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DEUTERIUM IN NEW ZEALAND RIVERS AND STREAMS

by

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ABSTRACT

Over 750 deuterium measurements on rivers and streams in New Zealand are reported. Monthly samples were collected for periods of several years from a number of representative rivers; these show irregular storm-to-storm as well as seasonal deuterium variations. The seasonal variations range from as low as 1‰ for lake-fed rivers to 8-10‰ for rivers with large spring snow-melt contributions. Variations in mean annual δD* values are believed to reflect changes in climatic variables; the present data will be used to compare with future changes. The bulk of the data are single samples; these show a geographic variation related to the altitude, latitude and climatic character of the catchments, with the highest deuterium contents (δD = -20‰) occurring in the far north, and lowest contents (-80‰) in the inland Otago region. Regression equations derived for the δD dependence on altitude (h) and latitude (l), are $\delta D = -0.0169\ h - 30.2$ and $\delta D = -1.76\ l + 41.6$ respectively, for climatic zones dominated by westerly influence. Eastern climatic zones have lower deuterium contents because of rainout effects on the axial ranges. Contours of constant δD values in New Zealand precipitation are given.

KEYWORDS

DEUTERIUM; HYDROLOGY; RIVERS; CLIMATE; GROUNDWATER; PRECIPITATION.

INTRODUCTION

To gain knowledge of the natural distribution of deuterium in New Zealand waters, sampling of a wide range of accessible waters, but particularly rivers and streams, was carried out. This report presents and discusses these deuterium measurements. The data show interesting correlations with altitude, latitude, climate and predominance of westerly or easterly flows over regions of New Zealand. The deuterium measurements will be valuable as baseline data in future studies, such as the use of deuterium to trace the sources of recharge in groundwater systems, or for comparison with future isotopic measurements in climatic studies. The data set also shed light on the geographic distribution of deuterium in New Zealand precipitation.

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* δD values are defined by equation 2 (see below)

We first discuss the variations of the deuterium content in a number of representative rivers to assess the range of variation of deuterium content in individual rivers. Then, deuterium data from many rivers and streams throughout New Zealand are discussed in terms of the physiographic features and climate of their catchments.

CAUSES OF VARIATION OF DEUTERIUM

The main source of atmospheric vapour, which forms precipitation, is evaporation from the oceans. Fractionation of deuterium (or oxygen-18) during atmospheric processes results from the different saturation vapour pressures of HDO and H_2O (or $H_2{}^{18}O$ and $H_2{}^{16}O$); the lower vapour pressure of HDO causing deuterium depletion in vapour compared to co-existing liquid water. Practically all precipitation forms by condensation brought about by cooling of air on rising. Since the D/H ratio is higher in the liquid phase than in the vapour phase, the D/H ratio of atmospheric vapour becomes progressively lower as cooling proceeds and precipitation is removed. This temperature effect leads to altitude, latitude and seasonal effects; higher altitudes and latitudes and cooler temperatures (winter) having precipitation with lower mean D/H ratios. $^{18}O/^{16}O$ ratios of water behave similarly and the D/H and $^{18}O/^{16}O$ ratios of precipitation and vapour are found to be related by the equation

$$\delta D = 8.0\ \delta^{18}O + d \qquad (1)$$

$$\text{where } \delta D\ ‰ = \left[\frac{(D/H)_{sample}}{(D/H)_{standard}} - 1\right] \times 1000 \qquad (2)$$

and $\delta^{18}O$ is defined similarly. The internationally accepted standard V-SMOW (i.e. Vienna Standard Mean Ocean Water), has a composition close to that of the world's oceans, which vary only slightly in composition. d is the intercept on the δD axis; it has a value of about +13‰ in the New Zealand region (Stewart & Taylor, 1981), although the world-wide average is about +10‰ (Craig, 1961). Using equation 1, which holds for precipitation and most streams but not for lakes or geothermal waters, we can calculate the δD value of a water sample if the $\delta^{18}O$ value only is known. We have made use of this property for some of the results given below.

Streams deriving water from local catchments are often similar to the mean δD of the local precipitation. Precipitation generates run-off mainly by transport through the soil layers and/or by groundwater displacement; evaporation from soil and transpiration from plants, while reducing the amount of soil water, are believed to be non-fractionating because transport to the surface occurs in capillaries and fractionation at the surface is not transmitted back to the soil water. Consequently, soil water should have mean δD values approximately equal to that of the precipitation that contributes to recharge, which in most cases, is close to the mean δD values of the precipitation.

Larger rivers draw from catchments covering a wider range of altitudes. The river integrates water with different storage times within the catchment, the storage times depending on the nature of the vegetation, soils, bedrock, slopes and precipitation characteristics. Other factors are the presence of lakes, active groundwater systems and snowpack in the catchment. The mean δD of the river reflects the "precipitation weighted" mean altitude of the catchment, since precipitation amount varies with altitude and aspect.

Lake waters generally have δD values which are quite distinct from the δD values of the input streams, because of evaporation at the surface of the lake. Such evaporation causes a non-equilibrium enrichment of deuterium and oxygen-18, which moves the isotopic composition of the lake water away from the meteoric water line (equation 1). The characteristic δ values of the lake waters which result are represented in rivers deriving from the lakes and can be useful in tracing lake-derived waters issuing in springs (Taylor *et al.*, 1977). The δD values of lake waters cannot be related simply to the δD of local precipitation.

DEUTERIUM IN NEW ZEALAND WATERS

New Zealand is a narrow mountainous land mass lying between latitudes 34^{o}S and 47^{o}S in the southwest Pacific Ocean. A circle drawn around New Zealand encompasses ocean almost totally with Australia featuring to the northwest and Antarctica to the south. This oceanic situation causes relatively small seasonal differences in temperature and δD values of precipitation, as well as plentiful rainfall over much of the country.

Warm air masses originating from the southern oceans at low latitudes tend to move towards the pole, while cold air over Antarctica tends to move to lower latitudes. New Zealand falls within the area of conflict between the sub-Antarctic and sub-tropical air masses, where westerlies are predominant, the effects covering the entire country during the winter, but only the South Island in summer. The air masses are modified by their lengthy passage over the ocean to cool maritime or temperate maritime. Water vapour in polar and tropical air masses have very different δD values, polar vapour being much lower in deuterium. Large fluctuations in the δD values of precipitation may be expected with succeeding air masses of different type.

The other major factor affecting New Zealand climate and deuterium content in precipitation is the mountain barrier which lies across the dominant westerlies. Particularly in the South Island, this causes less precipitation and lower δD values on the east side of the country. However, near the east coast, this effect is moderated by easterly winds.

SAMPLING AND MEASUREMENTS

Samples have been collected during a number of years by several different collectors. Care was taken during collection of samples from rivers, streams and lakes to ensure that sampling points were free of backwash or stagnation by sampling one to two metres from the bank with the aid of a long rod. Samples were stored in glass bottles with neoprene-lined metal caps to prevent evaporation.

The deuterium measurements were made by converting the water to hydrogen gas over zinc in a matrix of sand at 420^{o}C (Lyon & Cox, 1980). The hydrogen was collected with a Toepler pump and the D/H ratio measured against that of an INS working standard previously calibrated against V-SMOW and SLAP. (V-SMOW and SLAP (Standard Light Antarctic Precipitation) are standard waters held by the IAEA in Vienna. On the δD scale, δD of SLAP w.r.t. V-SMOW is defined to be -428^{o}/oo. Our results are normalised to this value; see Hulston et al. (1981).

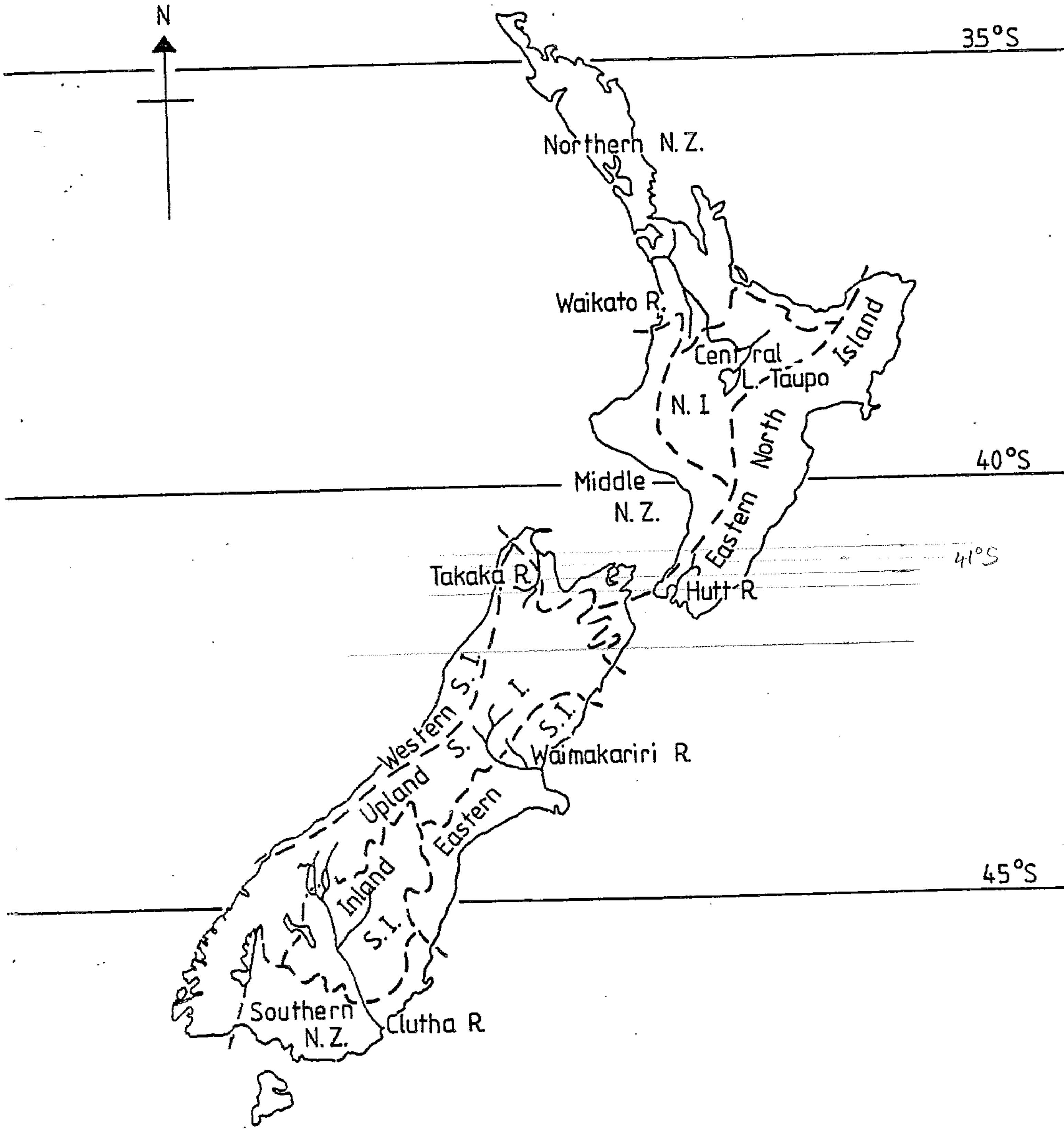

Fig. 1: Climatic zones of New Zealand and the locations of some rivers discussed in the text. Horizontal lines show latitudes in °S.

