0200	2.1	1.2	2.0	1.7	2.8	3.0
0300	2.1	0.0	2.0	1.7	2.8	3.0
0400	2.1	0.3	2.0	1.7	2.8	3.0
0500	2.1	0.0	2.0	1.7	2.7	2.9
0600	2.1	-0.7	2.0	1.7	2.7	2.9
0700	2.1	-1.0	2.0	2.0	2.7	2.9
0800	2.2	-1.1	2.0	2.0	2.7	2.9
0900	2.2	-1.6	2.0	2.0	2.7	2.9

Date: 16-17 August 1978 Site: USC, Mt Mawson

Time	Temperature °C					
	Probe 1	Probe 2	Probe 4	Probe 6	Probe 8	Probe 9
1000	2.2	-1.8	2.0	1.9	2.7	2.9
1100	2.1	-1.9	1.9	1.9	2.6	2.8
1200	2.1	-2.1	1.9	1.9	2.6	2.7
1300	2.0	-1.7	1.8	1.8	2.6	2.7
1400	2.0	-2.4	1.8	1.8	2.4	2.7
1500	1.9	-2.2	1.8	1.8	2.3	2.6
1600	1.9	-2.4	1.8	1.8	2.3	2.6
1700	1.9	-2.6	1.8	1.8	2.3	2.6
1800	1.9	-2.5	1.8	1.8	2.3	2.6
1900	1.9	-2.7	1.8	1.8	2.3	2.6
2000	1.9	-2.8	1.8	1.8	2.3	2.6
2100	1.8	-3.3	1.8	1.8	2.2	2.4
2200	1.8	-3.7	1.8	1.8	2.2	2.4
2300	1.8	-3.8	1.7	1.8	2.1	2.3
2400	1.8	-3.7	1.7	1.8	2.1	2.3
0100	1.9	-2.8	1.7	1.8	2.1	2.3
0200	1.9	-2.8	1.8	1.8	2.1	2.3
0300	1.9	-2.7	1.9	1.8	2.1	2.3
0400	2.0	-2.6	1.8	1.8	2.1	2.3
0500	2.0	-2.8	1.8	1.9	2.1	2.4
0600	2.0	-2.8	1.8	1.9	2.2	2.4
0700	2.0	-2.8	1.9	2.0	2.2	2.4
0800	2.1	-2.7	1.9	2.0	2.2	2.4
0900	2.1	-2.0	1.9	2.0	2.2	2.4

Date: 17-18 August 1978 Site: USC, Mt Mawson

Time	Temperature °C					
	Probe 1	Probe 2	Probe 4	Probe 6	Probe 8	Probe 9
1000	2.1	-1.3	1.9	2.0	2.2	2.4
1100	2.1	-0.8	1.9	2.0	2.2	2.4
1200	2.0	-1.1	1.9	2.0	2.2	2.4
1300	2.0	-0.9	1.8	2.0	2.2	2.4
1400	2.0	-0.6	1.8	1.9	2.1	2.3
1500	1.9	-0.6	1.8	1.9	2.1	2.3
1600	1.9	-0.8	1.8	1.9	2.1	2.3
1700	1.9	-1.2	1.8	2.0	2.1	2.3
1800	2.0	-0.1	1.8	2.0	2.1	2.3
1900	2.0	-1.3	1.8	2.0	2.1	2.3
2000	2.0	-2.7	1.9	2.0	2.1	2.3
2100	2.0	-0.9	1.9	2.0	2.1	2.3
2200	2.1	-1.1	1.9	2.1	2.2	2.3
2300	2.1	-2.8	1.9	2.2	2.2	2.3
2400	2.1	-2.6	1.9	2.2	2.2	2.3
0100	2.1	-2.6	2.0	2.2	2.2	2.4
0200	2.1	-2.3	2.0	2.2	2.2	2.4
0300	2.1	-2.1	2.0	2.2	2.2	2.4
0400	2.1	-2.2	2.0	2.2	2.2	2.4
0500	2.2	-3.3	2.1	2.3	2.2	2.4
0600	2.2	-2.7	2.1	2.3	2.2	2.4
0700	2.2	-2.4	2.1	2.3	2.2	2.4
0800	2.2	-2.5	2.1	2.3	2.2	2.4
0900	2.2	-2.4	2.1	2.3	2.2	2.4

