The Resources of Lake Wanaka

Edited by B. T. Robertson & I. D. Blair

TGMLI

Lincoln Papers in Resource Management No. 5 - 1980
Published for the Guardians of Lake Wanaka by Tussock Grasslands & Mountain Lands Institute, Lincoln College

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Cover photograph: Wanaka Cameracraft

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Contents

Preface

The purposes of the Lake Wanaka Preservation Act 1973 and the functions of the Guardians appointed by the Minister for the Environment appear to allow a wide or liberal interpretation. While the specific purposes of the Act are to preserve the water levels and shoreline in their natural state and to maintain and improve the quality of the lake water, a function directed to the Guardians is to report and make recommendations on any matter concerning the use of the lake for recreational purposes. With these considerations in mind the Guardians have deemed it important, if not imperative, to arrange for the compilation, publication and distribution of a definitive record of Lake Wanaka in its present natural ecological state, and as a regional locality of development with some problems to be resolved and resources maintained or preserved.

In short, the guardians have posed these questions: What does the Wanaka system comprise in terms of natural resources that are implicit in the concept of guardianship? What problems are identified with the resources that may be reported within the purposes of the empowering Act?

A report of the Guardians published in 1976, "The issues relating to the level of Lake Wanaka", discussed the significance of the lake and its levels within the context of the Clutha hydro-electricity plans. This critically important controversial topic is not further discussed at this stage.

Information of scientific and general interest on Lake Wanaka is possessed by various people, most of whom signified willingness, when approached, to prepare reports on their subject areas of authority or knowledge. Further, it was both timely and fortuitous that the Working Party on *Lagarosiphon* weed in Lake Wanaka set up by the Officials Committee on Eutrophication had commissioned the Chemistry Division DSIR to provide detailed analyses of the Lake Wanaka waters as background information to the inquiry on ingress and spread of this aquatic weed. Through this agency, therefore, the basic information on water quality became available.

Until these data were provided, the Guardians would have been unable to plan or think in accord with one of their purposes: "to maintain and as far as possible improve the quality of water in the lake". The water and its chemical properties are reported on in this publication including two practical problems identified with Wanaka water, viz (1) *Lagarosiphon*: aquatic weed, a potential danger to the efficiency of hydro-electric dams in the Clutha River and (2) the public health problem, Duck or Swimmers' Itch, linked with a host/parasite syndrome.

Other subjects the Guardians believe to be basic to an understanding and appreciation of the habitat include the fish and wildlife resources; the physical characteristics and morphology of the lake including bathymetric maps, together with geological features; the climate and meteorology of the region and botany and ecology of the shoreline.

It is suggested that justification for this report may lie in its use as a base line for the status of the lake and some of its systems against which changes and development in the future may be measured. The report may be a present day balance sheet of the Wanaka natural resources. The papers compiled (see Contents) are technical or scientific in form but the authors have been encouraged to emphasise facets of general interest.

It is hoped that this publication will serve the interests of scientists but will also have acceptability among the general public, who are concerned that Wanaka, its resources and amenities, be preserved. The Guardians are deeply appreciative of the work devoted to this exercise by the authors, and believe that readers of this publication will also esteem the quality and merit of the individual reports.

Finally it is acknowledged that the completion of this publication has resulted from the encouragement and financial support provided by Mr I. L. Baumgart, Commissioner for the Environment, Wellington, and Professor K. F. O'Connor, Director, Tussock Grasslands and Mountain Lands Institute, Lincoln. The editorial work has been derived from the integrated efforts of Dr I. D. Blair, member of the Guardians Committee and Mr B. T. Robertson, Scientific Information officer, Tussock Grasslands and Mountain Lands Institute, Lincoln College. The assistance of Miss S. P. Townsend, Tussock Grasslands and Mountain Lands Institute, is gratefully acknowledged.

A S Scaife
Chairman, Guardians of Lake Wanaka
October 1980

General Introduction

R. CLELAND
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The lake appears as Lake Oanaka on a map sketched in 1844 by Maori Chief Huruhuru. Little, however, was known about earlier Maori use of Lake Wanaka when in 1853 Nathanial Chalmers became the first European to see it. Although outlined roughly in a sketch by J.T. Thomson from the distant Grandview Range in 1857, it wasn't until 1862 that James McKerrow produced a map showing the shoreline nearer to where it actually is today.

The Maoris had never settled permanently in the area, having only summer camps for food gathering. Thus when the Europeans arrived in the late eighteen fifties there were no Maoris to dispute ownership of the land and the lake.

Pastoral runs in the vicinity of Lake Wanaka were first taken up in 1858. Wanaka Station homestead was built 2½ miles from the lake outlet on the West bank of the Clutha River, "Undoubtedly the largest single physical factor that has affected the human history of the region." (Roxburgh 1957). The nearby ford and subsequently the Albert Town ferry were keys to further exploration, gold discovery, grazing and settlement in the Wakatipu and Wanaka regions.

By the 1890s, large runs had been subdivided and the smaller runs and farms were set back by rabbits, droughts and the flood in September 1878 which severely affected every aspect of the district. Following a particularly severe winter and unusually fine spring weather, the flood raised the level of the lake fourteen feet above normal (Roxburgh 1957), now known as the 925′ level. It was the greatest flood known in the history of the district and was reckoned by hydrologists to be a "1000 year" flood. (Fowler 1978).

As early as 1861, the lake was used for transporting timber from West Wanaka. Later, timber from sawmills in the West Matukituki and Makarora valleys was also rafted down the lake, the last raft of posts leaving Makarora as late as 1930. In the sixties, Albert Town had been the commercial hub of the Wanaka district but by the mid-seventies Pembroke (surveyed in 1865) had taken over. Tourism started in 1867 with the building of the first sailing ship on the lake and the first Wanaka Hotel. A schooner was built in 1869 for servicing lake runs and in 1881 a paddle-steamer was carrying passengers, timber, flax and general cargo.

Hydro-electric power

The nature and purposes of this publication do not justify further historical outline of the socio-economic development of the Wanaka region, information already being recorded in Otago regional histories by Garnier (1948) and McLintock (1949). The objective of this section of the bulletin is to provide an outline of the events and negotiations within the Wanaka community that gave impetus to Government action, bringing about safegards for the region with respect to the environment and its resources.

Investigations for a major hydro-electric station on the Clutha River commenced in 1945, resulting in the construction of the Roxburgh Station which produced power in 1956. Lake Hawea was controlled in 1960 (Clutha Valley Advisory Committee 1976). Proposals for using Lake Wanaka for hydro-electric generation were officially confirmed when the area now known as Pembroke Park was designated as a Reserve in May 1948. Nineteen of the 26 acres were subject to control by the State Electricity Department when "the lake level is raised 8′ above normal lake level." (C. Fowler, 1978).

An examination of the hydro-electric potential of the whole Clutha River system began in 1963. The 1968 Annual Meeting of the Wanaka Ratepayers and Householders requested that the Minister of Electricity cease to consider any form of control of the level of Lake Wanaka, and in February 1969 a joint submission by Lake County Council, Wanaka Town Committee, Wanaka Islands Domain Board, Wanaka Improvement Society and Albert Town Ratepayers Association to the Hon. T.L. Shand, Minister of Electricity, concluded with the opinion that there should be no control of Lake Wanaka, it being one of the last of the beautiful unspoiled Southern Lakes. It appears that Mr Shand stated there would be "no interference with natural seasonal levels" yet implied that there might be control with the natural range of levels. This use of words caused much subsequent confusion. In 1969, Mr J. H. George introduced a Private Members Bill in Parliament. This was aimed at restricting the upper controlled level of the Lake Wanaka to 912′ above sea level between December and March each year. It was withdrawn because of Government assurance that it would observe the spirit and intent of the Bill. An Interdepartmental Committee, established by the

Commissioner of Works in 1968, published a report in March 1972, assessing the regional effects of the proposals for six areas upstream of Roxburgh and four downstream. All proposals affected Lake Wanaka and Albert Town in the same manner, by artificially controlling the level of Lake Wanaka between approximately 906.5ft and 914.5ft, the former being just above the lowest natural winter level and the latter being the level of the top of the lake end of the wharf at Wanaka, and considered a mean high level. The head water level of the nearest downstream dam at Luggate was to be 910ft (the natural mean lake level). However, the crest level of the dam was to be 930ft owing to its waterholding capacity of approximately 924ft during extreme flood periods. The proposed 914.5ft as an artificially controlled upper level was completely unacceptable as the water would have been held too high for too long. The proposed lowering of the outlet of Lake Wanaka would also have had many detrimental effects below present mean lake level.

Following a meeting of representatives of the Wanaka Town Committee and Wanaka Islands Domain Board on 5 April 1972, representatives of Upper Clutha organizations met the Minister of Electricity, the Hon. L.W. Gandar, on 26 April 1972 and resolved that they were not prepared to accept artificial control of the level of Lake Wanaka, or the lowering of its outlet. The Minister, however, indicated that Lake Wanaka would be artificially controlled along those lines.

In May 1972, an Interim Committee called a public meeting and erected signs showing suggested dam levels. At the public meeting, the Interim Committee was constituted as an Action Committee which strongly supported a suggestion that there should be a comprehensive and independent Committee of Inquiry to report on all aspects of Clutha Valley development. In view of the multiple and devastating side effects, and the irreparable damage to bathing beaches, boating, fishing, scenic beauty, tourism, existing housing (mainly at Albert Town) and camping areas, picnic spots and farmlands that would result from the current hydro-electric proposals, the meeting rejected any suggestion of artificial control of the level of Lake Wanaka, including any proposal to lower the existing outlet.

Committee

At its first meeting in June 1972, the Committee became known as the "Hands off Wanaka Lake (HOWL) Committee, and an Executive was elected with the objectives of collecting and distributing information relative to the above resolution, ascertaining all facts relative to the Clutha proposals and discussing all lawful means available to ensure that the level of Lake Wanaka would not be artificially controlled nor its existing outlet lowered. Two HOWL bulletins were published during the year. The first gave an interpretation of daily lake levels from figures for the period 1939-70 supplied by the New Zealand Electricity Department. It was noted that the highest recorded level of 917.5ft occurred on 3 November 1948. The lake was above 914.5ft for 191 days only, and was at 906.5ft or lower for two periods totalling 25 days in the 32 years, the lowest recorded level being 906.24ft in September 1955. The figures 906.5ft–914.5ft delimited the proposed NZED control range of 8 feet. (HOWL Committee from New Zealand Electricity Department records).

The Prime Minister, the Rt. Hon. J.R. Marshall, was unable to visit Wanaka in September 1972 when he came to Alexandra to meet Clutha River Development Committee representatives. However the HOWL Committee was invited to send two representatives and made a written submission, which included an urgent request that Government reject all current proposals to impose controls on the water levels of Lake Wanaka for hydro-electric purposes, and included a statement that "At a time when the emphasis is on conservation and the environment, and with the knowledge of what is happening at Manapouri and Te Anau, we find it difficult to believe that a responsible Government would make the same blunder at Wanaka."

In his reply the Prime Minister stated "Lake Wanaka is a scenic gem of New Zealand" and added "I won't be wanting to spoil it. I really believe that people matter." At the same meeting the Vincent and Lake County Councils expressed concern about artificial control of Lake Wanaka, and the Clutha River Development Committee found difficulty in understanding why control of Lake Wanaka should be considered necessary.

At a combined meeting in November 1972, representatives of the Lake Manapouri campaign, Te Anau Preservation Committee, Friends of the Clutha, the Albert Town Ratepayers' Association and the HOWL Committee exchanged papers and other information and agreed unanimously on a policy of hands off Lake Wanaka, the last of New Zealand's great lakes hitherto unimpaired by development.

Preservation Act

On 14 December 1972, the HOWL Committee was informed that the Minister for the Environment, the Hon. Mr Walding, had given instructions for the preparation of a Private Members Bill to preserve Lake Wanaka in its natural state in perpetuity. On 11 February, a final draft was discussed with the HOWL Committee and, in November 1973, the Lake Wanaka Preservation Act 1973 became law. The purposes of the Act were:

(a) To prevent the water in the body of the lake from being impounded or controlled by, or, as far as possible, obstructed by, any works except in an emergency;

(b) To prevent the natural state of flow of lake water between the outlet of the lake which forms the source of the Clutha River and the confluence of that river and the Cardrona River from being varied or controlled by any works except in an emergency;

(c) To preserve, as far as possible, the water levels of the lake and its shoreline in their natural state;

(d) To maintain and, as far as possible, to improve the quality of water in the lake.

Section 5 provided for the appointment of the Guardians of Lake Wanaka whose functions were to be:

(a) Generally, to report and make recommendations to the Minister for the Environment on any matter affecting the purposes of the Act, on the use of the lake for recreational purposes, and on any other matter concerning the lake which the Minister for the Environment may from time to time specify; and

(b) In particular–

(i) To declare as an emergency any state of affairs existing when the lake water appears likely to attain such a level as to cause loss or damage to human life, livestock, or property by flooding;

(ii) To consult the National Water and Soil Conservation Authority from time to time on those functions of the Authority which may affect the lake, and to advise the Minister for the Environment of any such consultation and its outcome;

(iii) To give advice to the Minister for the Environment on any matter referred to him under *subsection* (1) of *section* 11 of this Act.

In November 1973 the Chairman of the HOWL Committee was informed that six names were under consideration for the membership of the Guardians of Lake Wanaka. As a final gesture in their campaign, the committee resolved that a suitable painting of Lake Wanaka be presented to the House of Representatives in appreciation of the preservation of the Lake in its natural state.

Guardians

In March 1974, the following were gazetted as Guardians of Lake Wanaka; Mr A. S. Scaife (Chairman), Professor T. W. Walker, Dr I. D. Blair, Mr P. D. Gordon and Mr W. F. Hunt. Subsequently Mr J. R. Scurr (Chairman, HOWL Committee) was appointed and Mr R. W. Cleland was co-opted. The first meeting was held at Wanaka on 9 April 1974.

The administrative structure provides for the funding of the Guardians by an annual grant from the Commission for the Environment and for clerical servicing to be provided by the Lands and Survey Department in Dunedin. The work of the Guardians has been greatly aided and encouraged by several departmental officers.

The Guardians have continued to involve themselves unobtrusively in issues or problems of fundamental significance to the natural region. Other contributors to this publication will be enlarging on these.

Meanwhile, the work of the Inter-departmental Committee was reviewed by the Clutha Valley Development Commission established by Government in 1973. The Commission submitted its findings to Government in 1974 and the concommitant recommendations were in turn reappraised by the Clutha Valley Advisory Committee set up by Government. The Commission's report took into account the fact that the Lake Wanaka Preservation Act 1973 precluded any form of control above the Cardrona River confluence (Clutha Valley Advisory Committee 1976).

Following the Clutha Valley Development Commission's report of November 1976, the Clutha Valley Advisory Committee defined its preference for Scheme 'H' as the best of three options for the development of the Clutha River. Scheme 'H' included alternative means of providing daily storage by replacing UC6 & UC7 dam proposals by a larger upper Pisa dam and canal scheme located near Luggate township (Clutha Valley Development Commission 1974). With a Design Flood Level of 895', it met Statutory requirements as provided by the Lake Wanaka Preservation Act, 1973. On 23 December 1976, Government opted for Scheme 'F', which was the same as 'H' as far as the effect of the Upper Pisa dam on Lake Wanaka was concerned.

On 21 May 1976, the Chief Engineer of the Otago Catchment Board advised the Chairman of the Guardians that the Otago Catchment Board and the Regional Water Board were producing a Water Allocation Plan for the whole of the Clutha Catchment. At a combined meeting on 4 June, the Chief Engineer sought the Guardians' opinion on a daily fluctuation in the level of Lake Wanaka which would be acceptable if a pump-generation station was installed between Lakes Wanaka and Hawea. Bearing in mind their own responsibilities under the Lake Wanaka Preservation Act and the downstream problems, the Guardians indicated that they would willingly examine the consequences after more detail was available, but would not agree to any interference whatsoever with the outlet of Lake Wanaka (Guardians 1976).

Following a report that the Guardians of Lake Wanaka were to be reappointed only until a Clutha Valley Authority was established, the HOWL Committee wrote to the Prime Minister in June 1976, requesting that the Guardians remain responsible for the preservation of Lake Wanaka. The Prime Minister's reply stated that there would be discussion with the Guardians and the HOWL Committee on the matter.

The Guardians also advised the Minister for the Environment that they would like to see themselves continue either as a sub-committee of a Clutha Valley Authority, or in their present capacity under the Lake Wanaka Preservation Act. In the reply received from the Minister, further discussion with the Guardians was assured before any final discussions were made on the Authority.

In December 1976, the Government announced its decision to establish the Clutha Valley Authority by adding to the Otago Catchment Board two additional people (one to represent the Upper Clutha and the other the Lower Clutha). The Minister for the Environment sought the view of the HOWL Committee which stated that "the Guardians are a happy blend of local and specialized knowledge and have proved to the public their responsible interest in many environmental aspects in addition to hydro-electric power development."

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Morphology

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Introduction

During the last glaciation, valley glaciers developed on both sides of the Southern Alps. Those to seaward in the Fiordland region have become deep indented fiords. The lower parts of the abandoned overdeepened glacial troughs on the eastern slopes are in many instances now occupied by large lakes.

Lake Wanaka, latitude 44°30′S longitude 169°08′E and altitude 277 m, is one of these glacial lakes. Wanaka is classed as occupying a glacially excavated rock basin that is partly or wholly closed by moraine and its contemporary outwash deposits (Gage 1975). The shoreline form is subrectangular-elongate (Hutchinson 1957) with a maximum length of 45.5 km and maximum breadth of 11.6 km. The major axis lies north-north-east, this being the axial trend of the main glacial lakes lying east of the main divide, with the exception of Lake Manapouri which lies east-west. With a surface area of 180 km², Lake Wanaka is the fourth largest New Zealand lake; only Lakes Taupo, Te Anau and Wakatipu have greater surface areas (Irwin 1975a) (Fig. 1).

Main inflows to the lake are the Makarora River at the north end and the Matukituki River at the south-west side; the outflow is to the south-east side by way of the Clutha River. Many small lateral streams enter the lake. Six islands, Harwich and Rabbit or Crescent Island in the main body of the lake, Stevensons and a smaller island in Stevensons Arm, Ruby Island at the south end and Bull Island near the outlet, give some complexity to the morphology at the southern end of the lake.

With a smaller surface area of 138 km² and lying at the higher elevation of 346 m, nearby Lake Hawea is separated from Lake Wanaka by a narrow 1.6 km wide ridge known as "The Neck" (Fig. 2).

The Lake basin

All lakes are transitory. Sediments are continually accumulating within lake basins, and, together with

Figure 1: Southend, Lake Wanaka looking north west. Roys Peninsula and Rabbit Island middle distance; Matukituki River, top left; Ruby Island, lower left, "The Peninsula" at right.

Photo: Whites Aviation Limited.

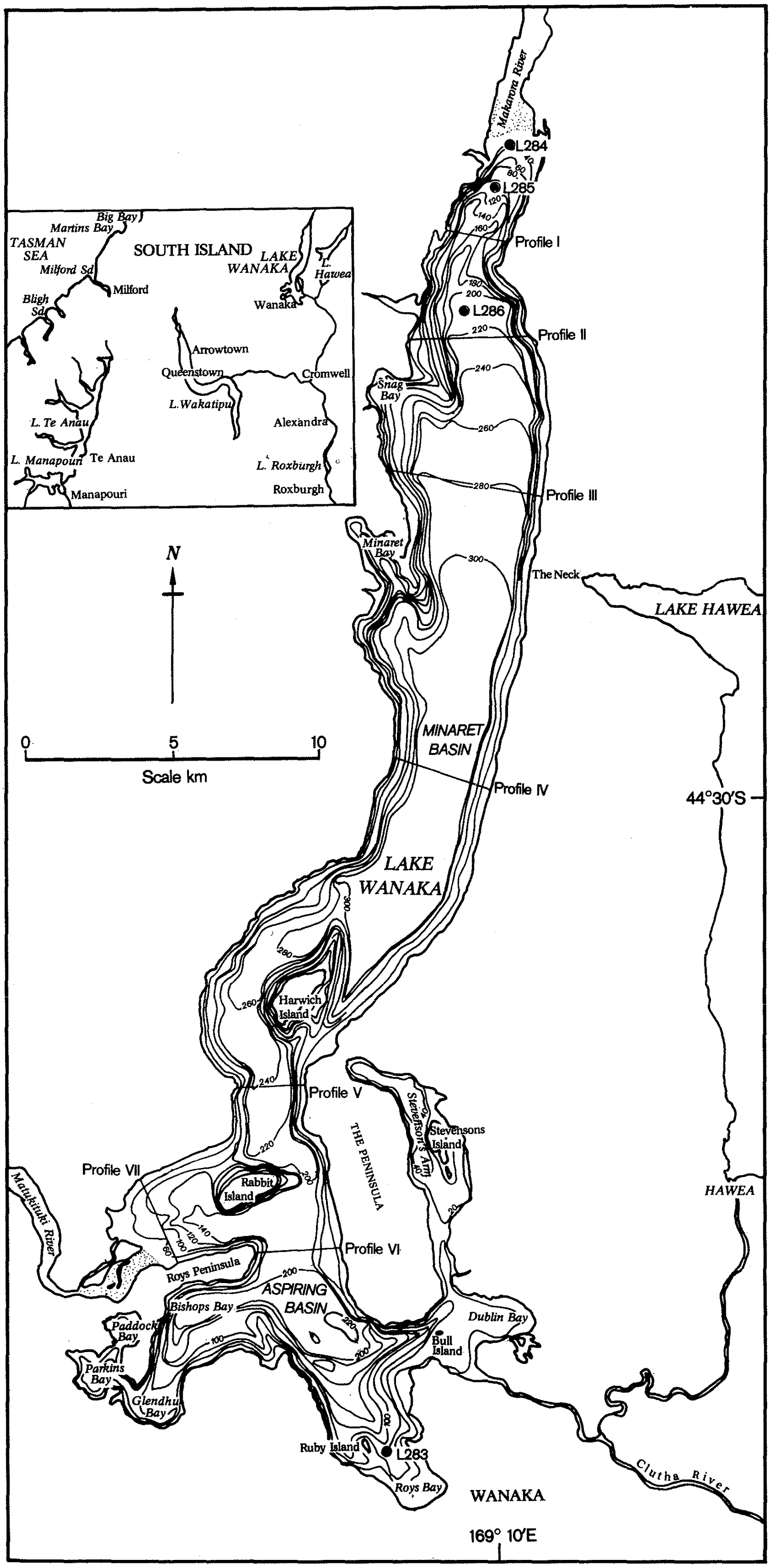

Figure 2: Locality map and sketch bathymetry of Lake Wanaka. Depth contours at 20m intervals. I-VII traverse profiles — see Figs. 3, 4, 5. Sediment sampling stations L 283 — L 286 5.8.71.

downcutting at outlets and subsequent draining, move lakes towards extinction. The sublacustrine morphology or underwater form of a lake reflects the origin and events subsequent to formation. The present underwater form shown by the bathymetric chart depicts the stage the lake has reached in its evolutionary cycle.

During 1971, Lake Wanaka was surveyed, using an echo sounder giving continuous depth records. From this depth data using 2069 plotted soundings a bathymetric chart has been compiled (Irwin and Ridgeway, 1976).

Typical of lakes of similar glacial origin, the lake is steep sided with large flat-floored basins (Fig. 2). A large delta occupies the head of the lake where the Makarora River enters. The bottom topography is characteristically rugged on the delta forest slope area and for about 8 km down lake.

The large central basin, "Minaret Basin", is approximately 14.5 km long by 2.0 km wide; all sides are steep except to the north, where the lake bed slopes gradually to a basin depth of 308 m east of the north end of Harwich Island. A localised maximum depth of 311 m is recorded in a small area northeast of the island. This main basin extends southwards west of Harwich Island until a depth of 200 m is reached east of Rabbit Island. The channel east of Harwich Island attains a depth of 136 m. Fig. 3 shows an echo sounder record across Minaret Basin to illustrate the steep lake sides and flat central basin area.

A sill, less than 200 m deep east of Roys Peninsula, divides Minaret Basin from Aspiring Basin. The latter extends west to Bishops Bay, south of Roys Peninsula and south to the southern tip of "The Peninsula". A maximum depth of 220 m is reached on an essentially featureless section of floor, with the exception of a small high of 182 m near the southern limit.

Comparatively shallow areas of less than 100 m depth occur around Minaret and Snag Bays, the north and east of Harwich and Rabbit Islands, and the bays at the southern end of the lake. Glendhu, Parkins and Paddock Bays to the west, Roys Bay to the south, Dublin Bay to the east and all of Stevensons Arm are also less than 100 m deep. A minimum depth of 8 m was recorded in the narrow southern entrance to Stevensons Arm and a maximum depth of 51 m was found in the north-west extension of this area. The bottom topography becomes more rugged in the south end of the lake away from the main, flat-floored sediment-mantled basins, a feature common with this type of lake..

Deltas

A detailed echo sounding survey of the Matukituki River delta area, carried out at the time of the main survey (1971), showed a decreasing *foreset slope* with increasing distance from shore. The angle of dip between 0 m and 30 m is about 17.5°, decreasing to about 11.5° between 30 m and 50 m and to about 7.5° between 50 m and 70 m. The delta of the Makarora River at the head of Lake Wanaka shows similar foreset slope angles. The underwater contours on the Matukituki River delta follow the line of the shore and are remarkably even to a depth of about 70 m. Soundings taken on deltas on other lakes show this parallelism to be common.

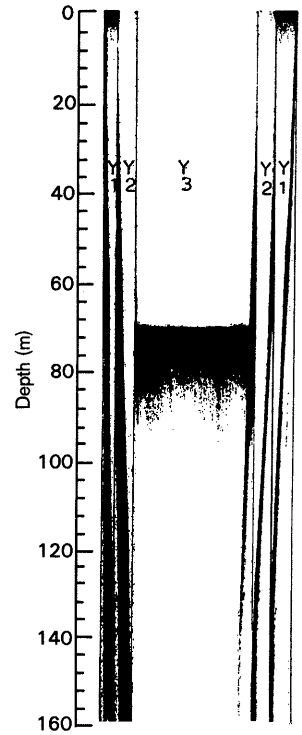

Figure 3: Echo sounder traces of profile at position IV. Numerals on records refer to depth phases of sounder. 1 = 0-160m; 2 = 120m-280m; 3 = 240-400m; 4 = 360-520m. (Y scale) Vertical scale exaggerated.

As a comparison, the measured foreset slope of the large, inflowing Tasman River in Lake Pukaki is approximately 2° to a depth of 47 m. This far lower angle of dip is discussed by Irwin (1975b) and may be attributed to the comparatively large amount of sediment being carried to this lake by the glacier-fed Tasman River.

Features of the underwater form

Basin areas

The steepness of the sides in the main body of the lake and around the south and west sides of Harwich and Rabbit Islands is characteristic of glacial lakes. Depth contours, which are evenly spaced, indicate constant slope; the side slope of lakes of glacial origin is usually fairly even. "Oversteepening", or a noticeable increase in slope, is pronounced between the 100m and 200 m depth contours in some areas and between the 200 m and 300 m contours in other areas, about Minaret Basin. In other South Island glacial lakes, oversteepening is either absent or poorly developed. Similarly, it is poorly developed in those fiords with reliable bathymetries. The exception is Caswell Sound which has marked oversteepening.

Sublacustrine channels

Channels on the lake floor may be formed under subaerial conditions and later covered by water as in the hydro storage lakes on the Waikato River or formed by processes of subaqueous erosion such as density or turbidity currents as documented for Lake Geneva (Forel 1885, 1887).

Sublacustrine channels in Lake Wanaka may be traced 13 km down-lake from high on the delta of the inflowing Makarora River to a position opposite Minaret Bay in about 300 m of water (Irwin 1980). The channels are from 4-14 m below the general lake floor and from 50-250 m wide. Figure 4, Profiles I-III, show echo sounder traces traversing this system of channels at three positions down-lake (see Fig. 2).

These channels are similar to those found in Lake Wakatipu which originate high on the delta slope of the main inflowing Dart and Rees Rivers at the head of the lake and continue 30 km down-lake. The depth of the channels is variable, usually 3-15 m deep, with a maximum of 30 m recorded, and the width ranges from 10-200 m. They are deepest in the steeper bottom slope area to 15 km down-lake from the inflowing rivers, but are still evident where the bottom slope is near level and the surface horizontal in a transverse sense (Brodie and Irwin, 1970).

Another system of sublacustrine channels exists off the Matukituki River. These are well formed off the foreset slope of the delta at depths over 70 m and pass into deeper water south of Rabbit Island before trending southwards. Another channel system exists north and west of Rabbit Island and joins yet another well formed system that passes south and west of Harwich Island. This latter system is also identifiable southwards to a position east of Roys Peninusla. Off the delta, the channels are up to 16 m deep but decrease to 1-4 m depth towards their extremities. Figure 5, profiles V-VII, show echo-sounder traces traversing this system of channels (see Fig 2).

There is no evidence of channels in the flat floor of Minaret Basin; the two systems are divided by a distance of 10 km and each is associated with a large inflowing river. Figure 6 is a schematic diagram of the channel systems, the paths of which have been interpreted from echo sounder records on the traverses shown.