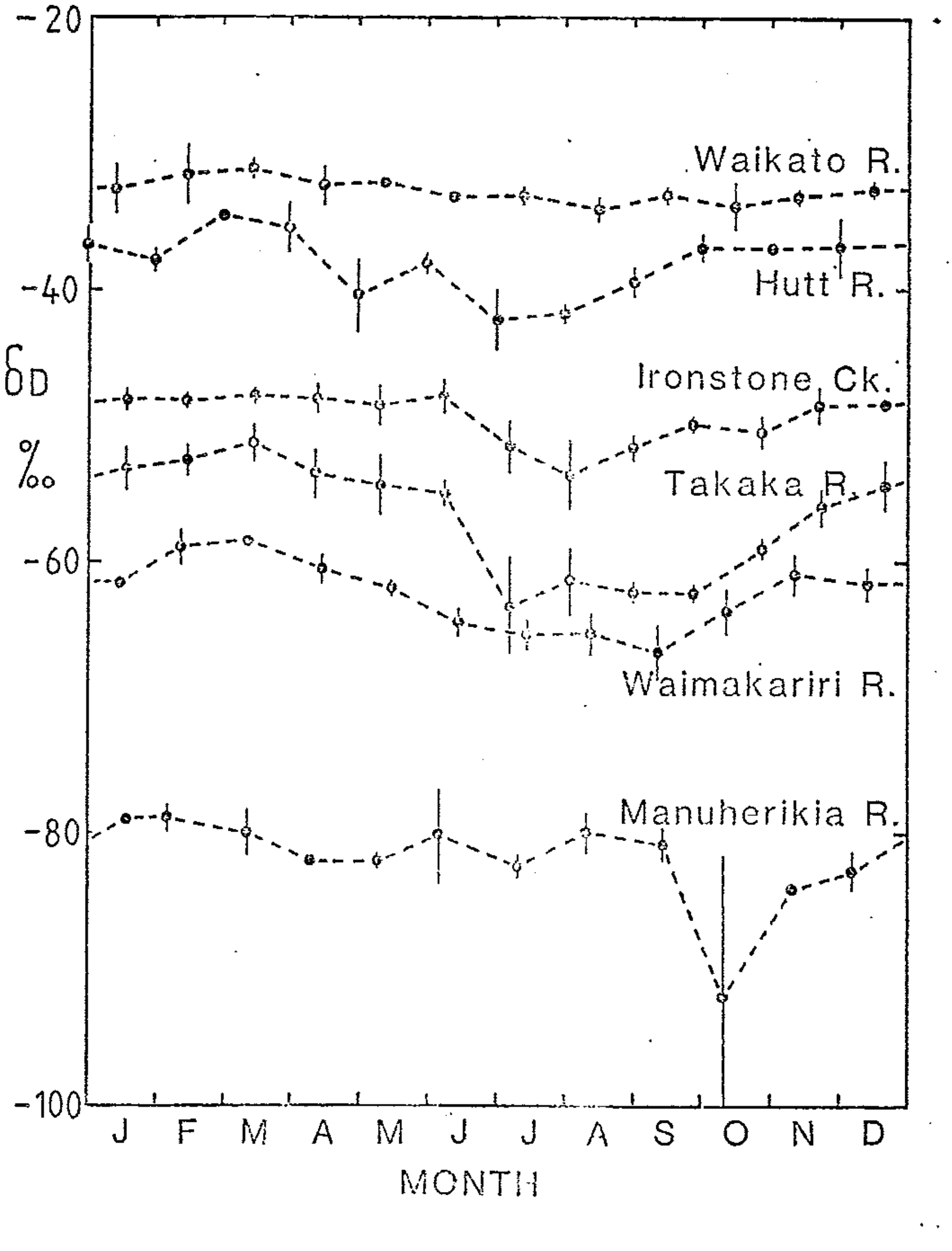

Fig. 2: Average monthly δD values of representative New Zealand rivers. The standard deviations of the mean monthly values are shown by vertical lines.

RESULTS

Results of the deuterium measurements are given in the tables. Tables 1-5 contain δD values of samples collected from rivers at monthly intervals to investigate the variation of δD in individual catchments over periods of several years. Where available, δD values of precipitation from nearby stations are also given. Some of New Zealand's major rivers are included; rivers discussed are the Waikato and Hutt in the North Island, and the Takaka, Ironstone, Waimakariri, Clutha, Shotover and Manuherikia in the South Island. The locations of these rivers are shown in Fig. 1, which also shows climatic zones in New Zealand according to the classification of Garnier (1958).

In Table 6, average monthly δD values for a number of rivers are given and these are plotted in Fig. 2. These illustrate the average seasonal variation of δD in several regions in New Zealand. Table 7 summarises the mean annual δD for the rivers.

The δD values of samples from a large number of rivers and streams throughout the North and South Islands of New Zealand are given in Tables 8 and 9, with collection dates, locations of sampling points and estimated mean catchment altitudes. The data are listed under the climatic zones described by Garnier (1958). Samples were collected during a number of years and at different times of the year for different rivers, so that annual and shorter-term variations may affect the results. Most of the samples were collected between 1971-74; the rest were from 1974-81. For the Eastern North Island and Northern New Zealand, sampling was mostly in summer and autumn, whereas for the rest of the North Island it was in late winter. For the South Island, sampling was mostly in summer and autumn. However, some of the results including those for the rivers given above were averages over a full year or longer of sampling and therefore shorter-term variations should have been screened out.

The mean catchment altitudes were arbitrarily taken as the mean of the highest altitude in the catchment and the altitude of the sampling location. (In a number of cases, this was compared with the weighted mean altitude estimated from the distribution of annual precipitation and ← altitude within that catchment and found to agree quite well.)

The data are plotted in Figs 3 and 4; the sampling locations being indicated by dots and the estimated centres of run-off generation in each catchment by lines. The climatic zones are also shown. 'Centres of run-off generation' were estimated to allow the data to be used, in conjunction with precipitation deuterium data, to obtain contours of deuterium content in precipitation.

A smaller number of δD values for New Zealand lakes are given in Tables 10 and 11.

DISCUSSION

δD Values of Individual River Systems

Lake Taupo and Waikato River

The Waikato River has been sampled at three locations since 1971 to monitor the effects of the Tongariro power development scheme on the deuterium contents of Lake Taupo and the Waikato River since the system was initially suggested as a relatively deuterium-enriched water source for a heavy water extraction plant. Data for the period 1973-75 are discussed here, the complete data set will be discussed elsewhere. The river was sampled at the Lake Taupo outlet, upstream of Broadlands and downstream of Broadlands (Te Mihi Bridge). The lake outlet gives the composition of Lake Taupo, the downstream locations are slightly depleted in deuterium due to input of run-off with more negative δD along the course of the river.

There is very little variation in δD at any of the locations because of the lake source, since the residence time of water in Lake Taupo is about 10.6 years (13 years before the Tongariro power development scheme), and the lake is well mixed as shown by tritium measurements (C.B. Taylor, pers. comm.). The δD values of the lake (about -30‰) are considerably enriched compared with Taupo airport precipitation (δD = -46‰) and tributory streams, because of evaporation from the surface of Lake Taupo. Input water to the lake, with δD of -45 to -50‰, derives principally from the south and west. The Tongariro project will probably divert more low-deuterium water into the lake, and decrease the deuterium content of the lake and river. Any changes are expected to become apparent after

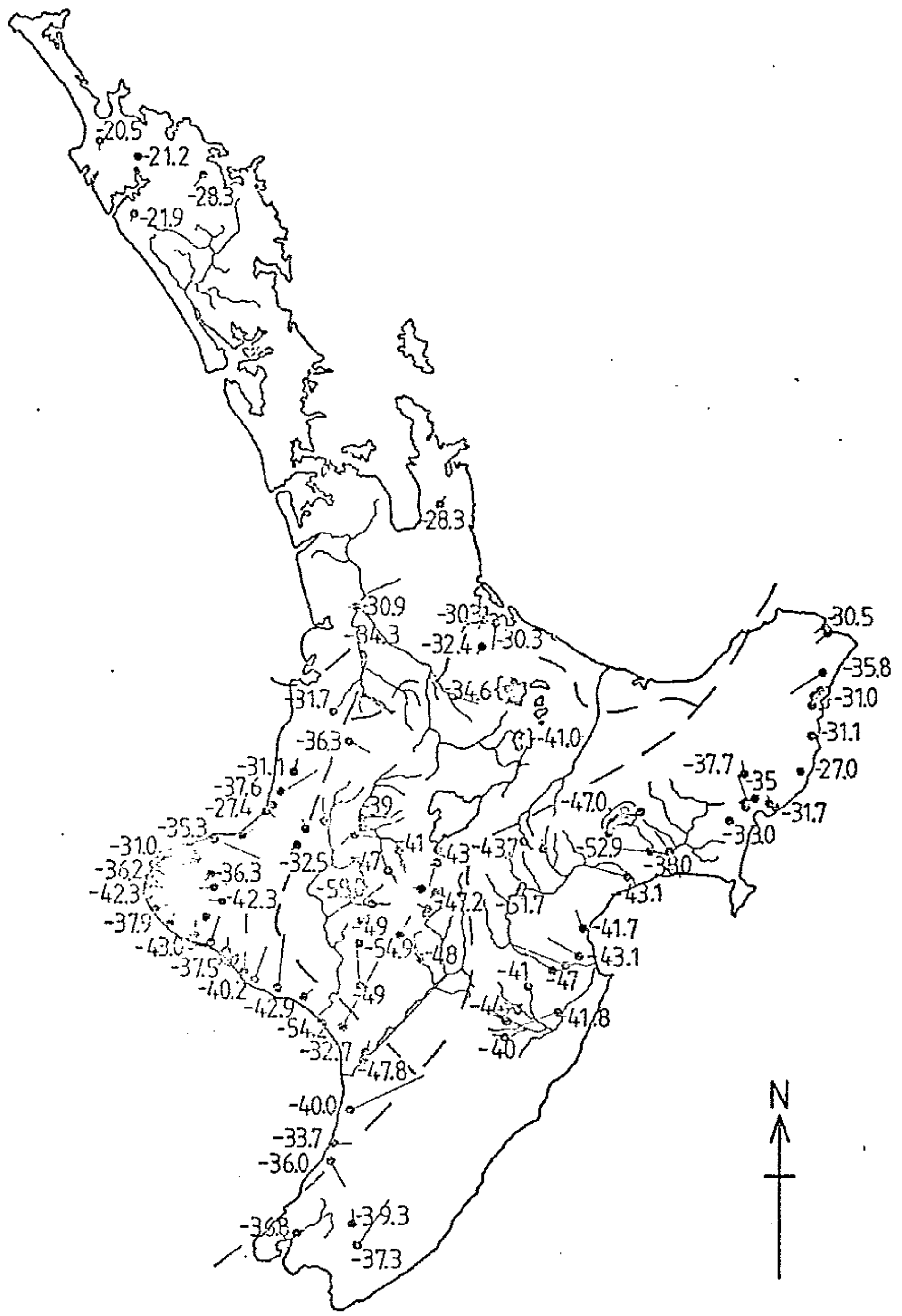

Fig. 3: δD values of rivers and streams from the North Island of New Zealand. Some values have been omitted because of difficulties in fitting them in.

