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A SURVEY OF SUBFLOOR GROUND EVAPORATION RATES

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PREFACE

Present building controls for subfloor moisture are based mainly on experience, with little explicit knowledge on the amount of ground water which must be disposed of or how this varies. This investigation, which forms part of BRANZ ongoing work on subfloor moisture problems, was undertaken to improve information on subfloor moisture evaporation rates. The project was carried out principally by Kingston, Reynolds, Thom & Allardice (KRTA) Ltd, Consulting Engineers, Auckland, under contract to the Association. BRANZ acknowledges KRTA Ltd's assistance, in particular that of the principal researcher, Dr J. E. Abbott.

This report is intended for researchers working in the field of moisture related problems in buildings, and designers.

A SURVEY OF SUBFLOOR GROUND EVAPORATION RATES

BRANZ Study Report SR13 H.A. Trethowen

REFERENCE

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ABSTRACT

This report describes the methods and observations of moisture evaporation rates from subfloor soils under New Zealand houses with suspended floors, obtained in surveys 1982-1984. The measurement in a pilot survey used both soil and free-water lysimeters and in the main survey free-water lysimeters only were used. Measurements were taken in (nominally) 20 houses in each of three main centres - Auckland, Wellington, and Christchurch. They showed evaporation rates averaging about 300, 550, and 300 g/m^2 day respectively with no clear seasonal variations.

CONTENTS

	page
INTRODUCTION	1
MOISTURE TRANSFER	2
PILOT SURVEY	3
MAIN SURVEY	4
Method	4
Equipment	5
Procedures	5
Results	6
Discussion	7
CONCLUSIONS	8
REFERENCES	8

FIGURES

		page
Figure 1:	Relative humidity/moisture content curves for a sand and a clay	13
Figure 2:	Field weighing lysimeter (after Atkinson, 1971)	13
Figure 3:	Section of evaporation rate v conditions. Daily variation. Pilot survey	14
Figure 4:	Comparison of soil lysimeter and free-water lysimeter rates, evaporation v moisture, pilot survey	15
Figure 5:	Plan of site locations of cases used, main survey, Auckland	16
Figure 6:	Plan of site locations of cases used, main survey, Wellington	
Figure 7:	Plan of site locations of cases used, main survey, Christchurch	
Figure 8:	Principle of the bird-bath type free-water lysimeter, main survey	17
Figure 9:	Summary of free-water lysimeter evaporation over one year for cases where soil m.c. deemed high enough	18
Figure 10:	Lysimeter evaporation rate and subfloor temperature for one house	19
Figure 11:	Comparison of lysimeter evaporation with vent area	20

TABLES

		page
Table 1:	Free-water lysimeter evaporation rates and moisture content (Auckland)	10
Table 2:	Free-water lysimeter evaporation rates and moisture content (Wellington)	11
Table 3:	Free-water lysimeter evaporation rates and moisture content (Christchurch)	12

INTRODUCTION

This project was set up to determine typical rates of subfloor evaporation rates from the ground under suspended floors in New Zealand. Its primary purpose was to establish some quantitative base of the mean and range of such evaporation and how these varied in short term, seasonally, or regionally.

The work was initiated from the viewpoint that high subfloor moisture is a widespread but not universal problem in this country; that compliance with building codes on subfloor venting is frequently not achieved; and that those codes are based on experience, with little explicit information on how much moisture is released from the subfloor soil nor how this varies with the site and conditions. Subfloor evaporation was perceived as a complex result of three interacting systems; (a) the supply of water to the subfloor ground surface (b) the thermal conditions (temperatures of ground surface, subfloor air, floor, and the perimeter enclosures) and (c) the ventilation (quantity, distribution, and local velocity of subfloor ventilating air).

Whilst present knowledge would allow some progress to be made in examining any one of these topics, combining these into a composite theory would be a massive task with no adequate indication that the results would be reliable. The outcome of these considerations was a decision to cut straight through those difficulties and measure ground evaporation rates directly.

Previous information on evaporation rates is available but only for soils exposed to the weather. Reported evaporation rates range from 700g/m^{2}day (Holmes, Greacen, and Gurr 1960) to 7000 g/m^{2}d. (Rose and Krishnan 1967).

A method for measuring the moisture flow rate across a soil surface has been well established in soil mechanics and horticultural research (Curtis and Trudgill 1974). It uses an extremely simple device called a "lysimeter", essentially a bucket. The principle is that a sample of soil is placed in the bucket which is in turn placed in the soil surface where the sample was taken. The bucket is periodically weighed, and the weight changes indicate what loss (or gain) of moisture has occurred. In practice the method is not easy. Great care must be taken that the soil sample is not internally disturbed, that the physical environment over the lysimeter is not unduly disturbed by the lysimeter, and that the lysimeter exterior is totally cleaned and dried for each weighing.

Because each lysimeter progressively loses water that is not replaced, it has a limited life. A programme of setting up new lysimeters of overlapping age allows very reliable data to be taken. Lysimeters from as small as a drinking-glass up to many cubic meters volume have been successfully used.

A fairly extensive technology of lysimetry and soil surface moisture balance exists (e.g., see Curtis and Trudgill 1974). This knowledge, however, has been developed for horticultural or agricultural purposes and applies only to soils exposed directly to the natural weather. Conditions for subfloor soils are different, and it would be unwise to attempt to extrapolate that knowledge to a condition of zero rain, sunshine, and low or zero wind, and without normal dew or frost-forming influences.

Moisture Transfer

The general flow of water involved in subfloor conditions in normal circumstances clearly originates with rainfall on surrounding soil, migration of some of this water to the subfloor soil, the evaporation of water to the subfloor air, and final disposal by ventilation of the evaporate to outdoors.

Most regions of New Zealand have rainfall around 50-200 mm/month, distributed around the whole year. The moisture in the soil moves by a combination of gravitational, capillary, and vapour flow processes. Each process depends strongly on the soil moisture content and moisture content gradient, on the soil temperatures and temperature gradients, and on the soil nature itself. Without going into detail on these topics, it may be said that moisture movement is more rapid at high moisture content, and that moisture storage capacity in the soil is very large (see, e.g., Transport and Road Research Laboratory,TRRL 1957). Although there are exceptions, subfloor soils in New Zealand are observed to be rather moist. This comment applies to many that appear to be dry - covering a section of subfloor ground with an impervious cover such as a sheet of plastic will usually result within hours or days in the ground underneath showing visible symptoms of moistness.

The evaporation of moisture from a surface to an air space has been well established to be a function of the difference in vapour pressure between the two, and the boundary conditions of air movement and turbulence. Many soils have hygroscopic properties, and the vapour pressure over the soil may differ from that over water. The transfer of moisture from soil to the subfloor air is not confined to the soil surface either. Abbott (1983) has illustrated that some of the evaporation may take place perhaps half a metre down, and diffuse to the surface. This is especially significant in apparently dry soils. The apparent vapour pressure of the moisture in the soil will be a strong function of the soil temperature, and can be expected to change only very slowly. On the other hand, the vapour pressure in the subfloor air can be expected to change very quickly in response to changes in weather conditions, especially temperature, unless the subfloor ventilation is very restricted.

Consequently, one would expect to see strong short term increases in subfloor evaporation rate in response to a sudden drop in outdoor temperature, and vice versa. However, it is not clear whether there would be any such response on a seasonal basis, as soil and air temperature on that time scale would tend to move together. If so, the seasonal changes would not create additional differences in vapour pressure to trigger variation in evaporation rate. However, if there were sufficient phase delay between seasonal warming or cooling of subfloor air and subfloor soil temperatures, there would be a seasonal evaporation rate variation, with the minimum rate in spring and maximum in autumn.

Data in Figure 1 is reproduced from the TRRL handbook, and shows typical sorption curves for sand and clay soils. These follow the classical pattern for hygroscopic materials. By analogy with other materials (e.g., timber) we may describe the knee point where humidity approaches 100 per cent, as the (fibre) saturation point. There are two important implications of this data for the present purposes:

- at "low" moisture contents (less than 6 per cent for sand, 15 per cent for clay) the equilibrium relative humidity and hence apparent vapour pressure is strongly sensitive to the soil type.

- at "high" moisture contents (over 6 per cent for sand, 15 per cent for clay) the equilibrium relative humidity is near 100 per cent and hence apparent vapour pressure is independent of soil type.

This transition is extremely important.

It means that evaporation behaviour can not be considered without detailed information on soil type if the moisture content is low. However at higher moisture content, the soil type becomes irrelevant, and the evaporation behaviour will be indistinguishable from that of free water.