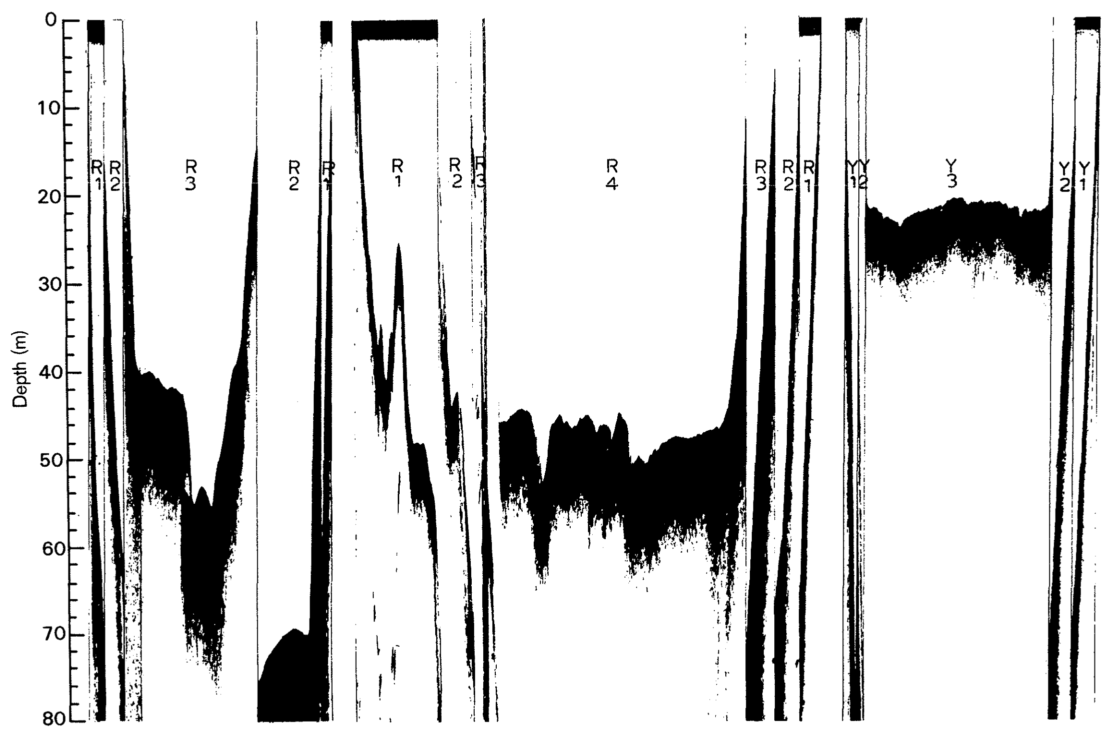

Figure 4: Echo sounder traces of profiles at positions I-III Makarora River channel system. Numerals on records refer to depth phases of sounder. Vertical scale exaggerated.
1 = 0-80m; 2 = 60-120m; 3 = 120-200m; 4 = 180-260m. (R scale)
1 = 0-160m; 2 = 120-260m; 3 = 240-400m; 4 = 360-520m (Y scale)

Some channels are shown as discontinuous lengths, a feature also evident on Lake Wakatipu and interpreted to be channels not actively engaged in sediment transport. It is of note that, although the other main glacial lakes east of the Southern Alps have been surveyed, Lakes Wanaka and Wakatipu are the only two that show sublacustrine channel systems, and these are remarkably similar.

Sedimentary regime

The sedimentary and temperature regime in Lake Wakatipu has been adequately documented (Brodie and Irwin 1970; Irwin and Jolly 1970). Lakes Wanaka and Wakatipu are geographically close and physically comparable, and it may be postulated that sedimentary processes occurring in each are similar.

Turbid water inflow from the major tributary rivers has been observed in both lakes to disappear abruptly within a short distance of the shore. This water was obviously sinking and flowing beneath the lighter waters of the lake in a manner originally described by Forel (1885) for the Rhone flowing into Lake Leman (Lake Geneva) and by later authors (Gould 1960, for Lake Mead).

During the bathymetric survey of 1971 (5.8.71), the turbid water boundary was 100 m off the Makarora River mouth under calm conditions. A surface water temperature of 7.68°C was recorded 20 m off the river mouth and depth of disappearance of a Secchi disc was 0.5 m. In clear water, close to the muddy-clear water interface, surface water temperature was 9.40°C and the secchi disc was visible to a depth of 16.0 m. The colder, denser, inflowing water was obviously sinking abruptly and flowing beneath the surface waters. Similar conditions presumably occur off the mouth of the Matukituki River but have not been observed by the author. Lake water temperatures at any depth are probably never less than 8.9–9.0°C in Lake Wanaka and this colder, denser, inflowing water will flow as a bottom current or a density current, described by Bates (1953) as "hyperpycnal flow". Interflow at appropriate levels with higher water temperatures is possible. In times of flood, density currents are probably confined to bottom flows.

The channels which originate off the mouths of the two major rivers provide a preferred path for density flows, whether these are continuous or intermittent. Sediments high on the delta slope may become unstable from time to time and slump. In the study of the channels in Lake Wakatipu, Brodie and Irwin (1970) postulated that the existence of abandoned sections of channel indicates that the process of channel

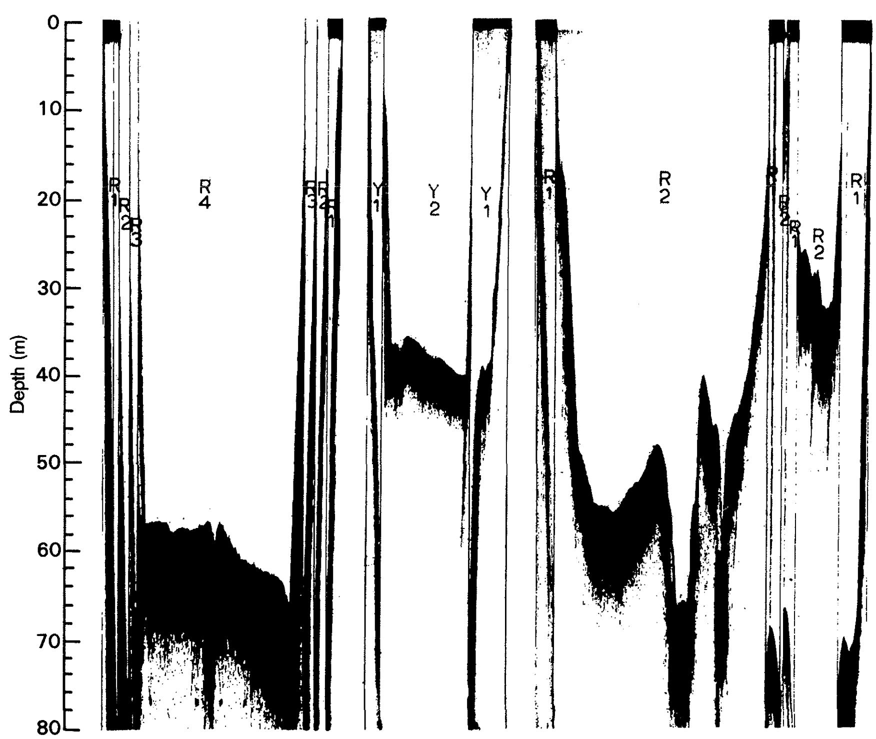

Figure 5: Echo sounder traces of profiles at position V-VII Matukituki River channel system. Numerals on records refer to depth phases of sounder. Vertical scale exaggerated.

=0.80m;	**2=60-120m;**	**3=120-200m;**	**4=180-260m (R scale)**
1=0-160m;	**2=120-280m;**	**3=240-400m;**	**4=360-520 (Y scale)**

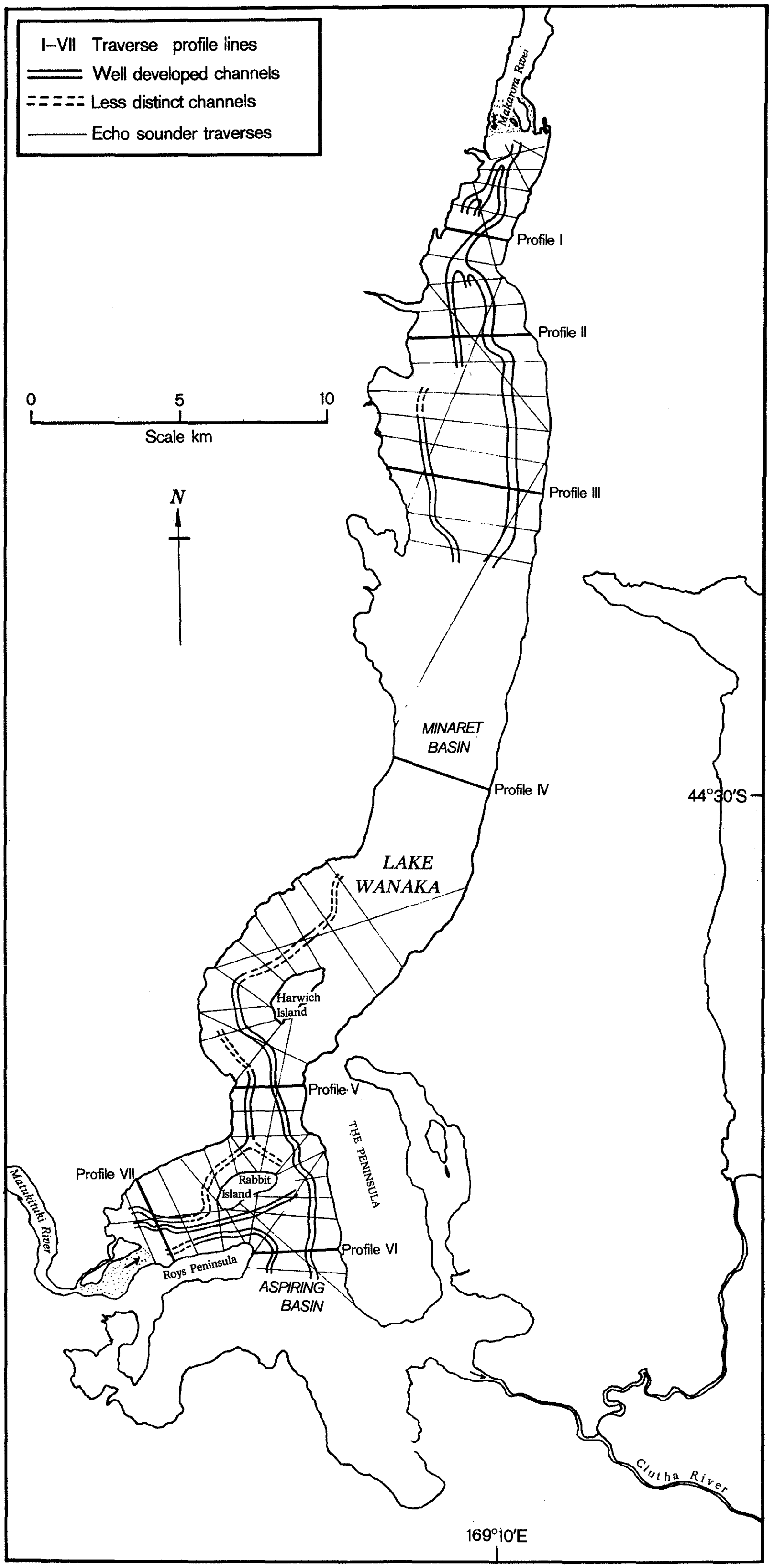

Figure 6: Schematic diagram of sediment channel system in Lake Wanaka.

formation was recently active, as sedimentation has not completely obscured the sections. The channels are a phenomenon of sediment from the foreset and bottomset beds being deposited in the lake. They end where the horizontal sediment surface in the deep lake basin begins, and are thus intimately involved in the present day sedimentary processes.

The morphology of the channels, the water temperature and conditions of inflowing water and the temperature regime existing in Lake Wanaka are remarkably similar to those in Lake Wakatipu. It is reasonable to assume that the processes involved are the same.

Three variants of density flow or turbidity currents that can be expected in lakes actively receiving sediments from rivers with waters at appropriate temperatures are given by Brodie and Irwin (1970).

(a) Continuous underflow or interflow of relatively low-density currents from the normal flow of rivers; sediment load very fine-grained;

(b) High-density underflows at discrete intervals related to flood discharge of rivers into the lake; sediment load includes a proportion of coarser grade sediments.

(a) and (b) are PRIMARY density currents, the sediment initially involved not being already deposited in the lake.

(c) High-density turbulent flows generated by slumping of previously deposited slope sediments; initial sediment load may contain a high proportion of coarse grade sediment.

(c) may be classed as a SECONDARY density current.

Bottom sediments

Grain size

During the 1971 survey, four bottom sediment samples were collected using a small pipe dredge (Fig 2). Although the number and distribution of samples collected are limited, grain size analysis shows size distributions similar to those of nearby Lakes Tekapo, Pukaki and Ohau, where grain size decreases downlake from the main inflowing rivers (Table 1).

Table 1: Grain Size analysis (% weight grades in μm) in samples from Stns. L 283, July 1971, L 284-L 286 August 1971).

Stn. No.	Depth (m)	Grade μm Clay<4	Silt 4-64	Sand>64
L283	60	50.0	49.3	0.7
L284	18	0.3	1.2	98.5
L285	110	2.7	59.6	37.7
L286	212	9.6	77.9	12.5

Sample L284 from the Makarora River delta in 18 m of water contains 98.5% sand and gravel which decreases at Stn. L285 in 110 m, finer silts increase to predominate at Stn. L 286 from 212 m. Sediment from Stn L 283 at the south end of the lake contains nearly 100% silt and clay size particles and the greatest percentage of clay.

Geochemistry

Mineralogical analysis of 26 lake sediment samples from six South Island lakes have been described by Glasby (1975). Lakes covered were Wakatipu, Ohau, Pukaki, Tekapo, Wanaka and Hawea. Mica chlorite, quartz and feldspar were found to be the major minerals in all samples with smaller amounts of cristobalite being present. Amorphous material makes up an appreciable proportion of each sample. Sediments from Wanaka and Hawea contain higher concentrations of mica chlorite and lower concentrations of quartz than those from Lakes Pukaki and Tekapo. Glasby concludes that this may reflect differences in the lithology of the surrounding country rock.

Trace metal concentrations in the sediments from each lake are similar; although minor differences in concentration are apparent, they could not be readily categorised according to the lithology of the rocks comprising the drainage basins. Organic carbon content is low in each sample, suggesting that trace metal abundance in the sediment is not controlling organic productivity of the lakes.

Thermal conditions

Few measurements of seasonal water temperature changes throughout the water column exist for New Zealand lakes. Records from Lake Wanaka are limited and are restricted to measurements by Jolly in 1952 and 1953 (Jolly unpublished 1959) and those recorded during the bathymetric survey of July/August 1971. These data are combined and shown in Figure 7.

The known maximum surface temperature of 16.7°C was recorded in February 1953 and the minimum of 8.5°C in August 1953. Jolly notes that this temperature was recorded "after frost". An average temperature of 9.6°C was recorded from seven readings taken over the body of the lake ((3) 24.7.71, (4) 5.8.71). In August 1953, Jolly recorded a temperature of 8.75°C at 209 m and an average of 9.0°C at 280 m was recorded from seven readings in July/August 1971. A bottom temperature of 9.08°C was recorded on 5.8.71 at 308 m in Minaret Basin.

Thermal conditions in New Zealand lakes are summarised by Jolly and Irwin (1975). Effects of altitude, latitude and depth on water temperatures are discussed and it is concluded that these three factors determine to some degree the temperature differences found between lakes. Climate, particularly the lakes' exposure to wind, is also an important factor.

Although of smaller surface area, Lake Wanaka (180 km^2) is similar in other respects to Lake Wakatipu (289 km^2). Separated by only one half a degree of latitude, their altitudes differ by 33 m (Wanaka 277 m, Wakatipu 310 m), and both are deep lakes, reaching depths of over 300 m. Oriented in a general north-south direction, Lakes Wanaka and Wakatipu are bounded by mountain ranges along their lengths and are subject to strong winds. On data that have been recorded and from similarities listed, it is probable that the thermal regime of Lake Wanaka closely follows that of Lake Wakatipu.

Seasonal water temperature conditions in Lake Wakatipu are discussed by Irwin and Jolly (1970) in which the lake is found to stratify and is classed as "warm monomictic"; that is, it has summer stratification and circulates fully in winter with temperatures above 4°C.

Surface water temperatures are highest during January through to March. A maximum surface temperature of 16.9°C, recorded in Lake Wanaka in February 1953, compares with a maximum of 16.5°C recorded in Lake Wakatipu. A minimum surface temperature of 8.75°C was recorded in mid August in Lake Wakatipu when isothermal conditions prevailed throughout the water column. This compares with isothermal conditions, featuring temperatures of 9.1°C at the surface and 9.08°C at 308 m recorded on 5.8.71 in Lake Wanaka.

The few temperature profiles recorded in Lake Wanaka (Fig. 7) probably include the near seasonal maximum and minimum surface temperatures and the winter bottom temperatures. Deep water temperatures in Lakes Wakatipu and Manapouri show little seasonal variation below 200 m and this condition probably applies to Lake Wanaka (Irwin and Jolly 1970; Irwin 1971). Another feature of these large, deep, glacial lakes, probably also applicable to Lake Wanaka, is that, on stratification, the thermocline forms late in the warming period, and, because of frequent and strong winds, consistent with an insular position, the lakes develop very deep epilimnia (Jolly and Irwin 1975).

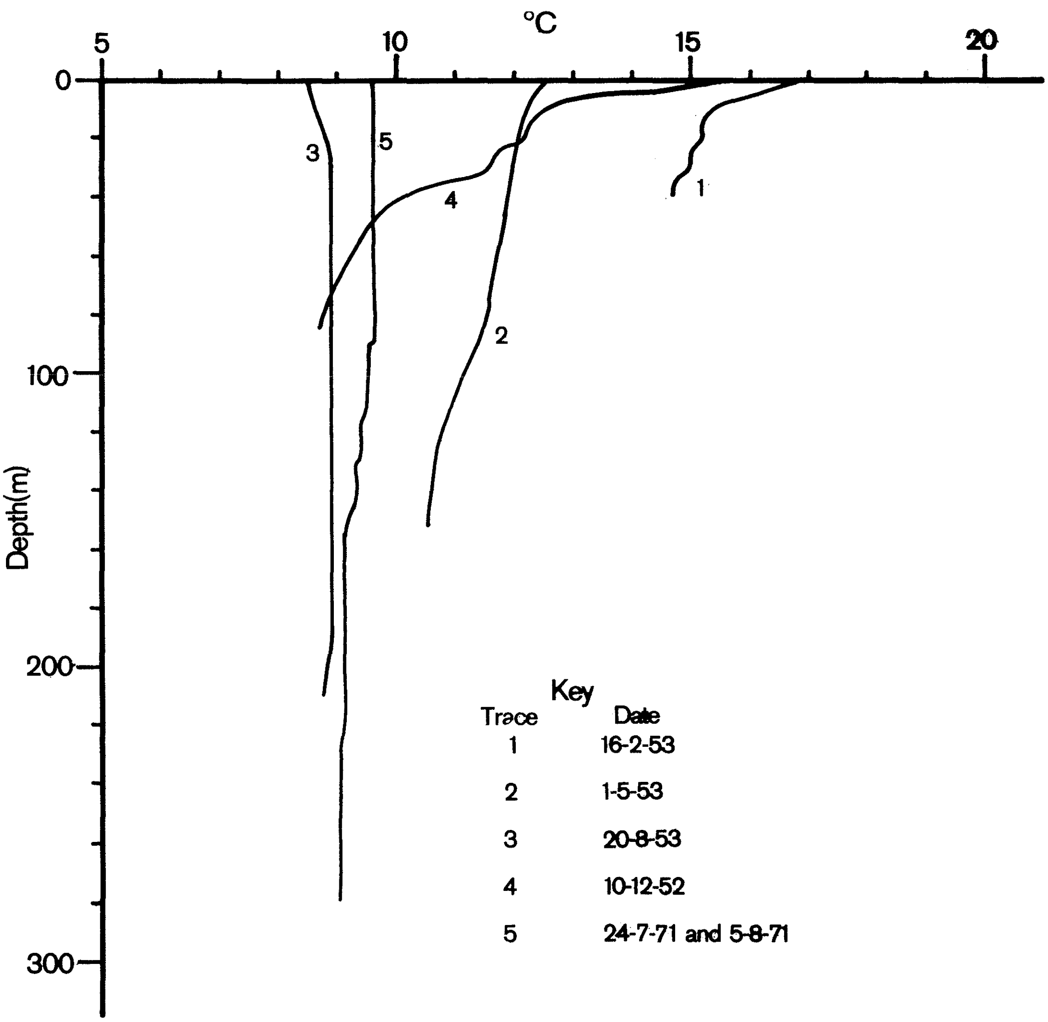

Figure 7: Vertical water temperature profiles; Lake Wanaka 1-4 from Jolly unpublished 1959; 5 from 1971 survey.

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Geology

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Lake Wanaka is a body of water ponded in a depression carved out by glaciers in rocks of the Haast Schist Group, and dammed at the south end by the moraines deposited by ice age glaciers. In bays and river mouths on each side of the lake, gravel and sand deposited since the last ice age border the lake margin and encroach into the lake basin. The most important of these are the alluvial deltas at the mouths of the two largest rivers, the Makarora and the Matukituki. As there are no rocks intermediate in age between the ancient schists and the very much younger glacial and post glacial deposits, other than rare lamprophyre dykes, the geological picture is relatively simple.

Haast Schist

This is a metamorphic rock derived from sediments laid down in late Paleozoic or early Mesozoic time as part of the New Zealand Geosyncline. These were silt, sand, and in some places gravels and volcanic rocks deposited in a progressively sinking pile of marine sediments that eventually suffered alterations in mineral composition and rock texture under high pressures and temperatures due to depth of burial. Mountain-building forces deformed the sediments and folded the bedding planes, and increasing metamorphism changed the texture of the rock, till the original sedimentary structures became almost unrecognisable and the metamorphic grade reached that of textural zone IV in the area now occupied by the lakeside rocks (Bishop 1972). Schists of this zone are strongly foliated, with the light coloured minerals quartz and albite segregated into layers greater than 0.2 mm thick (usually several millimeters thick at least) separated by grey layers, mainly of albite, epidote, muscovite and chlorite. The schist around most of the lake shore has not been studied in detail, but one area along Highway 6 east of Lake Wanaka, from Dinner Flat to the Neck on the roadside overlooking Lake Hawea, has been carefully examined. This and other sections show that rocks immediately east of Lake Wanaka fall off in metamorphic grade from textural zone IV, through rocks where the segregation layering is less pronounced and appearing as a succession of lenses. Further east, there are foliated rocks without mineral segregation, but with splitting along parallel plane surfaces that show a micaceous lustre. Rocks still further east are foliated but are sufficiently low in metamorphic grade for the original sedimentary bedding to be still recognisable, especially where beds of sandstone and siltstone alternate. The boundaries of these metamorphic zones extend north-north-east up the lake parallel to the Makarora Valley, as shown on the relevant sheets of the N.Z. Geological Survey 1:250,000 map series (Mutch and McKellar 1964, Wood 1962). Some of the streams draining from the east will intersect these lower grade rocks and add boulders and pebbles to the alluvium reaching the Makarora delta extending out into the north end of the lake.

In the western part of the Makarora Catchment, the tributary streams encroach on higher grade Biotite Zone schists. These are well exposed in the road cut outcrops down the Haast river, from the Landsborough junction to the coast. They are more massive rocks, with foliation and segregation layering less well marked. Only a very small part of the total alluvial material in the Makarora River will be derived from these rocks.

Round the lake shore, the Haast schist is resistant to wave action though it is closely jointed, and angular blocks can break off the outcrops by cleaving along foliation planes, and fracturing along joints that form the irregular and complex joint pattern characteristic of the schist of Central Otago. The light coloured quartz-albite layers form the hardest part of the rock, and beach gravel of subangular to sub rounded quartz pebbles are derived from wave action, breaking up the schist outcrops and fallen schist blocks along the lake margin. More rounded quartz pebbles on beaches come from streams rising in the surrounding schist terrain and transporting rounded gravel particles out onto the lake beaches.

The grey chlorite-muscovite fraction of the rock is softer, and will break down more readily than the quartzose fraction into sand-sized particles.

Glacial deposits

Round the south end of the lake from east of Stevensons Arm to the west side of Roys Bay, moraine deposited at the maximum of the last glacial advance shows a characteristically hummocky topography underlain by a bouldery till. This is an unstratified glacial deposit resulting from the transport of schist and some greywacke debris from the mountains to the north and west, on and within a glacier that filled the lake basin 15,000 to 20,000 years ago. Before this event, within the last 100,000 years, other ice floods had occurred. The valley glaciers from the Hawea and Wanaka basins merged and extended south, at least as far as Queensberry and Bendigo during the Lindis Advance (McKellar 1960). The Wanaka glacier submerged Mt Barker and Mt Iron, shaping Mt Iron into the characteristic "roche moutonnée" shape for which it is famous.

The last time the Hawea and Wanaka glaciers merged was during the Albert Town advance (McKellar 1960 p.447), when a continuous moraine loop was formed at the terminus of the glacier from the foot of Mt Barker through Albert Town, to Lagoon Valley south of Hawea Flat. At this stage the ice in the two lake basins must have joined across The Neck, and both lake basins would have been progressively deepened by the eroding action of the southward moving ice during the height of each glacial advance, and infilled to some degree during the interglacial periods, when ice may well have abandoned the lake basins and retreated far up into the mountains.

The event most important in shaping the present form of Lake Wanaka was the Hawea Advance, when two glaciers, probably contemporaneous but with separate terminals, and joining across The Neck, deposited the massive terminal moraines that pond the present day Wanaka and Hawea, and determined the south end of the lake (McKellar 1960 p. 436 and Fig. 2). The embryonic lake would have formed about 18,000 years ago, probably about 30 m above present lake level, and bounded on the north side by the retreating ice front. Once the ice terminal started floating in the lake, carving and retreat would have been rapid, the ice tongue breaking up into icebergs and the plentiful water flow from the melting ice entrenching the outlet river into the soft glacial silt at the lake outlet and lowering the lake to its present level.

Post-glacial deposits

The falling lake left old strand lines and beach deposits in the form of stratified sand and gravel beds. These are most likely to be well developed at the mouths of rivers and streams where supplies of unconsolidated alluvium were available to be reworked into gravel beaches, and on those parts of the coast exposed to strong winds where wave energy was greatest. These old lake beach deposits and the history of post glacial lake levels have not been studied in detail and are worthy of further research.

Large and small streams poured sand and gravel into the lake basins during glacier retreat and this process continues to the present day, especially at the mouths of the two main rivers, the Makarora and the Matukituki. As in other southern glacial lakes in schist country, deltas of gravel and sand at the mouths of streams provide some of the best materials for growth of lake beaches. Stream alluvium derived from the schist hinterland has the harder components such as quartz pebbles worn down during transport so that they are rounded or subrounded. Particle size is small enough to be easily sorted by waves into gently sloping beaches suitable for recreation, and the deltas form convex sections of shoreline, giving shelter from winds blowing either up or down the lake.

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Climate and weather

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Summary

Taken over a period of years, the rainfall at Lake Wanaka is rather evenly distributed throughout the year. Falls of 1 mm or more occur on 24% of days and are normally associated with a front passing across the South Island. Heavy rains sometimes develop with a slow-moving front over the south of New Zealand, and inflows to the lake can reach very high levels. Extended periods without rain are relatively frequent and soil moisture is likely to be deficient at the south end of the lake nearly every summer.

Day temperatures in summer are, on the whole, warm. Nevertheless, snow in December and January is not unknown and frosts are possible throughout the year. In winter, day temperatures reach 8-10°C on average and most nights are frosty.

Wanaka is markedly more windy in summer than in winter. At this time of year, westerly airstreams are more frequent but in the winter southerlies tend to predominate. The lake is favourably placed relative to the mountains for clear skies and a high percentage of the possible sunshine is expected to occur there.

Introduction

Over most of New Zealand, the land form is an important factor in modifying weather systems moving onto the country and thus in producing local climate. In few other districts are the results of the modifications more marked than in Otago. This region embraces the area with the lowest annual rainfall (Alexandra, about 300 mm/year) in New Zealand and one of the highest annual rainfalls (Milford Sound, about 6000 mm/year). In Central Otago, the heating and cooling of the land seems to play as important a part in the climate as the weather systems moving across the sea. These weather systems bring abundant rain to the West Coast, and the southerlies and easterlies associated with them exert a strong marine influence on the east coast of Otago.

Lake Wanaka is immediately east of the main mountain range and lies roughly between Milford Sound and Alexandra. Annual rainfalls over the lake average between 700 and 2000 mm, the larger falls occurring closer to the mountains (Fig. 1). It appears that the deep cloud masses which occur in active fronts moving onto New Zealand often produce precipitation up to 50 km east of the main divide. Rain carried by the wind also affects the distribution of the isohyets. The climate of Lake Wanaka has elements of the marine weather systems of the West Coast and of the continental climate of Central Otago; these are discussed in the subsequent sections.

The data network for the Lake Wanaka vicinity is sparse. Climatological measurements have been made in Wanaka township since August 1972, using thermometers and a raingauge. Weather reports have been made at Wanaka or nearby since 1962. Visual estimates of the wind, cloud, and weather provide coverage throughout much of the day. Climatological observations have been made near Lake Hawea since 1955. Rainfall measurements at Wanaka extend back to 1930 and at Hawea to 1921. Rainfall measurements have also been made at Makarora, at the head of Lake Wanaka, since 1930. Lake Hawea and Makarora have recording raingauges. These, and other stations having rainfall measurements over a period of years, are shown in Fig. 1.

Rainfall and lake flows

The annual rainfall distribution over the high country, shown in Fig. 1, is largely conjectural where there are no observations available. The average rainfall over the entire Lake Wanaka catchment may be indirectly obtained from the average outflow from the lake (190 m^3/sec) when allowance is made for evaporation. The catchment of the lake is 2575 km^2 and an estimate of the evaporation over this area is 700 mm/year. On this basis, Jowett and Thompson (1977) have estimated the mean annual rainfall in the catchment at about 3000 mm.

Heavy rain conditions over the catchment of Lake Wanaka occur when an active frontal zone or depression moves slowly over the South Island (for example, see Figure 2). The warm, moist air which flows southward ahead of the front is available as a continuously renewed moisture source to the front. The persistence of the rain about and west of the ranges depends only on the persistence of the front. In the example shown, Lake Hawea showed a recording of 69 mm on 27 July 1962 and there were heavy falls recorded on the 26th and 28th as well.

The maximum rainfall expected, in periods ranging from 10 minutes to 72 hours with a return period of two and 20 years, is shown in Table 1. In a 10-minute period, rainfall intensities are similar at Lake Hawea and Makarora. Over 72 hours, however, Makarora can be expected to have twice the amount of rain.