Date: 18-19 August 1978 Site: USC, Mt Mawson

Time	Temperature °C					
	Probe 1	Probe 2	Probe 4	Probe 6	Probe 8	Probe 9
1000	2.2	-1.0	2.1	2.3	2.2	2.4
1100	2.2	0.5	2.1	2.3	2.2	2.4
1200	2.2	0.3	2.0	2.2	2.2	2.3
1300	2.1	1.2	1.9	2.2	2.1	2.3
1400	2.0	1.7	1.8	2.1	2.1	2.3
1500	2.0	1.3	1.8	2.1	2.0	2.2
1600	1.9	1.4	1.8	2.1	2.0	2.1
1700	1.9	0.9	1.8	2.1	2.0	2.1
1800	1.9	0.2	1.7	2.0	1.9	2.1
1900	1.8	0.3	1.7	2.0	1.9	2.0
2000	1.8	0.3	1.7	2.0	1.9	2.0
2100	1.8	0.3	1.7	2.0	1.8	2.0
2200	1.8	0.2	1.7	1.9	1.8	2.0
2300	1.8	0.0	1.7	1.9	1.8	2.0
2400	1.7	0.8	1.7	1.9	1.8	2.0
0100	1.8	-0.3	1.7	1.9	1.8	2.0
0200	1.8	-0.2	1.7	1.9	1.7	2.0
0300	1.8	-0.3	1.7	1.9	1.8	2.0
0400	1.8	-0.4	1.7	1.9	1.8	2.0
0500	1.8	0.0	1.8	1.9	1.8	2.0
0600	1.8	0.0	1.8	1.9	1.8	2.0
0700	1.9	0.6	1.8	2.0	1.9	2.0
0800	1.9	0.8	1.8	2.0	1.9	2.0
0900	1.9	1.0	1.8	2.0	1.9	2.0

Date: 19-20 August 1978 Site: USC, Mt Mawson

Time	Temperature °C					
	Probe 1	Probe 2	Probe 4	Probe 6	Probe 8	Probe 9
1000	1.9	1.3	1.8	2.0	1.9	2.0
1100	1.9	1.9	1.8	2.0	1.8	2.0
1200	1.8	1.9	1.8	2.0	1.8	2.0
1300	1.8	1.9	1.7	1.9	1.8	2.0
1400	1.8	1.9	1.7	1.9	1.8	2.0
1500	1.8	1.9	1.8	2.0	1.8	2.0
1600	1.9	1.9	1.9	2.0	1.8	2.0
1700	1.9	1.9	1.9	2.0	1.8	2.0
1800	1.9	1.8	1.9	2.1	1.9	2.0
1900	1.9	1.8	1.8	2.1	1.9	2.0
2000	1.9	1.7	1.9	2.1	1.9	2.0
2100	1.9	1.4	1.9	2.1	1.9	2.0
2200	1.9	1.2	1.9	2.1	1.9	2.0
2300	1.9	1.2	1.9	2.1	1.9	2.0
2400	2.0	1.0	2.0	2.1	2.0	2.0
0100	2.0	1.0	2.0	2.2	2.0	2.0
0200	2.1	1.0	2.0	2.2	2.0	2.0
0300	2.1	1.3	2.0	2.2	2.0	2.0
0400	2.2	1.0	2.1	2.2	2.0	2.0
0500	2.2	1.2	2.1	2.3	2.0	2.0
0600	2.2	1.6	2.3	2.3	2.0	2.0
0700	2.2	1.3	2.3	2.3	2.0	2.0
0800	2.2	0.2	2.3	2.3	2.0	2.0
0900	2.2	0.4	2.3	2.3	2.0	2.0