Two further steps are needed before this information can be applied. Firstly it is necessary to establish what the saturation moisture contents are for subfloor soils (if they do indeed differ from those in Figure 1). Secondly, the moisture contents of typical subfloor soils must be determined. Together these will show whether the soil behaviour will be affected by its type. On the former point, comment by the New Zealand Soil Bureau (pers.comm., Gradwell, 1982) indicates that New Zealand clays may have higher saturation moisture content than overseas clays. The presence of organic material or volcanic material raises the saturation moisture content. Thus we may expect that some soils may have sorption curves which are further to the right on Figure 1.

Pilot Survey

A full description of the pilot survey has been given in an unpublished report by Abbott (1983). The essential feature of this work was to establish, for identical subfloor conditions, the relative evaporation rates from four different Auckland soil types and for free water. Each of the soil samples was tested in both short (400 mm) and long (800 mm) lysimeters. The tests were done at a site in Auckland during July to October 1982.

The principal results of the pilot survey are shown in Figure 4. These curves follow the same pattern as that of the TRRL data shown in Figure 1 but some are shifted. The Auckland sand samples indicate a saturation point about 7 per cent moisture content, very similar to the TRRL data.

However the Auckland clay, loam, and topsoil samples all indicate saturation points close to or over 30 per cent moisture content. Auckland, however, is a region with an active volcanic history, and it is not unlikely that it may have soils with a high saturation point.

The reported evaporation rate for clay appears in Figure 4 to exceed that of free water. This is not regarded as a physically real event. It was attributed by Abbott to be largely due to surface roughness and cracking, extending the available evaporative surface. Minor differences in surface temperatures, due to different material thermal conductivities, could also introduce such discrepancies.

The evaporation rate is expressible as:-

$$W = g. (P_1 - P_2) \tag{1}$$

where W = rate of evaporation kg/s

g = evaporation coefficient kg/N.s

$P_1 - P_2$ = vapour pressure difference, N/m^2

Abbott's observations also indicate a lower value of the free water evaporation coefficient g (1.3×10^{-8} kg/N.s) than has been previously reported e.g., IHVE Book C 1970 (3.7×10^{-8} kg/N.s). No serious attempt to account for this variation has been made. It may be noted that (a) the difference between Abbott's result and commonly used values is no greater than the variation between other reported measurements (b) the coefficient may well be lower with the very low air movements speeds and low turbulence typically encountered subfloor.

Main Survey:

Method:

The main survey was carried out using free-water lysimeters, in 60 houses selected from a range of sites in Auckland, Wellington, and Christchurch. The locations of the sites are indicated in Figures 5 to 7.

The choice of free-water lysimeters was in part forced by cost, since the equipment cost, and labour requirements for soil lysimeters were expected to be up to five times as great. Water lysimeter equipment was simple, easy to instal, and monitoring was little more than a meter-reading exercise.

From historical observation there was good reason to expect that, in a majority of houses, the subfloor soil moisture content would be sufficiently high that evaporation rate would be adequately represented by the simpler instrument. By combining a requirement to sample soil moisture contents with the choice of free-water lysimetry, a cost-effective compromise was possible. In the event, soil moisture contents were not recorded as comprehensively as would have been desirable.

The lysimeter evaporation rate may alternatively be regarded as a "potential" evaporation rate which would not be exceeded.

Equipment

The details of the lysimeter equipment used are shown in Figure 8. The three main elements are the evaporation tank which is partially immersed into the soil, a feed reservoir tube with height scale, and a pair of feed tubes which together provide rather precise control (< 1mm) of the water level in the evaporating tank. The evaporating tank is buried so that it is as nearly as possible at the same temperature as the top layer of soil. The edge height is a compromise between conflicting needs to have zero obstruction to air cross currents, and to keep soil from falling into the tank. Because the water level is controlled to precisely the height of the "air pipe" outlet, any evaporation (or condensation) from the evaporator tank is accompanied by a change in stored volume in the reservoir, and may be directly read from the height scale. The reservoir rested on two support rings and could be directly lifted off for easy recharging with water.

Observation of the device showed the following features in its behaviour: changes to barometric pressure and to absolute temperature produced minor short-term influence on the readings, but no long-term effect; the "control cup" ensures that water level adjustments occur in small rather than large steps; the "air pipe" outlet is obviously influenced by surface tension, and can reliably detect differences no finer than the height of meniscus; by using a control cup which has an equilisation time constant of some four or five seconds, the water discharge volume is always small; control is finer than 1 mm on the height gauge, by contrast to the 3-5 mm steps otherwise.

Procedures

Twenty houses in each of the three cities were selected by the consultant. The sites were distributed over different suburbs of the three towns, and were mostly occupied by employees of the consultant firm. This is not particularly desirable, although no resulting bias was evident.

A free-water lysimeter of the type in Figure 8 was installed in the subfloor space of each house. The initial installation took place in late winter, August 1983.

The reservoir was charged to an arbitrary level near the top of its measuring scale, and the value recorded after allowing the water levels time to equilibrate. This usually took a few minutes.

Further readings of the lysimeter reservoir levels were taken on five occasions, ending approximately one year later (see Table 1). When required, the lysimeter reservoirs were refilled, with "before" and "after" water levels recorded. In some instances the reservoir was found to be empty, and for these cases the observers were able to establish the "water debt", and the true evaporate quantity could be determined. This is possible because after exhaustion of the reservoir, further evaporation takes place from the evaporating tank with only a very small drop in water level, and no change in exposed surface area.

At the start and end of the monitoring period, a soil sample was taken from the vicinity of the lysimeter in each house. The moisture content of these soil samples were then obtained by weighing and oven drying at 105°C. Some of the soil samples included an appreciable fraction of pebbles, which as normal were not screened out. However for the purposes of this project, they should have been screened out, and some of the soil moisture contents are in effect reported low.

Attempts were made to establish directly the sorption curves for some of these soils, but were abandoned. One difficulty encountered was that there were distinct signs of biological activity (such as fungal growth) in the soils, and therefore a difficulty in determining that weight changes were due wholly or mainly to water transfer.

Finally, to give some indication of short-term behaviour patterns, one additional house in Tawa, Wellington, was monitored intensively for one year, with twice-daily measurements of evaporation, soil, water, and air temperatures. The house had a continuous concrete perimeter foundation wall, and the measurements were made under a foil-insulated floor.

Results

The mean evaporation rates for each measurement period are indicated in Figure 9, which shows the extreme values, mean and quartiles. The results range over about one order of magnitude and the distribution is skewed towards the lower end, but both features vary from report to report. The results are summarised in Table 1-3.

The Auckland results indicated a rather well-defined central range of evaporation rates (310 g/m^2 day), with no hint of any seasonal variation. The soil moisture contents for Auckland were mostly very high, and about 85% of them would have exceeded even the very high saturation moisture content indicated by Abbott.

The Wellington results show much higher evaporation rates, much more scatter, and suggest an increase during summer. By contrast, the intensively-monitored case showed little seasonal variation, with what peak there is showing up in late autumn/early winter. The mean observed rate was about 550 g/m^2 day. However, the Wellington soil samples were much drier, and no more than 50 per cent of the cases could be regarded as wet enough for the observed lysimeter or potential evaporation rate to adequately represent the true soil evaporation rate.

The Christchurch results show a mean evaporation rate of 300 g/m^2 day, and soil moisture content sufficiently high that some 70 per cent of the results can be regarded as representing the true soil evaporation rates. Because of missing data any seasonal changes are not clearly indicated, but the expected behaviour of rates falling in spring, rising in autumn may be present.

The intensively-monitored Wellington house (see Figure 10) had lower evaporation rates than the region average, and this also peaked in autumn, but the seasonal variation was quite small. The soil was typically 1^{o}-2^{o} warmer than the subfloor air space which was in turn some 3^{o}-4^{o}C warmer than the outdoor air temperature. In a short time scale, however, a totally different pattern applied.

Any sudden drop in outdoor temperature was accompanied by a (probably smaller) drop in subfloor air temperature, and a sharp increase in evaporation rate. The reverse was also true for a sudden warming of outdoor temperature, and on a few occasions this even reversed the moisture flow by condensing water on to soil and evaporation pan. These patterns would last over several days, perhaps declining in that period. Normal daily changes in evaporation rate, if present, could not be resolved from this equipment.