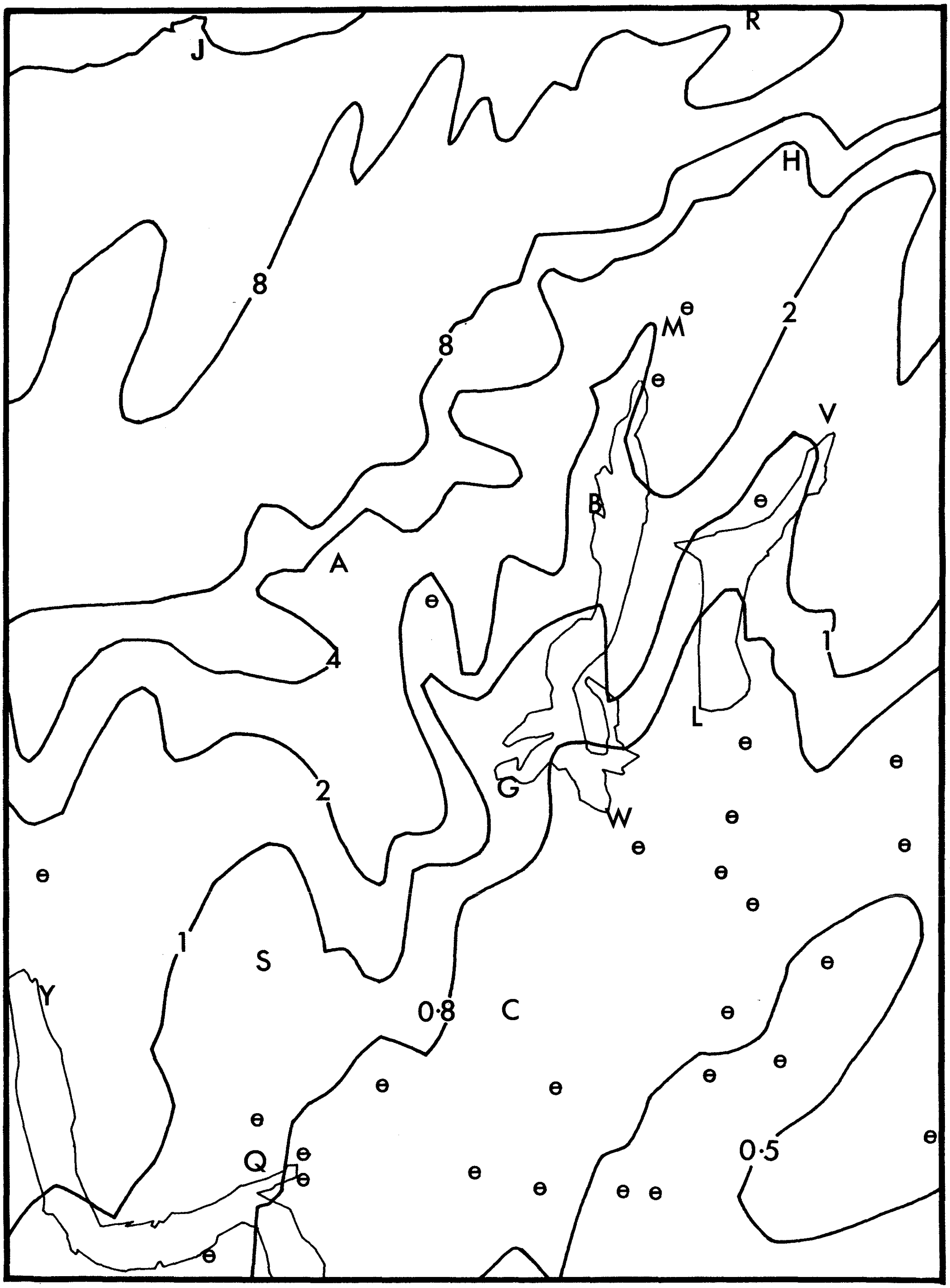

Fig. 1. Average annual rainfall (m) in the vicinity of Lake Wanaka. Rainfall normals for 1941–1970 at stations shown by a ɵ or a capital have been used. It is believed that annual precipitation over and west of the main divide is greater than 8 m. A denotes the rainfall station at Mt Aspiring station, Minaret Bay (B), Cardrona (C), Glendhu Station (G), Haast Pass (H), Jackson's Bay (J), Lake Hawea (L), Makarora Station (M), Queenstown (Q), Roaring Billy Haast (R), Skippers (S), Hunter Valley (V), Wanaka (W), Glenorchy (Y).

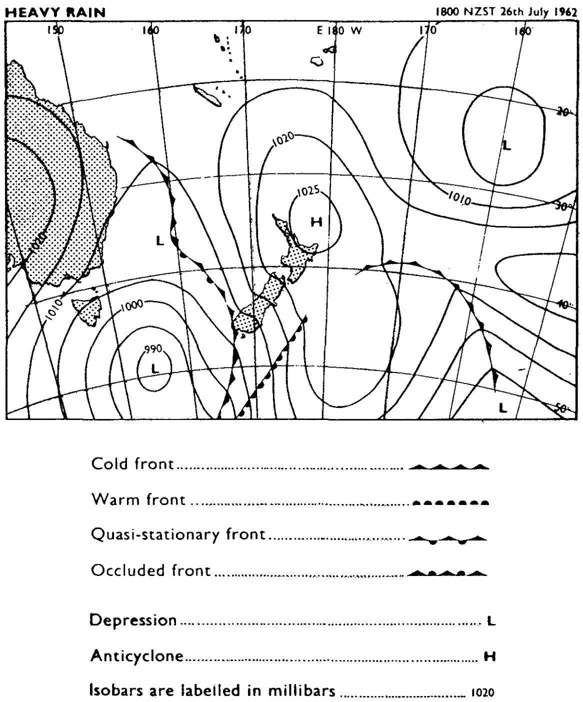

Fig. 2. Weather map at 1800 NZST 26 July 1962. A front over the south of the South Island is slow-moving as a developing depression in the mid-Tasman Sea moves southeast along it. Rain was falling in Central Otago at the map time and continued until the 28th. Rainfall at Lake Hawea on the 27th was 69 mm. (Taken from de Lisle and Browne, 1968.)

Under heavy rainfall conditions, inflows to Lake Wanaka have exceeded 4000 m³/sec in one day. Discharges from Lake Wanaka are strongly modified by the storage in the Lake, and daily values have been estimated to rise to about 700 m³/sec.

At Lake Hawea, there is a fall of rain of one mm or more on about one day in four. In the ranges, the frequency rises to about one day in two, and is highest in spring. There is a maximum rainfall at Makarora at this time of the year but little seasonal variation at Lake Hawea. One or more periods of drought (14 or more days without rain) occur in most years at Wanaka and Lake Hawea. Soil moisture around these stations during summer usually falls below field capacity. At the head of the lakes, soil moisture is probably less frequently in deficit, and the situation on the hills around the lakes is not clear.

An annual cycle is found in the flow entering Lake Wanaka; the maximum in November is, on the average, about 70% greater than the minimum in July. This variation is related partly to rain in the catchment and partly to seasonal snow melt. There are marked variations in the inflow to Lake Wanaka from year to year, peak flows having occurred in 1949, 1958 and 1970.

Weather

An assessment of the frequency of fronts over the south of the South Island has been made using synoptic charts. Many features marked as fronts on the charts do not produce significant rain at Wanaka, nor even significant cloud. These are not classed as frontal days in the present study. On the other hand, as some fronts approach the South Island, cloud develops at Wanaka well ahead of the weather system and some heavy falls of rain can occur. If more than a few millimetres of rain were measured at Wanaka, and cloud associated with it persisted for a substantial period, the day was classed as frontal. On this basis, 17 percent of the days in a recent three-year period were thus classed.

The frequency of occurrence of frontal days is almost constant throughout the year (Fig. 3), although individual months show large fluctuations. It is uncommon for fronts to become slow-moving over the south of the South Island; only 24 percent of frontal days occur in groups of three or more. A small percentage of days were dominated by the presence of a low pressure centre over the south of the South Island and these were included with the frontal category.

The non-frontal days were classified according to the direction of the prevailing airstream, or as anticyclonic. Airstreams from between north and southwest were classed as westerly. Before reaching Wanaka, these pass across the Southern Alps. Days which were predominantly westerly were mostly fair or fine at Wanaka. Some of the days, principally those before the arrival of a front, had strong northwesterlies. Winds were occasionally strong from other directions when the gradients were intense.

Airstreams from the south and east were classed as southerly. Days which were predominantly southerly were sometimes cloudy and cold and sometimes fine. Anticyclonic days were mostly fine with light winds, warm day temperatures and cold night temperatures.

The variation of each of these weather types is shown in Fig. 3. The data have been smoothed using running means. Westerlies have a maximum frequency in

TABLE 1: Rainfall depths (mm) with a return period of 2 and 20 years.

Station:	Period	10M	1 H	6 H	12 H	24 H	72 H
Lake Hawea	2 yr	3	9	31	48	60	78
	20 yr	7	13	51	87	116	146
Makarora	2 yr	4	14	53	81	114	173
	20 yr	7	21	77	130	203	294

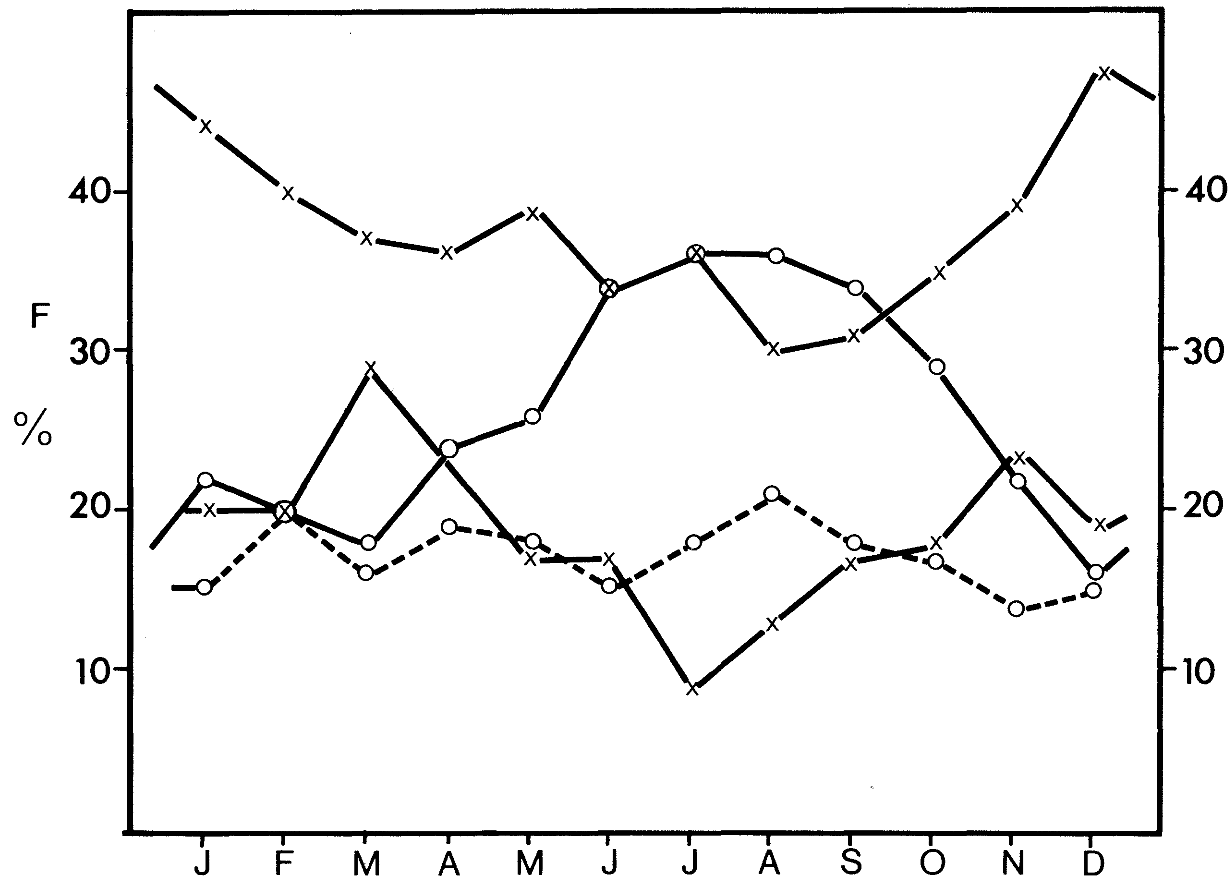

Fig. 3. Average frequency of weather type at Lake Wanaka as a function of month. Each day in 1974, 1975 and 1976 has been classed as westerly (top crosses), southerly (circles and solid line), frontal (pecked), or anticyclonic (lower crosses).

summer and a minimum in August and September with an overall frequency of 37 per cent. Southerlies have a broad maximum in the late winter and have a total incidence of 26 per cent. Anticylonic days peak in March and November and have an overall frequency of 19 per cent.

Westerly conditions are the most persistent as well as the most frequent and 56 per cent of these days occur in groups of three or more. Southerly conditions persist for three days or more on 43 per cent of the occurrences and anticyclonic days on 41 per cent of the occurrences.

The variations of weather type throughout the year are not particularly large and show a strong variability from year to year. Anticyclonic days during the three year period of study varied from 0 to 15 days per month. Frontal days varied from 1 to 11, and westerly and southerly days had smaller variations. The seasonal variation of the southerlies and westerlies probably makes the winter a little colder and the summer a little milder. However, the more extreme weather types associated with anticyclonic and frontal days show a great deal of unsystematic variability, and do not distinguish one season from another.

The New Zealand Meteorological Service has a network of sunshine recorders over the South Island. There is no instrument at Wanaka, the nearest being at Haast, Queenstown, Alexandra, and Omarama. The number of hours of sunshine at each site has been expressed as the percentage possible allowing for the horizon obstructions around the instrument. Averaged over a period of several years, these percentages are respectively 46, 58, 51 and 51. The variation through the year at Haast has maxima in August and April and a minimum in November; it is broadly consistent with the variation of westerlies throughout the year. The variation at Alexandra is quite small, apart from a pronounced minimum in winter which is probably due to the high frequency of southerlies carrying cloud inland. Omarama and Queenstown are in a similar position with respect to the main divide as Wanaka, and their variations throughout the year are quite small; Queenstown evidently has much less cloud than Omarama but seems to be affected by cloudy southerlies in the autumn and early winter.

Wanaka is surrounded on all sides by mountains and should be at least as well protected as Queenstown from low-level cloud. On the other hand, low cloud can reach Omarama through the Waitaki Valley. Sites in the Mackenzie Basin at Lake Tekapo and Mount John have percentages of possible sunshine comparable with Queenstown, and it appears that Wanaka should have a similar percentage (about 58%). On this basis, those parts of Lake Wanaka where the terrain does not significantly obstruct the sun probably have 2200 to 2400 sunshine hours per year.

A comparatively high frequency of clear skies not only produces large isolations by day but permits long-wave radiation to escape more readily at night. Ground frosts occur on about 70% of the nights during the winter months.

Temperatures

Temperature readings at Lake Hawea form the longest record for the district and mean values are given in Table 2. The mean daily maximum temperature in summer is about 22°C and daily minimum temperatures average about 11°C. High maximum temperatures are a feature of the climate, and low maxima likewise occur on some summer days. A shortened climatological summary is given in Table 3 for the readings from Wanaka Post Office. Mean daily maxima and minima indicate a slightly more extreme climate than at Lake Hawea, both in the diurnal range and in seasonal variation. The normal temperatures, which are reduced to a common period, are slightly higher at Wanaka than at Lake Hawea. It is likely that much of the difference between Lakes Hawea and Wanaka is due to the siting of the instruments. At the former, the enclosure is on an exposed site on top of the embankment on the southern rim of the Lake, where air is likely to circulate at all times. The instruments at Wanaka are in a sheltered location behind the Post Office and the air is likely to be stagnant from time to time.

For comparative purposes, some climatological figures are given for Alexandra (Table 4). The normalised annual mean temperature is the same as at Lake Hawea and 0.2°C below that at Wanaka. These latter stations are respectively about 200 m and 150 m higher than Alexandra, and, by virtue of the temperature lapse with height, could be expected to be about 1°C colder. The normal temperature is slower to rise in the spring; this is consistent with the proximity of a large body of water.

Under the cloudier skies at the head of Lake Wanaka, temperatures are probably less extreme, although katabatic winds may be more pronounced. On the mountains, generally, colder temperatures can be expected. Experience at mountain stations in New Zealand shows that the mean temperature decreases at a rate of about 6°C per 1000 m. By the time the 1000 m contour is reached on the mountains around Lake Wanaka, the annual mean temperatures would be about 5°C. Maximum temperatures tend to be much lower than at lower altitude stations, but for temperature minima the difference tends to be smaller. At 1500 m, the annual mean temperature would be about 2°C and frosts could persist for periods of several days. Daily freeze-thaw cycling could be present for much of the year.

TABLE 2: Lake Hawea climate
(350m. a.s.l.)

		Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Year
Rainfall (mm)														
Highest monthly/annual total	1955–1975	192	154	148	155	204	102	167	187	289	192	213	177	1067
Normal	1941–1970	69	61	71	58	71	58	58	58	71	66	71	58	770
Lowest monthly/annual total	1955–1975	14	3	12	13	5	5	16	14	16	9	13	11	529
Average number of days with rain 1.0 millimeters or more	1955–1974	7	6	7	7	9	7	6	7	8	9	9	7	89
Maximum 1-day rainfall mm.	1955–1973	106	54	65	35	51	72	68	52	87	49	97	70	106
Temperature. Degrees Celsius														
Highest maximum	1955–1975	35.6	31.7	32.8	24.1	19.5	17.2	16.2	16.9	20.0	29.4	28.2	32.3	35.6
Mean monthly/annual maximum	1955–1975	30.0	28.6	26.1	21.4	17.2	14.3	13.1	14.8	17.4	21.4	23.9	28.0	31.0
Mean daily maximum	1955–1975	22.9	22.9	19.9	16.2	11.5	8.3	7.5	10.0	13.2	15.8	17.9	21.2	15.6
Normal	1941–1970	16.9	16.7	14.4	11.0	7.2	4.2	3.7	5.6	8.3	10.7	12.9	15.4	10.6
Mean daily minimum	1955–1975	11.7	11.4	9.5	6.4	3.1	0.4	−0.3	1.0	3.6	5.9	8.0	10.2	5.9
Mean monthly/annual minimum	1955–1975	5.2	5.1	3.1	0.2	−2.3	−3.8	−4.5	−3.5	−1.5	0.1	1.9	4.0	−4.8
Lowest minimum	1955–1975	2.2	2.6	−0.9	−1.7	−5.0	−6.3	−8.3	−6.1	−5.9	−3.9	−0.3	1.1	−8.3
Mean daily range	1955–1975	11.2	11.5	10.4	9.8	8.4	7.9	7.8	9.0	9.6	9.9	9.9	11.0	9.7
Mean daily grass minimum	1955–1975	8.3	8.3	6.0	2.7	−0.3	−3.0	−3.6	−2.5	−0.4	1.9	4.2	6.8	2.4
Days with frost														
Ground frost average	1955–1975	0.5	0.3	2.0	7.5	15.2	21.1	23.9	21.0	14.9	9.2	3.8	1.1	120.5
Frost in screen average	1955–1975	.	.	.	0.4	5.9	14.3	18.3	12.7	2.9	0.6	0.1	.	55.2
Relative humidity (%)														
Average at 9 a.m.	1955–1970	65	67	74	79	83	86	86	82	77	70	66	66	75
Vapour Pressure (MBS)														
Average at 9 a.m.	1971–1975	11.6	12.5	11.5	9.5	7.6	6.3	6.1	6.2	7.3	8.2	10.0	10.6	9.0
Special phenomena														
Average No. of days with hail	1971–1975	.	.	0.2	0.2	.	.	.	.	.	.	.	.	0.4
Average No. of days with thunder	1955–1975	0.3	.	.	0.4	0.1	.	0.1	0.1	0.4	0.3	0.2	0.2	2.1
Average No. of days with snow	1955–1970	0.1	.	0.1	0.5	0.9	1.1	1.6	1.4	0.8	0.9	1.1	0.2	8.7

Wind

There are no anemometers near Lake Wanaka, but the observer in Wanaka township makes visual estimates of the wind each week-day at 0900, 1200 and 1500 hours. Fresh to strong winds are present in about 15 per cent of the observations, occurring most frequently in summer (22 per cent of the observations) and least frequently in winter (seven per cent). These are most frequently northwesterly, as one might expect from the long fetch across the Lake in this direction. Gales are very rare. Calms occur in 31 per cent of the total observations and in 40 per cent of the 0900 observations.

Comparison of Wanaka winds with those at other stations in Central Otago suggests a similarity with locations which have a reasonably open exposure to the northwest, such as Glenorchy and Ranfurly. Winds at Cromwell and Alexandra, which are surrounded by hills, are much lower. Queenstown, which is sheltered from northwesterlies, also appears to be less windy than Wanaka.

Other aspects

Lake Hawea has an average of 8.7 days on which snow falls each year. This falls mostly between May and November, but snow in December and January is not unknown. In the short record at Wanaka, snow has been reported on an average of 5.5 days per year. Over a considerably longer period of observations at Alexandra, snow has only fallen between May and

TABLE 3: Wanaka climate

(296m. a.s.l.)

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Year
Rainfall (mm)													
Normal 1941–1970	58	53	61	51	61	51	53	51	61	58	61	51	670
Temperature (°C)													
Mean daily maximum 1972–1976	25.0	23.9	21.3	17.6	12.8	8.3	8.3	10.2	14.9	16.4	20.0	22.3	16.8
Normal 1941–1970	17.7	17.4	14.9	11.1	7.0	3.6	3.5	5.7	8.6	11.1	13.3	16.2	10.8
Mean daily minimum 1972–1976	10.5	10.7	8.6	5.0	1.8	−1.7	−1.6	−0.3	2.6	4.9	7.0	9.4	4.7
Mean daily range 1972–1976	14.5	13.2	12.7	12.6	11.0	10.0	9.9	10.5	12.3	11.5	13.0	12.9	12.1
Days with ground frost 1972–1976	.	.	0.3	3.0	11.7	22.0	24.0	19.0	10.3	4.0	1.5	.	95.8
Mean 9 am Vapour Pressure (mb) 1972–1976	11.1	12.0	10.8	8.9	7.1	5.6	5.8	6.1	7.4	8.3	9.3	10.4	8.6
Special Phenomena													
Average No. of days with hail 1972–1976	.	.	0.3	.	.	.	0.3	0.3	0.3	0.3	.	0.3	1.8
Average No. of days with thunder 1972–1976	0.5	.	.	0.3	0.3	1.0	1.0	0.3	.	.	.	1.8	5.2
Average No. of days with snow 1972–1976	.	.	.	.	.	1.0	2.3	1.7	0.5	.	.	.	5.5

TABLE 4: Alexandra climate

(141m a.s.l.)

		Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Year
Rainfall (mm)														
Normal	1941–1970	46	38	38	28	28	20	15	15	20	28	33	30	339
Maximum 1-Day rainfall	1928–1973	58	45	36	39	26	28	20	20	47	50	41	35	58
Average No. of days with 1 mm or more	1928–1974	6	5	6	6	5	5	4	4	4	5	6	6	62
Temperature (°C)														
Highest maximum	1928–1975	37.2	35.3	32.1	27.7	23.1	19.8	19.9	20.4	25.3	27.8	31.7	33.4	37.2
Mean monthly/annual maximum	1929–1975	31.3	30.5	28.4	23.8	19.2	15.2	14.8	17.1	20.8	24.3	27.0	29.4	32.1
Mean daily maximum	1929–1975	23.2	23.1	20.8	16.8	11.7	7.9	7.2	11.0	14.9	17.8	20.0	22.2	16.4
Normal	1941–1970	17.2	16.8	14.6	10.7	6.3	3.3	2.6	5.3	8.8	11.6	13.8	15.9	10.6
Mean daily minimum	1929–1975	10.8	10.4	8.3	4.8	0.9	−1.3	−2.2	−0.6	2.5	5.3	7.5	9.8	4.7
Mean monthly/annual minimum	1929–1975	4.5	3.9	1.7	−1.6	−5.1	−6.3	−7.2	−5.0	−3.1	−0.7	1.0	3.5	−7.7
Lowest minimum	1929–1975	1.4	0.7	−0.8	−4.6	−7.1	−10.0	−11.7	−8.4	−5.6	−3.4	−1.8	0.6	−11.7
Mean daily range	1929–1975	12.4	12.7	12.5	12.0	10.8	9.2	9.4	11.6	12.4	12.5	12.5	12.4	11.7
Days with ground frost	1928–1975	0.9	1.2	4.4	11.0	19.6	25.0	27.7	25.1	18.4	12.3	5.7	1.5	152.8
Relative humidity average at 9 am (%)	1963–1970	63	66	74	78	85	90	91	84	73	62	57	59	74
Normal Sunshine Hours	1941–1970	229	197	187	155	122	98	104	149	169	203	208	226	2047
% of possible	1941–1970	50	52	51	50	44	39	39	49	50	51	49	48	48
Special phenomena														
Average No. of days with hail	1971–1975	.	.	.	.	.	.	.	.	.	.	.	.	.
Average No. of days with thunder	1955–1975	0.4	0.2	0.1	.	.	.	.	.	.	0.3	0.4	0.6	2.0
Average No. of days with snow	1928–1970	.	.	.	.	0.5	1.1	1.4	0.6	0.4	0.3	0.1	.	4.4

November. This, and the smaller number of days of snow at Alexandra, is probably related to its lower altitude. Hail is uncommon at all stations. Thunder is confined to the warm part of the year at Alexandra, which is consistent with the role of convection in the precipitation process. The normal rainfall in January is three times that in July and August, demonstrating the continental nature of Alexandra's climate. At Lake Hawea and at Wanaka, however, thunder and rainfall are more evenly distributed throughout the year and appear to be related to the relatively constant occurrence of frontal weather. There are probably more than 20 thunder days per year near the main divide, and the head of Lake Wanaka can be expected to experience many more thunderstorms than the stations on Lake Hawea and at Wanaka. There is a much lower incidence of fog than at Alexandra and the humidity is low relative to many other parts of New Zealand.

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Water quality of Wanaka and its inflows

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(Introductory remarks and water analyses by Chemistry Division DSIR Christchurch)

Introduction

Within a research programme directed by the Officials Committee on Eutrophication, with specific reference to possible factors allied to the ingress of *Lagarosiphon* aquatic weed, the Chemistry Division of the Christchurch DSIR analysed water samples taken from Lake Wanaka and its inflows during 1976-78, and found the water to be comparatively pure. The lake shows little evidence of pollution and is very lightly mineralised. Nutrient levels are very low and the lake can be considered oligotrophic.

Water samples were taken from five positions in the lake; these were Roys Bay, the entrance to Roys Bay, the Clutha outlet, Glendhu Bay and the Makarora Arm. The data derived from the analyses of these samples are noteworthy for their uniformity, both with regard to month-by-month variation at any one point, and to variation between positions. No significant differences were revealed in water quality between Roys Bay and Glendhu Bay that would explain the presence of *Lagarosiphon major* in Roys Bay but not in Glendhu Bay. The opinion of the investigating group, that contamination of Glendhu Bay by the weed is inevitable unless remedial steps are taken, is supported by the analyses.

The inflow positions sampled included Bullock Creek, the mouth of Bullock Creek, the unnamed creek north of Bullock Creek, the Matukituki River, Waterfall Creek and Glendhu Stream. As would be expected, the analyses of these inflows show much more variable data. Levels of pollution, as indicated by total and faecal coliform organisms, can be quite high. Bullock Creek contains a consistent level of 1 g/m^3 of nitrate nitrogen which disappears almost completely in the lake. In fact, the level drops considerably between the hatchery and the mouth.

The most striking difference between the lake and its inflows is in the total hardness. The inflows run at two to three times the lake level, but the lake water values scarcely change. There is no information available on the volume of inflows or outflows, but a very large amount of calcium and magnesium is disappearing by some means not yet understood. The nitrogen to phosphorus ratios of the inflows are in excess of twenty to one, indicating that phosphorus limitation of plant growth is occuring in these waters.

For purposes of the research record, the details of the water analyses (Chemistry Div. DSIR Christchurch) are tabulated hereunder.

TABLE 1: Lake sites — Annual averages 16.9.75–16.8.76

Location		Roys Bay	Entrance Roys Bay	Clutha Outlet	Glendhu Bay	Makarora Arm
pH		7.65	7.65	7.6	7.65	7.65
				grams per cubic metre		
Nitrate nitrogen		0.045	0.045	0.03	0.045	0.045
Total organic nitrogen		0.05	0.06	0.04	0.04	0.045
Oxygen absorbed 30 mins at 100°C		0.35	0.35	0.4	0.4	0.4
Bicarbonate alkalinity (as HCO_3)		35	34	34	35	34
Hardness total (EDTA) (as $CaCO_3$)		33	31	31	32	30
Free carbon dioxide (calc.)		1	1	1	1	1
Total solids		57	57	63	61	55
Iron, total (as Fe)		0.05	0.03	0.03	0.04	0.20
Reactive silica (as SiO_2)		2	2	2	2	3
Total phosphorus (as P)		0.007	0.004	0.006	0.006	0.007
Soluble phosphorus (as P)		0.002	0.002	0.002	0.002	0.002
Coliform organisms, MPN/100ml						
– Medium values	Total	25	NIL	NIL	NIL	NIL
	Faecal	6	NIL	NIL	NIL	NIL
% samples with Nil MPN	Total	17	75	92	75	75
	Faecal	58	83	92	83	83

TABLE 2: Inflows

Annual averages 16.9.75–16.8.76

Location		Bullock Creek	Mouth of Bullock Creek	Unnamed Creek North of Bullock Creek	Matukituki River	Waterfall Creek	Glendhu Stream
pH		7.8	7.65	7.8	7.6	7.9	7.85
				grams per cubic metre			
Nitrate nitrogen		1.1	0.6	0.8	0.10	0.045	0.65
Total organic nitrogen		0.05	0.12	0.11	0.07	0.07	0.07
Oxygen absorbed 30 min at 100°C		0.5	0.8	0.4	0.5	0.8	0.7
Bicarbonate alkalinity (as HCO_3)		85	68	95	51	90	83
Hardness total (EDTA) (as $CaCo_3$)		72	55	80	44	78	71
Free carbon dioxide (calc.)		2	3	3	3	3	2
Total solids		122	100	105	98	120	108
Iron, total (as Fe)		0.05	0.18	0.07	0.7	0.13	0.07
Reactive silica (as SiO_2)		15	12	11	5	8	8
Total phosphorus (as P)		0.006	0.014	0.012	0.018	0.007	0.008
Soluble phosphorus (as P)		0.003	0.006	0.004	0.006	0.002	0.003
Coliform organisms, MPN/100ml							
– Medium values	Total	190	7,000	2,500	50	130	2,500
	Faecal	60	1,900	250	50	60	60

TABLE 3: Lake sites

Annual range 16.9.75–16.8.76

Location		Roys Bay	Entrance Roys Bay	Clutha Outlet	Glendhu Bay	Makarora Arm
pH		7.4–7.8	7.3–7.8	7.4–7.8	7.4–8.0	7.5–7.8
				grams per cubic metre:		
Nitrate nitrogen		<0.02–0.08	<0.02–0.05	0.02–0.08	<0.02–0.09	0.02–0.07
Total organic nitrogen		0.01–0.13	0.01–0.15	0.01–0.10	0.01–0.07	0.01–0.17
Oxygen absorbed 30 mins at 100°C		0.2–0.6	0.2–0.5	0.2–0.6	0.2–0.7	0.2–0.6
Bicarbonate alkalinity (as HCO_3)		31–39	26–35	32–35	33–38	31–35
Hardness total (EDTA) (as $CaCo_3$)		30–32	29–33	30–33	30–36	29–32
Free carbon dioxide (calc.)		1–2	1–2	1–3	1–2	1–2
Total solids		49–73	44–65	41–121	42–80	37–67
Iron, total (as Fe)		0.01–0.23	<0.01–0.08	<0.01–0.04	<0.01–0.16	<0.01–2.0
Reactive silica (as SiO_2)		2–4	1–4	2–4	1–4	2–8
Total phosphorus (as P)		0.002–0.014	0.002–0.016	0.002–0.007	0.002–0.018	<0.002–0.014
Soluble phosphorus (as P)		<0.002–0.008	<0.002–0.004	0.002–0.004	0.002–0.004	<0.002–0.006
Coliform organisms MPN/100ml	Total	0–700	0–60	0–250	0–25	0–700
	Faecal	0–25	0–25	0–60	0–25	0–700

TABLE 4: Inflows

Annual range 16.9.75–16.8.76

Location		Bullock Creek	Mouth of Bullock Creek	Unnamed creek north of Bullock Creek	Matukituki River	Waterfall Creek	Glendhu Stream
pH		7.4–8.1	7.6–7.8	7.3–8.0	7.0–7.9	6.7–8.3	7.5–8.0
				grams per cubic metre:			
Nitrate nitrogen		0.8–1.2	0.5–0.7	0.5–1.2	0.02–0.2	0.03–0.1	0.5–0.8
Total organic nitrogen		0.01–0.23	0.05–0.18	0.01–0.8	0.01–0.4	0.03–0.22	0.01–0.15
Oxygen absorbed 30 mins at 100°C		0.1–0.9	0.5–1.1	0.2–0.7	0.1–1.5	0.5–1.6	0.3–1.6
Bicarbonate alkalinity (as HCO_3)		81–88	60–72	86–99	28–59	56–148	74–88
Hardness total (EDTA) (as $CaCO_3$)		70–85	54–58	78–82	24–56	60–121	63–74
Free carbon dioxide (calc.)		0–5	2–3	2–8	1–10		1–5
Total solids		96–146	81–127	107–129	70–155	94–161	93–121
Iron, total (as Fe)			0.025–0.4	<0.01–0.15	09–3.6	0.1–0.6	0.01–0.13
Reactive silica (as SiO_2)		12–20	10–16	10–14	2–8	2–10	6–8
Total phosphorus (as P)		<0.002 – 0.01	0.005 – 0.033	<0.002 – 0.02	0.002 – 0.08	<0.002 – 0.013	0.006 – 0.012
Soluble phosphorus (as P)		<0.002– 0.005	0.003– 0.009	0.002– 0.010	<0.002– 0.015	<0.002– 0.003	<0.002– 0.006
Coliform organisms, MPN/100ml	Total	6–2500	700–25000	60–25000	25–700	0–2500	6–2500
	Faecal	6–250	25–25000	0–7000	25–700	0–250	6–700

From her wide experience in studies on limnology of South Island lakes, Dr V. M. Stout has been able to provide the following comments on the Wanaka water analyses and has expounded the relationship between these data and results obtained from other studies made in comparable mountain lakes.