Date: 20-21 August 1978 Site: USC, Mt Mawson

Time	Temperature °C					
	Probe 1	Probe 2	Probe 4	Probe 6	Probe 8	Probe 9
1000	2.2	1.2	2.3	2.3	2.0	2.0
1100	2.2	1.2	2.3	2.3	2.0	2.0
1200	2.2	1.3	2.2	2.3	2.0	2.0
1300	2.1	0.9	2.2	2.3	1.8	1.9
1400	2.1	1.2	2.1	2.2	1.8	1.9
1500	2.1	1.2	2.0	2.2	1.7	1.7
1600	2.1	0.8	2.0	2.2	1.7	1.9
1700	2.1	1.2	2.1	2.2	2.1	2.0
1800	2.1	1.1	2.1	2.2	2.0	2.0
1900	2.2	0.7	2.0	2.1	2.0	2.3
2000	2.2	1.1	2.0	2.1	2.0	2.4
2100	2.2	0.8	2.0	2.1	2.0	2.4
2200	2.2	0.6	2.0	2.1	2.1	2.4
2300	2.2	0.5	2.0	2.1	2.1	2.4
2400	1.9	0.7	2.0	2.0	2.1	2.4
0100	1.9	0.8	1.9	2.0	2.1	2.3
0200	1.9	1.0	1.9	2.0	2.1	2.3
0300	1.9	1.2	1.9	2.0	2.1	2.3
0400	1.9	1.8	2.0	2.1	2.1	2.3
0500	2.0	2.2	2.0	2.1	2.1	2.3
0600	2.0	2.1	2.0	2.1	2.1	2.3
0700	2.0	2.4	2.0	2.1	2.1	2.3
0800	2.0	2.8	2.0	2.1	2.0	2.3
0900	2.0	3.0	2.0	2.1	2.1	2.3

Date: 21-22 August 1978 Site: USC, Mt Mawson

Time	Temperature °C					
	Probe 1	Probe 2	Probe 4	Probe 6	Probe 8	Probe 9
1000	2.0	3.3	2.0	2.1	2.1	2.3
1100	1.9	3.5	1.9	2.1	2.3	2.2
1200	1.9	3.8	1.8	2.0	2.4	2.2
1300	1.9	4.2	1.8	1.9	2.3	2.2
1400	1.9	3.8	1.8	1.9	2.3	2.4
1500	1.9	3.7	1.8	1.8	2.3	2.4
1600	1.9	3.7	1.8	1.7	2.3	2.4
1700	1.9	3.7	1.8	1.4	2.3	2.4
1800	1.9	3.6	1.8	1.2	2.6	2.4
1900	1.9	3.3	1.8	1.2	2.8	2.5
2000	1.9	2.9	1.8	1.2	2.8	2.7
2100	1.9	3.0	1.8	1.2	2.8	2.7
2200	1.9	1.3	1.8	1.2	2.8	2.8
2300	1.9	1.0	1.8	1.2	2.8	2.8
2400	1.9	-0.2	1.8	1.2	2.8	2.9
0100	2.0	-0.4	1.8	1.2	2.9	2.9
0200	2.0	-0.8	1.8	1.2	2.8	2.9
0300	2.0	-1.1	1.8	1.3	2.8	2.9
0400	2.0	-1.2	1.9	1.3	2.8	3.0
0500	2.2	-1.8	1.9	1.4	2.8	3.0
0600	2.2	-2.2	1.9	1.5	2.7	3.0
0700	2.2	-1.9	2.0	1.5	2.7	3.0
0800	2.2	-2.0	2.0	1.6	2.7	3.0
0900	2.2	-2.2	2.0	1.6	2.7	3.0