A comparison of lysimeter evaporation rates with subfloor vent provisions is summarised in Figure 11. The data itself indicates that there is no particular correlation between the two. However, it must be noted that the estimating of subfloor vent provision is subject to one-way error. Whilst some important vent openings can be identified and measured, others can not be measured, and still others are completely concealed. So, the actual vent area will be equal to or larger than the estimate, but not less. Some 50 per cent of the houses had identifiable vent openings meeting or exceeding the NZS 3604 (Standards Association of New Zealand 1984) requirement of 3500 mm^2 per 1 m^2 of floor area.

Discussion

The survey described above reports on the observed free-water lysimeter evaporation rates under some 60 suspended floors. It has previously been established that if the soil is saturated or near-saturated this rate will closely approximate the evaporation rate from soil. The moisture content corresponding to "this condition" varies with the soil type.

In all cases, the observed results reported here will represent the maximum potential evaporation rate, the maximum rate at which subfloor soil, however wet, would be able to evaporate. These limits may be useful in their own right, for instance in establishing the moisture-removing potential required of a subfloor ventilation scheme.

In some cases only (85 per cent of the Auckland cases, 75 per cent in Christchurch, and 50 per cent in Wellington), the soil moisture contents were high enough that the lysimeter readings can be equated to actual soil evaporation rates. This equivalence is based on the relations shown in Figure 1 and Figure 4. The cut-off point for acceptability of results under this criterion has been taken to be 25 per cent m.c. for Auckland, 20 per cent for Wellington and Christchurch. In fact the exclusion of the results from drier sites made no appreciable difference to mean or variance of evaporation rate. The higher figure for Auckland was chosen because of the reported tendency for soils with volcanic material to have higher saturation moisture content, and the demonstration in the pilot survey (Abbott 1983) that this did indeed occur. The figure of 25 per cent is suitable for Abbott's soils with saturation m.c. of 30 per cent, as at that point the difference between lysimeter and soil evaporation rates becomes less than about 20 per cent. For the present purposes this is satisfactory. Lower moisture contents were permitted for the other centres on the assumption that soils were less likely to contain volcanic material.

Alternatively, if one compares the lysimeter evaporation rates with soil moisture content, then in all three centres there appears to be no correlation. The estimates given for the mean evaporation rates are in fact little altered whether the drier soils are included or excluded.

CONCLUSIONS

From a one year survey of 60 houses in three major cities in New Zealand, supported by a pilot survey in Auckland and close monitoring of one house in Wellington, the main conclusions drawn are:

- The subfloor soil evaporation rates as indicated by free-water lysimeters, did not show a clear seasonal variation and averaged about 300g/m^2 day in Auckland and Christchurch and 550g/m^2 day in Wellington. The subfloor soil moisture content averaged 25-30 per cent in Auckland and Christchurch, but only 15 per cent in Wellington.

- Free-water lysimetry is a cheap and convenient method for observing subfloor soil evaporation, and under certain conditions (i.e., sufficiently damp soil) represents soil evaporation rates with adequate reliability in 50-85 per cent of houses in this survey.

- The identifiable amount of vent opening in the subfloor perimeter was highly variable, and exceeded the prescribed level of 3500 mm^2 per m^2 floor area in some 50 per cent of houses.

- The lysimeter evaporation rate showed no clear correlation with measurable subfloor vent area, or with soil moisture content.

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AUCKLAND

House No.	Initial Soil mc%	Final Soil mc%	Aug-Oct	Oct-Dec	Dec-Feb	Feb-May	May-Aug	Whole Year	Whole Year soil mc > 20%
			Evaporation Rate			g/m^2 day			
1	18	14	970	752	810	480	498	655	-
2	26	24	231	138	207	88	434	215	215
3	21	16	431	300	300	111	317	267	-
4	31	53	331	*	*	*	*	331	331
5	44	34	948	731	*	318	*	582	582
6	33	34	417	262	324	289	407	337	337
7	22	22	614	593	500	439	407	493	493
8	35	40	410	524	*	1017	398	667	667
9	20	22	231	176	245	270	268	245	245
10	21	23	345	262	348	384	402	357	357
11	18	11	203	162	38	39	85	95	-
12	20	17	748	472	*	338	222	409	-
13	21	19	162	203	231	225	202	207	207
14	21	20	272	276	200	236	229	241	241
15	28	38	152	31	31	29	*	55	55
16	10	*	462	372	572	488	*	475	-
17	22	24	117	28	210	146	83	118	118
18	25	31	352	159	169	229	324	250	250
19	23	26	197	179	262	*	244	222	222
20	65	89	424	452	500	186	363	353	353
Mean	26.2	29.3	401	320	309	298	305	295	312

Table 1: Free-Water Lysimeter Evaporation Rates and Moisture Content (MC) for Each House

(Main Survey)

WELLINGTON

House No.	Initial Soil mc%	Final Soil mc%	Aug-Oct	Oct-Dec	Dec-Feb	Feb-May	May-Aug	Whole Year	Whole Year soil mc > 16%
			Evaporation Rate g/m^2 day						
1	18	17	1270	645	1320	908	503	910	910
2	5	8	714	679	1936	*	1780	1321	-
3	11	18	952	165	1584	519	478	697	-
4	11	11	230	389	1056	393	668	538	-
5	13	11	121	1019	204	432	441	448	-
6	7	8	266	225	309	23	290	202	-
7	6	13	2380	2038	2684	1297	2225	2049	-
8	18	14	295	253	*	*	228	254	245
9	29	29	16	133	1056	279	668	427	427
10	13	11	1309	1019	1408	778	668	988	-
11	19	18	348	1206	331	778	211	585	585
12	13	*	233	165	265	*	*	220	-
13	18	23	207	123	331	23	166	150	150
14	6	10	952	1019	1408	691	1001	981	-
15	17	18	803	*	73	204	*	332	332
16	16	16	275	*	1232	243	*	490	490
17	21	*	292	305	*	216	1001	462	462
18	11	29	952	1019	720	*	1001	934	934
19	32	*	873	*	1056	*	*	959	959
20	15	11	793	594	1584	1037	946	1008	-
Mean	14.95	15.59	664	647	1031	521	767	698	550

Table 2: Free-Water Lysimeter Evaporation Rates & Moisture Content (MC) for Each House

(Main Survey)

CHRISTCHURCH

House No.	Initial Soil mc%	Final Soil mc%	Aug-Oct	Oct-Nov	Nov-Dec	Dec-Feb	Feb-Apr	Apr-May	Whole Year	Whole Year soil mc>20%
			Evaporation Rate g/m^2 day							
1	33	*	24	40	11	*	90	74	39	39
2	20	*	1252	18	73	*	12	116	408	408
3	31	*	531	833	145	*	*	*	454	454
4	12	*	1252	458	113	*	*	*	509	-
5	29	*	290	316	116	*	*	832	760	760
6	24	*	324	0	4	*	49	1368	115	115
7	42	*	186	*	*	*	*	158	140	140
8	28	*	448	*	*	*	*	*	448	448
9	10	*	290	65	55	*	*	589	149	-
10	20	*	1502	*	*	*	171	632	758	758
11	3	*	486	280	11	*	453	811	318	-
12	26	*	834	338	131	*	253	1116	403	403
13	28	*	759	*	*	*	192	1253	424	424
14	29	*	172	145	84	*	37	474	101	101
15	11	*	290	196	127	*	257	95	210	-
16	11	*	321	207	55	*	163	411	186	-
17	24	*	145	84	36	*	69	*	92	92
18	25	*	7	11	0	*	*	*	8	8
19	31	*	0	0	*	*	*	*	-	-
20	56	*	121	80	58	*	131	95	95	95
21	*	*	*	*	*	*	37	*	37	-
22	*	*	*	*	*	*	61	*	61	-
23	*	*	*	*	*	*	82	*	82	-
24	*	*	*	*	*	*	69	*	69	-
Mean	24.6	*	462	192	68	*	133	573	255	303

Table 3: Free-Water Lysimeter Evaporation Rates & Moisture Content (MC) for Each House

(Main Survey)