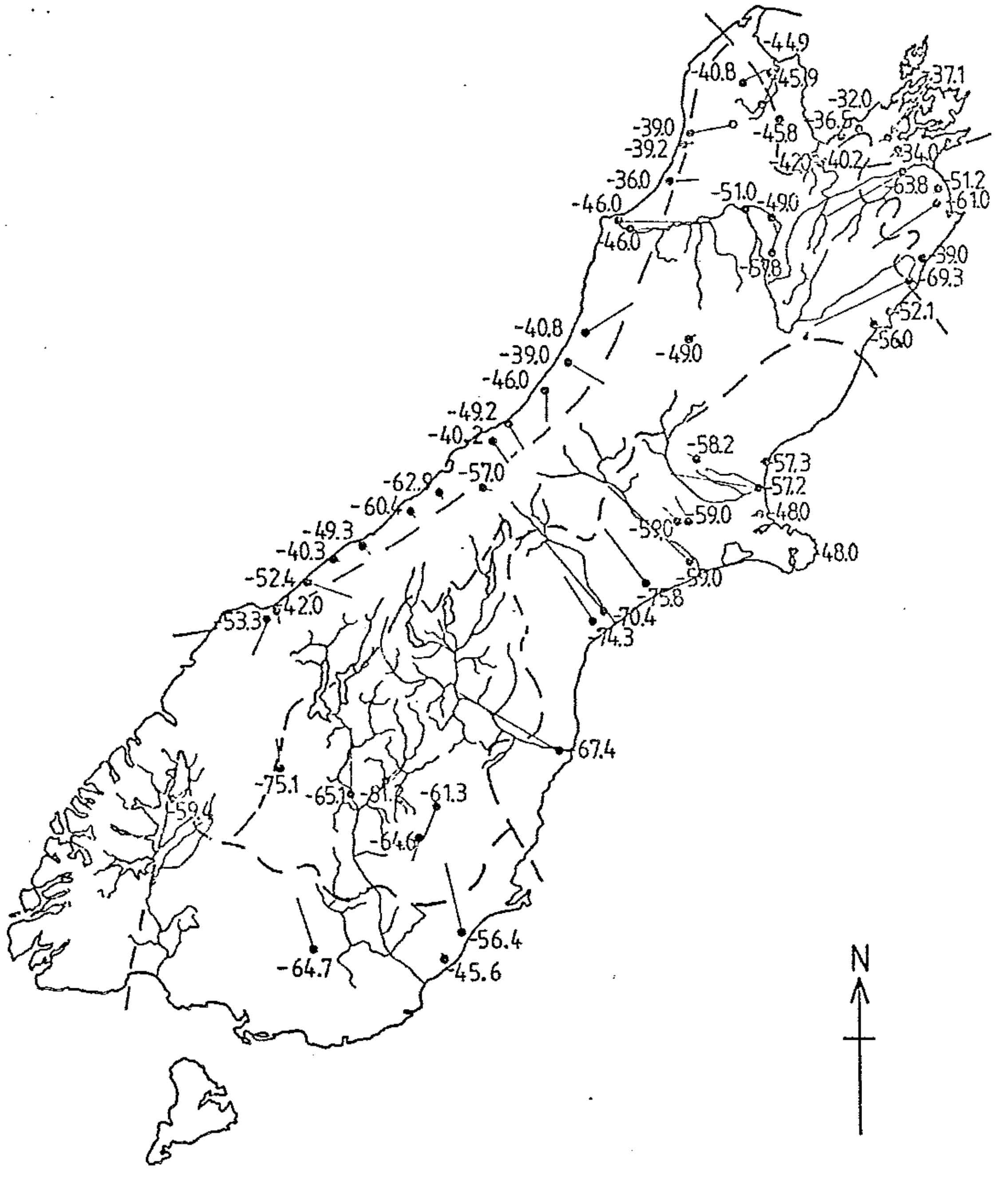

Fig. 4: δD values of rivers and streams from the South Island of New Zealand.

1983, because of the 10-year residence time of water in the lake, as the main Tongariro diversions were started in 1971, 1973 and 1979, respectively.

The data for downstream Broadlands are averaged (Table 6) and plotted in Fig. 2. The δD value shows no more than a 1-2‰ difference between summer and winter. Because of the evaporation, the δD values of the river and lake are not consistent with the climate of the sampling locations in the Central North Island zone.

Hutt River

The Hutt River catchment lies in the greywacke ranges that extend up the east side of the North Island. It is between the Middle New Zealand and Eastern North Island climatic zones (Fig. 2), which are dominated by westerly and easterly influences respectively. Both influences affect the Hutt River catchment.

δD values of Kaitoke rainfall and the Hutt River for September 1971 to August 1972, and for the Hutt River from 1979-81, are given in Table 2. The weighted mean δD for the rainfall is -38.9‰ and the δD variation is extremely irregular with approximately the same average δD value in summer as in winter. The river δD has a much smaller variation, due to smoothing of the variations in the rainfall δD, but there is a regular seasonal variation of amplitude about 5‰, showing that the catchment precipitation overall must have a seasonal variation in δD. The mean δD value for the river varies considerably from year to year, with the 1971-72 value being particularly high (i.e. less negative), perhaps reflecting higher mean temperatures or more westerly precipitation.

Takaka Valley

The Takaka Valley lies within the Middle New Zealand climatic zone, but the Takaka River draws water from Upland South Island at altitudes up to 1800 m. Westerly precipitation predominates in this area. Table 3 gives δD data for Takaka precipitation, well water within the valley, Ironstone Creek draining marble to the east and the Takaka River draining from the south (Stewart & Williams, 1981). The δD values in Table 3 (except for the rainfall) were calculated from $\delta^{18}O$ measurements using equation (1). This equation was verified to hold for the Takaka Region by the above authors.

The rainfall δD values show large variations, but have a prominent seasonal component as well. The seasonal variation is more pronounced at Takaka than at Kaitoke because precipitation amount is greater at Takaka and there is less easterly precipitation. The well water has very constant δD values, which are very similar to the weighted mean δD values of the rainfall. This groundwater is recharged at low altitude by rainfall.

Ironstone Creek, drawing from a marble plateau at about 900 m on the east of the valley, has lower δD. The δD value tends to be constant, due to baseflow from a large reservoir of water within the marble, with occasional departures due to quick flow from (generally winter) storms. The Takaka River has a seasonal variation of 8-10‰ and more negative δD, reflecting its high catchment. Its δD value becomes significantly more negative in spring because of input from melting snow. Part of the flow is drawn from the Cobb Reservoir.

Waimakariri River

The Waimakariri River draws from the Eastern South Island and eastern Upland South Island zones, where precipitation can be from easterlies and air masses sub-Antarctic in origin. Westerly air flows dominate over parts of the upland zone. δD values calculated from $\delta^{18}O$ values using equation (1) are given in Table 4, for September 1977 to August 1981. Between September 1977 and August 1978, samples were collected every week; the values in Table 4 are averages of four measurements (Taylor & Stewart, 1979). The δ values normally varied very smoothly, but there was one strong departure from the mean (δD = -49‰) during a high flow episode (1200 m^3/sec) on March 29, 1977 (normal flow is 50-100 m^3/sec). There is considerable variation in the annual δD values (these were calculated over the September-August year because of the availability of the data). Taylor & Stewart (1979) noted that during 1970-73 the δD values of the river were between -54 and -61‰ ($\delta^{18}O$ = -7.4 to -8.2‰), compared with mean values of -63.3 and -64.0 in 1977-78 and 1978-79, and correlated this with temperatures recorded at Craigieburn Forest in the

Waimakariri catchment. The temperature decrease between 1970-73 and 1977-79 (expressed by the three-year running mean temperatures) of $1^{o}C$ is sufficient to explain the change in annual δD values of the Waimakariri River. This temperature change may reflect reduced westerly flow over the Waimakariri catchment. The importance of rainout or lee side effects on the δD values of precipitation on the east side of the mountain barrier is shown below. Since 1979, the δD values have begun to increase (to -60.1‰ in 1980-81). These considerable changes indicate the sensitivity of the δD value of Waimakariri River to climatic changes in the catchment.

The seasonal variation of δD is about 5‰ (Fig. 2). This relatively small variation reflects the large area and long residence time of water within the catchment (about three years on average from tritium measurements (C.B. Taylor, pers. comm.)); and indicates that snowmelt is not a large direct contributor to the flow.

Clutha River Catchment

The main contributors to the Clutha River at Clyde are Lakes Wanaka, Hawea and Wakatipu, and the Shotover River. The three lakes receive precipitation from the dominant westerlies over the Upland South Island climatic zone. The Shotover River catchment (1063 km^2, 39 m^3/sec mean flow) has no major lakes and lies generally 40 km east of the main divide and near the Inland South Island climatic zone, a region generally sheltered by high ranges from both westerly and easterly influences. The Manuherikia River (2036 km^2, 14.7 m^3/sec mean flow) has its whole catchment more than 120 km east of the main divide and is separated from the west coast by several parallel north-south ranges, so that it receives much less precipitation than the main Clutha catchment. The Manuherikia receives more of its precipitation from easterly storms.

Table 5 gives data for the three rivers for 1974 and 1975. The δD values decrease with distance of their catchments from the main divide, although evaporation from the lakes may have affected the Clutha River δD values. Such a decrease is consistent with a "rain-out" effect, whereby the precipitation becomes lower in deuterium (and oxygen-18) as moisture is progressively removed from the air.

The degree of evaporation from the lakes - Wanaka, Hawea and Wakatipu - is thought to be quite small because of a fairly rapid turnover of these lakes ($\sim$ one year). Further measurements are necessary to evaluate this enrichment, which depends on the lake area and volume, water residence time and atmospheric parameters.

The Clutha River δD value shows very little variation. The lowest δ values occur in the spring when storms produce significant melting of the snow pack. This mechanism is much more prominent for the other two rivers. At other times, melting snow probably displaces groundwater or is otherwise mixed with precipitation from other seasons.

The Shotover and Manuherikia Rivers show much greater δD variation, which is rather irregular and affected much more by individual storms or snow-melting episodes than seasonal variations. The δD value for the Manuherikia during October 1974 shows an astonishing departure from the mean due to the snow-melt contribution. The rivers were most enriched in deuterium during summer periods of low flows, such as in December 1974 for the Shotover River.

δD Variation in Rivers

Time variations

Short-term variations in δD of precipitation due to storm-to-storm and within-storm variations are quite considerable and vary with location. Precipitation samples are usually collected as monthly averages to screen out the very short-term variations, but storm-to-storm variability often exceeds that due to seasonal variations. The seasonal variation can be seen more clearly if data for two or more years are averaged month-by-month. δD values for rivers vary much less than for precipitation because mixing of waters of different ages takes place within the catchments before discharge. However, during high flow episodes the δD values can deviate strongly from the means (e.g. the Waimakariri River had δD = -49‰ on March 29, 1977, compared with the average of -63‰, and the Manuherikia River had δD = -102.5‰ during October 1974, compared with -83‰).

Averaged monthly δD data for some representative rivers are given in Table 6 and plotted in Fig. 2. The amplitude of δD variation ranges from about 1‰ for a typical lake-fed river (the Waikato) to about 5‰ for catchments in which snow-melt does not provide a major direct contribution to the flow (the Hutt and Waimakariri Rivers), to 8-10‰ for catchments in which snow-melt contributes strongly in spring (the Takaka and Manuherikia Rivers). In general, New Zealand rivers do not show a large seasonal variation in δD because the climate tends to be "oceanic" rather than "continental". The dominant factors affecting New Zealand's climate are - (i) its location in the zone of travelling anticyclones and troughs, leading to considerable δD variability within seasons, (ii) the oceanic environment, leading to relatively small seasonal differences in temperature and hence δD, and (iii) the effects of the mountain barrier, causing less precipitation and lower δD values to the east. This effect is moderated by the input of precipitation derived from the east.

Long-term variations include year-to-year and longer-period variations in δD. The annual mean δD values of the rivers discussed above are given in Table 7. For the Waimakariri River, there appears to have been a climate-related change in δD between 1970-73 and 1978-81. The same change may also affect the Hutt River. In both cases, the δD values are lower (more negative) in 1979-80 than in 1971-72. In other cases, the mean δD values are for relatively short periods (three years maximum). However, the Takaka data suggest a change in temperature or origin of precipitation from 1976 to 1978. Such changes are to be expected, given the variability of annual temperatures and precipitation (Vines & Tomlinson, 1980; Tomlinson, 1981; Salinger, 1982). The present data has been collected partially to be able to observe future changes by comparison with the past.