Date: 22-23 August 1978 Site: USC, Mt Mawson

Time	Temperature °C					
	Probe 1	Probe 2	Probe 4	Probe 6	Probe 8	Probe 9
1000	2.2	-2.5	2.0	1.7	2.7	3.0
1100	2.2	-1.9	2.0	1.7	2.8	3.0
1200	2.1	-2.1	2.0	1.6	2.8	3.0
1300	2.1	-1.8	2.0	1.6	2.8	3.0
1400	2.1	-1.9	1.9	1.6	2.7	3.0
1500	2.0	-1.5	1.9	1.6	2.7	3.0
1600	2.0	-1.8	1.9	1.5	2.6	3.0
1700	2.0	-1.8	1.9	1.5	2.5	2.8
1800	2.0	-1.6	1.9	1.5	2.5	2.8
1900	2.0	-1.7	1.9	1.5	2.5	2.8
2000	2.0	-1.9	1.9	1.5	2.4	2.8
2100	1.9	-1.4	1.9	1.5	2.4	2.8
2200	1.9	-1.2	1.9	1.5	2.3	2.7
2300	1.9	-1.0	1.8	1.5	2.3	2.7
2400	1.8	-0.2	1.8	1.5	2.3	2.7
0100	1.8	-0.8	1.7	1.3	2.2	2.5
0200	1.8	-0.8	1.8	1.3	2.2	2.5
0300	1.8	-0.8	1.7	1.3	2.2	2.5
0400	1.8	-0.3	1.7	1.3	2.1	2.5
0500	1.8	-1.0	1.7	1.3	2.1	2.5
0600	1.8	-0.8	1.7	1.3	2.1	2.5
0700	1.8	-0.5	1.7	1.3	2.1	2.5
0800	1.8	-0.2	1.7	1.3	2.1	2.5
0900	1.8	0.0	1.7	1.3	2.0	2.5

Date: 23-24 August 1978 Site: USC, Mt Mawson

Time	Temperature °C					
	Probe 1	Probe 2	Probe 4	Probe 6	Probe 8	Probe 9
1000	1.8	0.2	1.7	1.3	2.0	2.3
1100	1.8	0.3	1.7	1.3	2.1	2.3
1200	1.7	1.1	1.7	1.3	2.3	2.3
1300	1.7	0.8	1.7	1.3	2.3	2.3
1400	1.7	0.9	1.7	1.3	2.3	2.4
1500	1.8	0.9	1.7	1.3	2.3	2.4
1600	1.8	0.6	1.7	1.3	2.3	2.5
1700	1.8	0.5	1.7	1.3	2.3	2.5
1800	1.8	0.2	1.7	1.3	2.3	2.5
1900	1.8	-0.2	1.7	1.3	2.3	2.6
2000	1.8	-0.1	1.7	1.3	2.3	2.7
2100	1.8	0.8	1.7	1.3	2.3	2.7
2200	1.8	-0.5	1.7	1.3	2.3	2.7
2300	1.8	-0.3	1.7	1.3	2.3	2.7
2400	1.8	-0.2	1.7	1.3	2.3	2.7
0100	1.8	-0.9	1.7	1.2	2.2	2.7
0200	1.8	-1.0	1.7	1.2	2.2	2.7
0300	1.9	-1.2	1.8	1.2	2.2	2.8
0400	2.0	-1.3	1.8	1.3	2.2	2.8
0500	2.0	-1.3	1.9	1.3	2.2	2.8
0600	2.0	-0.9	1.9	1.4	2.2	2.8
0700	2.0	-1.2	1.9	1.5	2.2	2.8
0800	2.0	-0.8	1.9	1.6	2.2	2.8
0900	2.1	-0.7	1.9	1.6	2.2	2.8

Date: 24-25 August 1978 Site: USC, Mt Mawson

Time	Temperature °C					
	Probe 1	Probe 2	Probe 4	Probe 6	Probe 8	Probe 9
1000	2.1	0.1	2.0	1.8	2.3	2.8
1100	2.1	0.2	2.0	1.8	2.2	2.8
1200	2.1	1.2	2.0	1.8	2.3	2.8
1300	2.1	1.2	2.0	1.8	2.3	2.8
1400	2.1	1.5	2.0	1.9	2.4	2.9
1500	2.2	1.8	2.0	1.9	2.4	2.9
1600	2.2	1.8	2.0	1.9	2.4	2.9
1700	2.2	1.4	2.0	2.0	2.5	2.9
1800	2.2	1.0	2.1	2.0	2.5	2.9
1900	2.2	1.0	2.1	2.0	2.5	2.9
2000	2.2	0.7	2.1	2.0	2.5	2.9
2100	2.1	0.5	2.1	2.0	2.6	2.9
2200	2.2	0.3	2.1	2.0	2.6	2.9
2300	2.2	0.4	2.1	2.0	2.7	2.9
2400	2.2	0.4	2.1	2.0	2.7	2.9
0100	2.2	0.8	2.1	2.0	2.7	2.9
0200	2.2	0.8	2.1	2.0	2.7	2.9
0300	2.3	0.8	2.1	2.0	2.7	3.0
0400	2.3	0.9	2.2	2.0	2.8	3.0
0500	2.3	1.0	2.2	2.0	2.8	3.0
0600	2.3	1.0	2.2	2.0	2.8	3.0
0700	2.3	1.2	2.2	2.0	2.8	3.0
0800	2.3	1.2	2.2	2.0	2.8	3.0
0900	2.3	1.2	2.2	2.0	2.7	3.0