The only previously published chemical analyses of Lake Wanaka water appear to be those recorded by Jolly (1968) for two samples, taken near the entrance to Roys Bay, on 1 May and 21 August, 1953. Jolly's results indicated that the lake was clear, with low levels of nutrient salts, and could be considered oligotrophic. Her paper includes single analyses from each of three other large South Island lakes (Wakatipu, Te Anau and Manapouri) made in February and April, 1953. Nitrate-nitrogen was not detected in any of the four lakes. The levels of hardness in Lake Wanaka (36–38 mg/1 = g/m^3) were similar to Wakatipu (38 mg/1), but higher than in Te Anau and Manapouri (24 and 22 mg/1 respectively). The values for total solids in Lake Wanaka (40–50 mg/1) were slightly higher than in Wakatipu (38 mg/1) and distinctly higher than in Te Anau and Manapouri (25 and 24 mg/1 respectively). Total iron (Fe) was not detected in Lake Wanaka, but values of 0.05 mg/1 were recorded for the other three lakes. Reactive silica (SiO_2) values were slightly higher in Te Anau and Manapouri (4 and 3 mg/1) than in Wanaka (2–3 mg/1) and Wakatipu (2.5 mg/1). Phosphate, recorded as PO_4, was registered as 'trace' in all analyses, except that in August (the only winter sample–when values are often higher) from Lake Wanaka, when a value of 0.15 mg PO_4/1 is given in the two tables, and 0.015 mg PO_4/1 in the text. These analyses therefore suggest that Wanaka and Wakatipu had slightly higher total solids and hardness levels, but less silica.

As procedures and techniques for the chemical analysis of lake waters have changed considerably since 1953, these results should be treated with caution, particularly any comparisons made with results recorded from recent analyses. The 1953 samples were stored in glass bottles, and there is no mention of the length of storage time; both of these factors would probably affect (usually by increasing) the phosphorus values recorded.

1975–1976 Survey

The results from the five different stations, all in the southern end of the lake, are similar. Different stations in the deep water areas of other large South Island lakes, such as Te Anau and Manapouri, give equally uniform results (Stout, in prep.). There is little seasonal variation in these analyses from Lake Wanaka, which also agrees with results from similar lakes.

Compared with the lake water, the results from the inflows are considerably more variable, as has been found for other lakes. The inflows differ especially in nitrogen, bicarbonate, hardness and iron content. They also vary more at different times of the year; this may be partly related to variations in amounts of water flow. This is suggested, for example, by the wide range of values for total solids recorded for each inflow.

The results obtained from this survey will be compared with values recorded in recent analyses of four other large South Island oligotrophic lakes (Te Anau and Manapouri, Stout, in prep., and the Nelson lakes, Rotoroa, and Rotoiti, Stout, 1975); a smaller, less oligotropic Canterbury high country lake (Grasmere, Stout, 1972) and the most oligotrophic of the Rotorua lakes studied by McColl (1972). The inflows will be compared with those into Lake Grasmere (Stout, 1972).

pH

The pH values recorded (7.6–7.65 in the lake, and 7.6–7.9 in the inflows) are slightly more alkaline than those found in other South Island lakes, although not as alkaline as Okataina. However, this difference could reflect the effects of storage of the samples. The values are also more alkaline than those (7.1, 7.0) recorded by Jolly (1968).

The inflows are mostly more alkaline than the lake water, especially Bullock Creek above the hatchery, the unnamed creek north of Bullock Creek, Waterfall Creek and Glendhu Stream. The results recorded are also more alkaline than the inflows into Lake Grasmere.

Nitrate nitrogen

In the lake water, the annual averages for the five stations are 0.03–0.045 g/m^3, and the total range of values recorded is from less than 0.02 to 0.09 g/m^3. These values are generally similar to those recorded for Te Anau and Manapouri, higher than those for the Nelson lakes and Okataina and slightly lower than those found in Lake Grasmere. Although Jolly (1968) did not detect nitrate nitrogen in Lake Wanaka in 1953, of the 19 lakes studied, nitrate nitrogen was recorded (as 'trace') in only three. Improved techniques have made more refined measurements possible.

Thomas (1969) classifies some European lakes by the maximum summer surface water nitrate nitrogen, and considers those with values greater than 0.045 g/m^3 to be oligotrophic and those with values less than 0.045 g/m^3 mesotrophic-oligotrophic. In Lake Wanaka, values were greater than 0.045 g/m^3 during summer, but usually only in January.

Values for the inflows are higher than those for the lake water, with annual averages of 0.045–1.1 g/m^3, and a range of 0.02–1.2 g/m^3. These results are similar to those found for Lake Grasmere inflows. Bullock Creek above the hatchery gives the most consistently high values, but the unnamed creek north of Bullock Creek sometimes also has values as high as 1.2 g/m^3.

Total organic nitrogen

In the lake water, the annual averages of total organic nitrogen are 0.04–0.06 g/m^3, and the total range of values from 0.01–0.17 g/m^3. These values are higher than those for the Nelson lakes, but lower than those recorded for Te Anau and Manapouri, and markedly lower than those for Grasmere. Total organic nitrogen was not analysed by Jolly.

Values are higher in the inflows (annual averages, 0.05–0.12 g/m^3; range, 0.01–0.8 g/m^3). They are especially high at times in the unnamed creek north of Bullock Creek, but the annual average is slightly higher at the mouth of Bullock Creek. Higher values than recorded in these analyses have been found in some of the inflows to Lake Grasmere, especially inflows from springs.

Oxygen absorbed in 30 minutes at 100°C

These values are all low, and comparable to those found in other oligotrophic South Island lakes. Highest values are recorded in the Matukituki River, Waterfall Creek and Glendhu Stream.

Bicarbonate alkalinity (as HCO_3)

Bicarbonate values found in the lake water (annual averages, 34–35 g/m^3; range, 26–39 g/m^3) are generally higher than those found in the Nelson lakes, and considerably higher than Te Anau and Manapouri (10 and 9 g/m^3 respectively), but slightly lower than those in Grasmere (39 g/m^3).

Higher values are found in the inflows, the largest amounts being recorded in Waterfall Creek, and the smallest in the Matukituki River and the mouth of Bullock Creek. The values are higher than those found in the inflows to Grasmere.

Total hardness (EDTA) (as $CaCO_3$)

The hardness values (annual averages, 30–33 g/m^3; range, 29–36 g/m^3) are considerably higher than those for Te Anau (12 g/m^3) and Manapouri (10 g/m^3), and slightly lower than those recorded by Jolly (36–38 g/m^3).

Values are higher in the inflows (annual averages, 44–80 g/m^3; range, 24–121 g/m^3); highest in Waterfall Creek, and lowest in the Matukituki River and the mouth of Bullock Creek.

Free carbon dioxide (calculated)

Amounts found in the lake water (annual average, 1 g/m^3; range, 1–3 g/m^3) are insignificant, but larger quantities occur in the inflows (annual averages, 2–3 g/m^3; range, 0–10 g/m^3), especially in the Matukituki River and the unnamed creek north of Bullock Creek.

Total solids

Values for total solids in the lake water (annual averages, 55–63 g/m^3; range, 37–121 g/m^3) are higher than those recorded for Te Anau (32 g/m^3), Manapouri (34 g/m^3) and the Nelson lakes, but lower than for Grasmere and Okataina (78.7 g/m^3). The values agree with those found by Jolly (40 and 50 g/m^3), being slightly higher in the present survey in the same months.

Higher and more variable values are recorded in the inflows (annual averages, 98–122 g/m^3; range, 70–161 g/m^3).

Total iron (as Fe)

The values recorded for the lake water (annual averages, 0.03–0.2 g/m^3; range, less than 0.01–2.0 g/m^3) are higher than those found in Te Anau, Manapouri, the Nelson lakes or Okataina, but (except for the single record of 2.0 g/m^3) similar to those found in Grasmere. Iron was not detected in the lake water by Jolly.

Values in the inflows are higher (annual averages, 0.05–0.7 g/m^3; range, less than 0.01–3.6 g/m^3), especially in the Matukituki River, and also higher than in the Grasmere inflows.

Reactive silica (as SiO_2)

The mean values recorded in the lake water (2–3 g/m^3) correspond to the two measurements by Jolly, although values found in the present survey ranged from 1–8 g/m^3. The values are similar to those found for Te Anau, Manapouri and Grasmere, slightly higher than for the Nelson lakes (1.6–1.8 g/m^3), but lower than for Okataina (13 g/m^3).

Larger amounts are found in the inflows (annual averages, 5–15 g/m^3; range, 2–20 g/m^3), especially in Bullock Creek above the hatchery, the mouth of Bullock Creek, and the unnamed creek north of Bullock Creek. The range of values is similar to that found in the Grasmere inflows (6–16 g/m^3). Silica is an important requirement for the growth of diatoms, which are a major component of the plant life of the open water of lakes, and can be a limiting nutrient. It is usually present in larger amounts in the inflows than in the open water of a lake.

Total phosphorus (as P)

Values for total phosphorus in the lake water (annual averages, 0.004–0.007 g/m^3; range, less than 0.002–0.018 g/m^3) are similar to those found in Te Anau and Manapouri, and higher than those in the Nelson lakes. They are lower than in Okataina (mean, 0.014 g/m^3) and Grasmere. It is difficult to compare the present results with Jolly's, partly because of differences in analytical procedure and partly because values recorded in the tables differ from those in the text. It is also possible that the analyses are for soluble phosphorus. The value given in the text would correspond to a phosphorus value of 0.005 g/m^3, which is similar to those found in the present survey; the table value, equivalent to 0.05 g P/m^3, might merely reflect storage conditions.

Vollenweider (1965, 1968) considers that values of 0.000–0.010 g/m^3, or (in his later paper) of about 0.005 g/m^3, are characteristic of oligotrophic lakes in Europe; and Sakamoto (1966a, b) considers that values of 0.002–0.020 g/m^3 are characteristic of Japanese oligotrophic lakes. Both these authors would therefore consider that Lake Wanaka is an oligotrophic lake, according to its total phosphorus content.

Higher values are recorded in the inflows (annual averages, 0.006–0.018 g/m^3; range, less than 0.002–0.08 g/m^3). The highest values are found in the Matukituki River, although the annual average is also high in the mouth of the Bullock Creek and, to a lesser extent, in the unnamed creek north of Bullock Creek. However, larger amounts of total phosphorus have been recorded in the inflows to Grasmere (up to 0.42 g/m^3).

Soluble phosphorus (as P)

Soluble phosphorus (annual average, 0.002 g/m^3; range, less than 0.002–0.008 g/m^3) is found in larger amounts than in Te Anau or Manapouri, but in similar amounts to Grasmere. Most recorded values for the Nelson lakes are less than those found in Lake Wanaka, but larger amounts are present in Okataina. If Jolly's values are for soluble phosphorus, the value recorded in the text would fall within the range found in the present survey.

Higher values are found in the inflows (annual averages, 0.002–0.006 g/m^3; range, less than 0.002–0.015 g/m^3), the highest being in the Matukituki River, but the annual average is similar in the mouth of Bullock Creek. The amounts are similar to those found in most of the inflows to Grasmere.

General discussion

The results from the 1975–1976 survey indicate that Lake Wanaka is still oligotrophic, with a sparse mineral and nutrient content. The values found are higher than those recorded in the Nelson lakes Rotoroa and Rotoiti; higher for minerals but similar for nutrients to Te Anau and Manapouri; usually lower than Grasmere, but similar in silica and soluble phosphorus; and lower than Okataina (especially for phosphorus and silica) except possibly for nitrogen.

The inflows analysed contain larger and more variable amounts of the chemicals measured than the lake water, but constitute only a small proportion of the total inflows to the lake. Although Bullock Creek above the hatchery contains a relatively large amount of nitrate nitrogen, the creek water contains considerably less at the mouth, although the total organic nitrogen value has increased, probably due to the uptake of nitrate by organic material. Silica values are high, both above the hatchery and at the mouth, and total and soluble phosphorus are both present in relatively large amounts at the mouth of the creek. The unnamed creek north of Bullock Creek contains quite large amounts of nutrients, such as nitrate nitrogen, total organic nitrogen, total phosphorus and silica, whereas the Matukituki River has high phosphorus (total and soluble) and iron values.

The results suggest that phosphorus is the most likely chemical requirement limiting plant growth, although they do not include analyses for trace elements.

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Aquatic weed management

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Introduction and background

Lake Wanaka is a large glacial lake which supports a submerged vegetation type typical of nutrient-poor waters. Native submerged plants are generally low-growing and inconspicuous.

Lagarosiphon major (Ridl) Moss (see Plate 1) was recorded in the lake during 1973. This is an exotic water plant which has caused severe weed problems in the central North Island, particularly the Rotorua lakes, since 1950.

No information was available on the performance of this plant in the colder South Island lakes at that time, but its density and dominance over native species suggested that it has a similar nuisance potential in the Clutha Valley. It was recognised as posing a threat to recreational usage of lakes in the area, to existing and proposed hydro-electric power stations on the Clutha River, and obscuring the now rare condition of native vegetation in Lake Wanaka. *Lagarosiphon* is also present in the Roxburgh hydro-electric impoundment.

A containment or holding policy was adopted by the Lands and Survey Department in 1974, to prevent the spread of this weed (from Roys Bay) whilst aspects of its spread and nuisance potential were assessed.

The national importance of the project became clear when an inter-departmental committee was established to co-ordinate and direct the control programme during 1975. It was the first time an adventive submerged waterweed had been identified and contained at a sufficiently early stage of its invasion, and that eradication was shown to be feasible. This project can set a precedent in the preventive management of future weed problems throughout the country, and will furnish novel technology to remove weeds from local areas of previously weed-free catchments. This report covers progress up to 1977.

Submerged vegetation

A provisional species list for submerged macrophytes in Lake Wanaka is presented in Table 1. Three species are exotic: *Lagarosiphon major, Elodea canadensis* and *Ranunculus fluitans*. Each is a recognized nuisance at other New Zealand localities and has had a profound influence on the structure of submerged native vegetation.

Submerged macrophytes are generally restricted to soft sites where the net effects of shore physiography, exposure to wave action, plant cover and current velocity, permit the accumulation of finely divided sediments (sands and silts) within the photic zone.

A schematic diagram of community structure in relation to water depth and the presence of these exotic species is given in the figure.

The native condition (see fig. part a) consists of:

(a) A community of *charophytes* occupying virtually 100 per cent of the lake bed between water depths of 6.0 metres and 16.0 metres and with a maximum height of 0.6 m at 16.0 m depth. A deep association of *Nitella* and the aquatic moss *Drepanocladus* was encountered between depths of 25 and 33.0 m north-west of Eely Point.

(b) A community between 0 and 6.0 m water depth which is dominated by *Isoetes alpinus* (frequently approaching 100 per cent cover). It is convenient to recognise two sub-communities within community b;

(i) a "low mixed community" which is floristically and structurally similar to the community recognised and described by Chapman *et al* (1971) in Lake Rotoiti (NI), and

(ii) An *Isoetes* community proper which is characterised by the absence of *Glossostigma*, *Lilaeopsis*, *Scirpus*, *Elatine*, *Chara* and *Nitella*.

Myriophyllum and *Potamogeton* are present as component species within both sub-communities of the *Isoetes* zone.

Isoetes grows to a maximum height of 0.2 m; the low mixed community occurs in discrete "mounds" which, with their accumulated fines, may be 0.3 m above the level of the surrounding lake bed. Flowering structures of both *Myriophyllum* and *Potamogeton*, and the floating leaves of *Potamogeton cheesmanii*, may emerge above water level (November to March).

Superimposed upon this basic vegetation pattern, the three introduced species may replace all or part of community b. *Ranunculus* forms locally dense, discontinuous, monospecific "clumps" between water depths of 0.6–3.0 m (see fig. part b). This plant is capable of colonising bare sand; hence it does not necessarily displace the low mixed community. It grows to a maximum height of 2.0 m.

Lagarosiphon forms extremely dense and continuous monospecific stands up to 6.0 m high in water depths of 0.6 to 6.5 m and displaces all members of community b in this depth range (see part c).

Table 1. Provisional species list for submerged macrophytes; Lake Wanaka 1973–1977

Species	Locality						
	Parkins Bay	Roys Bay	Clutha outlet	Dublin Bay	Glendhu Bay	Stevensons Arm	Makarora Arm
Lagarosiphon major (Ridl.) Moss	–	P	r	–	–	–	–
Elodea canadensis Michx.	–	–	–	–	–	P	P
Ranunculus fluitans auct. NZ	–	–	P	–	P	P	P
Potamogeton cheesmanii A. Benn	P	P	P	P	P	P	P
Potamogeton ochreatus Raoul.	P	P	P	P	P	P	P
Potamogeton pectinatus L.	P	P	P	P	P	P	P
Miriophyllum elatinoides Gaud	P	P	P	P	P	P	P
Myriophyllum pedunculatum Hook	–	P	P	P	P	P	–
Microphyllum propinguum A. Cunn	P	P	P	P	P	P	P
Scirpus chlorostachyus Levyns.	–	P	P	–	P	P	–
Isoetes alpinus T. Kirk	P	P	P	P	P	P	P
Glossostigma submersum Petrie	P	P	P	P	P	P	P
Glossostigma elatinoides Benth	–	P	P	P	P	P	–
Elatine gratioloides A. Cunn.	P	P	P	P	P	P	P
Lilaeopsis lacustris Hill	P	P	P	P	P	P	P
Limosella lineata Gluck.	P	P	P	P	P	P	P
Nitella hookeri A. Br.	P	P	P	P	P	P	P
Nitella hyalina (O.C.) Ag	P	P	–	–	P	P	–
Nitella pseudaflobellata A. Br.	P	P	P	P	P	P	P
Chara globularis Thuill	–	P	P	–	–	–	–
Chara fibrosa var. acanthopitys (A. Brann) Wood	–	P	–	–	P	–	P
Chara corallina Klein ex Willd	P	P	P	P	P	P	P
Drepanoclatus adnucus (Hedw.) Warnst.	–	P	–	–	P	–	–

Key: P Present
– not recorded
r removed by hand

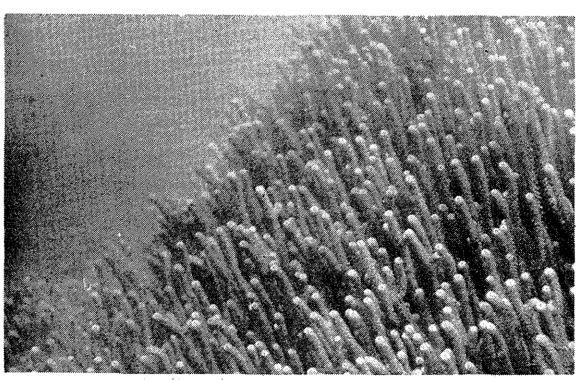


Plate 1. ***Lagarosiphon major*** **(Ridl) Moss**

Elodea can also displace native species from its apparent depth range (see Plate 2) but, as in 1977, it was more common for traces of *Myriophyllum* and *Potamogeton* to persist in a mixed association with *Elodea* (see fig. part d). *Elodea* grows to a maximum height of three metres in Lake Wanaka.

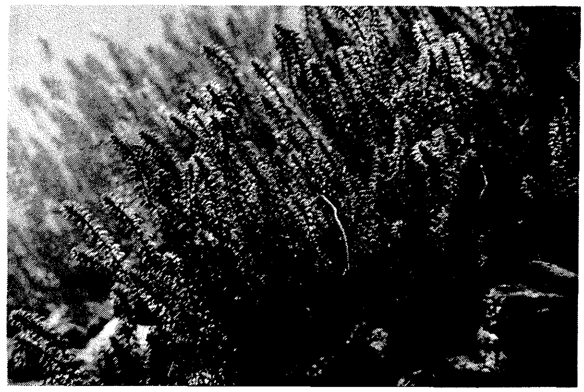


Plate 2. ***Elodea canadensis*** **Michx.**

No localities were surveyed where *Elodea* and *Lagarosiphon* are competing for growing space in Lake Wanaka, but it is likely that *Lagarosiphon* would dominate and displace *Elodea* from its apparent depth range (0.6–6.5 m), leaving a "fringe" of *Elodea* on either side of its depth range.

Elodea and *Ranunculus fluitans* are considered to be less troublesome species than *Lagarosiphon*, and they are widespread in adjacent lakes and waterways. It is only *Lagarosiphon* which has a sufficiently local distribution to warrant an eradication attempt.

Lagarosiphon major **(Ridl.) Moss**

Lagarosiphon major, a native of South Africa, is an obligate submerged macrophyte in the family Hydrocharitaceae. It grows to a maximum height of 6.5 m in New Zealand and is capable of forming "veritable underwater forests" (Chapman, 1970). A leafless flowering structure is the only emergent part of its life cycle.

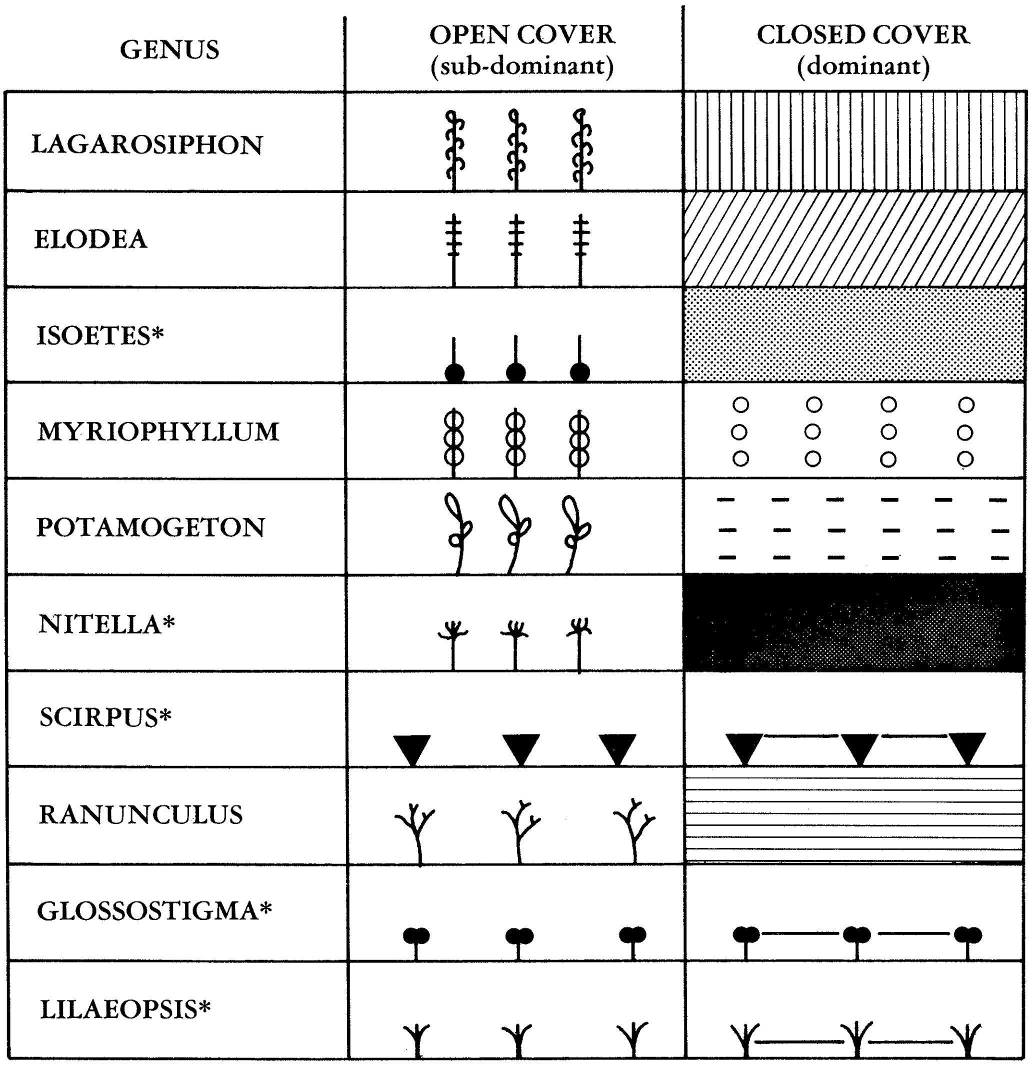
Only the female plant of this dioecious species is present in New Zealand; thus, although it flowers prolifically from mid-November through to early May in the Waikato/Rotorua, it does not set seed. Reproduction in New Zealand is by vegetative means only.

The usual habitat of *Lagarosiphon* is a gently sloping lakebed where moderate protection from prevailing winds allows the accumulation of finely divided particles (sands-muds-silts). These are also the areas used for swimming or boat anchorages.

This species competes best in oligotrophic waters and has caused weed problems in the Rotorua lakes (Rotorua, Rotoiti, Tarawera, Okataina, Rotoma, Rotoehu and Tikitapu), the Waikato River (Lakes Taupo and Aratiatia), Hamilton (Lake Rotoroa), and Taranaki (Lakes Ratapiko and Rotokare).

(continued P. 32)

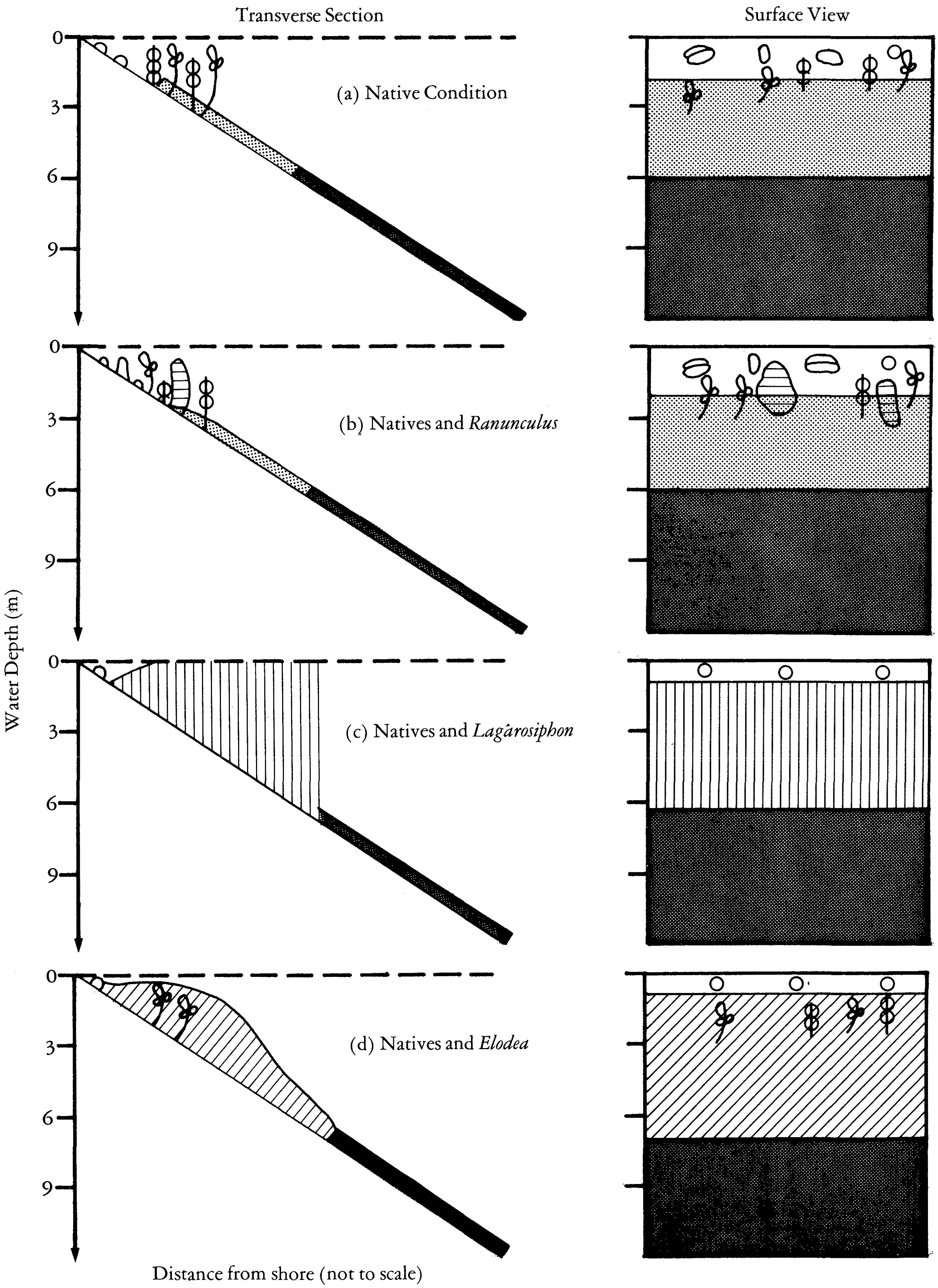
Figure 2. Key to plant symbols used in Figure 3.