Geographical variations

The δD values of the rivers (see Tables 8 and 9, and Figs 3 and 4) show a geographic variation that is related to the altitude and latitude of the catchments, the time of sampling and the climatic character of the catchment. The effect of altitude has been studied by plotting the δD values against the estimated mean altitudes of run-off generation in the catchments (Figs 5 and 6). Fig. 5 shows results from all parts of the

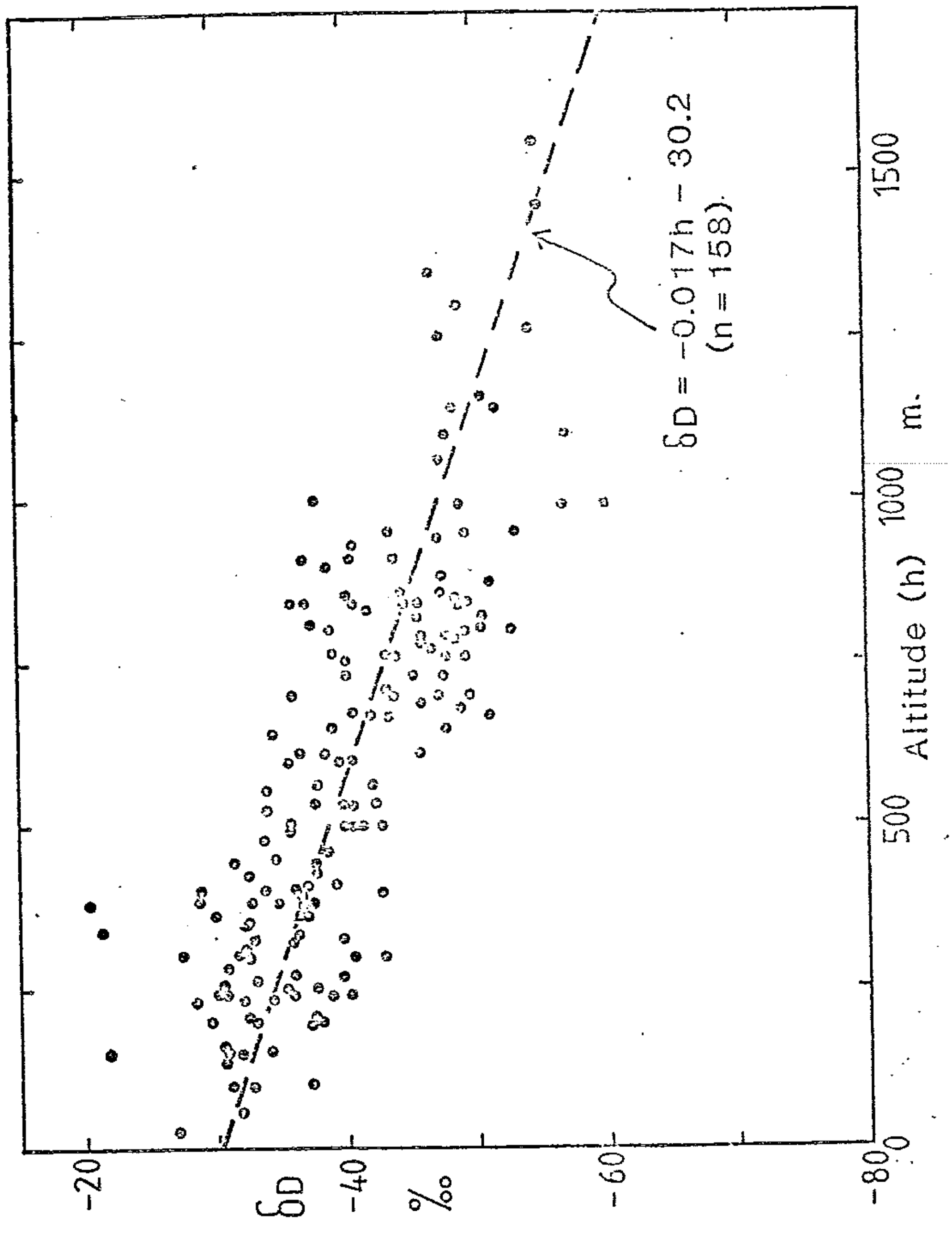

Fig. 5: δD values of rivers and streams plotted against the estimated mean altitudes of precipitation within the catchments, for all of the North Island and westerly zones of the South Island.

country exposed to the prevailing westerlies (Northern New Zealand, Middle North Island, Central North Island, Western South Island, westerly-draining rivers in Upland South Island and Southern New Zealand), as well as Eastern North Island. A clear relationship between δD and altitude (h) can be seen. Least-squares regression gives the line

$$\delta D = -0.0169\ h - 30.2 \qquad (3)$$

with a correlation coefficient of $r = 0.74$. (Three points each from the Northern New Zealand and Southern New Zealand zones have been omitted from this regression to avoid distorting the altitude relationship by the expected latitude effect.) Essentially, equation (3) expresses the decrease of δD values of precipitation resulting from removal of moisture from the air on rising over New Zealand uplands.

By contrast, results for east and south of the South Island (Fig. 6) show little correlation with altitude. The δD values plot below the "westerly" regression line of Fig. 5, because of the rainout effect. In this effect, air that has had moisture removed on the upslope (western) side of the mountains, produces precipitation with more negative δD values on the eastern side of the mountains.

There is considerable scatter in Fig. 5, although the altitude effect accounts for more than half of the δD variation ($r^2 = 0.55$). Another factor affecting the δD values is latitude, since mean temperatures are lower at high latitudes for any given altitude, and furthermore the vapour derives from a more southerly source. To investigate this effect, δD values were extrapolated to sea level (using equation (3)) and plotted against the mean catchment latitude (Fig. 7). Samples were taken from zones exposed to the prevailing westerlies (Northern New Zealand, Middle New Zealand, Western South Island and Southern New Zealand). (Every third sample was used from the Middle New Zealand zone to avoid over-weighting from this group.) Results from Eastern climatic zones were omitted because otherwise rainout effects (above) are likely to have obscured the latitude effect. The sea level δD values show a good correlation with latitude. The regression line is

$$\delta D = -1.76\ L + 41.6 \qquad (4)$$

where L is the latitude in ^{o}S, and this effect accounts for nearly 60% of the remaining scatter in δD ($r^2 = 0.59$). The variation of δD is from -20^{o}/oo at 35^{o}S to -40^{o}/oo at 46^{o}S.

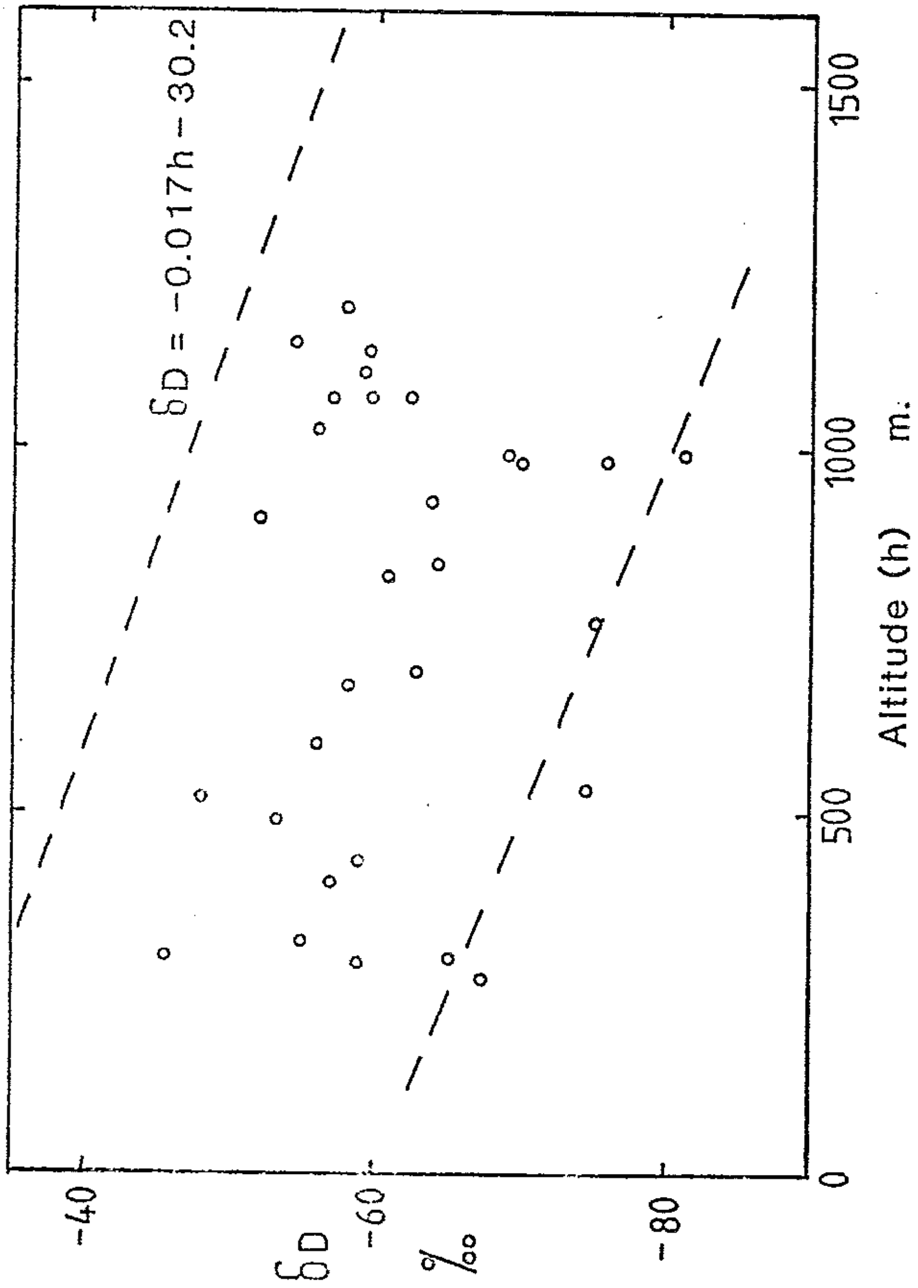

Fig. 6: δD values of rivers and streams plotted against the estimated mean altitudes of precipitation within the catchments, for easterly zones of the South Island.

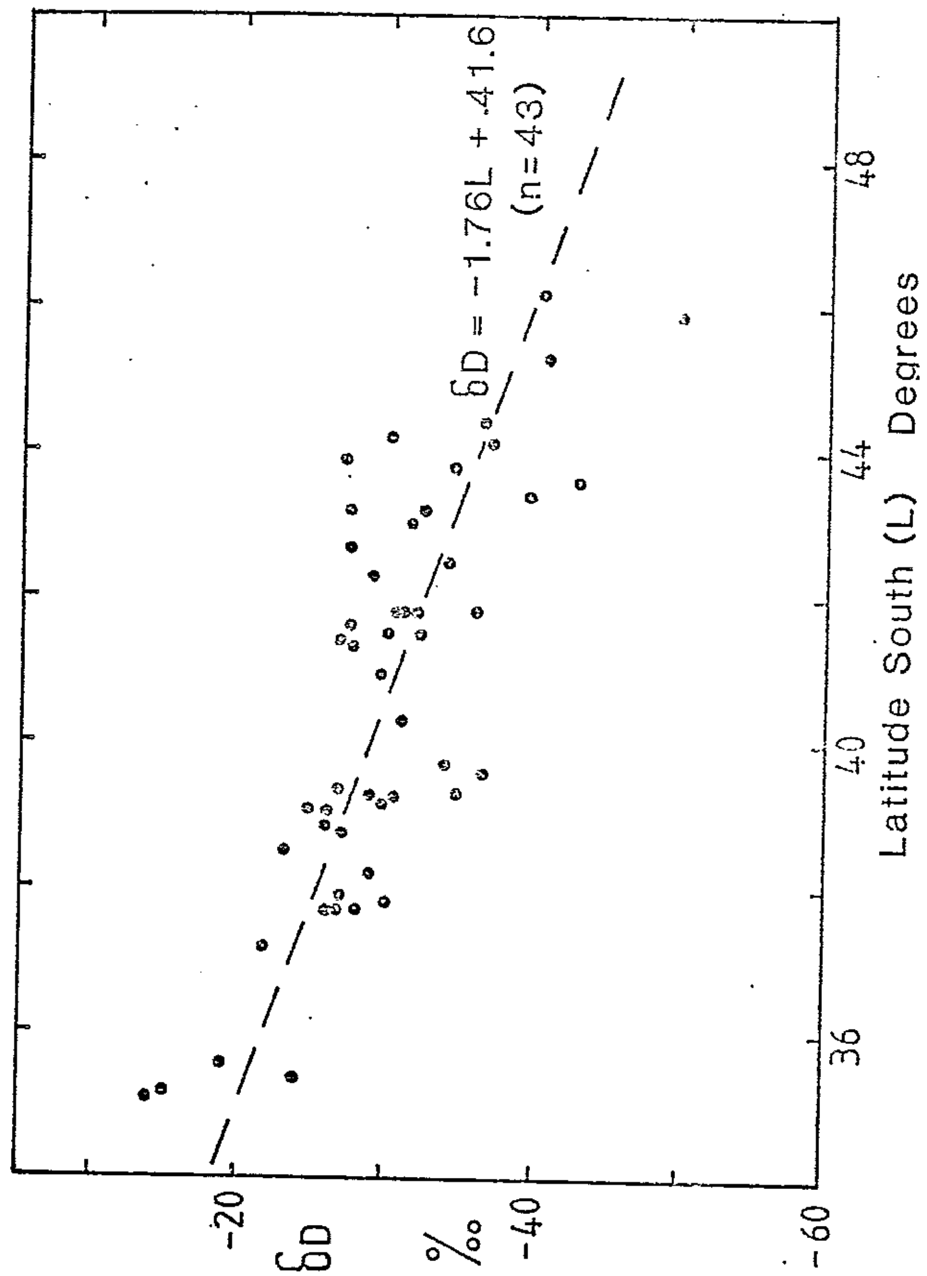

Fig. 7: δD values of rivers and streams plotted against the mean latitudes of the catchments for westerly zones of New Zealand. The δD values have been extrapolated to zero altitude (sea level) using equation (3) to eliminate effects due to altitude variations.