Date: 17-18 September 1978 Site: USC, Mt Mawson

Time	Temperature °C					
	Probe 1	Probe 2	Probe 4	Probe 6	Probe 8	Probe 9
1000	-	-	-	-	-	-
1100	-	-	-	-	-	-
1200	2.0	5.6	2.0	1.8	2.1	2.2
1300	2.0	5.7	1.9	1.7	2.0	2.1
1400	2.0	5.2	1.9	1.7	2.0	2.1
1500	2.0	3.6	1.9	1.7	2.0	2.1
1600	2.0	3.7	1.9	1.7	2.0	2.0
1700	2.0	3.7	1.9	1.7	2.0	2.0
1800	2.0	3.6	1.8	1.7	2.0	2.0
1900	2.0	3.2	1.8	1.7	1.9	2.0
2000	2.0	3.1	1.8	1.7	1.9	2.0
2100	2.0	3.6	1.9	1.7	2.0	2.1
2200	2.0	2.9	1.9	1.8	2.0	2.1
2300	2.0	2.8	2.0	1.8	2.0	2.1
2400	2.0	2.6	2.0	1.8	2.0	2.1
0100	2.1	2.3	2.0	1.8	1.9	2.1
0200	2.1	2.0	2.0	1.8	1.9	2.1
0300	2.1	1.8	2.0	1.8	2.0	2.1
0400	2.1	1.8	2.0	1.9	2.0	2.1
0500	2.1	1.9	2.0	1.9	2.0	2.1
0600	2.1	1.9	2.0	1.9	2.0	2.1
0700	2.1	2.2	2.0	1.9	2.0	2.1
0800	2.1	2.6	2.0	1.9	2.0	2.1
0900	2.1	3.2	2.1	1.9	2.0	2.1

Date: 18-19 September 1978 Site: USC, Mt Mawson

Time	Temperature °C					
	Probe 1	Probe 2	Probe 4	Probe 6	Probe 8	Probe 9
1000	2.1	3.6	2.1	1.9	2.0	2.1
1100	2.1	3.9	2.1	1.9	2.0	2.1
1200	2.1	4.2	2.1	1.8	2.0	2.0
1300	2.1	4.6	2.1	1.8	2.0	2.0
1400	2.1	5.0	2.1	1.8	2.0	2.0
1500	2.1	5.0	2.1	1.8	2.0	2.0
1600	2.1	4.8	2.1	1.8	2.0	2.0
1700	2.1	4.4	2.1	1.8	2.0	2.0
1800	2.1	4.4	2.1	1.8	2.0	2.0
1900	2.1	4.3	2.1	1.8	2.1	2.1
2000	2.1	4.2	2.1	1.8	2.1	2.1
2100	2.1	4.2	2.1	1.8	2.1	2.1
2200	2.1	4.2	2.1	1.8	2.1	2.1
2300	2.1	4.2	2.1	1.8	2.1	2.1
2400	2.1	4.2	2.1	1.8	2.1	2.1
0100	2.1	4.3	2.1	1.9	2.1	2.0
0200	2.1	4.2	2.1	1.9	2.1	2.1
0300	2.1	4.1	2.1	1.9	2.1	2.1
0400	2.1	4.2	2.1	1.9	2.1	2.1
0500	2.1	4.1	2.1	1.9	2.1	2.1
0600	2.1	4.2	2.1	1.9	2.1	2.1
0700	2.1	4.2	2.1	1.9	2.1	2.1
0800	2.1	4.1	2.1	1.9	2.1	2.1
0900	2.1	4.2	2.1	1.9	2.1	2.1