"LOW MIXED COMMUNITY"

see separate species*

Figure 3. Schema of submerged types: Lake Wanaka (see key Figure 2)



If its spread is not checked, it is considered that *Lagarosiphon* will dominate the climax vegetation on submerged soft sites in Lake Wanaka (between water depths of 0.5 and 6.5 m).

The lower depth limit (6.5 m) of this plant is similar in a wide range of oligotrophic lakes, suggesting that pressure determines the maximum depth to which it will grow.

The Vegetative Spread of Lagarosiphon major

Coffey (1970) has discussed the vegetative spread of *Lagarosiphon* in the Rotorua lakes. He recognises six stages:

Stage 1: Dislodgement of viable fragments from the parental clone

Any section of the primary or secondary axis (stem material) is capable of producing a new plant if it includes a bud node. Isolated root or leaf tissue will not propagate the species. Serial sectioning of stems has revealed bud nodes at the level of the tenth leaf base in the apical meristem. These "buds" appear as deepseated meristematic tissue within the cortex.

A range of material collected from Lakes Wanaka and Roxburgh has been examined to determine the number of bud nodes per metre length of stem. This varies from 30 to 60, indicating the reproductive potential of the plant by vegetative means.

Dislodgement of stem material from existing weed beds is due to:

- water currents
- wave action
- weed control procedures
- activities of man (boating, fishing, swimming) and of other animals (waterfowl and fish)

and stem fragments 2 to 4 cm or longer are capable of producing new infestations.

Stage 2: Dispersal of dislodged stem fragments of *Lagarosiphon*

(a) Long distance dispersal between catchments

natural agents

- water fowl may be important (water birds have been observed flying in the vicinity of North Island lakes with *Lagarosiphon* in their feet, presumably as nesting material).

man

- transport in water as aquarium plants
- transport in water with fish (to maintain oxygen supply during transit)
- as packing for fish eggs (to maintain humidity and oxygen supply)
- with boats (bilge water, anchor warp etc)
- with boat trailers (attached to trailer axles etc)
- with recreational equipment (fishing tackle, water skis etc.)

(b) Dispersal within individual lakes or within catchment (between lakes)

natural agents

- water fowl
- water currents (downstream transport of dislodged fragments) and wind-driven surface currents are important in transporting buoyant fragments within a lake.
- wind (drift of dry but viable material along shorelines or across short land areas)

man

- boats (adhering to jet units and propellers).
- boat anchors with adhering *Lagarosiphon* from an infested area must be thoroughly cleaned before travelling to an uninfested area.
- with recreational equipment (eg, water skis).

The appearance of new *Lagarosiphon* infestations is more usually associated with boating activity rather than with wildlife activities (eg, Lakes Taupo, Tarawera, Okataina).

Stage 3: Sinkage

Those fragments which survive the mass wastage of dispersal mechanisms must sink if they are to become established. Sinkage is common in the wave zone of a sandy beach, as turbulence tends to displace air from the lacunae and turbidity prevents the formation of oxygen in these lacunae. These sunken fragments are frequently covered with sediment which settles out of suspension as wave action ceases.

Stage 4: Establishment

Root production from these sunken fragments on the littoral zone is extremely rapid and unbranched adventitious roots can be produced, which effectively anchor the fragment, within two days.

Stage 5: Growth

New phototropic shoots emerge from the bud nodes once root production is established, and subsequent growth produces a multiple shoot system.

Stage 6: Lateral spread

Mason (1960) claimed that these plants are propagated by "stems which arise from creeping stems". This is not the case.

Stems which on casual inspection appear to be a form of "rhizome" or "creeping stem" are, in fact, stems which have lost their buoyancy and sunk. If the apical meristem of this fallen stem should continue to grow, then it is phototropic and grows vertically towards the water surface. It does not extend horizontally (see Plate 3).

The fallen stems of *Elodea* and *Lagarosiphon* are important in the lateral spread of these species. The bud nodes along the stem may produce new roots (which anchor the stem) and new shoots (which produce a new crop of photosynthetic tissue).

Records of maximum biomass and the areal extent of *Lagarosiphon* in Roys Bay are presented in Table 2.

Minimum biomass levels were encountered during November 1975 (82–105 g dry wt m^{-2}), and maximum biomass levels were encountered during November 1973 (520–700 g dry wt m^{-2}). These biomass values are comparable to those encountered within nuisance areas of *Lagarosiphon* growths in the central North Island.

Whilst it appears that the biomass of *Lagarosiphon* in Roys Bay has been limited by the herbicide control programme (p. 34), there has been an increase of area occupied by the plant since 1973 (see Table 2).

Hill (1970) failed to record other than native species in Lake Wanaka.

If it could be assumed that *Lagarosiphon* had become established in Roys Bay between 1970 and 1973, there would be little doubt of its colonisation potential and explosive growth in Lake Wanaka. By November 1973, its maximum biomass was causing a recreational nuisance, and it had a cover equivalent to some 2625 m^2 along 3.5 km of shoreline.

Only a minor input to the lake would have been expected during or after 1970, and an increase from 0.16 m^2 to something in the order of 2625 m^2 would require 14 doubling times in relation to area occupied. If this occurred in three years, the area of infestation would have doubled every 2.57 months.

Hence, either the weed was present in Lake Wanaka before 1970, or the rate of spread was faster than at any other known New Zealand locality.

Data from growth studies would tend to confirm that *Lagarosiphon* has a potential doubling time (in terms of area occupied) of about 3 months in Lake Wanaka.

The containment programme

A containment policy for *Lagarosiphon* was initiated during 1974, using the herbicide diquat.

The herbicidal property of diquat is associated with its redox potential (Calderbank, 1971), which is −349 m V (Homer *et al*, 1960). It is a general contact herbicide which is applied to the foliage. Diquat is so tenaciously bound by soil components (base exchange) that it is quite ineffective or biologically inactive in most soils (Ashton & Crafts, 1973). The other important property of diquat is that whilst it may be translocated via the apoplastic system, rapid herbicidal injury prevents effective translocation from the leaf to the xylem in the light (Ashton & Crafts, 1973).

One can expect diquat to kill any photosynthetically active tissue above the level of its rooting medium. Mees (1960) has reported that, whilst light increased the rate of development of diquat toxicity in broad beans, it was not essential for herbicidal activity. Hence diquat might be expected to inhibit respiratory tissue in a similar, although less rapid, manner.

The effect of diquat on *Lagarosiphon* has been described by Fish (1966) and Coffey (1970 and 1974b). It rapidly defoliates above-ground stems, which lose their buoyancy and sink. Regrowth is usually rapid, however, and new shoots and adventitious roots are produced from the fallen stems (see Plate 4).

Field observations suggest the first 10 cm of the apex is not viable following adequate diquat treatment (the cortical buds or bud nodes are inhibited by diquat). It is suggested that these newly formed structures are sufficiently active (respiration) to be killed by diquat. However, older buds (the development of which is inhibited by auxin production from the apex) are sufficiently dormant to survive diquat treatment. Once the apical inhibition is removed (defoliation with diquat), all of these dormant buds tend to develop at the same time. Coffey (1974a) proposed a follow-up spray to kill these developing buds before the new shoots exceeded 10 cm in length.

There are, however, several reasons why adequate diquat treatment is not achieved at a field site. The first is weed density. The virtually stagnant water within a weed bed is not adequately dosed by a surface/sub-surface boom application. The second is the deactivation of diquat due to training booms or the turbulence associated with manoeuvring the spray boat, disturbing bottom sediments.

NZED divers perfected an application technique to avoid these problems during 1974. The divers used 'Unisuits' and full face masks to avoid direct contact with the herbicide, and used conventional hand guns to inject the weed beds with diquat. By approaching the weed bed from downslope, or trimming their buoyancy to float at the level of the plant canopy, sediment disturbance was minimised.

Other major advantages of divers is that they have direct visual contact with the target species and it is possible to use a directed spray to selectively treat individual plants or small outcrops, and leave non-nuisance vegetation unharmed. Surface spraying techniques do not have this degree of sophistication.

Spraying began in June 1974 (injection from a boat mounted boom). A double spray by divers was applied during July and September 1974. During 1975 a diver application of diquat was made during May, September and November. Two sprays were administered dur-

Table 2: Maximum biomass and areal extent of *Lagarosiphon major* in Roys Bay, Lake Wanaka, 1973–1977

	Biomass Maxima (g dry wt m^2)		Area occupied by *Lagarosiphon*	
	Eely Point	Boat Harbour	% Frequency	% Cover[+] Estimate (m^2)
November 1973	520	700	30	2600
(1)				
July 1974	370	490	50	4500
September 1975	415	545	30	2800
November 1975	82	105	20	1900
(2)				
February 1977	350	233	40	4000

[+] Relative to lakebed between 0.6 and 6.0 m depth contours. The average width of this zone in the infested area is c 2.5 m relative to mean annual water level.

(1) Infestation spread to Beacon Point. Removed from Clutha Outlet by hand picking.
(2) Infestation spread to Ruby Island and Stevensons Arm.

Plate 3. Vertical growth of *Lagarosiphon.*

ing 1976 (March and September) and again in 1977 (February and November).

Isolated outcrops of the weed which have been identified outside of Roys Bay have been removed by hand-picking.

An intensive spray trial was commissioned during February 1976 to assess whether diquat could effectively remove *Lagarosiphon* from Roys Bay. Two plots 50 m x 7 m were sprayed whenever regrowth was evident. This trial was not successful and the best results have been achieved where dense stands of weed have been treated. It is suggested that the herbicide is held in the virtually static water under the weed canopy and contact time is prolonged in the case of dense weed beds, whereas spot spraying of isolated plants does not achieve adequate contact time.

A control programme in Lake Roxburgh during 1974 reduced the infestation of *Lagarosiphon* to less than one per cent of pre-control levels. This programme involved a lake drawdown and spraying of the exposed *Lagarosiphon* bed at 2.0 kg a.i. per hectare diquat. It was clear at that time that a staged drawdown of the lake could effectively desilt the photic zone and remove *Lagarosiphon* from this impoundment.

The management strategy, therefore, has been to remove *Lagarosiphon* from the catchment, starting from Bullock Creek to Roys Bay, thence to Lake Roxburgh.

Conclusions

Available evidence suggests that *Lagarosiphon* has the potential to dominate on all submerged soft sites in the catchment, and in the proposed hydro-electric lakes. Its spread from Roys Bay, and its biomass within Roys Bay, have been artificially limited by repeated diquat applications.

Diquat is a successful chemical mower to contain the plant, but comprehensive surveys are and will be required if new infestations are to be identified and removed. Eradication at present relies on hand-picking of small isolated outcrops and suction dredging of more extensive areas. In the case of Lake Roxburgh, a staged drawdown followed by hand-picking is required.

It is imperative that local residents who are holding plants of Lagarosiphon in *aquaria* or fish ponds destroy this material (burning after drying or burial) if the programme is to succeed. The effort and expense of


Plate 4. New shoots and adventitious roots produced from fallen stems of *Lagarosiphon.*

this project can be justified both on a national and catchment basis, but it will rely on the commitment and cooperation of researchers, managers, and the general public.

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Duck Itch (Schistosome Dermatitis) in Lake Wanaka

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Introduction

For many years, people swimming in Lake Wanaka during the summer have been subject to a skin condition variously called 'Duck Itch', 'Swimmers' Itch' or 'Lake Itch'. This condition is, in fact, schistosome dermatitis and is global in its distribution. Not only is it found in association with freshwater masses, but it has also been recorded in certain marine environments.

The first report in the scientific literature of a dermatitis produced by a species of bird or mammal schistosome was recorded by Cort in 1928. He had been collecting snails from Douglas Lake in Michigan, U.S.A., and was sorting them out from the bucket when he became aware of a prickling sensation on the wrist and forearm. This was followed by an urticaria which lasted for a further 30 minutes before it subsided, leaving minute spots on the affected sites. He further reported that at 1 a.m. the following morning he was awakened with an intense itching and could not sleep. Next day the itching, associated with small lumps which had developed, became unbearable and was followed by the swelling of the entire wrist region with pustules developing during the next 24 hours. After four days, however, all symptoms disappeared.

No doubt the above symptoms have been duplicated in many people who have been swimming or wading in Lake Wanaka, and in fact the above report could have been pre-dated, had the work been undertaken in New Zealand at the first sign of the irritation. MacFarlane reported in 1944 that one resident of Wanaka could remember being attacked in the first decade of this century. He further reported that the dermatitis became more prevalent after 1925 when swimming increased in popularity. The initial investigation by MacFarlane (1944) showed that the causal organism was *Cercaria longicauda*, the larval stage of an unidentified trematode (Fig. 1). Related trematodes in some overseas countries cause schistosomiasis in man.

Life cycle of the parasite

The parasite causing schistosome dermatitis is a trematode which spends its adult phase in warm-blooded hosts such as ducks or some small mammals where it produces eggs which pass out in the faeces of the host. From the eggs there develops a motile larval stage, the miracidium, which infects a water snail. Miracidia usually die within 12 hours of hatching unless they find an appropriate host to infect. On locating a host, they penetrate the host tissue and finally

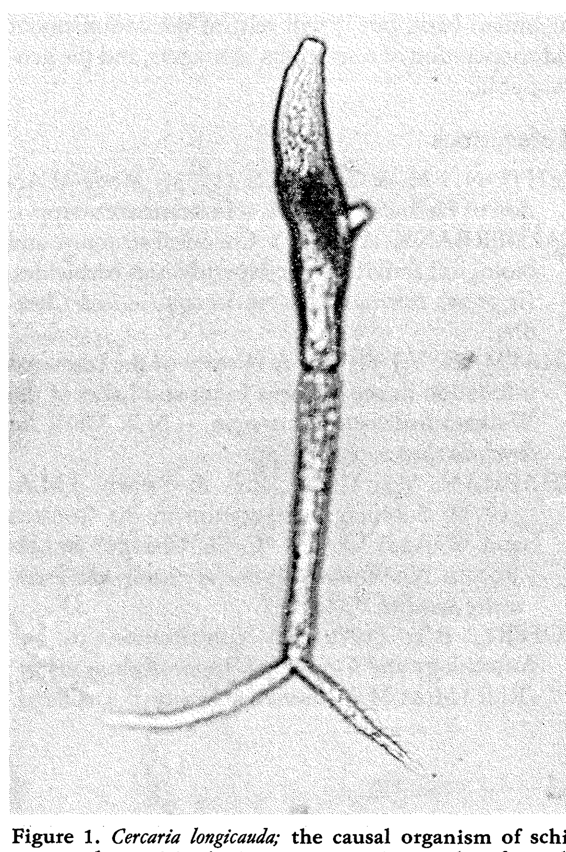

Figure 1. ***Cercaria longicauda;*** **the causal organism of schistosome dermatitis. An immature specimen taken from the snail** ***Lymnea tomentosa.*** **(X 1400)**

lodge in the digestive gland of the snail where development into a sporocyst occurs. Each sporocyst, in turn, is capable of producing hundreds of cercariae. These cercariae, under appropriate conditions, escape from the snail body and go in search of a final host, a warm-blooded vertebrate. Access to the final host is obtained by the cercaria attaching with its sucker, secreting histolytic enzymes and migrating through the skin. The tail is shed prior to penetrating the skin. This tail-less form, called a schistosomule, migrates in the blood vessels to the portal blood vessels in the liver, where it matures into an adult trematode. The female then moves into the mesenteric veins of the intestine, laying hundreds of eggs which break out of the capillaries into the intestine, and pass out with the faeces to complete the life cycle.

Overseas reports have shown that a variety of vertebrates act as the host for the adult trematode. Hoeffler (1974) recorded a number of birds, including mallard ducks and teals as well as goldfinches, cardinals, redwings and other marsh birds, as being hosts to the adult. Another species causing dermatitis is also found in mice, voles, muskrats and deer. A variety of species of lymnaeid snails are the most common hosts overseas for the larval stages of the parasite, but two other species of parasite are found in different species of *Physa*.

Figure 2. A severe case of schistosome dermatitis on the legs four days after exposure to the parasite.

Human responses to the parasite

Humans are accidental hosts to the parasite and provide only a blind alley in its development. The cercariae which are responsible for the dermatitis do not penetrate further than the epidermis of the skin. It is during the initial penetration of the skin by the cercariae that the itching sensation is produced. The host response varies from this point on, depending on whether the person has been previously exposed to the parasite. MacFarlane (1949b) reported that persons previously unexposed to the parasite responded with a prickling itch 10-15 minutes after leaving the water and developed small 1 mm diameter spots within 90 minutes, which lasted for up to 10 hours. In many cases the primary response probably went unnoticed by the subject. Those subjects previously exposed to the parasite generally developed a sharp intermittent itch lasting 10 minutes, followed by the development of small spots 90 minutes later. These small spots developed into small lumps on the skin within 10 hours. Bathers who were swimming in the lake for four to 12 days and responded to the parasite, tended to develop red lumps in subsequent exposures. These lumps persisted for up to 10 days before disappearing. A series of experimental infections on volunteer subjects was also undertaken by MacFarlane (1949b) in which the clinical observations seen in the field were reproduced.

The parasite at Lake Wanaka

Cercariae develop in the water snail *Lymnaea tomentosa* which is widespread in Lake Wanaka. While MacFarlane (1944) reports that the cercariae were restricted to the southern area of the lake, i.e. Roys Bay, he also reported later (1949a) that parasites had been found in Lakes Hayes and Wakatipu, and the dermatitis reported from Lakes Hawea, Te Anau, Alexandrina and Rotoiti (Nelson) and several lakes in the Rotorua district, but there was no confirmation of the latter reports.

There is no conclusive evidence as to which bird is host to the adult of *C. longicauda*. MacFarlane suspected the New Zealand Scaup (*Aythya novaeseelandia*) of filling this role on the basis of results obtained from infecting two specimens with *C. longicauda*. Seven weeks after being infected, one bird produced miracidia in its faeces and continued to do so for another five weeks until killed. Unfortunately, no adult stages of the parasite were obtained at autopsy, even though a thorough search was undertaken (MacFarlane 1949a). Attempts at infecting the domestic duck, pigeon, canary and domestic fowl all failed.

Since these initial studies of the parasite by MacFarlane, little work has been undertaken to fill gaps in our knowledge. In 1972, work undertaken as a student project by Reynolds of the Department of Zoology, University of Otago, showed that the incidence of the parasite in *L. tomentosa* was eight percent and that snails exceeding 4 mm in length were the only ones infected. It also showed that the absolute number of snails infected in a population was small (six infected snails from 75 snails collected). In addition to examining *L. tomentosa*, she also examined *Potamopyrgus antipodarum* and found that it was infected with a variety of other trematode cercariae.

An extensive study undertaken by McDonald during the summer of 1976-77, and continued by the author during 1977-78, has concentrated on the incidence of the parasite in snails and its distribution in the lower regions of the lake. McDonald showed that from 207 *L. tomentosa* snails collected between mid-November and the end of January only four were infected with *C. longicauda*, each of which was in excess of 4 mm in length. Collections were made at both ends of Roys Bay (Bullock Creek, Camping Ground), Glendhu Bay, Paddock Bay and Dublin Bay. In addition to these snails, McDonald also examined 2,479 *P. antipodarum* specimens exceeding 3 mm in length and found only 55 snails infected with a variety of different cercariae, none of which was *C. longicauda*.

A puzzling feature of McDonald's work was the virtual absence of *L. tomentosa* from the *Myriophyllum* beds in Glendhu Bay during the sampling period, yet there were between 30 and 40 cases of dermatitis treated by the first-aid post at the adjacent camping ground in January. In September 1977 and February 1978, a bed of the aquatic plant *Isoetes alpinus* located at the eastern end of Glendhu Bay yielded a population of snails infected with *C. longicauda* (18 infected snails from 140 examined in February). This population of snails, approximately 1200 m from the normal swimming areas of Glendhu Bay, seems to be the most likely source of cercariae. While this may appear to be a long distance for cercariae to travel, there are reports of the final host being infected 1500 m away from the source of infection in slow flowing streams (Radke *et al* 1961). A local surface current in Glendhu Bay, moving in the right direction, would be sufficient to drift freshly released cercariae across Glendhu Bay, bringing them into contact with swimmers.

In addition to the snails, McDonald also examined various birds from the lake for the presence of adult schistisomes. In a scaup (*Aythya novaseelandiae*) taken in late November, three specimens, identified tentatively as *Trichobilharzia* sp., were found in the liver and blood collected from the hepatic portal vein, while a mallard duck (*Anas platyrhyncos*) shot in mid-January had one specimen in the liver and another in the blood. No adult trematodes were found in six specimens of the black-billed gull (*Larus bulleri*) examined throughout the summer.

Control

Control of the parasite is usually achieved by limiting the spread of the intermediate host, the snail, through the use of chemicals which have molluscicide properties. This method can be quite effective in restricted volumes of water, or where there is little turnover of the water mass. To limit the distribution of the snail in a lake the size of Wanaka is far more difficult.

In the past, copper ions from copper sulphate have customarily been used. MacFarlane (1949b) reported that, in laboratory tests, copper sulphate in concentrations as low as 2 parts/10^6 killed snails in one hour or, at 4 parts/10^6, killed them in 30 minutes. This approach has been used at Wanaka on at least two occasions in recent years. In the summer of 1975-76, copper sulphate was spread across the weed beds of Roys Bay and Glendhu Bay prior to the Christmas holiday season, in an endeavour to kill snails following a bad outbreak of dermatitis the previous summer. Some success was achieved as little dermatitis was reported during that summer. In 1976-77, instead of spreading copper sulphate crystals across the surface of the water, woven bags containing copper sulphate were dumped close to the shore in an attempt to prolong the time the copper sulphate was in contact with the snails and to restrict the area of water contaminated with copper ions. This method was less effective, since many cases of dermatitis were reported during the summer and snails were collected from treated areas.

Before any further applications of copper sulphate are made, an investigation into its effects on other animal life in the lake should be undertaken. McKee and Wolf (1963) report that concentrations as low as 1 part/10^7 control plankton in water reservoirs, while most algae and protozoa are killed with dosages of 1 part/10^6. In addition, certain macrophytes are killed at this concentration. If snails in Lake Wanaka are to be controlled by chemical means, then the possible use of selective molluscicides such as Bayluscide should be investigated, as these have little effect on other organisms in the environment.

The only sure way of avoiding the dermatitis is to stay out of the water, a solution to the problem more drastic than most will be prepared to accept in high summer! Various preparations for application to the skin have all failed to prevent the penetration of cercariae. Treatment of the dermatitis has generally been limited to the relief of the itching sensation by means of antihistamines or other topically applied antipruritic medications. A vigorous rub down with a rough towel as soon as the swimmer leaves the water has also been reported to give some relief.

The final solution to the problem of controlling this parasite will not be achieved until a great deal more is known about the life cycle and habits of the hosts.

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The biology of "Wanaka Itch"

– a report of work in progress

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Introduction

During the 1977/78 holiday season, long hot summer days tempted residents and visitors into the cooling water of the lake with the result that large numbers of swimmers were affected. Attention was thus focused once more on schistosome dermatitis in the area.

Schistosome dermatitis was known clinically in the area for 30 years before the definitive work of W.V. MacFarlane (MacFarlane 1944), but he was the first to investigate the nature of the problem. He described the course of the infection and identified *Cercaria longicauda* escaping from the water snail *Lymnaea tomentosa* as the invasive organism causing Swimmers' Itch in man (MacFarlane 1949). *Cercaria longicauda* is an ocellate furcocercaria which closely resembles the cercariae which cause Swimmers' Itch the world over, and resembles in particular the cercaria or larval form of *Trichobilharzia ocellata*, a schistosome which develops as an adult in water birds such as teal or duck, and has larval stages in a molluscan intermediate host.

One possible way to control the Itch would be to intercept the life cycle of the parasite in such a way as to prevent infective snails from releasing cercariae during the swimming or summer season. In the past, attempts have been made to effect this control by killing the snails using chemicals (copper sulphate), or through removing the weed on which they live – either mechanically or by using herbicides. Little or no change in infection rates has been reported in either Roys Bay or in Glendhu.

A review of the New Zealand literature shows that there is little information available on the biology and ecology of the molluscs themselves or of the birds which may be final hosts to the parasite. Because the solution to the problem of control depends on exact knowledge of the life cycles of the various animals involved, the emphasis has been on this and related work in the following report (see diagram of interrelationships).

Extent of present work

The aim has been to clarify and extend basic knowledge of the life cycle of the parasite causing Wanaka Itch, adding to information published by W.V. MacFarlane in 1949, and examining the biology of the intermediate and final hosts of the causative organism with a view to suggesting appropriate measures to control the incidence of the dermatitis.

Work has centred around Lake Wanaka. A rough survey was made of areas affected, visiting localities studied by MacFarlane (1944) and Reynolds (unpublished project 1972), i.e. Roys Bay, Glendhu Bay, Paddock Bay. Lake Hayes and Queenstown were also surveyed. Additional Wanaka areas examined included Dublin Bay and Eely Point, and adjacent areas such as Diamond Lake and Matukituki River. Dublin Bay is the locality to which I have returned, as it is an accessible area, little affected by human activity. Molluscs were collected, a few birds examined, parasitic infections in the snails were recorded, and the behaviour of intermediate hosts, definitive hosts, and parasites were observed where possible. A total of four visits has been made to the Wanaka area in spring and autumn 1976-77 and 1977-78. Material collected has been supplemented by collections from Wildlife Officers.

The parasite

During the course of work on duck parasites, I have recovered, in all, five species of adult schistosomes, two of which have been collected from teal, grey duck and mallard from the Wanaka/Queenstown area, i.e. *Dendritobilharzia pulverulenta* and *Trichobilharzia* sp. In addition, eggs from two other species have been recovered from the mucosa of bird guts. It is possible, therefore, that *C. longicauda* is not the only organism causing dermatitis. This situation would parallel that which occurs in North America (Cort 1950). Unfortunately, only two adult schistosomes have been collected from teal and duck, and there is as yet no substantiated link with *Cercaria longicauda*. It is hoped that future experiments will confirm the connection.

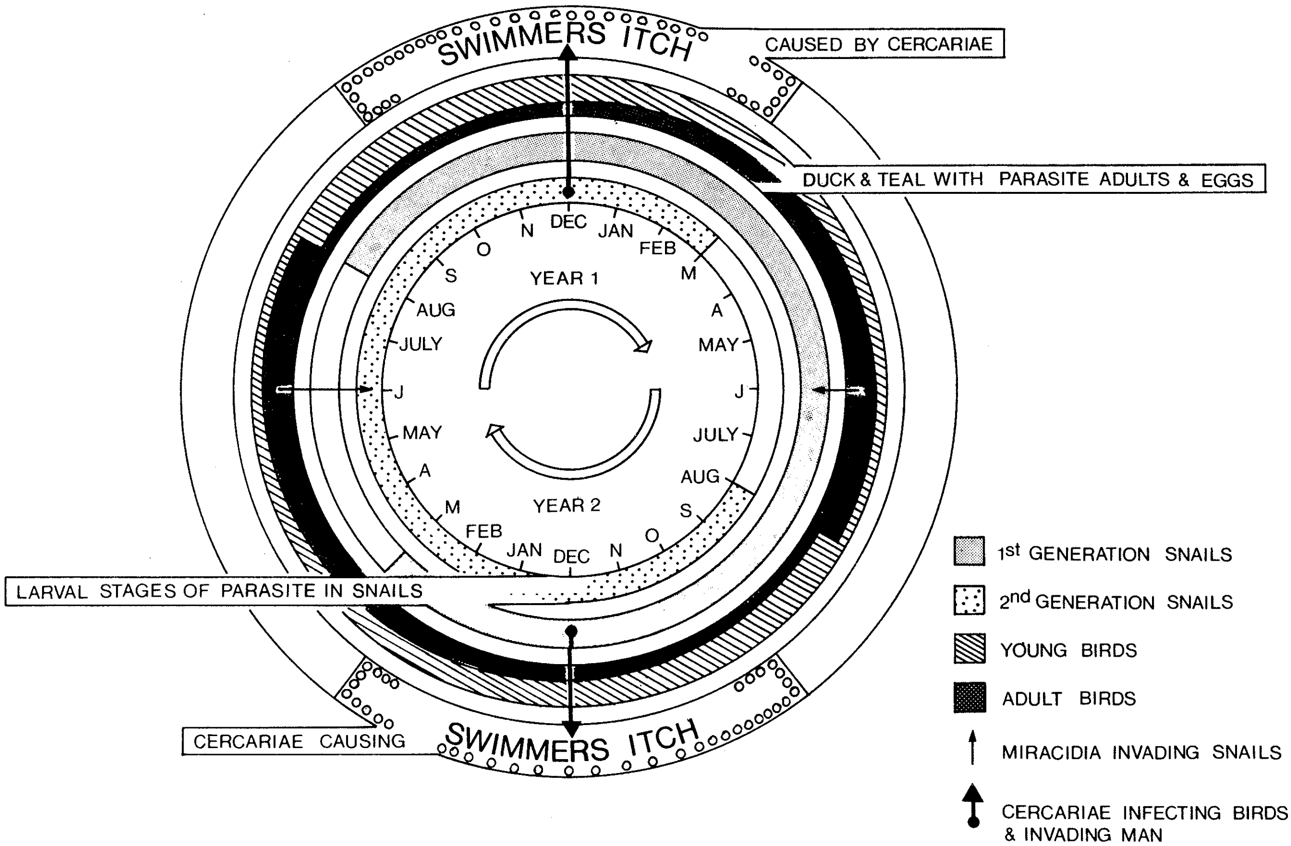
Mollusc and parasite

The following are listed as intermediate hosts for *Cercaria longicauda: Myxas ampulla, M. arguta* and *Lymnaea alfredi* (MacFarlane 1949). In these water snails, larval stages develop, giving rise to infective cercariae.