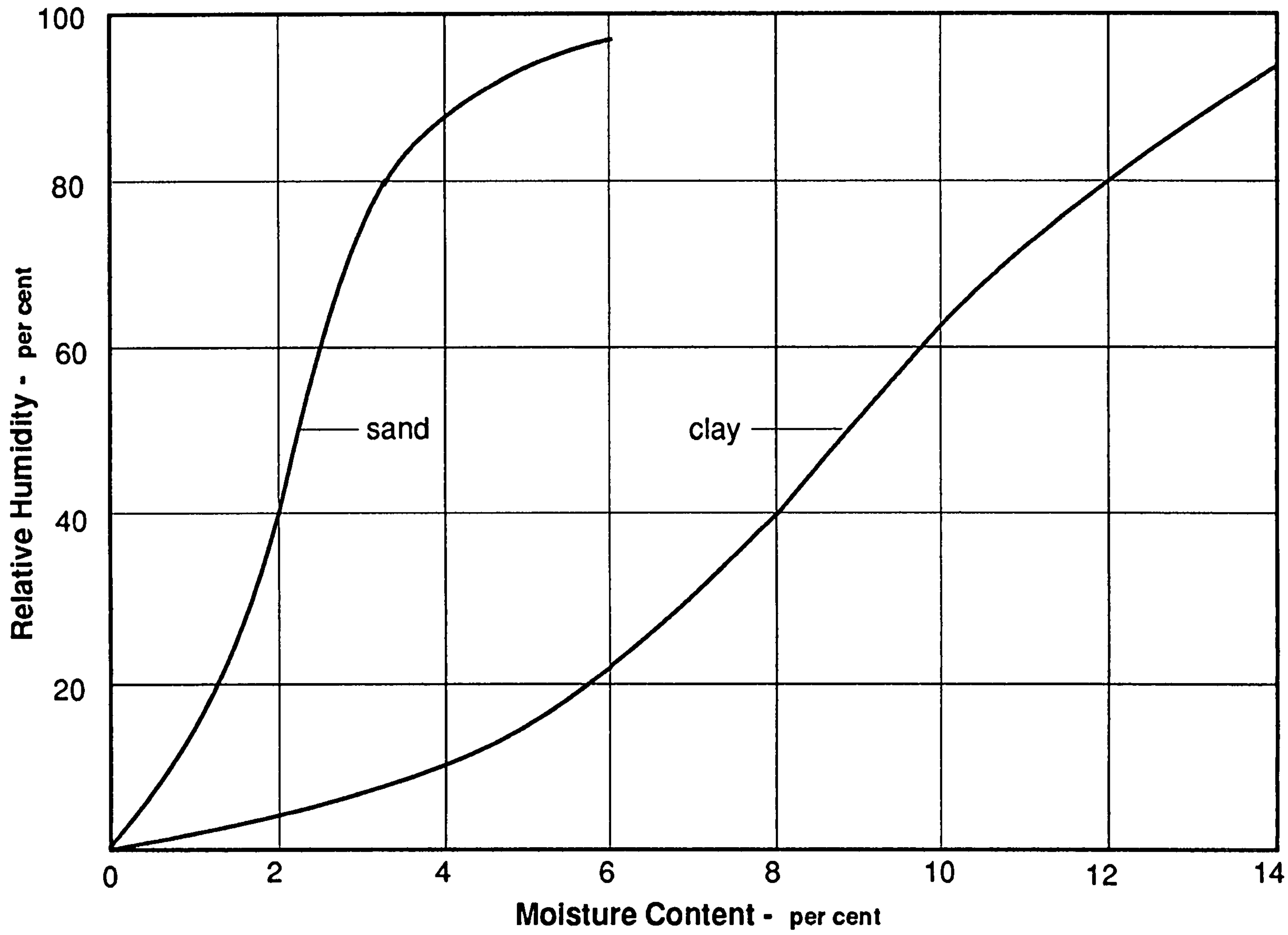

Figure 1 : Relative humidly / moisture content curves for a sand and a clay, from the TRRL handbook 1957.

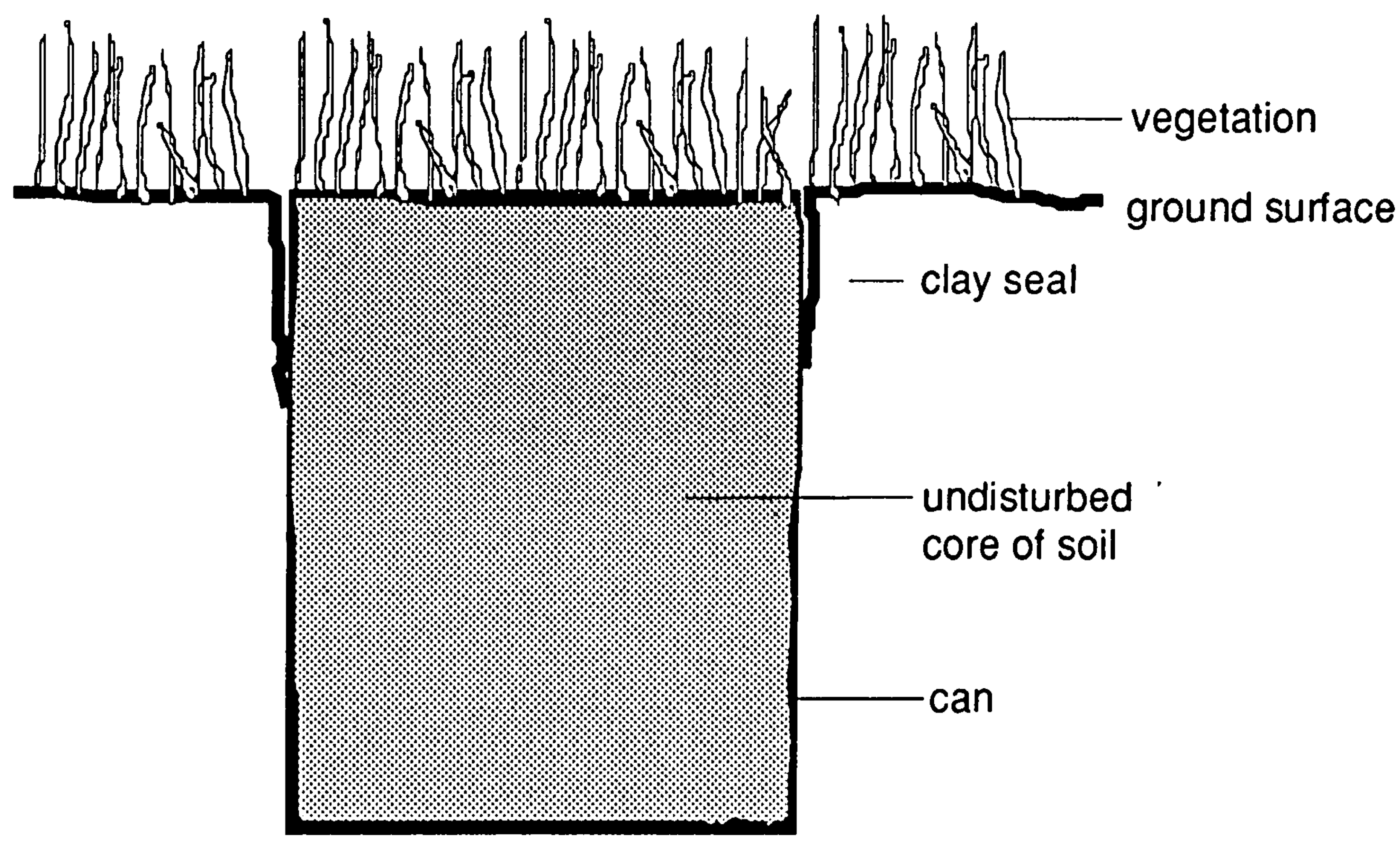

Figure 2 : Field weighing lysimeter, (**"The measurement of field moisture', by L.F. Curtis and S. Trudgill Technical bulletin 13 of the British Geomorphological Research Group**).