Date: 19-20 September 1978 Site: USC, Mt Mawson

Time	Temperature °C					
	Probe 1	Probe 2	Probe 4	Probe 6	Probe 8	Probe 9
1000	2.1	4.2	2.1	1.9	2.1	2.1
1100	2.1	4.2	2.2	2.0	2.1	2.1
1200	2.2	4.3	2.2	2.0	2.1	2.1
1300	2.2	4.2	2.2	2.0	2.1	2.1
1400	2.2	4.2	2.2	2.0	2.2	2.1
1500	2.2	4.2	2.2	2.0	2.2	2.1
1600	2.2	4.1	2.2	2.0	2.2	2.1
1700	2.2	3.9	2.2	2.0	2.2	2.1
1800	2.2	3.9	2.2	2.0	2.2	2.1
1900	2.2	3.8	2.2	2.0	2.2	2.1
2000	2.2	3.8	2.2	2.0	2.2	2.1
2100	2.2	3.4	2.2	2.0	2.2	2.1
2200	2.2	3.3	2.2	2.0	2.2	2.2
2300	2.2	3.2	2.2	2.0	2.2	2.2
2400	2.2	3.1	2.2	2.0	2.2	2.2
0100	2.2	2.8	2.2	2.1	2.2	2.2
0200	2.2	2.7	2.2	2.1	2.2	2.2
0300	2.3	2.4	2.2	2.1	2.2	2.2
0400	2.3	2.1	2.2	2.1	2.2	2.2
0500	2.3	1.8	2.2	2.1	2.2	2.2
0600	2.3	1.6	2.2	2.1	2.2	2.2
0700	2.3	1.3	2.2	2.1	2.0	2.2
0800	2.3	1.6	2.2	2.1	2.0	2.2
0900	2.3	1.9	2.2	2.1	2.0	2.2

Date: 20-21 September 1978 Site: USC, Mt Mawson

Time	Temperature °C					
	Probe 1	Probe 2	Probe 4	Probe 6	Probe 8	Probe 9
1000	2.3	2.2	2.2	2.1	2.0	2.2
1100	2.3	2.7	2.4	2.1	2.1	2.2
1200	2.3	3.1	2.4	2.1	2.1	2.1
1300	2.3	3.6	2.6	2.1	2.1	2.1
1400	2.3	4.6	2.8	2.1	2.1	2.1
1500	2.4	4.1	2.8	2.0	2.2	2.1
1600	2.4	3.9	2.8	2.1	2.3	2.1
1700	2.4	3.8	2.8	2.1	2.4	2.1
1800	2.4	3.3	2.8	2.1	2.4	2.1
1900	2.4	3.2	2.7	2.1	2.4	2.1
2000	2.4	2.1	2.7	2.1	2.4	2.1
2100	2.4	2.0	2.7	2.1	2.4	2.1
2200	2.4	1.8	2.7	2.1	2.4	2.3
2300	2.6	1.4	2.7	2.1	2.3	2.3
2400	2.6	1.2	2.7	2.1	2.2	2.2
0100	2.6	1.0	2.6	2.1	2.2	2.3
0200	2.6	0.7	2.6	2.1	2.2	2.3
0300	2.6	0.5	2.6	2.1	2.2	2.3
0400	2.6	0.2	2.6	2.1	2.2	2.3
0500	2.6	0.0	2.6	2.1	2.0	2.2
0600	2.6	0.1	2.6	2.1	2.0	2.2
0700	2.6	0.3	2.9	2.1	2.0	2.2
0800	2.6	1.3	2.9	2.1	2.0	2.2
0900	2.6	2.7	2.9	2.1	2.0	2.2