(i) Molluscs collected from Lake Wanaka and environs – The molluscan fauna was found to be rich

(continued Page 42)

Interrelationships of animals involved in the occurrences of Swimmers' Itch at Lake Wanaka



The diagram covers a two year period and indicates general trends.

Swimmers' Itch, Duck or Wanaka Itch is caused by cercariae from snails penetrating the skin of susceptible human subjects, often children. Man is not the natural host and often reacts violently to an invasion of cercariae.

The *cercariae* escape in the summer from snails and infect waterbirds such as duck and teal, in whose veins they develop into adult schistosomes.

Adult schistosomes live and lay eggs in the blood vessels of the waterbirds. The eggs pass out with faeces, and on contact with water hatch into active miracidia which infect the snail – which is the *intermediate host* of the parasite.

Duck and teal are the *final hosts* for the parasite (schistosome). Young birds each year are exposed for the first time in the summer when cercariae are escaping from the snails and infecting the birds.

Larval stages of the parasite develop in the young snails which will live through the winter. The following summer, these snails are mature and cercariae escape from them during the summer. The snails die in the autumn, and the infection dies with them.

and representative of that occurring elsewhere in New Zealand:

Lymnaea tomentosa (Pfieffer 1855) – on low growing weed particularly in Dublin Bay; also collected in Roys Bay, Paddock Bay and Lake Hayes in varying numbers and is the only mollusc in which *Cercaria longicauda* occurs.

Lymnaea stagnalis (Linnaeus 1758) – collected from ponds peripheral to Lake Wanaka, in shallow, marshy areas rich in plant and animal life, e.g. up the Matukituki River; also from Lake Hayes and Oldham's Pond, Queenstown.

Potamopyrgus antipodarum (Gray 1843) – in large numbers everywhere.

Gyraulus sp. – almost exclusively on weed and decomposing vegetation (particularly *Typha* and *Myriophyllum*); Paddock Bay, Eely Point, Diamond Lake and Lake Hayes.

Physastra sp. – on weeds at 2–3 metres in Dublin Bay, associated with *L. tomentosa.*

Physa sp. – collected down to 2 metres, on weed, also on bare stones at the shoreline.

Pisidium sp. – benthic bivalve, common everywhere.

Ferissia sp. – collected on weed (particularly Lagarosiphon)..

(ii) Molluscan taxonomy – The taxonomy of the molluscs has been clarified since MacFarlane worked in the area, but it is still difficult to know exactly what species was examined at different times. Of three species, *Myxas ampulla, Myxas arguta* and *Lymnaea alfredi* listed as intermediate hosts for *C. longicauda*, the first two are synonyms of *Lymnaea tomentosa* (Pfieffer 1855) [Dell 1956] and the third *L. alfredi* (Suter 1890) which has not been identified from any of the snails collected during the present study, is synonymous with *L. truncatula* (Mueller 1774) [Climo and Pullan 1972] which has not been collected in recent years as far south as Lake Wanaka.

Another genus which has been re-examined is *Gyraulus*, of which two species were known as *Planorbis kahuika* (Finlay and Laws 1931) and *P. corinna* (Gray 1850). These forms are now recognised as belonging to the genus *Gyraulus.* Furthermore, there is evidence to suggest these are the one species, i.e. *Gyraulus corinna* (Gray 1850) – (Winterbourn 1973).

Physastra and *Physa* are commonly confused.

(iii) Biology of *L. tomentosa* – Looking specifically at the known host of *Cercaria longicauda*, i.e. *Lymnaea tomentosa*, it was confirmed that very few infections occur in snails under 5 mm in length (MacFarlane 1949). Details of the biology of the snail were not known, and it is not known how long it takes for the snail to reach 5 mm. Also, while MacFarlane stated that *L. tomentosa* lives for at least two years, field observations do not confirm this. In the laboratory, *Lymnaea stagnalis* and *L. tomentosa* were reared from stock collected at Oldham's Pond, Queenstown, and it has been shown that *L. stagnalis* lives from 15-17 months. Snails hatched the previous November-December commenced egg-laying in August, and ceased in January. These adults died at the end of February or in early March. This was also seen to happen in the field.

L. tomentosa was not reared to maturity, but it seems most likely that this species has a similar life span. The following observations are presented as evidence supporting this. *L. tomentosa* of 5 mm were very scarce in the March collections; at the same time, in the collection of 29 March 1977, thousands of empty shells of this size and larger were dredged from Lakes Wanaka and Hayes. This indicates that this size group of snails died in the autumn. (Parasitic infections acquired up to that time die with these snails in the autumn, and the Duck Itch decreases and disappears.) Also at this time (March in both 1977 and 1978) young *L. tomentosa* up to 2 mm in length occurred in large numbers in Paddock Bay, Dublin Bay and in Lake Hayes. The snails significant in the life cycle involving *Cercaria longicauda* are these young snails which live through the winter, to mature the following spring and summer and die the following autumn. It is to this population that control methods should be applied. However, more detailed work should be carried out on this aspect of the biology of *L. tomentosa.*

Bird and parasite

Avian schistosomes lay their eggs in the bloodstream, the eggs being transported to the mucosa and submucosa of the bird intestine. *Trichobilharzia* eggs are carried in venous blood vessels. *Dendritobilharzia* eggs are carried in the arterial blood stream. Large numbers of eggs were found in the wall of the gut in juvenile birds in the late summer months. These are embryonated as they mature, the miracidia hatching on contact with the water. Such mature eggs have been collected from the gut of both adult and juvenile birds from November to March. (In addition, eggs from two other species have been observed. These have not been identified.) Miracidia hatching from these eggs infect an increasing number of *L. tomentosa* during the summer months and this may continue throughout the winter. This means that the level of infection in the snails probably increases in the maturing snail population during the winter. When warm spring weather arrives, mature cercariae are emitted on calm sunny days, and these infect the birds by burrowing through the skin. Water birds such as teal and duck are available and vulnerable. New infections mature in the ducks in as little as two weeks (Bourns *et al* 1973). Eggs are laid and miracidia develop continuously during the ensuing months. Young birds hatched the previous spring are, as a population, susceptible to parasitic attack (see diagram on interrelationships).

Man and parasite

Cercariae penetrate the skin of any warm blooded animal, and, although the parasite does not mature in Man, after successive and continued exposures to escaping cercariae, susceptible individuals exhibit either more or less violent reactions. In the case of Wanaka Itch, the dermatitis rarely follows the first exposure to the cercariae. The sequence of events is that, initially, the cercariae die after penetration of the skin, and cause a sensitisation in the susceptible subject who, on subsequent attacks from cercariae, suffers from the Itch. The symptoms may include a fiery burning all over the body, followed by the appearance of blisters. Children paddling and playing along the edges of the lake are particularly liable to infection and may develop sores that take weeks to heal. The areas of skin most likely to be attacked are those at the junction of clothes with the body beneath drying droplets of water. Well known methods of lessening the possibility of infection include showering and vigorous towelling following bathing. Various ameliorative measures are also prescribed.

Control

A preliminary assessment may be made at this stage in the work, and it is recommended that a combination of chemical and biological methods be examined. Overseas studies on schistosomiasis (Thomas 1973) clearly indicate that there is no hope of eradicating snails from any large lake, nor can it be attempted without endangering the balance of the lake biota. However, as suggested previously, it should be possible to restrict the incidence of the Itch by applying control measures at some point in the life cycle of the parasite in a particular locality. Significant reductions in the number of cercariae released can be achieved without seriously affecting other living organisms. From work already done, it would seem that young *L. tomentosa* in the Lake during the winter would be a good target. This may be practicable with the new molluscicides being developed*. Much work remains to be done to elucidate the life histories of both parasites and hosts before decisions on a comprehensive control programme can be made, but I would suggest that the most effective control will be very much a local matter. This will depend on local conditions (both topographic and climatic) which vary from area to area and from season to season. Not only does Wanaka differ from Te Anau and Frankton, but differences occur between the two ends of Wanaka, e.g. the Jetty compared with the Camp area at Glendhu. In the meantime, a suggestion which could be implemented early would be the establishment of shallow "Adventure" pools for younger patrons, and deeper Lido-type pools for older visitors. These could be a landscaped feature of the foreshore, with wind-protected and supervised swimming available for all. The pools could be filled from spring-fed, snail-free streams that run into the Lake, e.g. near the Post Office and further along near the Motor Camp. The aesthetic beauty of the Lake vista would not be marred and the added facilities could only enhance an already popular tourist attraction.

* It is interesting to note that *L. tomentosa* was absent from benthic samples taken from weed beds treated with the herbicide "Diquat" (pers. comm. Dr Carolyn Burns, March 1977). It was suggested that *L. tomentosa* did not survive in the absence of the weed. There are two other possibilities:
1. the Diquat was directly responsible for the death of the mollusc, or;
2. the sample may not have included very small size classes.

Acknowledgements

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The freshwater fishery

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Introduction

Lake Wanaka, one of a chain of high country lakes which border the eastern side of the South Island's main divide, is the third largest of the Southern Lakes and the primary source of the country's largest river, the Clutha. The lake occupies an ancient glacier trough, through which a river of ice once flowed, southward from the vicinity of what is now known as Haast Pass. Wanaka is some 48 kilometres in length, has a mean width of approximately 3.5 kilometres, a surface area of 180 square kilometres and drains a catchment of 2575 square kilometres. The glaciers and snowfields of Mount Aspiring (3035 m) are part of the mountainous region forming the Wanaka Catchment and the lake itself is walled in by mountains throughout its length. Major inflowing rivers include the Makarora and its tributaries, draining to the north end of the lake, and the Matukituki River system which drains eastward from the Mount Aspiring region. Numerous smaller tributaries, including the Nottingly River, Albert, Minaret and Fern Burns, enter the lake from the west and south. A major portion of the land within the catchment is scrub country and alpine tussock lands; part is clothed in native bush and lies within the boundaries of Mount Aspiring National Park and a small amount is improved grazing or crop land, located primarily around the southern shores or within the lower reaches of the Makarora and Matukituki Valleys.

Exotic introductions

There are few historic records of the early stocking of Lake Wanaka, but, considering the state of inland roads during the latter part of the last century and the time required to travel any distance over them, the brown trout was more than likely self-introduced to the lake via the Clutha River. Liberations were carried out in the lower reaches of the river during the late 1860s and early 1870s. Early records indicate that the brown trout (*Salmo trutta*) was firmly established in the lake by 1885, and the rainbow trout (*Salmo irrideus*) was becoming common by the turn of the century. Stocking of the whitefish (*Coregonus clupeaformis*), a coregonid species common to the Great Lakes of North America, was also attempted, but it did not become established.

Two species of salmon, the quinnat (*Anchorhynchus tschawytscha*) and the Atlantic (*Salmo salar*), complete the list of introduced species. In the case of the quinnat salmon, early records list only one consignment of ova to the Pembroke (Wanaka) Hatchery, and these were hatched and released into the lake during 1918. It is quite possible, therefore, that this species also found its own way into Lake Wanaka as acclimatisation work had commenced elsewhere in the South Island during the 1870s.

Two liberations of Atlantic salmon were made in Upper Clutha tributaries during the 1920s from ova produced by the stocks in Lake Te Anau. Both releases were apparently unsuccessful as the species was never subsequently recorded in the lake or the Upper Clutha.

Development

The acclimatisation work with salmonids did not cease after these early introductions; if anything, the stocking of brown and rainbow trout fry intensified until the early 1940s and continued at a high level until quite recently. The distribution of 1.25 million rainbow trout fry from the Pembroke Hatchery during 1935 gives some indication of the level of stocking activity during these years. Transfer of administration and control of the Lakes Acclimatisation District to the Wildlife Service of the Department of Internal Affairs in 1945 did not result in any appreciable lessening of liberation activity. During the 26 years up until 1970, more than 5.3 million rainbow fry and 387,000 brown trout fry were released into the inflowing tributaries of Wanaka.

Some rather spectacular angling for remarkably large trout was provided by the country's lakes and larger rivers for a number of years following the first successful introductions, and Lake Wanaka apparently proved no exception, as trout weighing up to 25 pounds were said to be not uncommon even as late as the first decade of this century. This situation, the result of a relatively small trout population having available an almost untouched food supply of aquatic insects and small indigenous fishes, inevitably had to decline as the trout population grew numerically, aided by both natural and artificial recruitment annually, checked only by predation and an angling pressure which by today's standards could be described as negligible.

Actual timing of the decline in size of trout from Wanaka is not recorded with any accuracy in early records. Complaints about the quality of angling generally are scattered at random throughout records for the 1930s, so by that time the decline, whether apparent or real, was being brought to the notice of the Society and Angling Association members. Corrective measures employed to improve an apparently declining trout fishery during those years included eel trapping, shag shooting, and netting programmes to increase trout numbers. Netting enjoyed a short-lived popularity but predator control was widely supported for many years.

The development phase of the Lake Wanaka fishery commenced during the early years of this century and involved three established salmonid species. In the case of the quinnat salmon, there was a spin-off for the lake fishery itself in the form of the landlocked salmon. Unlike their sea-run counterparts, these salmon remain to mature in the lake and were established even before completion of the Roxburgh hydro-electric dam. Development commenced while the catchment was probably still largely unmodified from pre-European times and progressed through the regional trauma of the gold rush, the introduction and spread of (now) noxious mammals and the commencement and development of grassland farming. The one aspect of the fishery during this period which remained unchanged by those involved was its primary use as a recreational fishery.

The modern fishery

The above-mentioned developments, with the possible exception of gold recovery, have all had their impact on the environment within the Lake Wanaka catchment and, ultimately, must have adversely influenced the quality of the salmonid fishery. The combination of large populations of noxious mammals throughout the catchment in the recent past, with domestic flocks of sheep and cattle (and the once common practice of regularly burning off the tussock grasslands to enhance grazing), contributed to loss of vegetative cover and increased erosion within the catchment. This has had a noticeable effect on the tributary rivers and streams, which, as spawning and nursery areas, form an integral part of the total fishery. The importance of a high degree of habitat stability throughout those waters, which contain the spawning areas for the trout and salmon populations, is crucial to the maintenance of a satisfactory level of natural recruitment.

Major developments during the past decade, including significant reduction of noxious mammal populations, retirement of critical high country lands from grazing and the implementation of soil and water conservation plans within the Matukituki and Makarora Catchments, should in the long term prove beneficial to the maintenance of a high quality fishery in Wanaka.

A significant impact on the fish population in Lake Wanaka during recent times resulted from the construction of the Roxburgh hydro-electric dam. Completed (without the incorporation of a fish pass) during 1956, the dam effectively ended the annual migration of anadromous quinnat salmon to the spawning grounds in the tributaries of the upper lakes, Wanaka included. The significance of this resource at the time of the Roxburgh dam's completion is uncertain, but considering the extent of spawning grounds available within the Wanaka Catchment, it is possible that runs were still developing. Apparently these salmon were still in excellent condition when they reached the mouth of the Matukituki or Makarora so their loss to the angling fraternity is to be regretted. The fact that the species still exists in the lake and contributes to the angler's catch is a minor consolation, as its average size as a landlocked fish is many times smaller than its anadromous counterpart.

Another negative consequence of the Roxburgh dam has been the impact upon the indigenous fishes of the Clutha system and Lake Wanaka. The downstream migration of adult long finned eels (*Anguilla dieffenbachi*) and the upstream migration of elvers has been stopped, as has any movement of smaller indigenous fish such as bullies (*Gobionorphus* spp), galaxias or smelt (*Retrapinna* spp), although none of these have yet disappeared from Lake Wanaka as a result.

The three salmonid species which make up the present-day recreational fishery provide for a highly efficient use of the lake's two major habitat types and their associated food resources, as well as offering anglers an interesting variety in the enjoyment of their sport.

The two major salmonid habitat types incorporated within Lake Wanaka are the littoral and the limnetic zones. The littoral zone, comprising the lake's productive shallows, is generally dominated by the brown trout throughout much of the fishing season, and large specimens can often be observed cruising along the shallow beaches or over the extensive weed beds of sheltered bays. The limnetic zone can be described as the productive offshore waters where the food chain is based on the lake's plankton production. Dominance of this zone is shared by the rainbow trout and the quinnat salmon, both of which appear to favour this pelagic existence for much of their life in the lake.

The distinction between the two zones, however, is rather blurred; an examination of anglers' catches at various times throughout the fishing season will readily disclose that it is often possible to capture all three species in the littoral, and at other times, within the limnetic zone. The above situation nevertheless satisfies the needs of both the shore-based threadline and fly fishermen and the troller without any serious conflicts arising. But because of the trollers' strong tendency to fish close inshore it is likely that the sal-

TABLE 1: Angling data. Lake Wanaka (1965–1977)

Angling Season	Number of Anglers	Fishing Hours	Fish Kept	Undersized Returned	Legal Size Returned	Fish Weighed and Measured	Ave. Length (cm)	Ave. Weight (kg)	Ave. C.F.*	Fish per Hour Kept	Fish per Hour Total	Fish Per Day Per Angler
1965–66	274	361.00	52	4	2	35	50.67	1.28	34.71	0.14	0.16	0.18
1966–67	155	243.75	51	2	–	47	46.73	1.19	43.21	0.21	0.21	0.32
1967–68	191	249.50	42	3	–	23	48.08	1.03	35.00	0.16	0.18	0.21
1968–69	238	316.50	52	1	–	41	48.10	1.08	33.65	0.16	0.16	0.21
1969–70	201	359.75	60	5	1	52	45.61	1.18	33.01	0.17	0.18	0.20
1970–71	33	57.75	15	–	–	5	52.07	1.34	33.41	0.26	0.26	0.45
1971–72	249	346.00	40	–	–	39	48.15	1.04	32.65	0.12	0.12	0.16
1972–73	193	300.75	62	6	1	45	45.69	1.03	34.17	0.21	0.23	.32
1973–74	90	122.50	15	–	–	15	49.17	1.17	34.41	0.12	0.12	0.16
1974–75	110	133.75	46	–	1	31	48.24	1.12	34.96	0.34	0.35	0.42
1975–76	109	128.40	25	–	–	23	47.84	1.10	35.85	0.19	0.19	0.23
1976–77	177	281.75	75	1	–	72	46.72	0.96	32.39	0.27	0.27	0.42

* Condition factor.

monids of the limnetic zone are subject to relatively light fishing pressure.

Collection of accurate statistics on angling effort and catch for the Lake Wanaka fishery began on a regular basis during the mid 1960s and, as a consequence, the summary of angling data set out in Table 1 shows only minor changes in the average size, weight and condition of trout caught, and in the catch rate. Figure 1, a graph of length frequency distribution for angler-caught trout measured over a six-season period from 1967, also displayed only minor changes from one season to another and these are probably attributable to the progress of different year classes through the fishery.

Management and angling

A prime objective of freshwater fishery management is maximum harvest of the available resource by anglers annually, while at the same time ensuring that escapement is sufficient to maintain a healthy balanced fishery by natural juvenile recruitment, and imposing the minimum of restrictions necessary to achieve this balance. The Southern Lakes Fishing Regulations of 1971, which apply to Lake Wanaka, are relatively unrestrictive, allowing anglers a wide choice of fishing methods in several types of water. The lake itself is open during a 10-month season extending from October to July, while a 7-month season applies on the inflowing rivers, from November to May. This shorter season for rivers is a conservation measure giving some protection to adult trout and salmon during their migrations from the lake to spawn in the tributaries, and their subsequent return journey to the lake. A minimum size limit of 30 centimetres applies for both trout and salmon, and the daily bag limit is twelve fish, of which not more than six may be salmon, and not more than six may be brown or rainbow trout. Anglers holding a whole season licence issued by any Acclimatisation Society may now fish Lake Wanaka, and short-term licences for periods of from one day to one month are available locally.

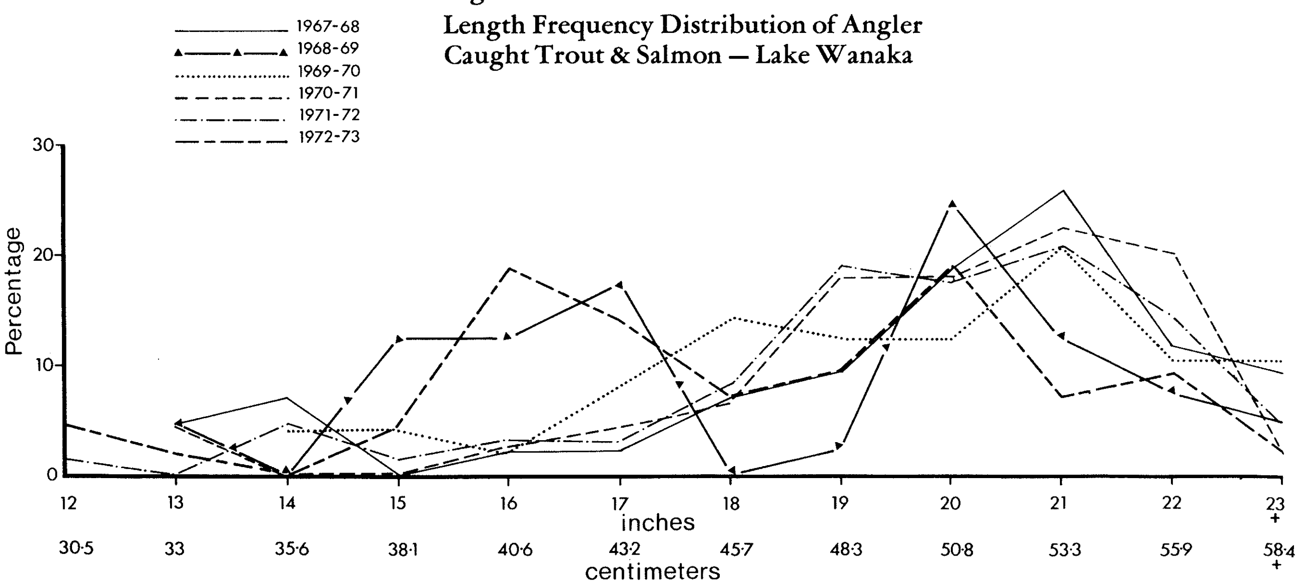
Choice of fishing method and locality can be influenced considerably by prevailing weather conditions, but as a general guide dry fly fishing is often productive in the sheltered waters of Glendhu Bay, Stevensons Arm and the outlet during the late spring and summer months, while threadline fishing often produces good results around stream and river mouths early and late in the season. Trolling can be depended upon to produce results at virtually any time but more particularly in the latter months of the season. This is particularly so at the Makarora end of the lake, when trout and salmon begin to congregate immediately prior to the spawning season.

The future

Development of any kind within the Wanaka drainage basin has a very great potential to influence the quality of the lake's salmonid fishery in the future, in most cases adversely, unless suitable protective measures are instituted. Land development continues throughout the Catchment in areas such as the Makarora, Matukituki and Motatapu Valleys to improve the country for grassland farming and cropping, and around the lake's southern shoreline to provide additional roads, building sections and community services for the expanding township of Wanaka.

The absence of stock-free, reserve buffer strips of land along stream and river banks may result in the progressive loss of vegetative cover presently utilised by both salmonids and indigenous fish, as well as contributing to an increase in the rate of bank erosion,

Figure 1
Length Frequency Distribution of Angler Caught Trout & Salmon — Lake Wanaka



Rainbow trout Photograph: D.C. Mahoney, N.Z. Department of Internal Affairs, Wildlife Service.

Brown trout Photograph: D.C. Mahoney, N.Z. Department of Internal Affairs, Wildlife Service.

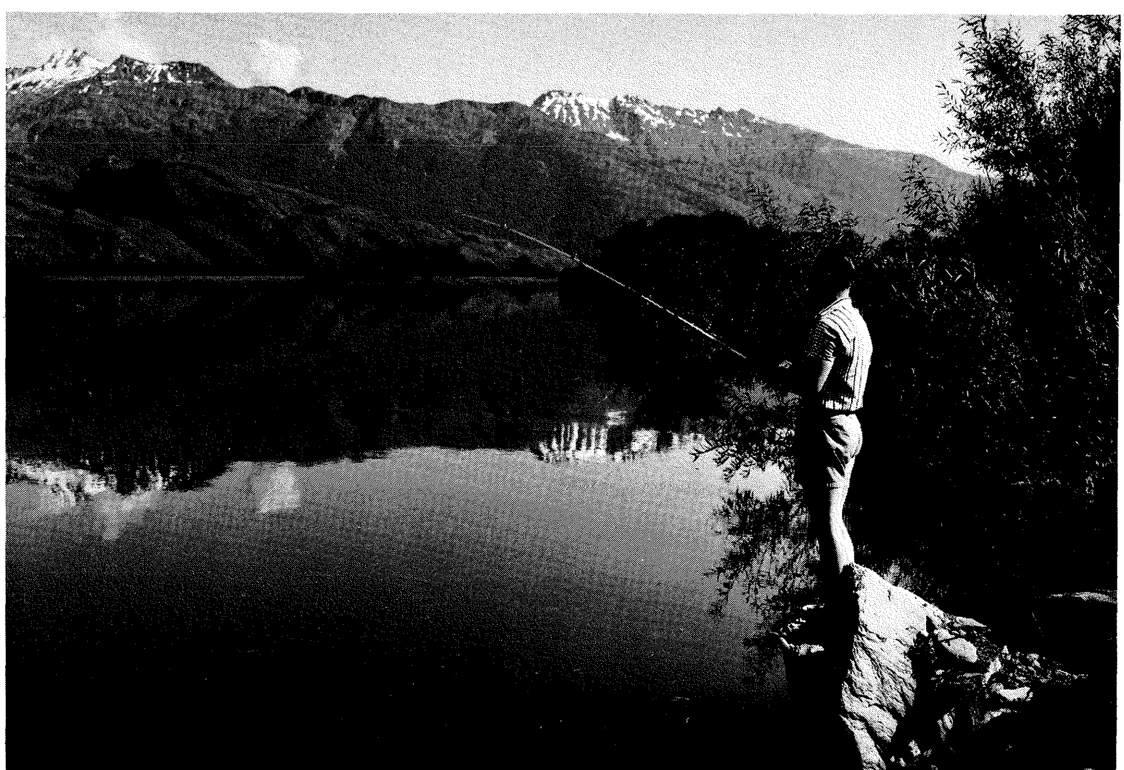
the silting up of spawning gravels and, as a consequence, a reduction in the ability of the fishery to sustain itself.

Nutrient inflow from developed land could rise with attempts to increase and expand primary production, resulting in declining water quality and increasing problems with weed growth such as *Lagarosiphon major* and *Elodea canadensis*.

Lack of any artificially imposed control on the natural annual range of lake levels is probably the most significant contribution to continued maintenance of the present high quality of the Lake Wanaka fishery. Like most forms of plant and animal life in similar situations, the lake's indigenous aquatic flora and fauna have adapted their life cycles to fit all but the most extreme natural lake level fluctuations over a long period of time. This adaptation is not easily or quickly changed, and the imposition of artificial control upon the outflow would cause major and rapid upheavals in the invertebrate communities, and, subsequently, a noticeable drop in littoral production that would be reflected in reduced condition and size of the salmonids.

Fishery management techniques and programmes for Lake Wanaka have been changing in recent years and will no doubt continue to change as more is learnt about the fishery, its recreational value and the areas in which its maintenance is threatened. In the past, management policy has been orientated strongly toward hatchery production and liberations, with a strong emphasis in favour of the rainbow trout. In addition, the present emphasis is on a wider distribution, and includes efforts to safeguard the future quality of the salmonid habitat and improvement of the landlocked quinnat salmon stocks. The ability of the quinnat salmon to provide a degree of sport for the inexperienced visiting angler, unfamiliar with the favoured angling spots around the Clutha source lakes, has become increasingly apparent in recent years and considerable effort is being directed toward increasing the numbers of this species.

Habitat protection is likely to assume increasing importance as development in all its various forms progresses within the catchment. Fortunately, occurrences such as the permanent retirement of the high alpine lands from grazing use for soil and water conservation, reduction in numbers of noxious mammals, activities of the catchment authorities in the field of flood control and a high level of public awareness of the need for environmental conservation generally, go a long way in assisting the maintenance of the considerable national asset provided by the recreational salmonid fishery of Lake Wanaka. It must be remembered always that, while the continued ability of this fishery to maintain natural recruitment at the required level is safeguarded, the high quality of recreational angling which the lake offers will be continued at minimal cost to all concerned.



Fishing at the head of Lake Wanaka

Photograph: National Publicity Studios

Birdlife

D. MURPHY
Department of Internal Affairs, Wanaka

Physical features

The topography of the land within the area of Lake Wanaka itself, the lower valley floor of the Matukituki and Makaroroa Rivers, the Clutha River downstream to Luggate and all the country contained within the main Wanaka valley has been much modified by glacial action. The lake shoreline is generally very abrupt, except for those areas influenced by the larger inflowing rivers, where silt deposition has produced a gently shelving shore and allowed the establishment of pasture grasses virtually down to the water's edge. These lacustrine pastures provide habitats for a variety of water-associated bird species. The steep, less fertile valley sides have reverted to growths of fern, tussock and scrub-type vegetation with only remnants of beech forest in some of the inflowing side valleys. Vegetation on the four small islands within Lake Wanaka shows signs of damage; however, the two largest have valuable and regenerating forest remnants.

Habitat types

The bird species found within any region are generally a reflection of the habitats available to them, and for the purpose of this article, I have chosen to group the species into those families favouring the following broad habitat types:

1. Water-associated birds. (This broad classification includes swampland, open ponds, lakes, streams and rivers, and their shores/flood plains.)
2. Birds of farmland and open country. (Includes all open and non-forested areas.)
3. Birds of forests, exotic plantations and scrubland. (Includes forest remnants, exotic trees generally.)

These habitat types are so broad that it could be argued that some species are commonly seen in a number of seemingly different environments. These "grey areas" of overlapping habitat requirements occur frequently, and to overcome the problem, I have listed the species under those habitats within which, in my view, they occur most naturally.