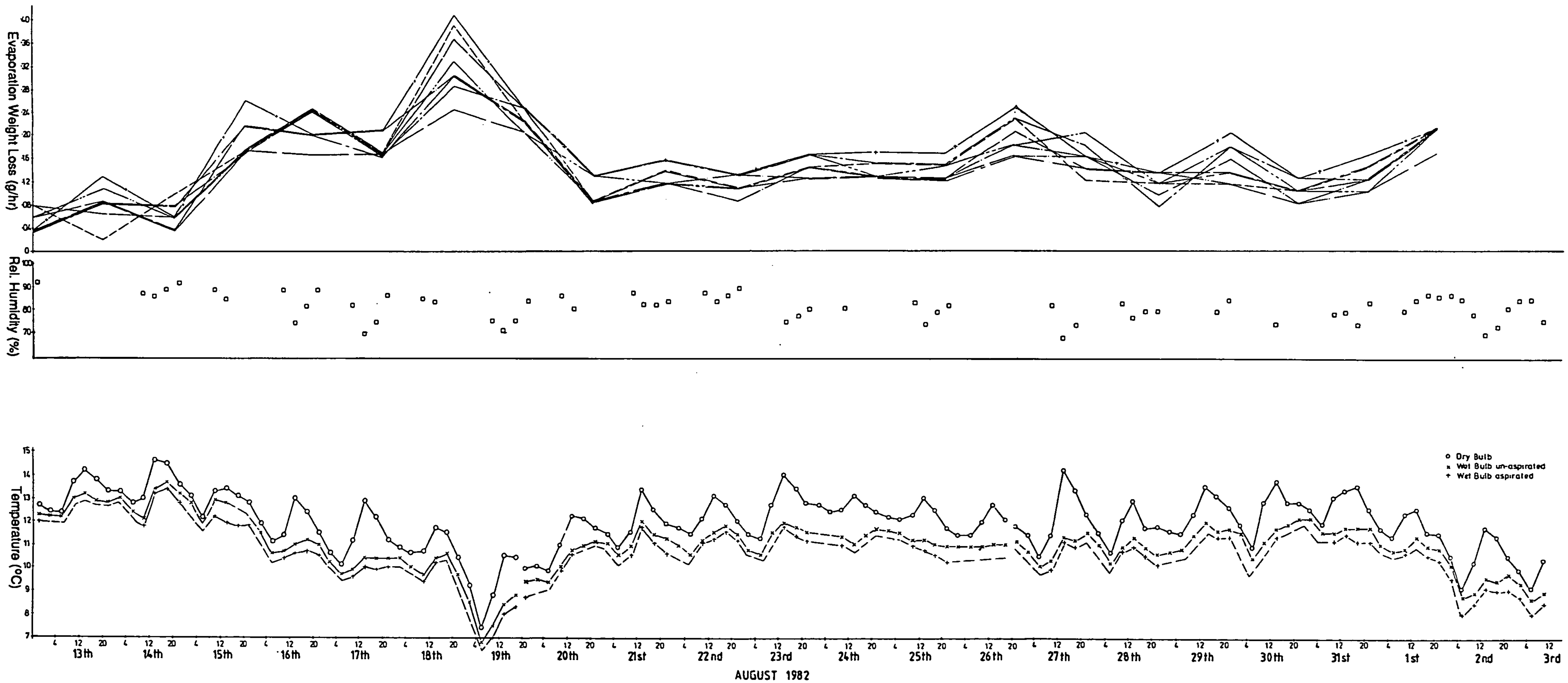

Figure 3 : Section of Evaporation rate v conditions. Daily variation. Pilot survey.

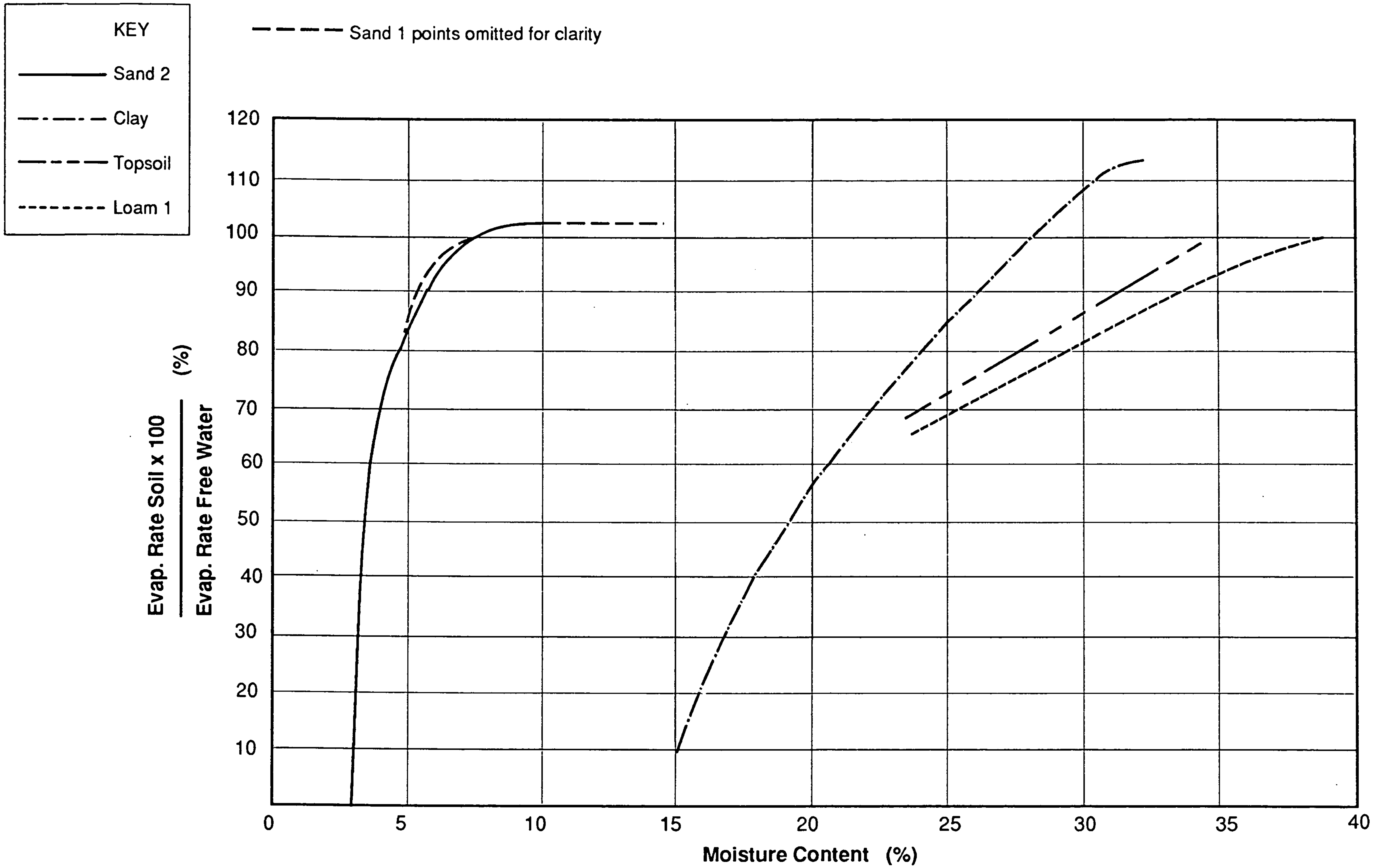

Figure 4: Comparison of soil lysimeter and free - water lysimeter rates, evaporation v moisture, pilot survey.