Date: 21-22 September 1978 Site: USC, Mt Mawson

Time	Temperature °C					
	Probe 1	Probe 2	Probe 4	Probe 6	Probe 8	Probe 9
1000	2.6	3.9	2.9	2.1	2.0	2.2
1100	2.6	5.3	2.9	2.1	2.0	2.2
1200	2.8	6.8	3.3	2.1	2.0	2.2
1300	2.8	8.2	3.7	2.1	2.2	2.2
1400	2.9	8.4	3.8	2.1	2.5	2.2
1500	3.0	7.7	3.9	2.1	2.2	2.2
1600	3.0	6.8	3.9	2.1	2.8	2.2
1700	3.2	5.8	3.8	2.1	2.8	2.2
1800	3.2	4.8	3.7	2.1	2.8	2.3
1900	3.2	3.7	3.6	2.1	2.8	2.4
2000	3.2	3.5	3.5	2.1	2.8	2.4
2100	3.2	2.9	3.4	2.1	2.8	2.4
2200	3.2	2.9	3.3	2.1	2.7	2.4
2300	3.2	2.9	3.2	2.1	2.6	2.6
2400	3.2	3.0	3.2	2.1	2.6	2.6
0100	3.0	2.8	3.0	2.2	2.5	2.7
0200	3.0	2.2	3.0	2.2	2.5	2.7
0300	3.0	2.2	3.0	2.2	2.4	2.6
0400	3.0	1.9	2.8	2.2	2.2	2.5
0500	3.0	1.9	2.8	2.2	2.2	2.5
0600	3.0	2.0	2.8	2.2	2.2	2.5
0700	3.0	3.0	2.8	2.2	2.1	2.4
0800	3.0	3.5	2.8	2.2	2.0	2.4
0900	2.8	3.9	2.8	2.2	2.0	2.4

Date: 22-23 September 1978 Site: USC, Mt Mawson

Time	Temperature °C					
	Probe 1	Probe 2	Probe 4	Probe 6	Probe 8	Probe 9
1000	2.8	5.1	2.8	2.2	2.0	2.4
1100	2.8	6.1	2.7	2.2	2.0	2.3
1200	2.8	6.3	2.7	2.2	2.0	2.2
1300	2.8	6.8	2.7	2.2	2.2	2.2
1400	2.8	6.9	2.5	2.1	2.3	2.2
1500	2.8	7.1	2.5	2.1	2.6	2.2
1600	2.8	7.3	2.5	2.2	2.7	2.2
1700	3.0	6.7	2.7	2.2	2.8	2.3
1800	3.0	5.7	2.7	2.2	2.8	2.3
1900	3.0	5.3	2.7	2.3	2.8	2.4
2000	3.1	4.3	2.7	2.3	2.8	2.4
2100	3.1	4.2	2.8	2.3	2.8	2.8
2200	3.2	4.3	2.8	2.3	2.8	2.8
2300	3.2	4.0	3.0	2.3	2.8	2.8
2400	3.3	3.9	3.0	2.3	2.8	2.8
0100	3.4	3.7	3.0	2.4	2.8	2.8
0200	3.4	3.2	3.0	2.4	2.7	2.7
0300	3.4	3.0	3.0	2.4	2.7	2.7
0400	3.4	3.2	3.0	2.4	2.7	2.7
0500	3.4	2.8	3.0	2.4	2.7	2.7
0600	3.4	2.6	3.0	2.4	2.7	2.7
0700	3.2	2.1	3.0	2.4	2.5	2.6
0800	3.2	2.2	3.0	2.4	2.5	2.6
0900	3.2	2.1	3.0	2.4	2.5	2.6

APPENDIX D

Three hourly dry bulb air temperatures at Hobart Airport from 1 August to 30 September 1978. (based on unpublished data from the Bureau of Meteorology).

Dry Bulb Temperature
(°C)

	1200 hours	1500 hours	1800 hours	2100 hours	0000 hours	0300 hours	0600 hours	0900 hours	Min.	Max.	Mean
1 - 2 August	5	5	11	8	9	7	7	7	7	11	7.4
2 - 3	12	13	10	11	11	9	8	10	8	13	10.5
3 - 4	13	13	11	8	8	9	8	11	8	13	10.1
4 - 5	14	16	13	12	10	10	7	11	7	16	11.6
5 - 6	14	16	13	11	10	10	9	10	9	16	11.6
6 - 7	16	15	9	9	9	9	9	8	8	16	10.5
7 - 8	8	8	8	8	7	7	7	7	7	8	7.5
8 - 9	8	7	7	7	7	7	7	8	7	8	7.2
9 - 10	8	9	8	6	6	7	2	8	2	9	6.8
10 - 11	11	12	11	7	9	5	7	9	5	12	8.9
11 - 12	14	14	13	10	7	1	4	5	1	14	8.5
12 - 13	7	6	4	3	2	6	2	5	2	7	4.4
13 - 14	9	12	10	7	7	7	5	9	5	12	8.2
14 - 15	11	12	11	9	7	7	6	7	6	12	8.8
15 - 16	8	8	6	7	7	6	5	6	6	8	6.6