Bird species by families

1. WATER-ASSOCIATED BIRDS

Family phalacrocoracidae (Shags)
(a) Black Shag. *(Phalacrocorax carbo)*
(b) Little Shag. *(Phalacrocorax melanoleucos brevirostris)*

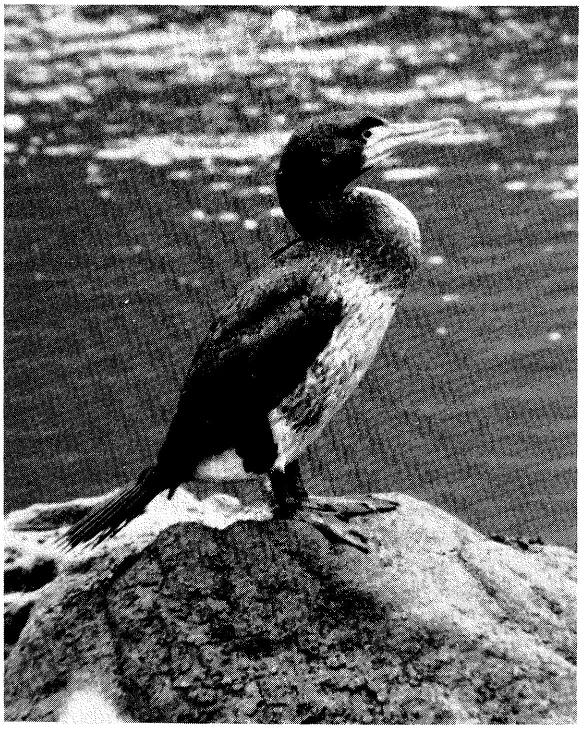
Large black shags are commonly seen fishing in Lake Wanaka and its inflowing and outflowing rivers. They are effective predators of small fish and have been known at times to take trout up to one kilogram in weight. This fact has made them the enemy of the majority of freshwater sports fishermen who look upon them as competitors for a limited resource. There are numerous places around the shores of the lake where these birds have established roosts. They usually choose steep rocky faces or tall trees overhanging or commanding a good view of the water, and shags on these roosts can commonly be seen with wings extended to dry in the sun.

The adult is a handsome bird when in breeding plumage, generally a glossy black with a tinge of green when seen in certain lights; the immature birds, however, look a little scruffy and tend to have varying amounts of white on their under-surface.

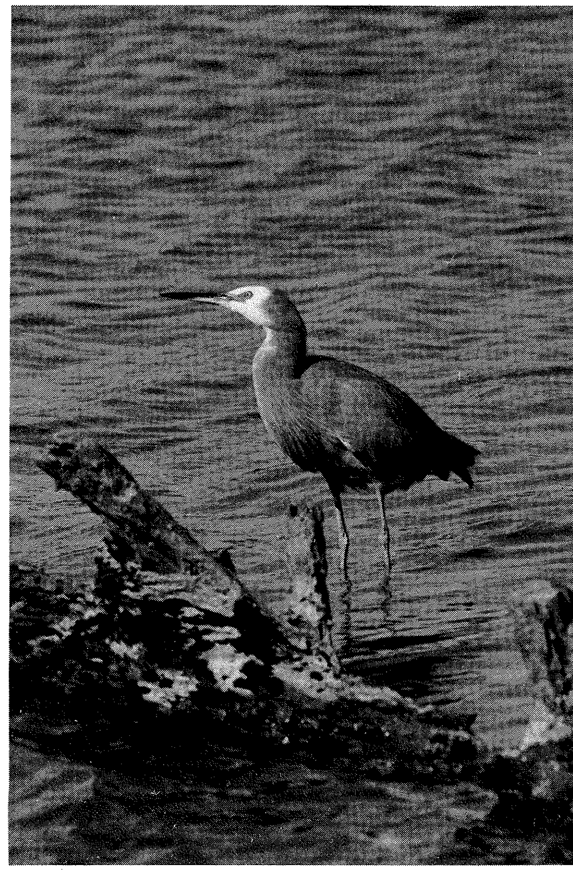
While the black shag is a frequent visitor to even small areas of water where fish are present, the little shag, or white-throated shag tends to favour a lake or large pond. This shag, which is considerably smaller than the black shag, may be present in a complete range of forms between almost completely black and truly pied; however, the most common local form has white cheeks, throat and chest. These small shags, while seen fairly frequently in the Wanaka area, are not as abundant locally as the black shag.

Family Ardeidae (Herons and Bitterns)
(a) White-faced heron. *(Ardea novaehollandiae)*
(b) White heron. *(Egretta alba)*
(c) Australian brown bittern. *(Botaurus poiciloptilus)*

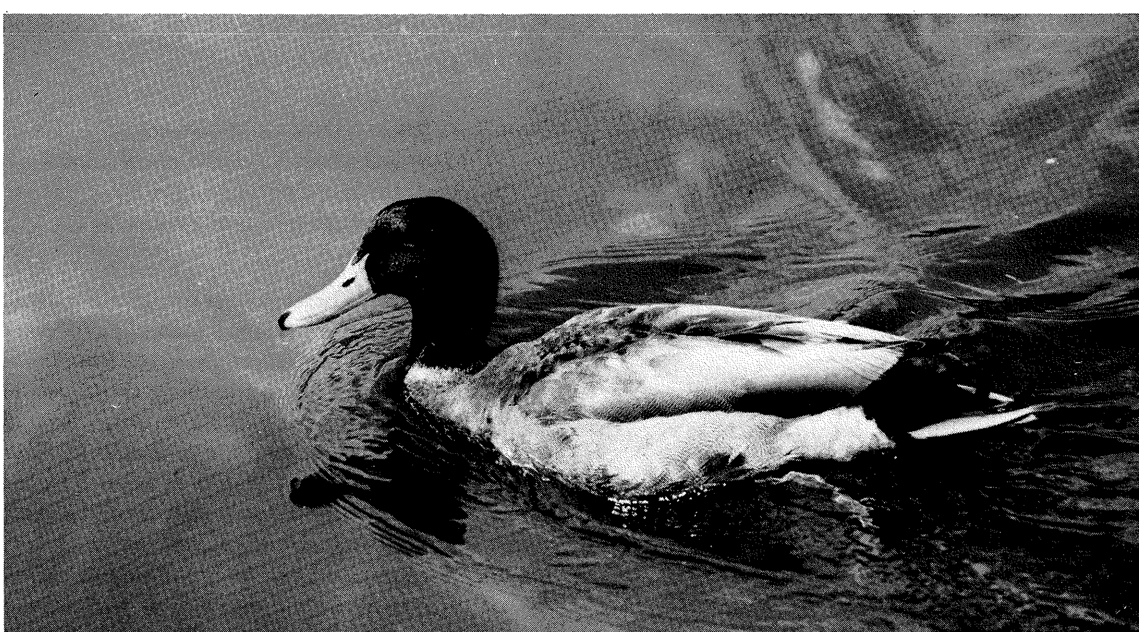
The white-faced heron, often mistakenly called the blue heron, is a self-introduced Australian species and has become a fairly common sight in the Wanaka area. It is often seen wading and probing in the shallows of the lake edge, especially in those areas where high lake levels inundate pastures, e.g. Paddock Bay and the Makarora shore. Farm paddocks flooded by heavy rain or irrigation often attract numbers of these birds, presumably feeding on displaced terrestrial invertebrates. A graceful bird to watch, it quietly stalks its prey, stepping slowly and deliberately with head and bill poised to strike. In flight, it shows a slow and deliberate wing beat. At times it may catch and kill small birds such as finches. It generally nests in tall



Juvenile Black Shag Photograph: J.L. Kendrick, N.Z. Department of Internal Affairs, Wildlife Service.



White-faced Heron Photograph: J.L. Kendrick, N.Z. Department of Internal Affairs, Wildlife Service.



Mallard Drake Photograph: J.L. Kendrick, N.Z. Department of Internal Affairs, Wildlife Service.

trees, especially pines. The most unattractive thing about this bird is its harsh, croaking call.

The past few years have seen an annual visit from at least one white heron, and this bird, oddly enough, has been attracted to the residential area where it has delighted many people with its meanderings up Bullock Creek. These visits usually occur during autumn and early winter and probably coincide with the dispersal from the nesting area at Okarito.

It is difficult to assess the number of Australian brown bitterns living in the Lake Wanaka area because of their secretive nature and surprisingly effective camouflage. They are at home in swamps and marshy areas and, on numerous occasions, I have noticed them in these situations in the lower Matukituki Valley. Because of their apparent dependence on swamplands, their numbers are probably declining locally as drainage destroys or modifies their habitat.

Although hard to see, their presence is sometimes given away by the call of the male (a booming sound). The bird is easily identified in flight as it flies characteristically with slow wing beats and neck tucked in.

Family anatidae (Swans, Geese and Ducks)

(a) Grey Duck. *(Anas superciliosa)*
(b) Mallard duck. *(Anas platyrhynchos)*
(c) Paradise shelduck. *(Tadorna variegata)*
(d) N.Z. Shoveler. *(Anas rhynchotis)*
(e) Canada goose. *(Branta canadensis)*
(f) Black swan. *(Cygnus atratus)*
(g) Grey teal. *(Anas gibberifrons)*
(h) N.Z. scaup. *(Aythya novaeseelandiae)*
(i) Blue duck. *(Hymenolaimus malacorhynchos)*

The first six species are well known to most sportsmen as being those waterfowl listed as game birds and therefore available in sufficient numbers to harvest during the waterfowl shooting season. For information relating to the shooting season, see "Waterfowl and upland game shooting season" below.

The paradise shelduck is probably the most common of the local waterfowl game species, and it can be seen on a trip around the lake or up the Matukituki and Makarora Rivers. This attractive bird favours open pastureland, especially that situated close to water, where, if the food available is plentiful, it can gather in quite large numbers. Breeding takes place up the major inflowing river and stream valleys, with isolated pairs selecting sites near farm ponds, even around the Wanaka/Luggate flats. When moulting occurs, usually in mid/late summer, large flocks can be seen on the open river flats, in the larger ponds and even on Lake Wanaka itself. The female is easily recognized by her white head, while the male bird is predominantly dark; the young birds, before their first plumage change, closely resemble the male colouration. Both birds, especially the female, have a very clear and penetrating alarm call that is well known to most shooters.

Like the paradise shelduck, the grey duck is a native of this country but, unfortunately, because it readily hybridises with the mallard and appears to be less tolerant of a changing environment, its numbers have decreased. While still fairly common locally, it is not seen as frequently as the mallard because of its tendency to prefer more stable and undisturbed surroundings.

A typical "dabbling" duck, it can often be seen feeding along the shallow margins of the more remote ponds and parts of the lake. It is frequently disturbed from the dense willow growth along the quieter parts of the Clutha River. Plumage is similar in both sexes.

The mallard, a bird successfully acclimatised from British and American stock, has become this country's most common dabbling duck, as it seems to have the ability to take full advantage of a man-modified environment. Although a common bird locally, the large populations evident in other parts of the country are not to be found in the area under discussion, probably because the semi-arid conditions do not allow intensive farming and thus the abundance of food found elsewhere.

The N.Z. shoveler is not a common bird locally, but if looked for can sometimes be seen at the head of Lake Wanaka (i.e. the Makarora area) and in the larger ponds of the Matukituki Valley. This species tends to be highly mobile, and I suspect that the majority of the birds I have seen are transient rather than full time residents. In breeding plumage, the male is extremely attractive and can be easily distinguished. The rather long, spatulate bill characteristic of both sexes is also useful for identifying the species. It is an extremely fast flier, tending to make irregular turns, especially when approaching water to land.

The Canada goose is a well known and sometimes controversial bird which at times can be seen in large numbers. Similar to paradise shelducks in their feeding habits, they often graze lakeside pastures e.g. at Paddock Bay, where they can do considerable damage if present in large enough numbers. Older residents have told me that, many years ago, very large numbers of these birds used to frequent the middle and lower reaches of the Matukituki Valley; today, however, only small numbers exist on the larger ponds, with an occasional visit by a larger group, probably en-route to Glenorchy or the Hunter Valley. They are a large and striking bird and an extremely wary quarry for the hunter.

Only about 12 black swans are to be found within the Lake Wanaka area and only 4-5 of these on the lake itself. In recent years, two pairs have nested in the backwaters at the head of the lake, with only partial success. Other nesting pairs are to be found in some of the larger ponds of the Matukituki Valley where, fortunately, the relative isolation gives them more protection. Although listed as game birds under the Wildlife Act, black swans are currently protected within the Southern Lakes Conservancy.

Recent banding studies have shown that the grey teal is extremely mobile and it seems that it is only an occasional visitor. I have observed a few at Makarora on two occasions, but it is probable that numerous ponds within the area are visited from time to time.

Wanaka residents are fortunate to have a flourishing population of N.Z. scaup (black teal) in residence at Roys Bay. These small native diving ducks are well established throughout the many small sheltered bays of Lake Wanaka, and many of the larger and deeper ponds throughout the area also have small populations. The nucleus of the lake population seems to centre around Roys Bay, with breeding pairs moving out during November/January to quieter parts for nesting, leaving a small number of non-breeders behind.

The blue duck is more typically a bird of mountain or semi-mountainous regions, where it lives along the length of turbulent streams and rivers. However, one specimen was sighted at the mouth of Boundary Stream during the winter of 1976. It seems that this species is becoming rare locally, as an extensive survey conducted by P. Child, for his report on the birdlife of Mount Aspiring National Park, shows that he located only a few pairs near the headwaters of the Makarora and its tributaries.

Family Laridae (Gulls and Terns)

(a) Southern black-backed gull. (*Larus dominicanus*)
(b) Black-billed gull. (*Larus bulleri*)
(c) Black-fronted tern. (*Chlidonias albostriatus*)

The most common gull in New Zealand and existing in good numbers around Wanaka, the familiar black-backed gull is a notorious scavenger and is always present around rubbish tips and other sites where offal may have been dumped. It sometimes raises the ire of local farmers during the lambing season by its habit of scavenging dead lambs and attacking new-born ones. The main breeding colony around Wanaka appears to be located on a shingle bar of the Cardrona River bed, but it is probable that many pairs nest separately over a wide area.

The smaller, black-billed gull is without doubt the most abundant gull of the Wanaka region and can be seen at any time along the lake forefront. A bird not well known for its scavenging behaviour, it is certainly quick to accept scraps and is often seen on freshly ploughed paddocks. Many breeding colonies are present in the Wanaka region and are found typically on shingle bars in the Clutha, Matukituki and Makarora Rivers, where they can gather in quite large numbers. During the breeding season, it is a common sight to see a flock working an area of river to catch aquatic insects during the evening hatch, or probing the shoreline for larval forms.

The black-fronted tern moves into this area during the spring/summer period for its nesting. It tends to nest in similar situations to the black-billed gull and sometimes even in association with it. Colonies in the river beds are mainly small and unobtrusive. Black-fronted terns are commonly seen along the main river courses as they feed on insects, and frequently over ploughed paddocks.

Family Haematopodidae (Oystercatchers)

(a) South Island pied oystercatcher. (*Haematopus finschi*)

The arrival of South Island pied oystercatchers in these inland areas is one of the first indications of spring. Initially seen in small groups while feeding on damp farm paddocks, they soon form pairs and disperse up the main river valleys for nesting. Commonly seen in pairs up the Matukituki and Makarora Valleys, where they nest on the shingle river flats and even on associated farmland, they are fairly early nesters, with young birds being seen from October onwards. The parents often exhibit a "broken wing" display if an intruder wanders too close to the nest or young. They return to coastal areas after nesting and remain there over the winter.

Family Charadriidae (Plovers and Dotterels)

(a) Spur-winged plover. (*Lobibyx novaehollandiae*)
(b) Banded dotterel. (*Charadrius bicinctus*)
(c) Wrybill. (*Anarhynchus frontalis*)

Although a self-introduced Australian species, the spur-winged plovers have now become common and accepted members of the local bird fauna. Fairly well dispersed over the farmland of the area during summer, they can congregate in large numbers on lake-side pastures during the winter. A recent count of 530 birds was made on the farmland around Paddock Bay during June 1977. This species is rather aggressive, and small groups can often be seen routing larger birds (e.g. Harrier hawks) from an area. The nests of this species I have seen seem to be placed generally in fairly open country and in or near damp/wetland areas, but it can probably nest in many other, open situations. This bird has a very clear and distinctive call, which carries for some distance.

The banded dotterel visits inland areas during spring and early summer for nesting. It is a small and attractive bird, though unobtrusive in its habits and needing at times to be carefully looked for. Nesting takes place in a variety of locations, but primarily on bare stony terraces or shingle flats, and islands of the Matukituki, Makarora and Clutha Rivers. Like the oystercatcher, it gives a very pronounced and amusing "broken wing" display. After nesting, most of these birds travel to the coast where flocking occurs prior to the migration to warmer, more northern parts. A few dotterel seem to over-winter here, for on several occasions I have seen them on lakeside farmland at that time of year.

The wrybill, a small plover found only in New Zealand and which has the peculiarity of a laterally curved bill, is a rare visitor to Central Otago. The wrybill migrates southwards from its northern wintering grounds, to nest amongst the gravel of the Canterbury/North Otago river beds. Although I have not been fortunate enough to observe these birds locally, surveys conducted over a number of years by P. Child (pers. comm.) show that a few isolated pairs nest on shingle flats in the lower and middle reaches of the Matukituki and Makarora Rivers.

Family Rallidae (Rails)

(a) Pukeko. (*Porphyrio melanotus*)

(b) Marsh crake. (*Porzana pusilla*)

According to local residents, the pukeko was once a fairly common inhabitant of swampland in the lower Matukituki and Makarora Valleys, but during the last four years, I have not seen one within the Lake Wanaka area. I am led to believe that a small population still exists in swampland near the lake shore on Minaret Station, but I cannot personally verify this.

Strangely enough, I have been told by several independent sources that a rapid decline in pukeko numbers occurred during the cold winter of 1968. It seems unlikely that one cold winter would be enough to cause the decline of a once vigorous population and I suspect that the decline has been more gradual and associated with habitat destruction or modification.

The marsh crake is a very small and secretive rail, found typically in swampland and around the reedy edges of ponds and small lakes. I have not personally seen one locally, but a sighting was reported from a marshy area in the lower Motutapu Valley. Marsh crakes tend to be easy prey for cats, stoats and rats.

Family Recurvirostridae (Stilts)

(a) Pied Stilt. (*Himantopus leucocephalus*)

A surprisingly uncommon bird on the local scene, the pied stilt arrives during September, presumably to breed, and is most commonly seen along lakeside pastures at Paddock Bay and occasionally on very wet, irrigated land in the Luggate/Hawea Flat area. They can apparently nest in a variety of habitats, from shingle bars along river beds, to swampy paddocks. I have not yet located a nest within the Wanaka region, but feel sure that they must be breeding here. After nesting, these birds retire to the coast and tend to migrate northwards for the winter.

Family Alcedinidae (Kingfishers)

(a) Kingfisher. (*Halcyon sancta*)

Kingfishers are rarely seen this far inland, but from time to time a bird may become obvious as it sits on a perch waiting for suitable prey to show. These are exciting birds to watch as they make dramatic dives into the water to capture small fish or insects. Unfortunately, those few birds that do suddenly appear within the district appear to be only transients.

2. BIRDS OF FARMLAND AND OPEN COUNTRY.

Family Accipitridae (Hawks)

(a) Harrier. (*Circus approximans*)

This bird is widely known as a large and graceful scavenger. It is commonly seen soaring on thermals over open country, or casually flying from the remains of a road-killed rabbit. The species probably performs a valuable service by cleaning the roads in this way. Nests are not frequently found, as the harrier prefers sites amongst dense Raupo growth in a wetland, or in thick fern on a hillside. This is certainly a common bird locally.

Family Columbidae (Pigeons)

(a) Rock pigeon. (*Columba livia*)

The rock pigeon is probably derived from an assortment of originally domestic birds, which, after many generations, have become completely wild and taken up a natural existence. There are quite a large number of these birds in the area; the main population seems to roost at a number of locations on the banks of the Clutha River. The roosting colonies disperse during the day to the farmlands of the Hawea Flat and Luggate, where, if conditions are favourable, they gather in large numbers to feed on croplands. Some damage to newly sown or freshy sprouted crops has been attributed to these birds. The roosting sites selected are always on steep inaccessible faces.

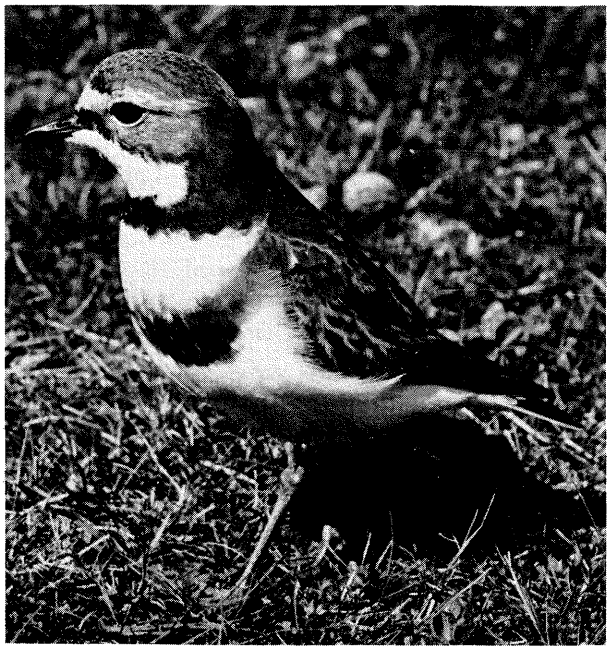
Family Alaudidae (Larks)

(a) Skylark. (*Alauda arvensis*)

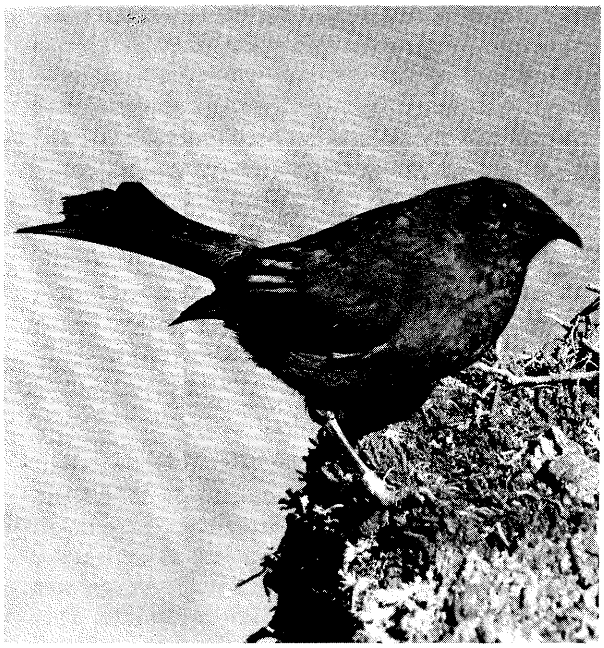
Confusion invariably arises about the identification of the introduced skylark and the native pipit.

The skylark, a bird of lowland, open, well developed farm country, and seeming to favour the drier areas, is reasonably common locally, especially in the lower Matukituki Valley and farmland around the southern sector of Lake Wanaka. It is commonly heard during an early summer evening, delivering a long, melodious song while hovering high above the ground. Nests may be found amongst relatively short grasses in small depressions on the ground.

Pukeko Photograph: P. Morrison, N.Z. Department of Internal Affairs, Wildlife Service.



Banded Dotterel Photograph: P. Morrison, N.Z. Department of Internal Affairs, Wildlife Service.



Bellbird Photograph: J.L. Kendrick, N.Z. Department of Internal Affairs, Wildlife Service.

Family Motacillidae (Pipits)

(a) N.Z. Pipit. (*Anthus novaeseelandiae*)

The pipit is fairly often encountered in the main Wanaka valley, but perhaps more frequently amongst the rough farmland (semi-grass, fern, scrub mixture) of the western lake edge. It seems to be attracted to small stream banks and wet areas, for at times small groups of these birds can be seen foraging amongst the stones of the water edge. It appears to avoid well developed farmland in favour of relatively undeveloped areas.

Family Fringillidae (Finches)

(a) Greenfinch. (*Chloris chloris*)
(b) Goldfinch. (*Carduelis carduelis*)
(c) Chaffinch. (*Fringilla coelebs*)
(d) Yellowhammer. (*Emberiza citrinella*)
(e) Redpoll. (*Carduelis flammea*)

Family Ploceidae (Sparrows)

(a) House sparrow. (*Passer domesticus*)

Family Sturnidae (Starlings)

(a) Starling. (*Sturnа vulgaris*)

Family Cracticidae (Magpies)

(a) White-backed magpie. (*Gymnorhina hypoleuca*)

The birds listed above have all been introduced to this country; so successfully, in fact, that they have become so commonplace as to be regarded by many as worthy of little attention, other than indicating their presence.

The redpoll, chaffinch and yellowhammer are common along the valley floors of the Matukituki Valley and in other less developed situations such as the western shore of Lake Wanaka. The goldfinch and greenfinch, while still seen in these areas, do not appear to be as numerous.

The starling is also a common bird on the local scene, especially favouring the farming sector; the habit this species has of flocking together for evening flights makes its numbers appear most impressive. A roost of several thousand birds exists amongst the pines growing on Ruby Island and many birds also roost amongst the thick scrub growth at the base of river-side cliffs down the Clutha River.

3. BIRDS OF FORESTS, EXOTIC PLANTATIONS AND SCRUBLAND.

Family Falconidae (Falcons)

(a) N.Z. Falcon. (*Falco novaeseelandiae*)

The falcon is a magnificent bird, only occasionally seen within the main Lake Wanaka basin. Though typically a bird of bush covered mountainous regions, on occasions I have seen them in the lower Matukituki Valley and along the access track to Minaret Station (i.e. the western lake edge). They are perhaps seen at lower levels more frequently during winter, when possibly the cold, or lack of suitable prey, forces them to descend in search of food.

Family Muscicapidae (Flycatchers)

(a) South Island fantail (*Rhipidura fuliginosa*)
(b) Tomtit. (*Petroica macrocephala*)

The fantail is a bird which favours the semi-forested areas, especially the under-canopy trees. This species is not especially common throughout the Wanaka area and is probably as abundant amongst the exotic back garden trees and shrubs of Wanaka township as anywhere else in the region. During autumn and early winter, numbers of fantails appear around the older, established properties of the township where they are attracted by insects and spiders living in the nooks and crannies of houses. Those damp valleys containing dense undergrowth of reasonable variety normally house a few of these birds.

Tomtits (Yellow-breasted tits) are quiet little birds, seeming to appear out of nowhere to look you over as you walk through their territory. They are fairly common on the damper, cooler northern side of the lower Matukituki Valley, where they live amongst the scrub mixture at the base of the valley sides. They are also frequently seen amongst the beech forest/scrub mixture of the western lake shore. A few birds live throughout Wanaka township, usually in the dense scrub along Bullock Creek.

Family Columbidae (Pigeons)

(a) N.Z. Pigeon. (*Hemiphaga novaeseelandiae*)

This is a large and beautiful pigeon, very rarely seen within the area under discussion. A few appear on occasions at the periphery of the forest near Makarora and others have been reported, usually during the spring, from the kowhai grove at Glendhu Bay and from willow and poplar trees at various locations up the western shore of the lake. Pigeons are probably attracted to these areas during times of a particular food abundance, i.e. when young willow shoots and kowhai flowers are present.

Family Meliphagidae (Honeyeaters)

(a) Bellbird. (*Anthornis melanura*)
(b) Tui. (*Prosthemadera novaeseelandiae*)

The bellbird is most frequently noticed during the spring and early summer as it invades the gardens of Wanaka residents to partake of the nectar available from the large variety of exotic flowering plants. For this reason, I suspect that the bellbird appears to be more abundant locally than it really is. During other times of the year it is only occasionally seen in the town belt, although present in second growth scrub and forest at Makarora and parts of the western Wanaka valley.

I have not personally seen tuis within this area; however, there has been a report of a bird amongst the spring growth of Wanaka gardens, and Child (1976) reports a small population a few kilometres north of the Makarora settlement.

Family Turdidae (Thrushes)
(a) Song thrush. (*Turdus philomelos*)
(b) Blackbird. (*Turdus merula*)
Family Prunellidae (Accentors)
(a) Hedge sparrow. (*Prunella modularis*)
Family Zosteropidae (Silvereyes)
(a) Silvereye. (*Zosterops lateralis*)

The four species listed above are all common locally, although the hedge sparrow and silvereye are probably not as often seen as the other two because they are smaller and relatively inconspicuous in their habits. All but the silvereye (which is self-introduced to New Zealand from Australia) have been introduced to this country and have spread widely throughout and over a wide range of habitats; the blackbird is even found frequently in bush areas. The silvereye tends to be gregarious and becomes more noticeable when in flocks during autumn and winter. The hedge sparrow, or dunnock, is a small grey-brown bird not often noticed but present in considerable numbers over the local range of habitats.

Family Phasianidae (Pheasants)
(a) California quail. (*Lophortyx californicus*)
(b) Chukor. (*Alectoris chukar*)
(c) Pheasant. (*Phasianus colchicus*)

All three of these species were introduced to this country to provide recreation in the form of game shooting. The California quail exists in good numbers throughout the semi-arid and scrub covered regions of Central Otago, but becomes less common towards the west as the rainfall increases. The western limit of its range, within the area under discussion, appears to be about level with the head of Lake Wanaka (a small covey has been seen at Wharf Creek).

The chukor has a similar range but usually prefers the higher sub-alpine rock and tussock areas.

A few "backyard" pheasant breeders are responsible for a very small population of ringneck/blackneck cross pheasants which exist around Wanaka township.

Family Sylviidae (Warblers)
(a) Grey warbler. (*Gerygone igata*)

A familiar bird to most people, the grey warbler has adapted well to second growth forest, scrub and exotic backyard trees and shrubs. More often heard than seen, this bird has a distinctive call. Found in reasonable numbers throughout the region, it inhabits scrubland areas and the residual forest of the western lake-shore.

Family Psitacidae (Parrots)
(a) Kea. (*Nestor notabilis*)
(b) Yellow-crowned parakeet. (*Cyanoramphus auriceps*)

The kea is primarily a bird of sub-alpine regions, frequenting rocky bluffs overlooking tussock land and forest fringes. It is frequently seen up the Matukituki Valley, but not actually within the area under discussion. It probably inhabits the higher Wanaka valley sides and the headwater basins of those inflowing western valleys, but I cannot personally verify this.

I have only recorded the yellow-crowned parakeet within this region once and that sighting, strangely enough, was made during the autumn of 1974, in scrub cover within Wanaka township.

Family Cuculidae (Cuckoos)
(a) Shining cuckoo. (*Chalcites lucidus*)
(b) Long-tailed cuckoo. (*Eudynamis taitensis*)

These two species are migratory birds, arriving in this country during spring to nest. The shining cuckoo has a clear and distinctive call (rather like that of a man whistling his dog) and is more often heard than seen; judging from the numbers of calls heard in the local areas, I suspect that this bird is not present in high numbers. It parasitises the nests of smaller passerines, especially the grey warbler.

The long-tailed cuckoo is also a nest parasite, and again, judging from the calls, seems to be present in only low numbers, appearing to favour the less developed parts of the region.

Family Strigidae (Owls)
(a) Little owl. (*Athene noctua*)

The little owl, or German owl, is not a New Zealand native species, but was introduced to Otago between 1906–1910. It appears to have acclimatised well to this area, for it now seems to be fairly common. Being mainly nocturnal, it is naturally difficult to assess its range and abundance, but it is certainly present amongst the small exotic plantations of the Wanaka area and can occasionally be seen amongst trees in the township itself.