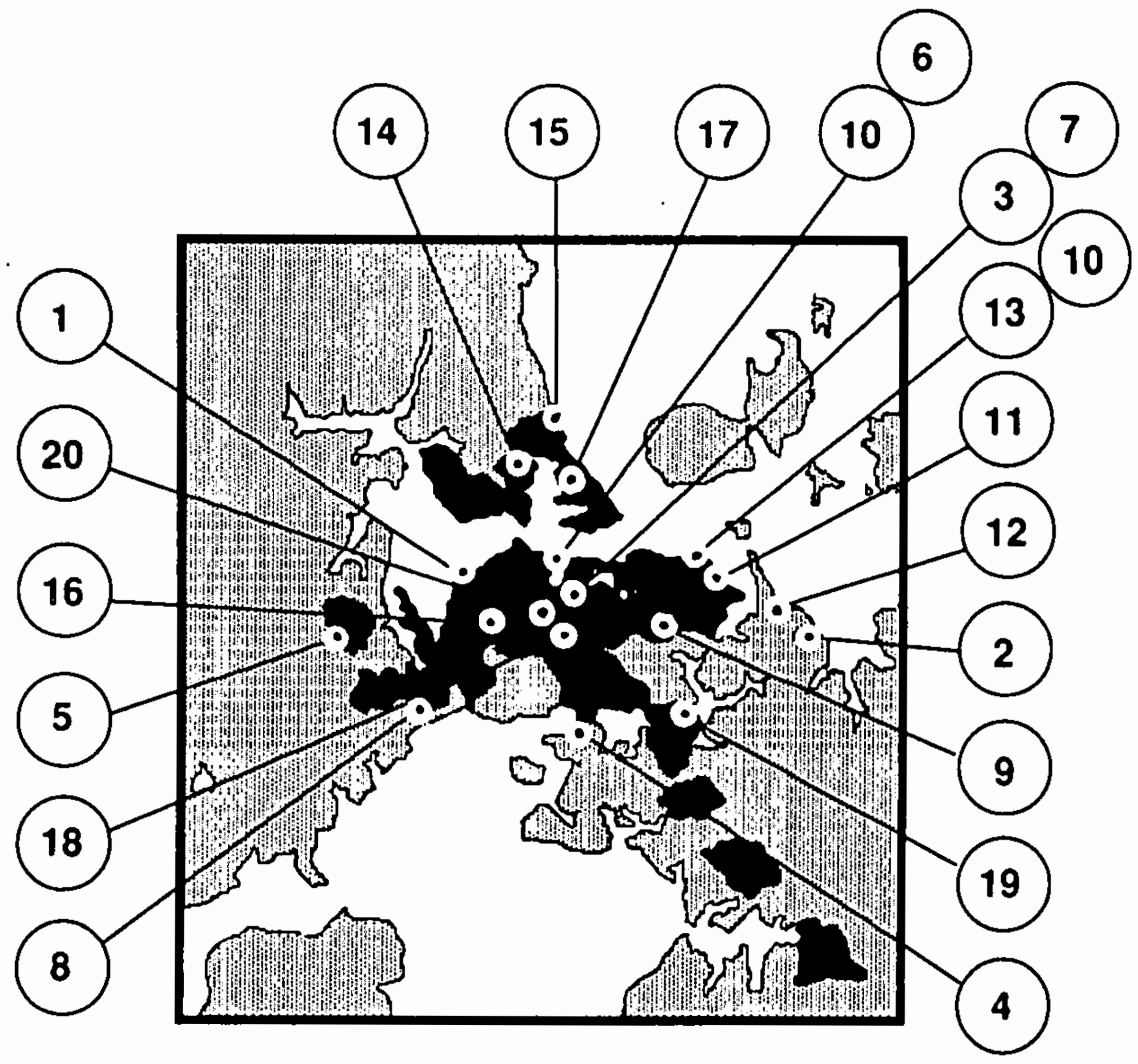

Figure 5 : Plan of site locations of cases used, main survey, Auckland.

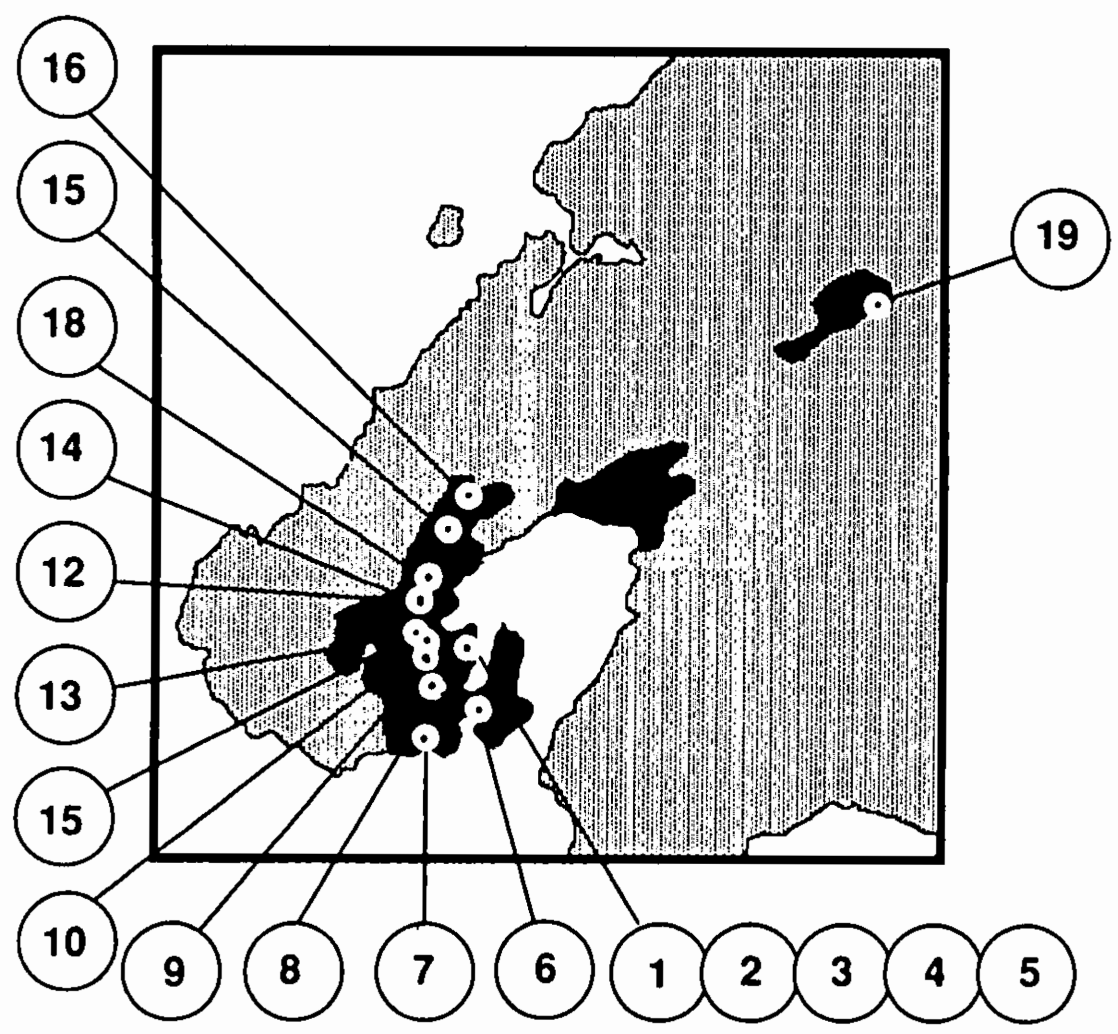

Figure 6 : Plan of site locations of cases used, main survey, Wellington.

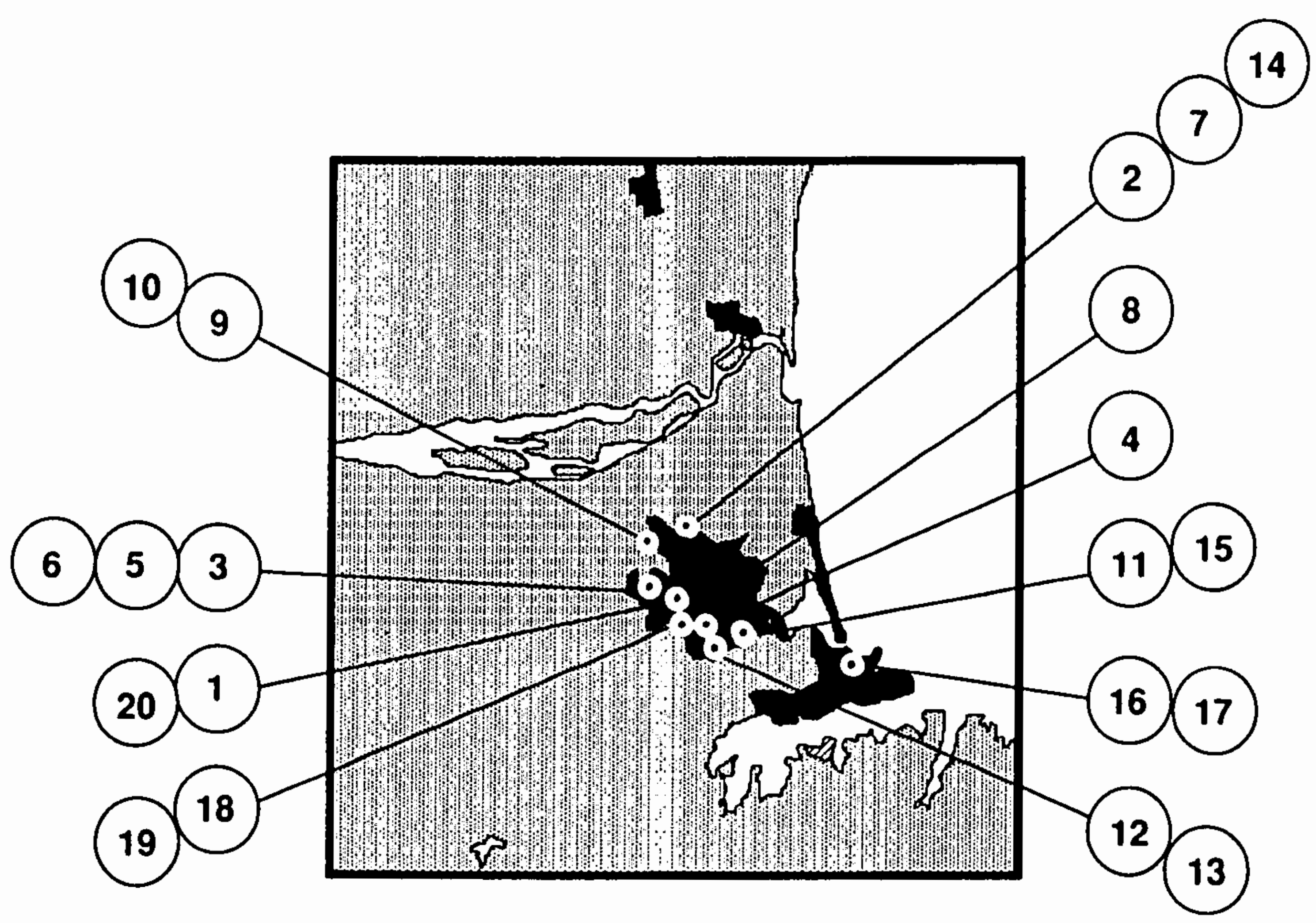

Figure 7 : Plan of site locations of cases used, main survey, Christchurch.