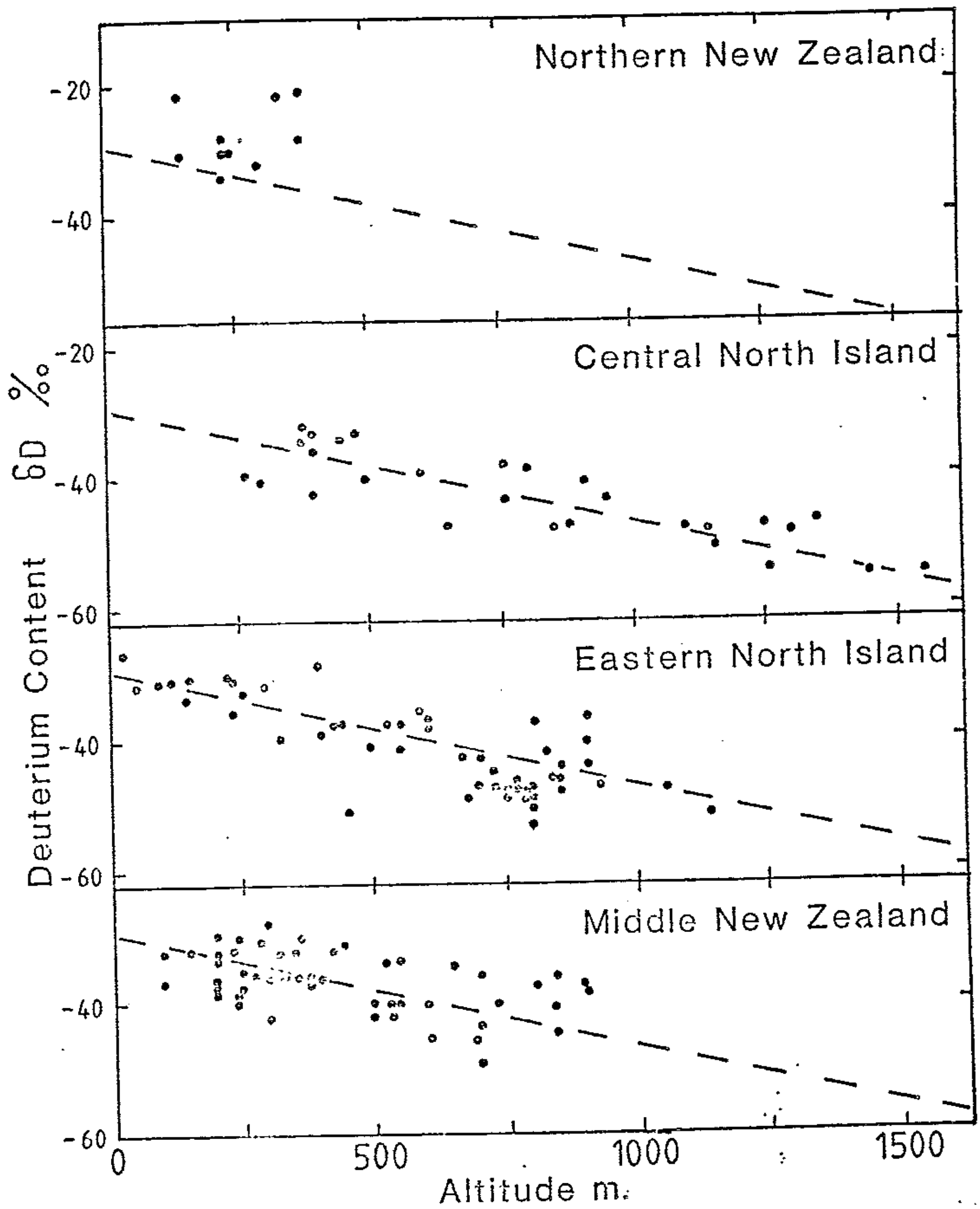

Fig. 8: δD values of rivers and streams plotted against estimated altitudes for different climatic zones in the North Island.

The time of sampling (e.g. whether sampling was carried out in summer or winter) can also influence the δD values since we wish to derive relationships valid for mean δD values. This is discussed for each individual zone along with the influence of the climatic character or more exactly the extent of the rainout effect for eastern zones. The Northern New Zealand zone is dominated by westerlies and has marked sub-tropical influences. The δD values measured range from -20 to -35‰ and, as can be seen in Fig. 8, lie above the δD-altitude line derived from Fig. 5 (i.e. equation (3)). This is mainly due to the latitude effect discussed above. However, the most northern samples were collected in summer (January) and are probably enriched in deuterium by a few permil (‰) for this reason.

The Central North Island zone is generally open to westerlies. The river δD values range from about -32‰ at low altitudes in the west and north to -45 to -55‰ at high altitudes in the south. The southern samples were collected in late August and early September, probably before significant snow melting had taken place, and are probably not very different from the mean annual δD values. The northern samples were from autumn (March and April). The samples show very good agreement with equation (3) (Fig. 8); the mountainous situation of this zone causing the wide δD variation.

The heterogeneous Eastern North Island zone is dominated by easterlies with some sub-tropical influences and shows a range of -27 to -53‰ in δD. Sampling was carried out during autumn (March to June) from 1972 to 1981, and δD values are likely to be close to mean annual values. Coastal situations in the northern part have δD about -30‰, while the headwaters in the ranges have about -45 to -50‰. Data are sparse in the Wairarapa region, but values are likely to be equal to or more negative than -35‰ depending on altitude. The samples plot near equation (3), but a number plot below the line (especially a group close to δD = -48‰, h = 750 m) and may indicate a rainout effect, similar to but less pronounced than the effect in the South Island.

In the Middle New Zealand zone, which extends down to northern parts of the South Island, δD values of low-altitude streams were about -30‰ north of Taranaki, -30 to -43‰ for streams draining Mt Egmont, and

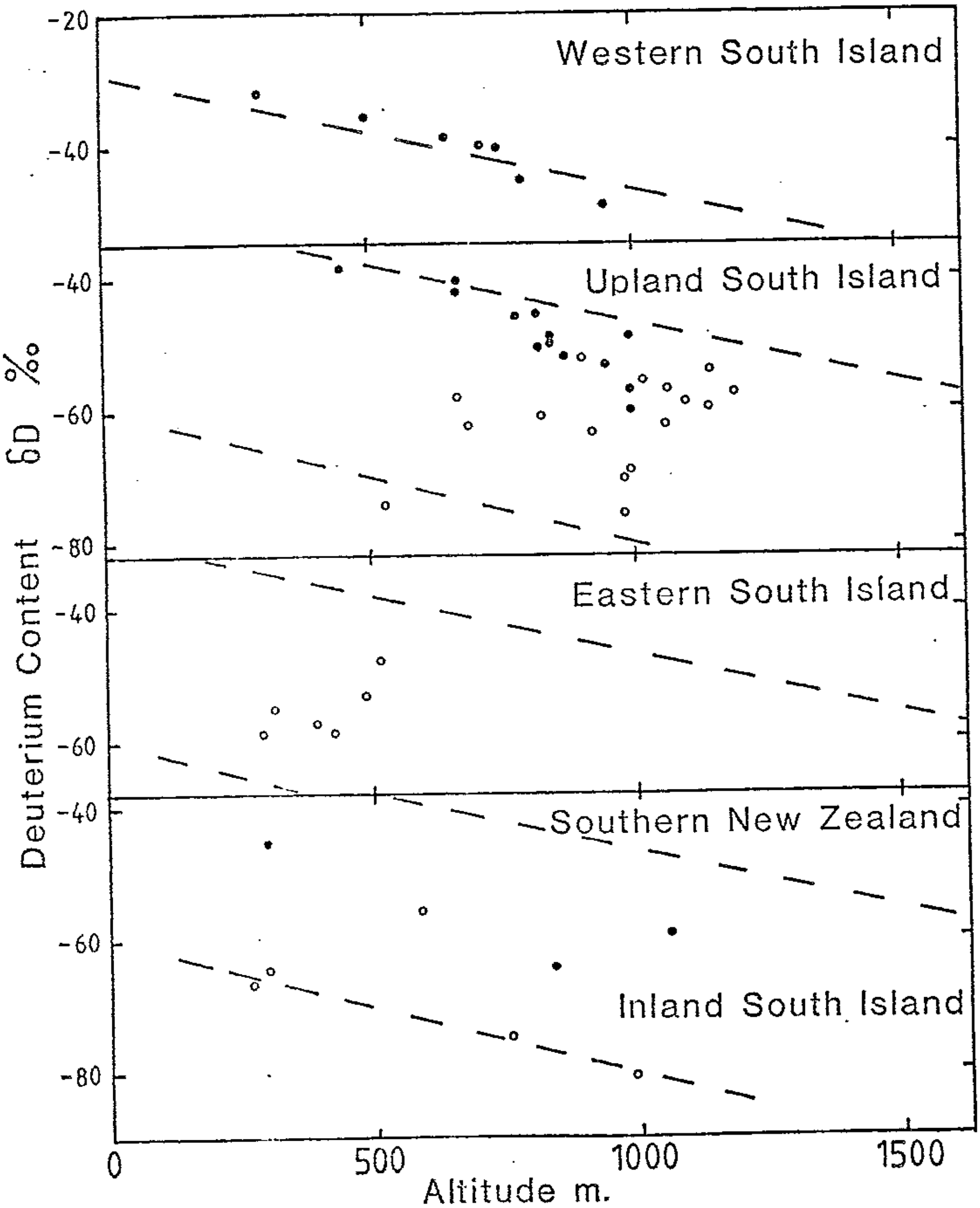

Fig. 9: δD values of rivers and streams plotted against estimated altitudes for different climatic zones in the South Island. (Black dots are used for westerly zones (Western South Island, westerly-draining rivers from the Upland South Island, and Southern New Zealand).)

about -35‰ south of Taranaki and in the South Island. This zone is exposed to westerly influence and some sub-tropical effects, and shows moderate climatic diversity. The samples plot near equation (3), although with considerable scatter. Although sampling was mainly carried out in late winter in 1974, there does not appear to be much indication that the samples have lower δD values than expected for the mean values.

Western South Island streams have δD values ranging from -30 to -50‰, depending on catchment altitude. Sampling was carried out in summer and the δD values are probably higher (less negative) than the mean values. There is high rainfall in this region dominated by westerlies because of the mountains to the east. The samples plot slightly above equation (3) in Fig. 9.