Although it is quite probable that the native owl, the morepork (*Ninox novaeseelandiae*), is present in low numbers, especially in the northern and western parts of the local region, I cannot verify its presence.

Discussion: Waterfowl and upland game shooting season.

The waterfowl shooting season allows licensed shooters the opportunity to harvest local populations of 5 species of waterfowl and 2 species of upland game. The shooting season generally commences during late

Kea Photograph: R.B. Morris, N.Z. Department of Internal Affairs, Wildlife Service.

April or early May and is timed so that populations can be harvested before the inevitable winter mortality occurs.

Statistics show that the returns to the hunter from the waterfowl shooting season are among the poorest in the country. This unfortunate fact is probably due to the limited number of productive wetlands in the region, and the natural refuge provided by the lake.

The paradise shelduck provides the mainstay of our local waterfowl sporting species and generally accounts for almost half of all birds shot during the season. Because of this heavy reliance on the sporting potential of this bird, it is necessary to watch their numbers closely to ensure that the population is not over exploited.

There is a growing desire among sportsmen to increase the harvest of mallard ducks, and it is pleasing to note that a number of small ponds are being created at suitable locations throughout the region; as mallards do well in this environment, these ponds will encourage mallard production and harvest.

Almost every major wetland within the area under discussion is shot over during the season and shooters thus tend to concentrate at the head of Lake Wanaka, Paddock Bay and at ponds throughout the lower Matukituki River valley.

As if to compensate for the relative paucity of wetlands and waterfowl species, nature has endowed this area with large tracts of habitat suitable for the california quail and the chukor, our two upland game sporting birds. The shooting season for these two birds opens at the same time as that for waterfowl but extends over a longer period, generally about four months.

Much controversy has existed in the past about the effect of noxious animal poisoning operations on quail and chukor populations, and it certainly was, and still is, a very real problem. Controlling authorities have begun to realise that they do have responsibilities in this area, and have introduced various methods to alleviate the problem.

This paper has looked briefly at the bird species found within the Lake Wanaka area and immediate environs. Perhaps, more logically, it could have been dealt with on a total catchment basis. However, a detailed report, which outlines the birdlife within Mt. Aspiring National Park (Child, 1976), presents findings for much of the catchment. None of the 56 species of birds which have been discussed in this paper is confined to this area, and a few such as the white heron, blue duck and yellow-crowned parakeet, while they have been seen here, could hardly be considered to be typical birds of the local scene. On the other hand, some species which are not mentioned, such as the brown creeper and rifleman, are quite likely to be present in small numbers but as yet I have not located them.

In my opinion, it is those bird species associated with wetlands and water which provide diversity and add elements of interest to the local bird fauna. At times, it is possible to observe a great variety of birdlife at a single location when conditions are ideal and it is interesting and sometimes amusing to watch feeding and courtship behaviour, and inter-specific relationships.

Lake Wanaka is the dominant feature of the landscape, and its "moods" and fluctuations have great impact on the birdlife on and around its shores. As long as we continue to ensure that Lake Wanaka remains basically clean and unchanged, we should be assured of the continuance of our interesting, healthy and varied bird fauna.

Acknowledgement:
Photographs in this section kindly provided by N.Z. Department of Internal Affairs, Wildlife Division.

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Shoreline vegetation

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Introduction

The shores of Lake Wanaka support vegetation which varies according to two main factors: lake level fluctuation, and nature of the substrate. Periodic fluctuations determine the level to which land plants can descend without being drowned, the level to which aquatic plants can ascend, and the extent of sub-aquatic plants which can live both in the water and out of it. Consequently, the shoreline plant communities show a horizontal zonation from the aquatic to a sub-aquatic turf of small herbs, to scattered sedges and rushes, to a scrub fringe, and then to bracken or forest. The shore can be solid rock, loose boulders or gravels, with or without a covering of silt and sand.

Daily lake level readings by the Ministry of Works have been analysed for 1953–76 inclusive (Fig. 1). During this period, total fluctuation has been 3.47 m, though the average annual fluctuation is 2.23 m. There is a marked seasonal variation, the lake being lowest during July and August, rising to high levels in November and December, and remaining relatively high during late summer and autumn.

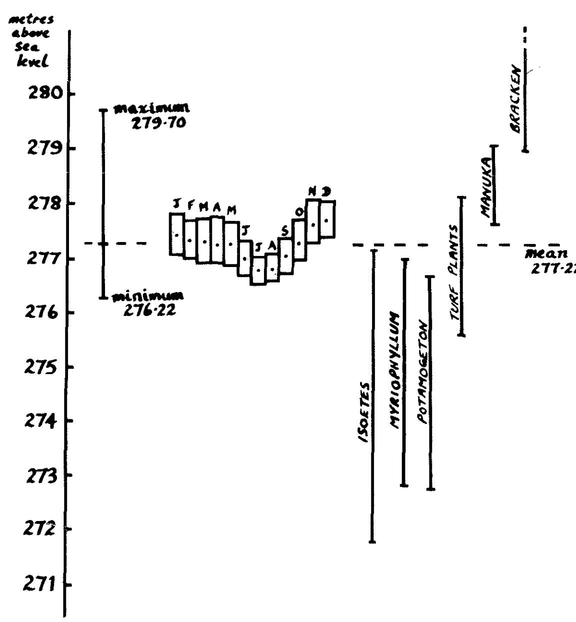

Figure 1. Lake Wanaka fluctuation 1953–1976. Extremes are shown on left, the blocks indicate mean monthly maxima, minima and means, and the vertical ranges of some shoreline plants are shown on right.

My studies on shoreline vegetation, mostly in March 1977, were made when the lake was near its mean level. Observations from a boat enabled aquatic plants to be identified to a depth of 5.5 m. Aquatic vegetation below that depth is not described here.

Flora

Aquatic and sub-aquatic plant species are listed in Table 1, and some of the main ones are illustrated in Figs. 2 and 3. *Isoetes alpinus*, a primitive fern, grows as short tufts in shallow water or as continuous carpets, up to 20 cm thick, down to about 6 m below mean lake level. Water milfoil (*Myriophyllum elatinoides*) forms rounded clumps 4–70 cm tall, to 4.5 m depth, preferring gravel substrates to silty ones. Pondweed (*Potamogeton cheesemanii*) has much the same depth range. It grows up to 3 m tall, particularly in sheltered bays, where the terminal leaves float on the surface. These leaves are much broader and more shiny than the underwater leaves. *P. ochreatus* is similar but shorter, and lacks floating leaves. Several algae contribute markedly to the aquatic vegetation. These are the stoneworts: *Nitella hookeri,* which dominates below 5 m depth but occurs less commonly in shallower water, and species of *Chara* which can be common as low cushions at 1–2 m depth.

Prior to 1972, no introduced water plants were known from Lake Wanaka. Three species have since been reported: South African oxygen weed (*Lagarosiphon major*), initially found in Roys Bay and subsequently discovered as far away as Parkins Bay and Stevensons Island; Canadian pondweed (*Elodea canadensis*) at the head of the lake, at Glendhu Bay and possibly more widespread; and water buttercup (*Ranunculus fluitans*), known at least from Glendhu Bay, near Mt Burke and below the outlet. It is abundant down the Clutha River. *Lagarosiphon* is the most aggressive of the three and *Ranunculus* probably the least aggressive, but all can compete with and replace the native plants.

Sub-aquatic plants are floristically diverse, comprising some 40 species of small herbs, including 10 adventives. Most have a creeping habit and the different species intermingle to form a tight turf. They are mostly plants typical of lake or river edges, or of tarns or kettle-holes where the ground is periodically inundated.

Vegetation pattern

Profiles at right angles to the shore were surveyed using an abney level and staff onshore, and by stretching a tape between shore and boat to locate depth measurements made with a weighted tape. Four profiles are shown in Fig. 4. Profile A is on the east side of Glendhu Bay and shows a lake-edge turf community just above water level (see also Fig. 5). This has small bushes of manuka (*Leptospermum scoparium*) on its upper part, with taller manuka upslope on a gravel substrate. Bare gravel extends 1.8 m above lake level, and is replaced there by bracken and grassland. Offshore, vegetation starts at 0.8 m depth, where there is a carpet of *Chara* sp. At 1 m depth, *Myriophyllum elatinoides* is dominant, giving way to *Isoetes* at 1.2 m, the latter then extending to 3.6 m depth and containing scattered plants of *Myriophyllum* and *Potamogeton*.

Profile B, at Stevensons Island, illustrates a sheltered bay, backed by a gravel beach bare of vegetation, and with *Isoetes* the dominant plant from 1.0 to 5.5 m depth. A feature of sheltered sites such as this is the luxuriant growth of *Potamogeton cheesmanii*, rooted between 2.0 and 4.1 m depth, and with stems up to 3 m tall.

Profile C, on the north side of the Quartz Creek delta in Stevensons Arm, shows a gentle slope on which *Myriophyllum elatinoides* is the dominant plant from 0.4 to 2.0 m depth, covering 30–40% of the gravelly substrate. *Isoetes* again dominates in deeper water on the shelf, but *Potamogeton* is absent or rare on this shore, which is less sheltered than that at B.

D shows a steep profile, below a hard rock shore north of Glendhu Bay, and indicates *Isoetes* and *Myriophyllum* growing in silt which has settled on lake bedrock at a slope of 45°.

TABLE 1. Aquatic and subaquatic herbs recorded at Lake Wanaka.

v = very abundant
a = abundant
f = frequent

o = occasional
r = rare
* = adventive

+ = aquatic, at least over part of its range

Agrostis 'canina'	o	J. pusillus	a
*A. tenuis	f	*J. tenuis	a
Carex berggrenii	f	*Lagarosiphon major	f+
C. buchananii	o	Lepidosperma australe	o
C. coriacea	o	Lilaeopsis sp.	f+
C. flaviformis	a	Limosella lineata	f
C. gaudichaudiana	v	*Mimulus moschatus	o
Centella uniflora	o	Muehlenbeckia axillaris	f
Chara spp.	f+	*Myosotis caespitosa	o
Cotula maniototo	f	Myriophyllum elatinoides	v+
C. perpusilla	o	M. pedunculatum	f+
*Crepis capillaris	o	M. propinquum	f
Deschanpsia caespitosa	o	Nitella hookeri	v+
Eleocharis acuta	v	Plantago triandra	f
Elatine gratioloides	r+	Potamogeton cheesemanii and P. ochreatus	a+
*Elodea canadensis	r+	Pratia angulata	o
Epilobium brunnescens	o	*Prunella vulgaris	f
Galium perpusillum	o	*Ranunculus fluitans	o+
Glossostigma spp.	a+	R. hirtus	r
Gratiola sextentata	f	*Rumex crispus	o
Gunnera dentata	o	Schoenus pauciflorus	o
Hydrocotyle tripartita	a	Scirpus spp. including A. aucklandicus	a+
Hypsela rivalis	a	Selliera radicans	f
Isoetes alpinus	v+	Tillaea sinclairii	o
*Juncus articulatus	v	*Trifolium repens	o
*J. bufonius	o	Triglochin striatum	f
J. gregiflorus	o	Utricularia monanthos	o+

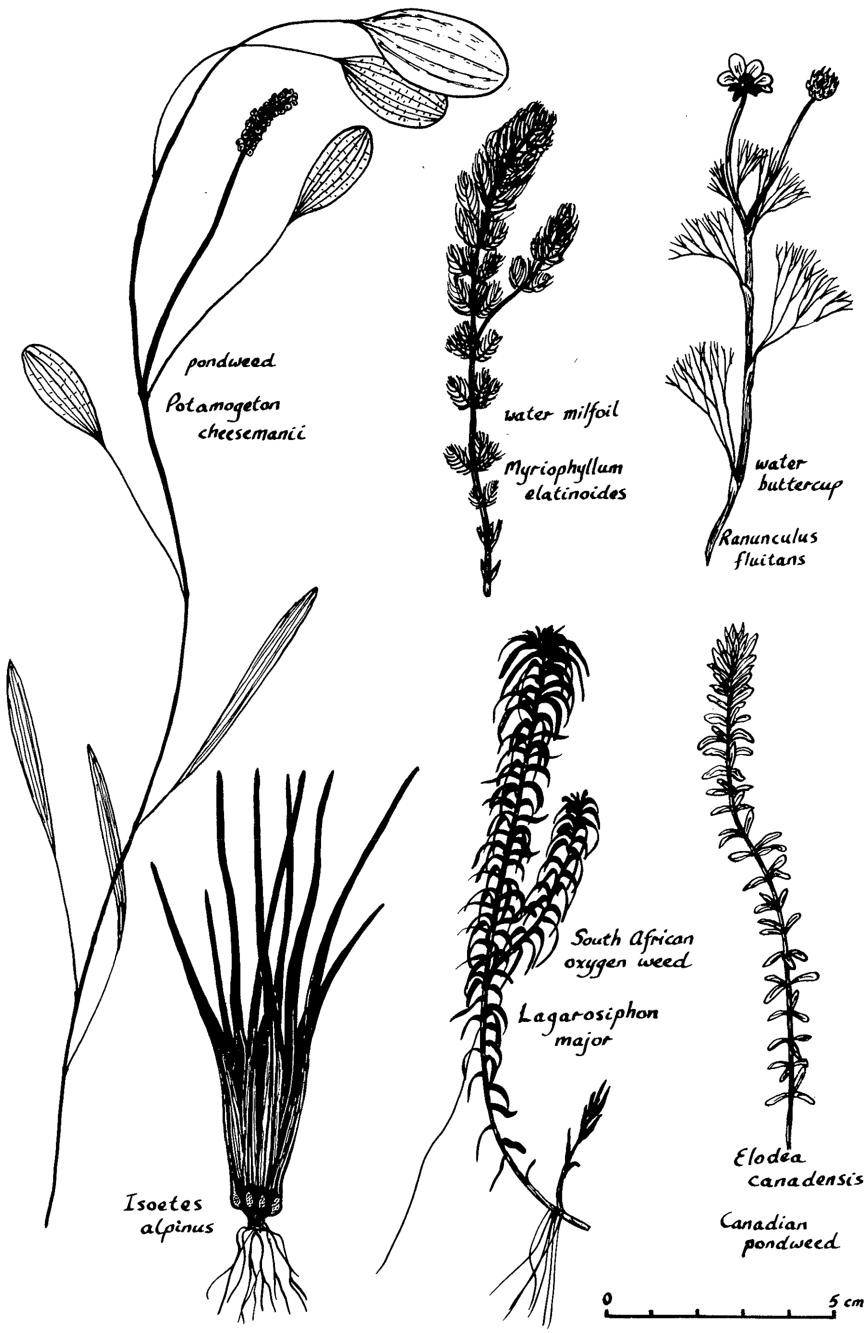

Figure 2. Some of the main aquatic plants found in Lake Wanaka.

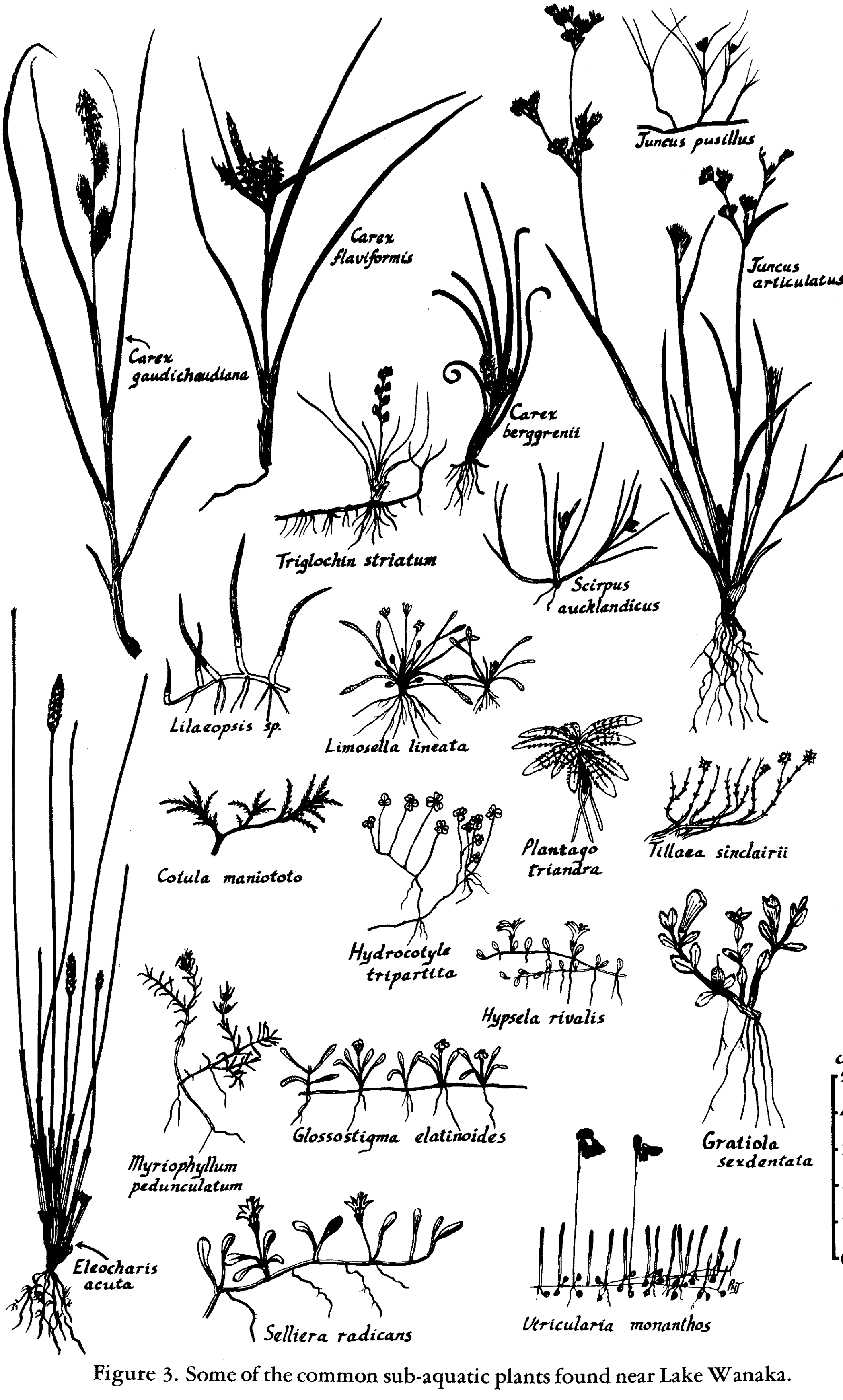

Figure 3. Some of the common sub-aquatic plants found near Lake Wanaka.

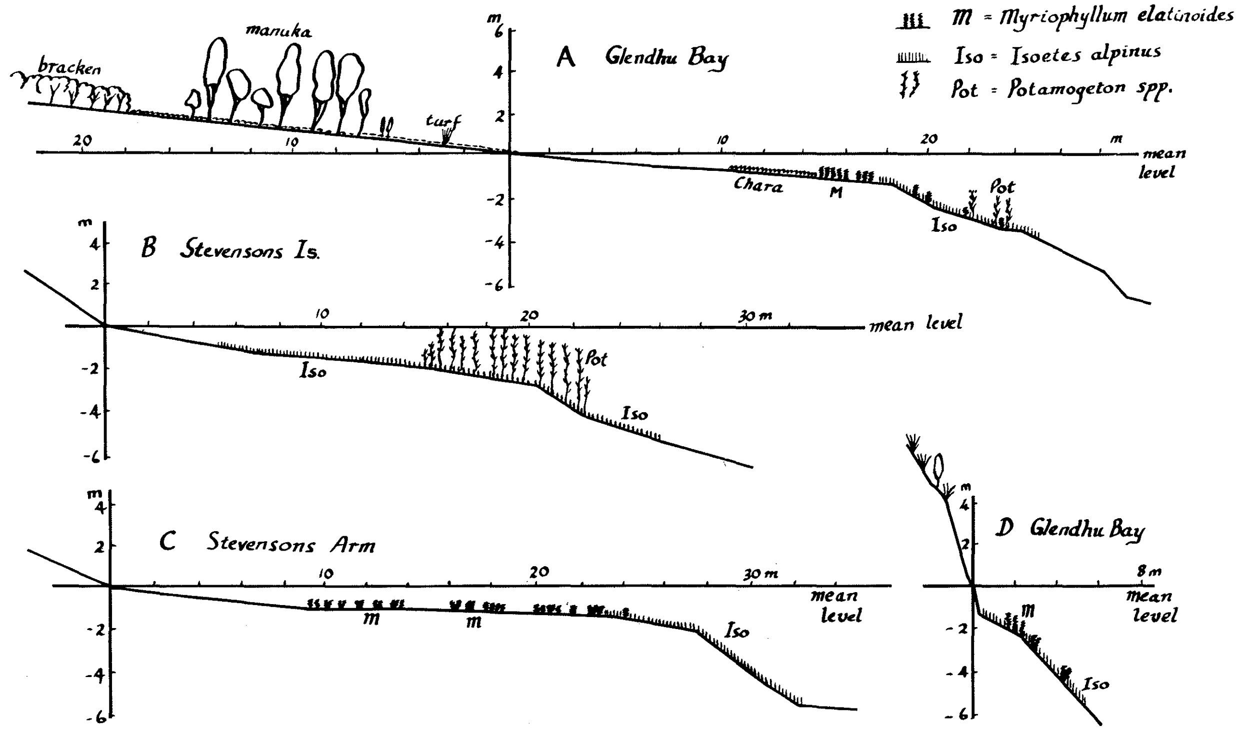

Figure 4. Profile diagrams showing vegetation pattern at four sites on Lake Wanaka shores.

Gravel shores

Most of the shoreline comprises beaches of gravel or coarse sand which are largely bare of vegetation, especially in exposed sites where bare gravel was recorded up to 2.5 m above mean lake level, or even higher on sites exposed to the greatest wind-fetch. Where there is more shelter, shrubs of manuka, matagouri (*Discaria toumatou*), sweet brier (*Rosa rubiginosa*) and *Coprosma propinqua* descend to between 1.2 and 1.5 m above mean level. In the most sheltered sites, mature manuka shrubs grow down to 0.8 m and young shrubs to 0.4 m above mean level, though these are probably drowned during periods of prolonged flooding. These shrubs make a narrow fringe around most of the shores, along with occasional kowhai (*Sophora microphylla*) or cabbage trees (*Cordyline australis*), or planted trees of crack willow (*Salix fragilis*). Where shelter is sufficient to give some stability to the gravel, the sedges *Carex buchananii*, or *Lepidosperma australe* will grow to within 10 cm of mean level.

Offshore from exposed gravel beaches there may be no aquatic plants to at least about 5 m depth. Where the shore is less exposed it is usual for the first 1 m below mean level to be fairly bare of plants, but beyond that, there is an increasing cover of *Myriophyllum elatinoides*, and, when the degree of shelter allows more silt deposition, of *Isoetes alpinus*.

Silty shores

In bays and coves, and particularly along shallow or sheltered shores, accumulations of silt encourage extensive aquatic communities and sub-aquatic lake-edge turf which spans the ground between water and land. These turf communities are best developed in Parkins Bay, Paddock Bay, along the east side of Glendhu Bay, and the east side of the lake from Eely Point past the outlet and up into Stevensons Arm.

Down to about 2 m below mean level, intermingled with small aquatic plants of *Isoetes, Potamogeton* and *Myriophyllum elatinoides*, the following turf plants occur: *Glossostigma, Lilaeopsis, Utricularia, Scirpus,* and *Elatine*. From mean level to 40 cm above, the usual dominants in the turf are *Myriophyllum pedunculatum, Cotula maniototo, Hydrocotyle tripartita* and *Plantago triandra*, with less *Carex berggrenii* and *Hypsela rivalis*. In cobbly ground, *Carex gaudichaudiana* and *Eleocharis acuta* grow down to water level (Fig. 5). Where the sediments are very fine (Fig. 6), the common plants are *Triglochin, Limosella, Glossostigma, Tillaea, Juncus pusillus* and *Myriophyllum propinquum*.

Further from the water, from 40 to 80 cm above mean level, *Carex gaudichaudiana* dominates, forming a short sward with *Juncus articulatus, Agrostis 'canina', Scirpus aucklandicus* and *Selliera radicans*. There may be scattered taller rushes of *Juncus gregiflorus* and small seedlings of manuka and brier. At about 1 m above mean level, the sward becomes taller, and additional plants such as *Crepis capillaris*, white clover *(Trifolium repens), Carex flaviformis* and the grasses *Agrostis tenuis* (browntop) and *Deschampsia caespitosa* occur.

Where flat farmland adjoins the lake, as at Mt Burke and Paddock Bay, the lake-edge turf merges with pasture. More usually it is backed by a zone of shrubs, particularly manuka (Fig. 4A).

Figure 5. Shore on east side of Glendhu Bay. Turf dominated by short sedges is interspersed with gravels which support scattered tufts of *Juncus gregiflorus* and shrubs of manuka. Lake level is 10 cm below the mean level.

Figure 6. Gently sloping shore near Wanaka motor camp, with turf growing on fine silt. On the right, sedge sward extends under manuka scrub. The hillsides beyond are mostly bracken covered, but low forest and scrub give Crescent Island (left of centre) its dark colour. Lake level is 10 cm below the mean level.

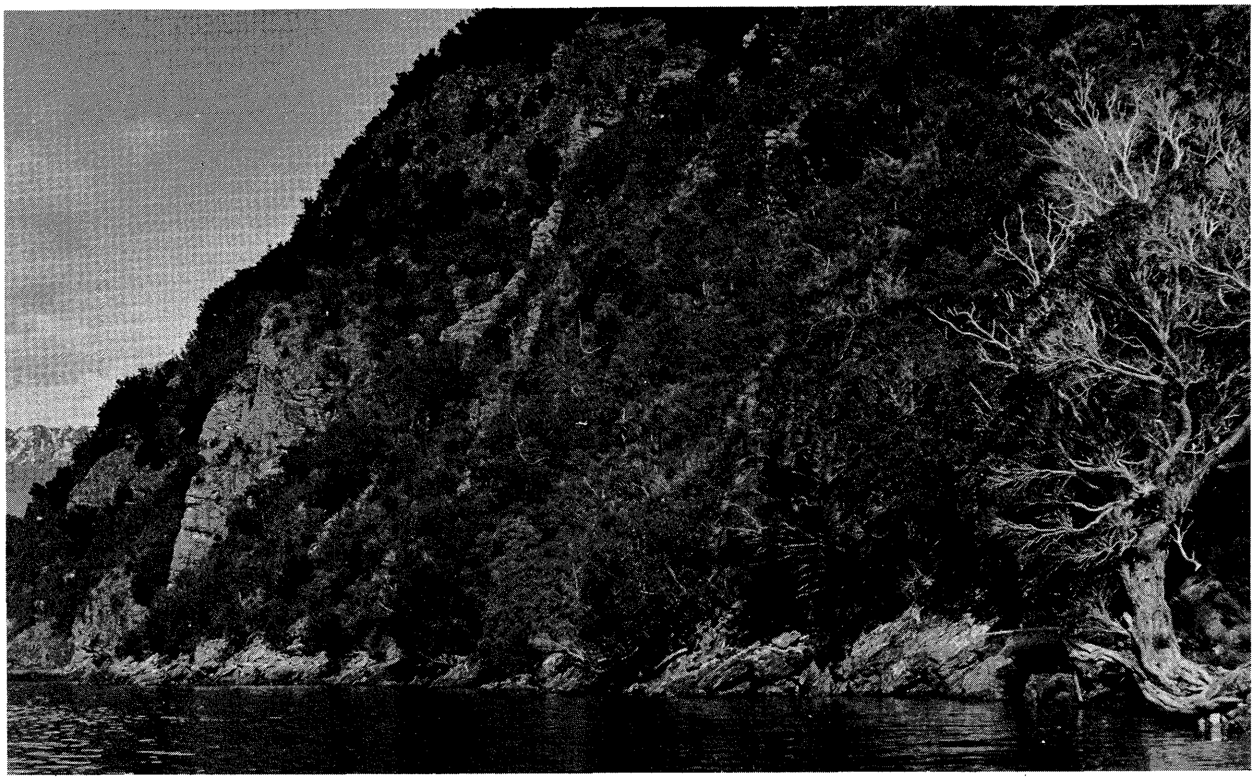

Figure 7. South-east shore of Crescent Island, with low forest and a rocky shore in foreground, and dark scrub of kanuka on ridge crest.

Rocky shores

Steep shores of in-situ rock or angular boulders have virtually no lake-shore vegetation as such, the plant cover typical of the hillside above descending to within about 1.5 m of mean lake level on sheltered sites (Fig. 7), and progressively further on more exposed shores, particularly headlands. Offshore, rocky sites are often bare of aquatic vegetation, at least to depths of 3 m or so, though *Isoetes* beds may be present in sheltered sites where silt has accumulated over the rock (Fig. 4D).

Vegetation surrounding the lake

Most of the lake surrounds are rough pasture in which bracken *(Pteridium aquilinum* var. *esculentum)* is usually more abundant than grasses. Above about 800 m altitude, bracken gives way to tussock grasslands. Much of the bracken has probably been induced by a long history of repeated fires since before European settlement, and by grazing. Low forest and scrub still persist on the islands, which have probably had a less severe fire history, and on some shady or steep faces on the mainland. Furthermore, some sites, where there has been no recent fire, show succession from bracken to scrub or forest. In places, this development is towards kanuka (*Leptospermum ericoides*) or manuka (*L. scoparium*) scrub, but more usually, as at the eastern head of the lake, it is mainly to dense, light green trees of *Pittosporum colensoi*, with scattered cabbage trees, lancewood (*Pseudopanax crassifolius*), mahoe (*Melicytus ramiflorus*) and small-leaved shrubs.

Less disturbed forest, as on Crescent Island (Fig. 7) and near the Minaret Burn, contains diverse tree species: broadleaf (*Griselinia littoralis*), kowhai, kanuka, lancewoods (both *Pseudopanax crassifolius* and *P. ferox*), mahoe, marble-leaf (*Carpodetus serratus*), southern rata (*Metrosideros umbellata), Pittosporum*, three-finger (*Pseudopanax colensoi*) and mapou (*Myrsine australis*). These are scattered among, or form a canopy over, shrubs of *Coprosma linariifolia, C. lucida, C. crassifolia, Melicope simplex, Helichrysum glomeratum, Corokia cotoneaster, Myrsine divaricata* and a native broom *Carmichaelia petriei*, all liberally laced with bush lawyer (*Rubus schmidelioides*) and other lianes.

A few stands of silver beech (*Nothofagus menziesii*) and mountain beech (*N. solandri var. cliffortioides*) reach the western shore of the lake, and one stand of forest south of the Minaret Burn is interesting in that it holds a few emergent podocarps, probably matai, an isolated specimen of which may also be found near the Matukituki bridge.

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