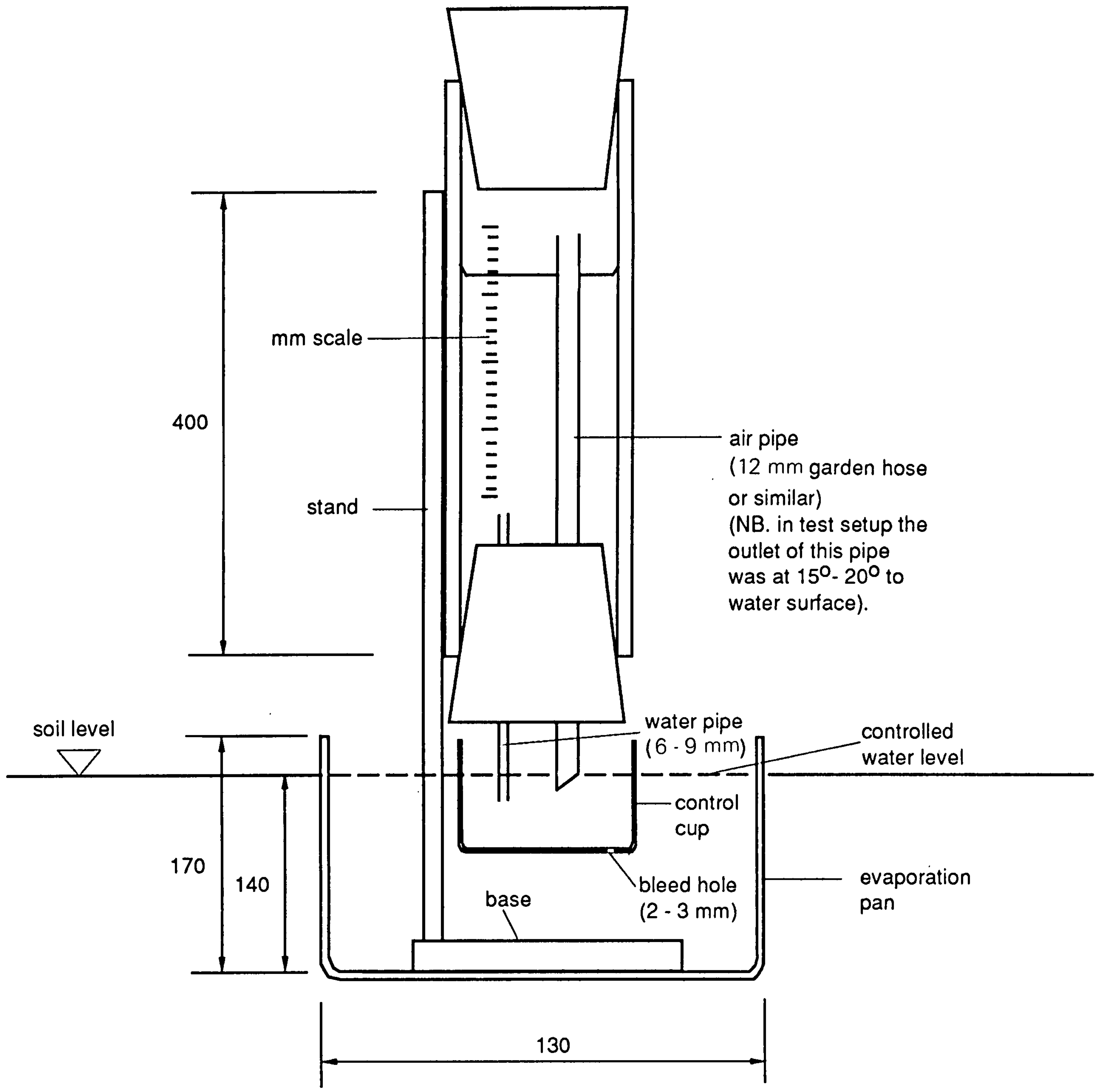

Figure 8 : Principle of the bird-bath type free-water lysimeter,main survey.

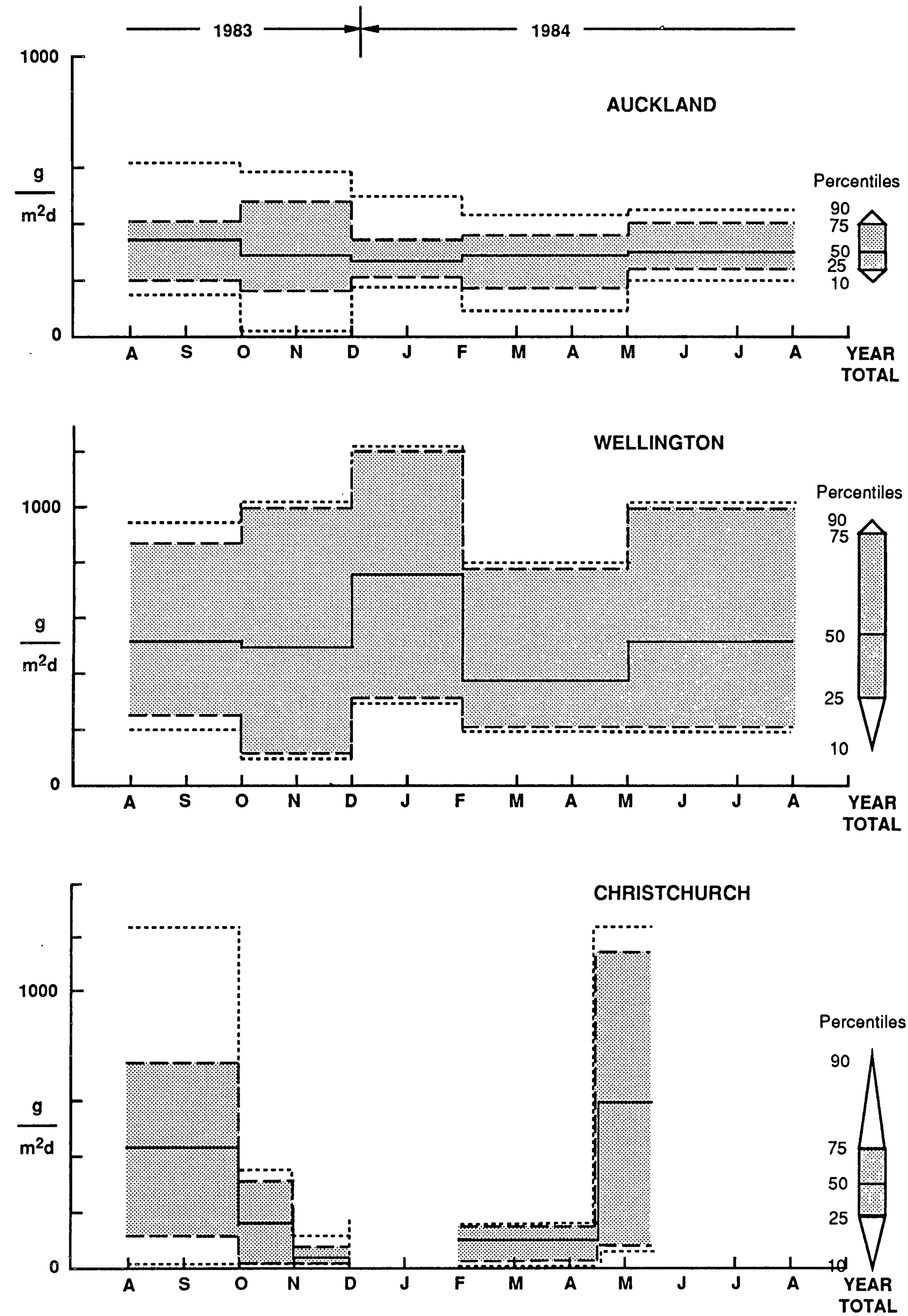

Figure 9 : Summary of free-water lysimeter evaporation over a year for cases where soil m.c. deemed high enough.