Upland South Island has diverse climate types because of the high mountains. The samples show a gradation in Fig. 9 between westward-draining rivers (solid circles) and eastward-draining rivers (open circles). The westward-draining rivers were sampled in summer and may be enriched in D compared with the means. They plot on or just below equation (3) showing influence of westerly air flow. The eastward rivers were sampled in autumn and are probably close to their mean values. They range from just below equation (3) to a long way below (Fig. 9). The data show an inverse altitude effect, i.e. δD values become more negative with decreasing altitude. This could result from the rainout effect, with δD decreasing with increasing distance eastwards from the high-altitude divide.

The latter pattern is also shown by some rivers in the Eastern South Island zone (Fig. 9). This and Inland South Island are sheltered from westerlies and have low rainfall, but Eastern South Island receives more easterly precipitation. Both are affected by sub-Antarctic influences. δD values measured ranged from -45 to -60‰ in Eastern South Island and -55 to -81‰ in Inland South Island, which had the lowest δD values measured. Some of the δD values are mean values based on several years of monthly sampling, while others are summer or winter samplings. All samples show low δD values compared with their altitudes due to the rainout effect. A line is drawn through the relatively most negative δD values. This has the same slope as equation (3) and the two lines encompass all of the Eastern South Island points.

Three δD values from the Southern New Zealand zone were sampled during summer. The zone has dominant westerlies with sub-Antarctic influences. The points plot below equation (3) in Fig. 9, mainly because of the latitüde effect. Eglington River in the west and Tokomariro River near the coast are probably not affected by the rainout effect, while the Mataura River probably is.

Deuterium in New Zealand precipitation

The source of rivers is of course precipitation and the river δD values can be used to determine the distribution of deuterium in precipitation. However, the "centre of run-off generation" needs to be determined for each catchment. The most desirable samples for this purpose are those from small streams, where the source of the water is nearby rainfall, or from the head waters of large streams. In addition, rivers have an averaging effect so that the highs and lows of deuterium content within a single catchment can be lost. To overcome these deficiencies, the river δD data need to be supplemented by δD measurements on precipitation (averaged over a year of sampling) and on groundwaters, where it is known that the groundwaters derive from local precipitation and not from rivers, lakes, etc. A more detailed evaluation of the deuterium distribution of precipitation will be given elsewhere, but the present data have been used to derive approximate contours of constant deuterium content in New Zealand precipitation. These are given in Fig. 10.

The significant points of these contours are the similarities to the climatic patterns of Fig. 1, the influence of the uplands of both islands in producing low δD values and the latitude effect with high δD values to the north and low δD to the south, all of which are attributable principally to the effect of condensation temperature on the δD of precipitation. In addition, the rainout effect causes relatively low δD values east of the uplands.

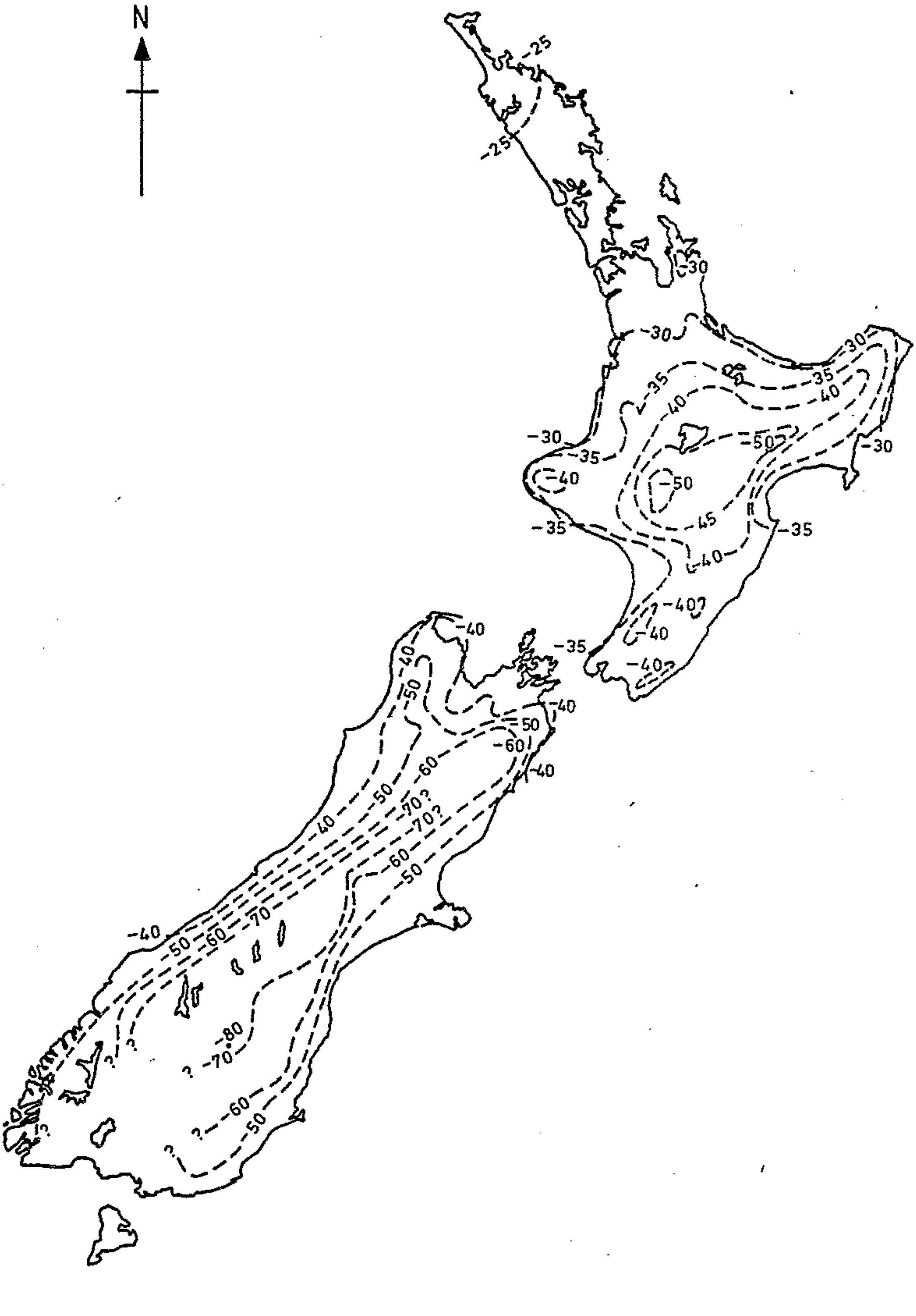

Fig. 10: δD values of New Zealand precipitation. Contours of equal deuterium content are shown.

SUMMARY

A large number of deuterium measurements on New Zealand rivers and streams has been presented.

The nature of the δD variation in rivers with time was investigated by sampling from a number of representative rivers at monthly intervals over periods of several years. The variations observed were - (1) irregular fluctuations when there were high river flows from individual storms or spring snow-melt episodes; (2) seasonal variations deriving from the temperature differences between summer and winter. In lake-fed rivers these were small (∿1‰), whereas rivers with significant snow-melt in spring had variations of 8-10‰. Average values were about 5‰. (3) Longer-term variations in the annual means. The Waimakariri River showed a maximum range of its annual mean δD value of about 8‰, and the variations appear to relate to climatic variables. If the climate changes in the future (perhaps because of the atmospheric "greenhouse" effect), we will be able to compare future δD values with the present ones.

The geographic variation of the δD values was investigated with samples from a large number of rivers and streams. The δD values vary with altitude, latitude and climatic character of the catchments. Equations have been derived for the effect of altitude and latitude on the δD values for areas exposed to the dominant westerlies. These will be compared with theoretical equations in a future work. Contours of δD values in New Zealand precipitation are also given.

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Table 1: δD values of the Waikato River sampled at the lake outlet, upstream of Broadlands geothermal area and downstream of Broadlands geothermal area.

Date collected	Lake outlet δD °/oo	Upstream Broadlands δD °/oo	Downstream Broadlands δD °/oo
10/ 5/73	-31.5	-31.9	-31.9
14/ 6/73	-31.9	-33.4	-33.2
12/ 7/73	-32.2	-32.8	-33.3
14/ 8/73	-31.2	-32.5	-33.1
15/ 9/73	-32.9	-33.4	-32.5
17/10/73	-33.0	-32.8	-32.0
15/11/73	-31.5	-32.2	-32.7
15/12/73	-31.3	-31.7	-33.1
11/ 1/74	-30.8	-31.9	-30.9
16/ 2/74	-30.5	-31.0	-29.3
14/ 3/74	-30.4	-32.5	-31.8
19/ 4/74	-31.2	-33.6	-33.6
Mean	-31.5	-32.5	-32.3
s.d.*	±0.8	±0.7	±1.2
15/ 5/74	-31.0	-32.2	-32.4
14/ 6/74	-29.9	-33.9	-33.0
16/ 7/74	-30.3	-32.1	-32.6
14/ 8/74	-33.0	-36.1	-35.1
13/ 9/74	-32.0	-32.3	-33.5
12/10/74	-36.3	-35.2	-35.7
9/11/74	-32.6	-34.7	-33.5
14/12/74	-32.0	-34.2	-32.3
13/ 1/75	-33.0	-36.0	-34.5
15/ 2/75	-32.9	-33.9	-33.9
21/ 3/75	-32.8	-37.4	-30.4
15/ 4/75	-32.4	-29.4	-30.8
Mean	-32.3	-33.9	-33.1
s.d.*	±1.6	±2.2	±1.6

*s.d. stands for sample standard deviation

Table 2: δD values of Kaitoke rainfall and Hutt River at Kaitoke.

Date collected	Kaitoke rainfall mm	Kaitoke rainfall δD ‰	δD of Hutt River at Kaitoke (‰) 1971-72	1979	1980	1981
	← 1972 →					
1 Jan.	130	-41.6	-32.4	-39.1	-36.2	-34.6
1 Feb.	123	-29.1	-33.0	-38.9	-36.3	-38.1
1 Mar.	81	-37.2	-32.5	-	-34.9	-34.4
1 Apr.	100	-65.1	-34.1	-38.5	-34.4	-33.0
1 May	186	-16.9	-33.1	-43.2	-37.8	-
1 June	275	-42.9	-34.8	-39.4	-37.0	-37.6
1 July	84	-31.5	-34.0	-43.2	-45.7	-37.7
1 Aug.	301	-38.1	-35.4	-40.5	-43.0	-41.5
1 Sept.	153	-49.9	-37.5	-41.3	-37.4	-39.3
	← 1971 →					
1 Oct.	182	-31.3	-34.2	-36.7	-37.3	-36.6
1 Nov.	425	-40.6	-34.9	-37.9	-36.5	-36.7
1 Dec.	115	-50.2	-34.9	-36.2	-33.4	-41.0
Mean	2155 (Total)	-38.9*	-34.2 ±1.4	-39.5 ±2.3	-37.5 ±3.5	-37.3 ±2.7

*weighted mean

Table 3: δD values of Pupu Springs rainfall, Hodgkinson's well water, Ironstone Creek and the Takaka River. (The δD values were converted from $\delta^{18}O$ measurements using equation (see text).