Dry Bulb Temperature
(°C)

	1200 hours	1500 hours	1800 hours	2100 hours	0000 hours	0300 hours	0600 hours	0900 hours	Min.	Max.	Mean
16 - 17 August	6	5	5	4	4	3	2	4	2	6	4.1
17 - 18	7	7	5	5	5	3	3	5	3	7	5.0
18 - 19	8	10	6	3	1	2	1	5	1	10	4.5
19 - 20	11	13	10	7	6	6	8	8	6	13	8.6
20 - 21	11	10	8	7	7	9	7	11	7	11	8.6
21 - 22	15	15	13	12	7	6	3	4	3	15	9.4
22 - 23	8	6	6	5	6	6	9	8	5	9	6.8
23 - 24	9	8	6	7	5	3	2	6	2	9	5.8
24 - 25	11	12	9	6	5	5	6	8	6	12	7.8
25 - 26	10	11	11	10	8	6	5	4	4	11	8.1
26 - 27	6	5	5	5	5	6	4	7	4	7	5.4
27 - 28	11	12	9	8	7	6	6	8	6	12	8.4
28 - 29	13	14	10	6	5	5	5	7	5	14	8.1
29 - 30	12	14	11	7	10	6	9	10	6	14	9.9
30 - 31	15	16	10	9	8	8	8	9	8	16	10.4

Dry Bulb Temperature
(°C)

	1200 hours	1500 hours	1800 hours	2100 hours	0000 hours	0300 hours	0600 hours	0900 hours	Min.	Max.	Mean
31 Aug. - 1 Sept.	11	12	11	7	7	6	5	8	5	12	8.4
1 - 2 Sept.	14	16	10	6	8	7	7	10	7	16	9.8
2 - 3	14	17	14	11	10	7	9	11	7	17	11.6
3 - 4	15	16	14	14	13	12	8	12	8	16	13.0
4 - 5	13	14	12	11	10	10	9	11	9	14	11.2
5 - 6	16	13	12	11	11	10	8	11	8	16	11.5
6 - 7	16	17	11	10	10	7	8	11	7	17	11.2
7 - 8	14	16	13	8	7	7	8	11	7	16	10.5
8 - 9	15	12	10	9	9	8	8	10	8	15	10.1
9 - 10	14	12	10	10	9	9	8	9	8	14	10.1
10 - 11	15	12	14	12	10	11	12	13	10	15	12.4
11 - 12	16	18	16	14	6	8	13	14	6	18	13.1
12 - 13	16	15	11	8	6	5	5	4	4	16	8.8
13 - 14	7	5	4	1	2	2	3	6	1	7	3.8
14 - 15	10	12	11	9	10	5	9	12	5	12	9.8
15 - 16	11	11	10	5	8	6	5	11	5	11	8.4

Dry Bulb Temperature
(°C)

	1200 hours	1500 hours	1800 hours	2100 hours	0000 hours	0300 hours	0600 hours	0900 hours	Min.	Max.	Mean
16 - 17 Sept.	14	14	12	11	9	8	5	10	5	14	10.4
17 - 18	13	14	11	9	7	8	8	11	7	14	10.1
18 - 19	14	14	12	11	11	11	11	12	11	14	12.0
19 - 20	13	12	10	10	9	8	8	10	8	13	10.0
20 - 21	12	12	11	9	6	4	7	10	4	12	8.9
21 - 22	14	15	11	9	6	3	2	8	2	15	8.5
22 - 23	13	14	10	5	13	6	9	10	5	14	10.0
23 - 24	12	12	10	6	4	3	3	3	3	12	6.6
24 - 25	12	13	10	11	9	8	7	12	7	13	10.2
25 - 26	15	16	14	11	8	6	5	13	5	16	11.0
26 - 27	19	20	16	14	13	12	12	12	12	20	17.1
27 - 28	9	10	8	7	4	4	5	11	4	11	7.3
28 - 29	12	14	12	10	8	9	8	13	8	13	10.8
29 - 30	16	15	13	8	7	9	8	12	7	16	11.0