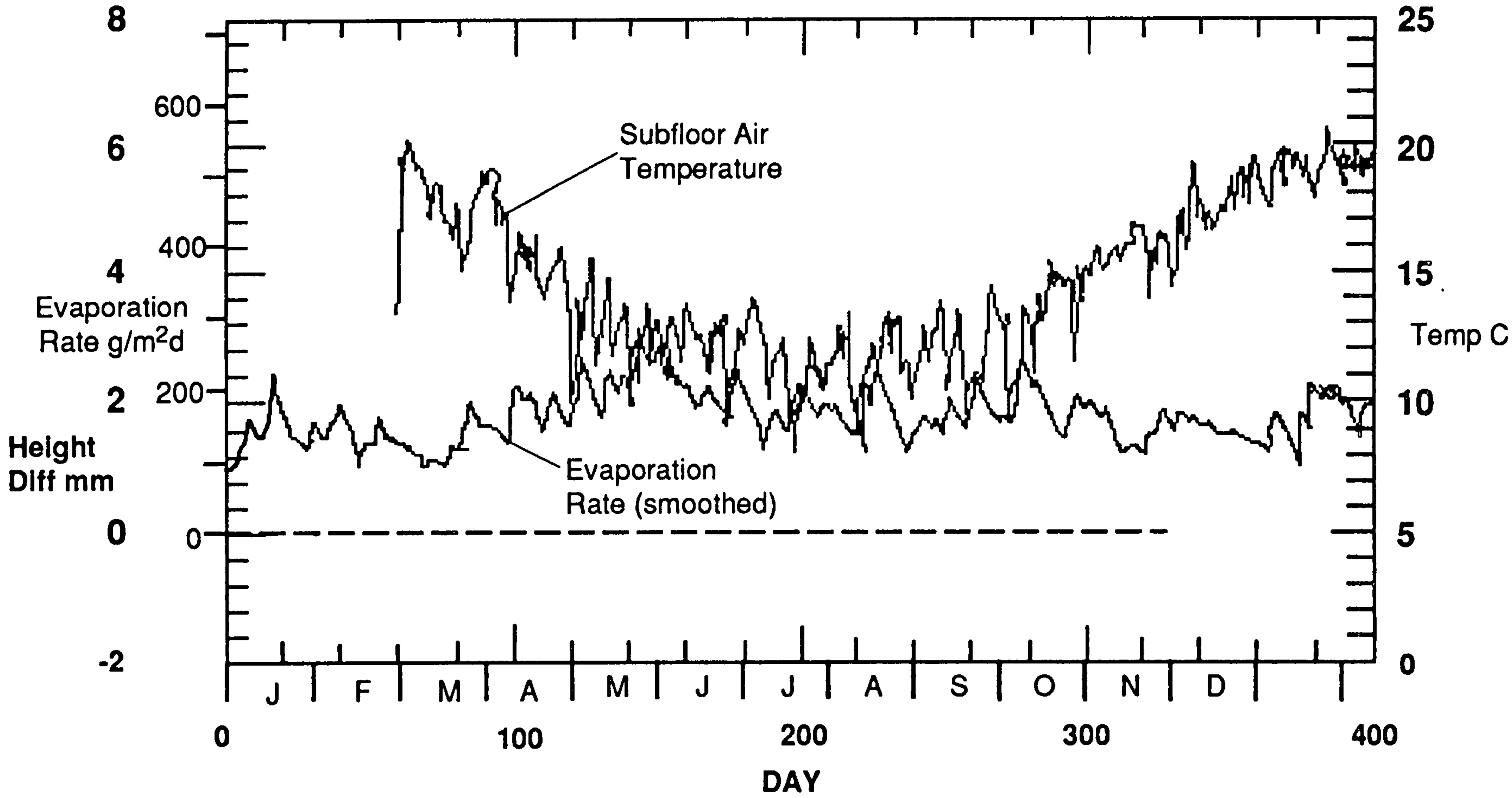

Figure 10 : Lysimeter evaporation rate and subfloor temperature for one house.
Day 0 = 1 January
From twice daily measurement.

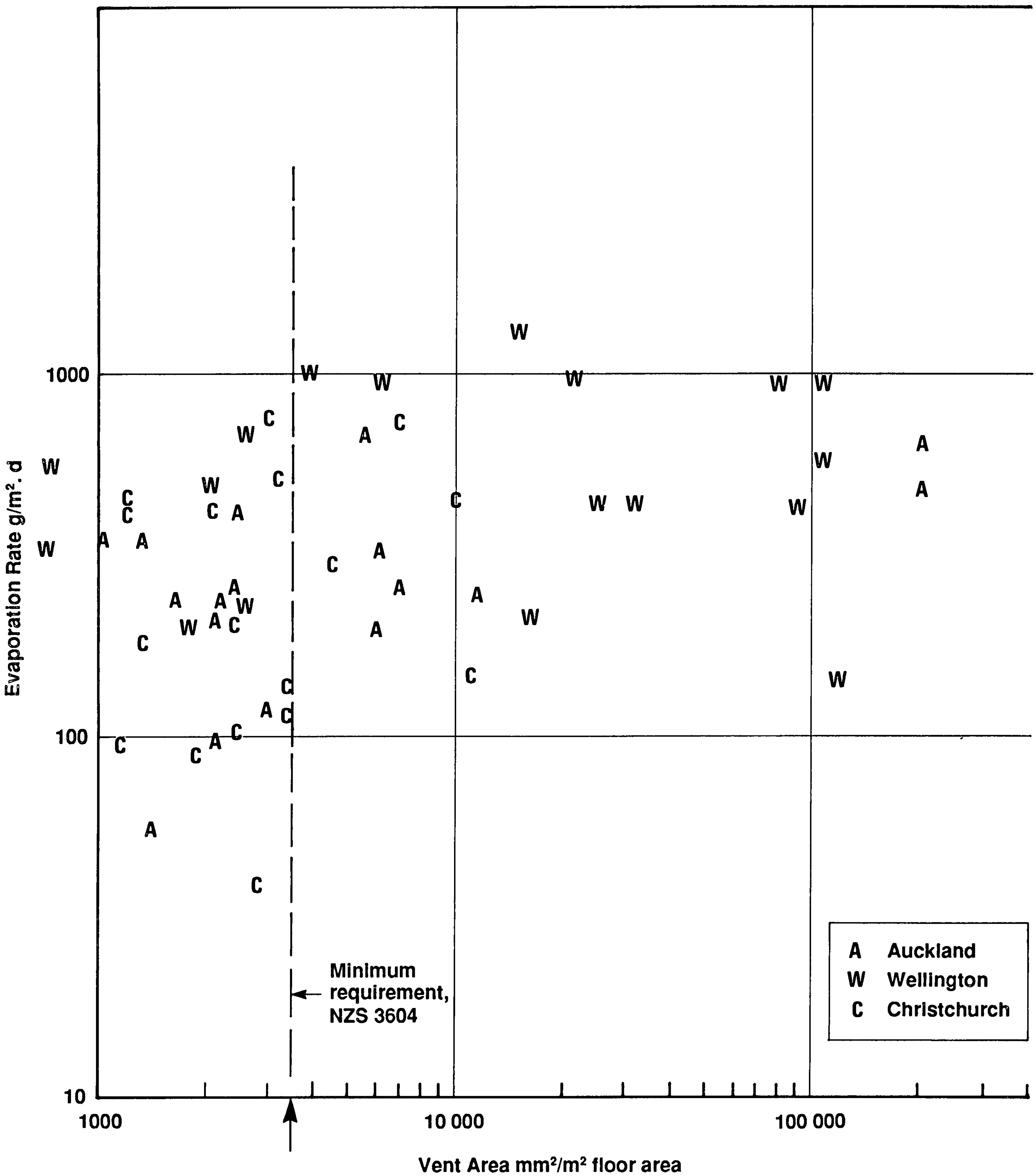

Figure 11 : Comparison of lysimeter evaporation with vent area.

A survey of subfloor
ground evaporation rates.

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