Date collected	Pupu Springs rainfall mm	Pupu Springs rainfall δD ‰	Hodgkinson's Well δD ‰	Ironstone Creek δD ‰	Takaka River δD ‰
1976					
5/2	531	-39.0	-36.0	-47.3	-53.2
10/3	29	-19.0	-36.0	-47.2	-52.4
8/4	233	-56.3	-36.8	-47.0	-53.4
5/5	173	-24.4	-36.0	-47.8	-55.8
4/6	187	-12.9	-35.8	-45.4	-53.6
1/7	200	-41.6	-35.8	-47.6	-56.6
29/7	184	-42.6	-35.6	-53.8	-58.2
26/8	291	-50.6	-36.8	-51.5	-63.1
23/9	121	-33.6	-38.0	-48.7	-63.0
21/10	264	-31.0	-36.0	-49.6	-59.2
19/11	106	+ 0.9	-34.8	-46.9	-58.3
16/12	411	-25.2	-37.4	-48.6	-55.8
Mean	2730	-34.6*	-36.3	-48.5	-56.9
s.d.	(Total)		±0.9	±2.3	±3.6
1977					
13/1	185	- 6.8	-37.5	-47.2	-54.7
10/2	68	-15.6	-36.0	-48.4	-54.1
10/3	128	-25.8	-36.0	-47.2	-52.7
6/4	65	-12.0	-	-46.9	-50.7
5/5	115	-36.6	-36.4	-46.5	-50.0
1/6	143	-53.7	-35.4	-48.0	-54.5
1/7	251	-59.8	-36.9	-54.3	-69.0
28/7	226	-39.1	-38.0	-57.9	-66.3
24/8	240	-39.4	-39.2	-53.2	-62.2
27/9	158	-40.6	-37.4	-50.4	-62.4
28/10	234	-43.8	-35.4	-49.2	-60.1
25/11	227	-28.8	-38.7	-48.4	-53.4
22/12	169	-22.2	-36.4	-48.1	-50.8
Mean	2178	-36.1*	-36.9	-49.7	-57.0
s.d.	(Total)		±1.2	±3.4	±6.3
1978					
26/1	31	-15.3	-36.7	-48.8	-51.4
23/2	25	-18.0	-37.0	-48.0	-50.1
23/3	39	-14.4	-37.5	-48.8	-48.3
20/4	167	-35.2	-37.1	-49.8	-56.7
18/5	346	-32.6	-38.0	-51.5	-57.2
15/6	156	-31.2	-39.6	-50.1	-56.6
13/7	343	-65.1	-36.6	-52.7	-64.0
10/8	111	-42.2	-35.3	-48.8	-59.2
7/9	186	-33.2	-37.3	-50.0	-61.1
5/10	222	-26.3	-39.3	-50.4	-61.7
2/11	193	-34.8	-37.5	-52.4	-57.8
29/11	141	-24.1	-38.0	-50.3	-56.0
21/12	78	-33.6	-36.2	-48.4	-56.4
Mean	2037	-36.9*	-37.4	-50.0	-56.7
s.d.	(Total)		±1.2	±15.	±4.5

*weighted means

Table 4: δD values of the Waimakariri River sampled at the old highway bridge during 1977-81. (The δD values were converted from $\delta^{18}O$ measurements using equation (1) (see text).)

Month collected	1977-78	1978-79	1979-80	1980-81
September	-65.5	-71.8	-68.0	-61.5
October	-65.7	-66.0	-64.1	-58.6
November	-62.8	-64.0	-59.0	-57.9
December	-62.0	-64.5	-59.1	-60.5
January	-61.3	-62.0	-61.4	-61.2
February	-60.7	-61.3	-56.4	-57.3
March	-59.0	-58.2	-59.0	-57.7
April	-59.8	-63.5	-60.6	-58.3
May	-63.2	-60.8	-63.1	-60.8
June	-65.6	-66.7	-63.9	-61.9
July	-66.8	-67.9	-63.6	-63.0
August	-67.3	-68.3	-62.6	-62.7
Mean	-63.3	-64.0	-61.7	-60.1
s.d.	±2.8	±4.0	±3.1	±2.0

Table 5: δD values of Clutha River sampled at Clyde, the Shotover River at Bowen's Peak and the Manuherikia River at Ophir.

Month collected	Clutha River 1974	Clutha River 1975	Shotover River 1974	Shotover River 1975	Manuherikia River 1974	Manuherikia River 1975
January	-63.0	-64.9	-76.6	-80.1	-79.0	-78.8
February	-	-	-	-74.3	-	-78.8
March	-64.2	-63.1	-75.0	-76.1	-81.5	-78.5
April	-65.0	-64.3	-74.4	-72.0	-82.3	-81.7
May	-64.5	-64.1	-74.9	-75.0	-82.5	-81.7
June	-64.9	-66.3	-78.3	-71.1	-83.5	-76.7
July	-65.6	-66.1	-71.7	-75.5	-81.8	-83.1
August	-65.5	-64.5	-78.2	-74.9	-78.5	-81.2
September	-66.9	-67.1	-76.8	-74.2	-79.8	-82.0
October	-70.0	-65.8	-89.2	-76.1	-102.5	-81.4
November	-65.4	-62.7	-82.9	-69.4	-84.4	-83.8
December	-65.8	-64.1	-67.7	-71.6	-84.0	-81.5
Mean	-65.4	-64.8	-76.8	-74.2	-83.3	-80.7
s.d.	±1.8	±1.3	±5.4	±2.8	±6.3	±2.1

Table 6: Mean monthly δD values of some New Zealand rivers.

Month collected	Waikato River 1973-75	Hutt River 1973-75	Ironstone Creek 1976-78	Takaka River 1976-78	Waimakakariri River 1977-81	Manuherikia River 1973-76
January	-32.7	-36.6	-48.0	-53.1	-61.5	-78.9
February	-31.6	-37.8	-48.2	-52.5	-58.9	-78.8
March	-31.1	-34.7	-47.7	-51.1	-58.5	-80.0
April	-32.2	-35.3	-47.9	-53.6	-60.5	-82.0
May	-32.1	-40.5	-48.6	-54.3	-62.0	-82.1
June	-33.1	-38.0	-47.8	-54.9	-64.5	-80.1
July	-33.0	-42.2	-51.5	-63.2	-65.3	-82.4
August	-34.1	-41.7	-53.5	-61.2	-65.2	-79.9
September	-33.0	-39.3	-51.6	-62.1	-66.7	-80.9
October	-33.8	-36.9	-49.8	-62.4	-63.6	-92.0
November	-33.1	-37.0	-50.4	-59.0	-60.9	-84.1
December	-32.7	-36.9	-48.5	-55.9	-61.5	-82.8
			-48.4*	-54.3*		

*samples collected four weekly, therefore 13 samples per year

Table 7: Mean annual δD values of New Zealand rivers.

	1972	1973	1974	1975	1976	1977	1978	1979	1980	1981
Lake Taupo		-31.5*	-32.3*							
Waikato River		-32.3*	-33.1*							
Hutt River	-34.2+							-39.5	-37.5	-37.3
Takaka rainfall					-34.6	-36.1	-36.9			
Ironstone Creek					-48.5	-49.7	-50.0			
Takaka River					-56.9	-57.0	-56.7			
Waimakariri River	←1970-1973→ -54 to -61						-63.3†	-64.0†	-61.7†	-60.1†
Clutha River			-65.4	-64.8						
Shotover River			-76.8	-74.2						
Manuherikia River			-83.3	-80.7						

* samples collected from May 1973 to April 1974

\+ " " " 1 October 1971 to 1 September 1972

† " " " September 1977 to August 1981

Table 8: δD values of rivers and streams in the North Island, New Zealand

R no.	Date collected	Location of sampling (Map ref)	Catchment altitude (m) (mean)	Sample description	δD ‰
Eastern North Island					
4086/1	30/8/71	N160/455319	610	Hutt River	-36.8
9202/1	19/11/80	N161/940323	810	Ruamahanga R, Martinborough	-37.3
/2	"	N161/872394	560	Tauherenikau R, Featherston	-37.5
4236/1	30/ 3/72	N161/995498	910	Waihone River	-36.9
/2	"	N158/100612	910	Waingawa River	-40.5
/17	"	N140/824802	330	Tukipo River	-39.8
/16	"	N140/797858	910	Tukituki River	-44.0
/15	"	N141/150875	830	Tukituki River	-41.8
/18	"	N140/884944	860	Waipawa River	-44.2
/19	"	N141/926018	500	Mangamauku Stream	-41.0
/20	"	N134/185275	730	Ngaruroro River	-47.3
4458	22/2/73	N134/138265	730	Ngaruroro River	-45.2
4236/21	30/3/72	N134/255322	710	Tutuakuri River	-43.1
/22	"	N134/297510	560	Esk River	-41.7
9101/4	1/6/80	N113/848794	1060	Mohaka River	-47.4
/3	"	N113/856784	1140	Makino Stream	-51.7
4236/26	31/3/72	N115/543892	670	Mohaka River	-43.1
/42	"	N114/000982	760	Waipunga River	-43.1
/34	"	N105/660078	610	Waiau River	-38.3
5885/10	24/4/79	N105/422215	760	Waitehetehe Stream	-47.9
/11	"	N105/443232	860	Whakenepuru Stream	-47.5
/12	"	N105/472232	800	Paengarua Stream	-49.2
/8	"	N105/411233	800	Te Korokoroowhaitiri Tributary Stream	-52.9
/9	"	N105/410234	800	Te Korokoroowhaitiri Stream	-50.3
/13	"	N105/478242	700	Stream close to Te Umutiti	-47.2
/7	"	N105/412273	760	Maraunui Stream	-49.1
/6	"	N105/418278	680	Marauiti Stream	-49.0
/5	"	N105/465299	790	Waapu Stream	-48.0
/2	"	N105/547292	770	Stream in Te Whero Bay	-46.8
/1	"	N105/580293	840	Aniwaniwa Stream	-45.9
/3	"	N96 /515314	790	Inlet stream to Mokauawa Bay	-48.2
/4	"	N96 /486338	940	Rahuiatemata Stream	-47.2
4236/33	31/3/72	N106/827050	530	Wairoa River	-37.6
9243/3	6/2/81	N106/203262	260	Te Arai River	-33.0
9324/3	17/5/81	N98 /455364	60	Hamanatu Stream	-31.7
9243/8	6/2/81	N98 /428383	160	Waimata River	-30.4
/4	"	N98 /277431	240	Whakaohu Stream	-36.0
/6	"	N98 /299453	430	Waiapaoa River	-37.7
/7	"	N98 /336453	150	Tawheru Stream	-33.9
9324/5	17/5/81	N98 /608556	30	Mangakari Stream	-27.0
9243/5	6/2/81	N89 /253615	440	Waipaoa River	-37.6
9324/7	17/5/81	N89 /656815	100	Mangatuna River	-31.1
/8	"	N80 /647970	120	Makokomuka Stream	-30.7
/9	"	N80 /683107	240	Makairika Stream	-30.8
/13	"	N71 /646206	300	Kapuaroa Stream	-31.8
/12	"	N71 /688302	600	Waiapu River	-35.8
/11	"	N63/748564	400	Awatere River	-28.7
/10	"	N63 /737624	240	Karakatuwhero River	-30.5

R no.	Date collected	Location of sampling (Map ref)	Catchment altitude (m) (mean)	Sample description	δD ‰
Middle New Zealand					
4827/9	7/9/74	N157/672847	700	Otaki River	-36.0
/10	"	N152/760968	550	Ohau River	-33.7
/1	4/8/74	N152/794173	500	Manawatu River	-40.0
4086/3	30/8/74	N143/896554	100	Stream, Rangitikei River	-32.7
4827/55	11/9/74	N137/468968	300	Kai Iwi Stream	-42.9
/51	"	N129/944215	200	Manawapau River	-37.8
/44	10/9/74	N129/827277	100	Waihi Stream	-37.0
/49	"	N129/734345	500	Kapuni Stream	-42.3
/14	7/9/74	N131/836217	700	Hapokopoku Stream	-49.3
/50	11/9/74	N129/915251	200	Tangahoe River	-37.2
/47	10/9/74	N128/545346	200	Oea Stream	-37.9
/53	11/9/74	N129/117033	490	Patea River	-35.5
/52	"	N137/105067	240	Whenurakura River	-40.2
/46	10/9/74	N129/657326	700	Kaupokonui Stream	-43.8
/43	"	N119/868449	240	Stream, S Eltham	-38.9
/42	"	N119/855575	600	Patea River	-40.3
/54	11/9/74	N137/285016	250	Waitotora River	-37.6
/34	8/9/74	N118/402576	200	Pungaerere Stream	-32.3
/33	"	N118/402642	530	Kapoaiata Stream	-40.3
/41	10/9/74	N119/833649	900	Manganui River	-38.7
/45	"	N129/788288	330	Waingangaro River	-36.2
/32	8/9/74	N108/410707	400	Waiweranui Stream	-36.2
/31	"	N108/462757	280	Kaihihi Stream	-30.9
/36	"	N108/543849	420	Oakura River	-32.2
/35	"	N108/508796	360	Timaru Stream	-29.8
/30	"	N109/682926	640	Waiwhakaiho River	-34.5
/37	9/9/74	N109/755959	240	Mangaoraka Stream	-30.1
/39	"	N109/713815	840	Waiwhakaiho River	-36.0
/38	"	N109/763802	320	Waiongana Stream	-35.9
/40	10/9/74	N109/780745	360	Waitepuku Stream	-36.3
/29	8/9/74	N109/832921	250	Waitara River	-35.3
/2	24/8/74	N110/960340	350	Stream, Tahora	-32.5
/28	8/9/74	N99 /037044	200	Mimi River	-29.4
/27	"	N100/179156	300	Tongaporutu River	-27.4
/26	"	N100/165224	200	Mangahutiwai Stream	-32.6
/3	24/8/74	N100/508191	320	Waitewhenua Stream	-32.9
/18	7/9/74	N101/816140	800	Wanganui River	-37.6
/19	"	N101/769139	730	Ongarue River	-40.1
/24	8/9/74	N91 /373508	440	Awakino River	-31.1
/25	"	N91 /192353	270	Mokau River	-35.8
/21	7/9/74	N83 /627707	400	Mokau River	-36.3
/23	8/9/74	N83 /621895	150	Waitomo River	-31.7
/22	7/9/74	N74 /721978	380	Waipa River	-37.2
Central North Island					
4086/2	30/8/74	N143/896554	650	Rangitikei River	-47.8
/4	"	N132/195306	850	Hautapu Stream	-48.4
4827/11	7/9/74	N143/689777	1260	Whangaehu River	-54.2
/13	"	N138/784039	1140	Mangawhero River	-48.5
/15	"	N121/795485	1300	Makotuku River	-48.8
4086/5	30/8/74	N122/073435	1550	Whangaehu River	-54.9
4827/16	7/9/74	N121/897628	1450	Mangaturuturi River	-55.0

R no.	Date collected	Location of sampling (Map ref)	Catchment altitude (m) (mean)	Sample description	δD ‰
4086/6	30/8/71	N112/262743	1100	Tongariro River	-47.7
4126/2	31/10/71	N122/229657	1250	Waikato Stream	-47.3
4086/7	30/8/71	N112/222734	1160	Waihohonu Stream	-50.6
/29	1/9/71	N112/037755	1350	Whakapapanui River	-46.6
/27	1/9/71	N112/260978	800	Pihanga Reserve	-38.9
/28	1/9/71	N112/080930	930	Wanganui River	-40.7
/8	30/8/71	N102/302016	950	Tongariro River	-43.4
/23	1/9/71	N102/302013	880	Tongariro River	-47.7
4827/20	7/9/74	N101/758170	600	Taringamotu River	-39.3
5614/60	March'78	N85 /755620	300	Waiotapu River	-40.6
/58	"	N85 /790655	270	Waiotapu River	-39.7
/52	"	N85 /852798	400	Waikekamuka Stream	-42.7
/50	"	N85 /835817	500	Hakatere Stream	-40.1
2742/1	11/4/70	N76 /710052	400	Utuhina Stream	-33.4
2735/1	"	N76 /776059	400	Waingaehu Stream	-36.3
2740	"	N76 /683109	380	Ngongotaha Stream	-32.5
2739	"	N76 /679122	450	Waiteti Stream	-34.2
4364/10	"	N76 /728167	380	Hamuranu Stream	-34.8
2737	"	N76 /685149	480	Awahou Stream	-33.5
4236/41	2/4/72	N103/827141	760	Rangitaiki River	-43.7
/38	"	N96 /356418	760	Whakatane River	-38.4

<u>Northern New Zealand</u>

R no.	Date collected	Location of sampling (Map ref)	Catchment altitude (m) (mean)	Sample description	δD ‰
9004	2/11/79	N58/456423	300	Kaukumautiti Stream	-32.4
"	"	N58/573590	240	Wairoa River	-30.3
"	"	N58/516595	240	Te Puna	-30.3
4827/7	30/8/74	N56/657617	230	Waipa River	-34.3
/6	"	N56/652603	150	Mangaohe Stream	-30.9
4740/1	20/1/74	N49/-	380	Kauaerangi River	-28.3
/5	"	N14/-	150	Waima River	-21.9
/4	"	N11/469578	230	Kerikeri Domain	-28.2
/3	"	N16/010590	340	Mangamuka River	-21.2
/2	"	N9 /73-64-	380	Pukepoto Stream	-20.5

Table 9: δD values of rivers and streams from the South Island of New Zealand

R no.	Date collected	Location of sampling (Map ref.)	Catchment altitude (m) (mean)	Sample description	δD‰
Eastern North Island (Top NE of SI)					
5541/1	30/11/77	S28/217919	670	Taylor River	-51.2
4496/9	11/ 4/73	S43/265393	410	Kekerengu River	-39.2
Middle New Zealand					
4408/4	1976-1978	S8/208776	1100	Takaka River	-57.0 (Av)
/1	4/12/72	S8/207791	840	Waingaro River	-44.8
/7	6/12/72	S8/195798	840	Anatoki River	-40.8
4166/1	27/12/71	S13/125391	610	Graham River	-45.8
4498/3	4/ 4/73	S20/409139	530	Wai-iti River	-42.0
/1	4/ 4/73	S20/492138	530	Wairoa River	-40.2
4171/3	4/ 1/72	S20/671274	380	Maitai River	-36.5
4520/1	10/ 4/73	S16/790354	230	Whangamoa River	-31.8
/2	10/ 4/73	S21/897290	840	Pelorus River	-37.1
4520/3	10/ 4/73	S21/988264	520	Wakamarina River	-33.9
Upland South Island					
4715/6	14/1/74	S12/577324	460†	Karamea River	-38.7
/7	"	S24/088713	780†	Buller River	-46.0
/1	"	S26/005782	990†	"	-49.0
/3	"	S31/255593	820†	"	-45.8
/2	"	S32/704692	820†	"	-50.7
4271/2	24/ 4/72	S33/176489	1190	Hopeless Creek	-57.8
4507	11/ 4/73	S21/102026	1140	Wairau River	-54.3
9239/1	8/12/80	S28/725677	1130	"	-59.6
5541/2	1/12/77	S28/037976	920	Waihopa River	-63.8
4615/2	18/ 9/73	S42/177204	990	Clarence River	-69.3
4496/8	11/ 4/73	S29/348807	820	Awatere River	-61.0
/7	11/ 4/73	S49/000025	900	Hapuku River	-52.1
/3	12/ 4/73	S49/919899	1021	Kowhai River	-55.9
2829/1	10/ 6/70	S54/179772	670	Chatterton River	-58.3
4715/8	14/ 1/74	S44/745885	670	Grey River	-40.8
4358/1	2/ 9/72	S45/401990	840	Upper Grey River	-49.0
4171/4	10/ 1/72	S76/902700	1065	Waimakariri River	-57.2
4518/7	14/ 4/73	S76/015703	1065	"	-57.0
4715/13	14/ 1/74	S71/027860	990*	Whataroa River	-57.0
4169/1	30/12/71	S83/473306	1100*	Rakaia River	-59.0
4715/4	14/ 1/74	S71/832727	690	Waiho River	-62.9
4518/9	14/ 4/73	S84/054532	90	Heathcote River	-47.7
4550/8	5/ 6/73	S92/208107	980*	Ashburton River	-75.8
/9	5/ 6/73	S102/918937	980	Rangitata River	-70.4
/10	5/ 6/73	S102/798945	530*	Orari River	-74.3
4715/15	14/ 1/74	S78/643594	990*	Cook River	-60.4
/16	"	S78/228378	840*	Paringa River	-49.3
/20	"	S87/843140	870*	Haast River	-52.4
/19	"	S87/628973	670	Waitoto River	-42.0
/18	"	S97/567903	950	Arawata River	-53.3

R no.	Date collected	Location of sampling (Map ref.)	Catchment altitude (m) (mean)	Sample description	δD‰
Western South Island					
4715/5	14/1/74	S17/525185	300	Little Wanganui	-32.2
/4	"	S23/425998	500	Mokohinui River	-35.5
/9	"	S50/885505	650	Taramakau River	-39.0
/10	"	S51/552520	790	Hokitika River	-45.9
/11	"	S57/272233	950	Big Waitaha	-49.2
/12	"	S64/220020	720†	Wanganui River	-40.2
/17	"	S77/033316	750†	Moeraki River	-40.3
Eastern South Island					
4171/5	10/ 1/72	S68/066965	400	Kowai River	-57.3
5240/24	30/ 6/76	S75/483679	430	Hawkins River	-59.0
/25	29/ 6/76	S74/446632	320	Waireka River	-55.0
5505	1977-1978	S74/406621	290	Selwyn River	-59.0(Av)
5240/26	30/ 6/76	S82/389561	490	Horata River	-53.2
-	1970-1973	S84/986400	520	Rhodes Spring	-48.0(Av)
Inland South Island					
-	1973-1976	S133/123530	300†	Clutha River	-65.1(Av)
-	1973-1976	S132/560754	760	Shotover River	-75.1(Av)
-	1973-1976	S134/356628	990†	Manuherikia River	-81.2(Av)
4169/7	12/ 1/72	S128/656864	270†	Waitaki River	-67.4
/2	30/12/71	S172/867582	590	Taieri River	-56.4
Southern New Zealand					
4169/6	4/ 1/72	S130/835516	1060†	Eglington River	-59.4
/3	30/12/71	S172/693403	300†	Tokomariro River	-45.6
/5	3/ 1/72	S171/843415	840†	Mataura River	-64.7

† Partially lake fed
* Partially glacier fed

Table 10: δD values of lakes from the North Island, New Zealand

R no.	Date collected	Location of sampling (Map ref)	Catchment altitude (m) (mean)	Sample description	δD ‰
4086/9	30/8/71	N102/232062	950	Lake Taupo	-33.1
/11	"	N102/306108	950	"	-33.5
/13	"	N102/537377	950	"	-30.9
/14	"	N94 /778583	950	Waikato River	-29.7
/15	"	"	950	"	-34.3
4827/5	30/8/74	N51 /461063	950	Waikato River	-36.4
4086/21	1/9/71	N94 /537377	950	Lake Taupo	-30.5
/24	"	N112/298943	950	Poutu Stream	-36.5
4364/17	21/9/72	N77 /0415	500	Lake Rotoma	-17.3
/2	26/9/72	N76 /8412	600	Lake Rotokawau	-17.6
4418/2	21/12/72	N86 /9189	760	Lake Rotomahana	-21.3
/3	"	N76 /8097	430	Lake Tikitapu	-21.0
/4	"	N76 /7894	450	Lake Rotokakahi	-20.1
/5	"	N76 /8900	300	Lake Tarawera	-20.2

Table 11: δD values of lakes in the South Island, New Zealand

R no.	Date collected	Location of Sampling (Map ref.)	Catchment altitude (m) (mean)	Sample description	δD ‰
4166/2	3/ 1/72	S13/042506	1371	Lake Sylvester	-53.4
/3	"	S13/091507	823	Cobb Reservoir	-48.8
4271/1	24/ 4/72	S33/215635	610	Lake Rotoiti	-52.6
4358/2	2/ 9/72	S101/107985	700	Lake Tekapo	-66.3
/3	"	S108/560690	910	Lake Ohau	-64.0
/4	"	S100/815762	610	Lake Pukaki	-68.6
/5	10/ 9/72	S65/966927	610	Lake Coleridge	-58.9
1943/3	7/ 9/66	S149/680018	300	Lake Manapouri	-50.5
4169/4	3/ 1/72	S149/727105	240	Waiau River, from Lake Te Anau	-48.9
-	1973-1976	S133/123530	370	Clutha River	-65.1