THE WATER BALANCE OF NEW ZEALAND

C. Toebes*

ABSTRACT

Using separate estimates of average annual precipitation, evapotranspiration and runoff, a water balance for approximately 10 years is given for New Zealand. It is postulated that equilibrium conditions are never reached within the New Zealand hydrological system, and the storage factor – although relatively small – is considered in relation to residence times of the various storage elements. It is thought that only depletion of the groundwater above the base level in New Zealand is likely to have an effect on the water balance for the period under discussion.

INTRODUCTION

The hydrological system of New Zealand can be most conveniently expressed by the continuity equation where inflow is equal to outflow modified by changes in storage, and this equation may be characterized in its simplest form as:

$$P = E + Q + \Delta S$$

where P is the precipitation, E the evapotranspiration, Q the runoff and S the change in storage in snowpack, glaciers, lakes, channels and other surface storage, soil moisture, groundwater and biological storage.

A knowledge of the water balance of New Zealand is essential for an evaluation of the effects of natural or artificial changes to either the New Zealand or global hydrological system, as well as for planning the utilization of the water resources on a national scale. A study of the water balance of New Zealand is part of the hydrological programme of the Ministry of Works; much of the information and analysed data on which this paper is based have been obtained as part of this programme.

Because hydrological data are of recent origin (Morrissey, 1970), few attempts have been made to evaluate the water balance of the entire country. Baumgartner and Reichel (1970) list 41 attempts to establish the world water balance between 1905 and 1969, and these attempts have presumably included the water

* Water and Soil Division, Ministry of Works, Wellington.

balance of New Zealand. However, the references sighted have given no separate estimates for New Zealand.

Toebes (1967) gave the water balance for New Zealand* as follows:

$$P - E = Q$$

$$1650\text{ mm} - 660\text{ mm} = 990\text{ mm}$$

He obtained P by planimetering Seelye's isohyetal map (1945) and E from a map of potential evapotranspiration by J. L. Taylor (pers. comm.), while Q was derived by subtraction. Lvovitch (1971) gave a value of 1095 mm for the runoff, a similar precipitation value and a somewhat lower value for the evapotranspiration. Although Lvovitch (pers. comm.) did consider some typical published discharges for New Zealand rivers, his approach is essentially similar to that of Toebes.

It is becoming clear that the runoff component, because of the integrated nature of streamflow, is the most reliable element of the water balance, and improvements must first of all be directed to obtaining better runoff data.

A revised water balance for New Zealand presented here gives separate estimates for the main elements. The data for these elements cover various periods, but it is assumed that the water balance is valid as an average for about 10 years. It is postulated that the hydrological system for New Zealand for a 10-year period does not reach equilibrium conditions, and by calculating the residence times for the various storages in the system it is concluded that it is the groundwater storage in particular that affects the equilibrium conditions.

WATER BALANCE ELEMENTS

Precipitation

Kidson (1932) and Seelye (1945) showed the average annual rainfall of New Zealand in the form of an isohyetal map to a scale of 1:5 000 000. Toebes (1967), by planimetering Seelye's map, obtained a value for the average annual precipitation for New Zealand of 1650 mm. It is considered that planimetering Kidson's map would give a similar value. Both maps require much subjective reasoning for their interpretation, since for the large area of high precipitation Kidson indicates >2500 mm and Seelye >2000 mm.

The New Zealand Meteorological Service has produced a table of rainfall normals (1921 to 1950) for 1904 stations, and an

* New Zealand as referred to in this paper comprises the North and South Islands only. It includes coastal islands but excludes offshore and oceanic islands.

isohyetal map to a scale of 1:500 000 (J. Finkelstein, pers. comm.). The arithmetic average of the normals gives the following values*:

North Island	1475 mm
South Island	1269 mm
New Zealand	1358 mm

The averages, especially for the South Island, appear low. They indicate that in spite of a high average density of rainfall stations (one per 139 km^2), the arithmetic averaging is unsuitable when few data are available for the mountainous regions. Planimetering the 1:500 000 isohyetal map gives the following:

North Island	1645 mm	
South Island	2375 mm	
New Zealand	2059 mm	(1)

The map shows considerable areas with rainfall >7500 mm. A mean value of 8750 mm has been taken for this class interval, which is realistic in view of the fact that several estimates of precipitation values of >10 000 mm per annum have been made for the steep country on the West Coast of the South Island (NWASCO, in press; Toebes, 1972). Flow measurements on rivers arising from the Alps also indicate very high average annual rainfalls. For instance, the Rakaia River, draining the eastern Alps – an area with a considerable rainshadow effect – has a catchment area at the Gorge of 3198 km^2 and a measured average annual runoff of 2670 mm. The average annual rainfall as measured from the 1:500 000 isohyetal map gives only 2590 mm for this catchment. Admittedly, there are some doubts about the accuracy of the runoff because of the difficulties of rating the gauging station, but it is considered that the rating errors lead to underestimates of the runoff rather than to overestimates.

The accuracy of much information on which the 1:500 000 map is based is doubtful, and quite considerable systematic errors may occur. Recent studies in the USSR (USSR Committee for the IHD, 1967) have shown that in areas with a large snow contribution to the annual precipitation, great underestimates of the annual rainfall may occur. The Russians apply multiplication factors of as high as 1.2 and 1.5 to measured rainfall amounts.

Flohn (1970) considered that because of the effects of the prevailing daytime circulation (thermally induced) in mountain areas in the tropics, subtropics and outer tropics, the rainfall from stations which are usually located near the bottom of the valleys is

* Subsequent recalculation using data up to 1970 has given values about 2½ percent higher than the figures shown here (J. Finkelstein, pers. comm.).

greatly underestimated. This condition is very likely to occur on the West Coast of the South Island. In addition, most catchments in this area face the prevailing north-westerlies, and with the very steep slopes a general underestimation of the rainfall occurs because areal rainfall estimates are based on a plan area. Toebes (1972) noted this when trying to reconcile the very high runoff in some of these catchments with the areal rainfall estimates, and Morrissey (1972) has referred to similar difficulties in Taranaki. Pardé (1960), considered that such underestimates may be in the order of 15 percent.

Although the mean annual precipitation values as given in (1) appear the best estimates that can be made, it is considered that they are possibly an underestimate of the true values, but more precise data may be difficult to obtain. Rodda (1971) stated: "the reliance placed on rainfall readings in many hydrological studies is quite unwarranted and leads to inaccurate estimates in hydrometric surveys and contradictory conclusions in hydrological research."

Evapotranspiration

Potential evapotranspiration estimates – calculated by either the Thornthwaite or Penman method – have been made by a number of workers, and for representative and experimental basins in New Zealand are calculated on a routine basis. Values range from 723 mm at Kaikohe to 488 mm at the Ski Basin in the Craigieburn Range (1710 m altitude), and reflect latitudinal and altitudinal differences. The evapotranspiration decreases approximately 9 mm per degree latitude (S) and 20 mm per 100 m elevation in New Zealand.

Fitzgerald and Rickard (1960) compared potential evapotranspiration estimates by Thornthwaite and Penman methods and considered that for Canterbury, at least on an annual basis, both methods give good agreement. Jackson (1967) studied the effect of the radiant-energy regimen on the potential evapotranspiration, and concluded that a collective consideration of slope, aspect and albedo differences will result in lower potential evapotranspiration estimates on an areal basis at Taita.

Both Thornthwaite and Penman estimates refer to a short uniform grass cover and assume that the evaporating surface is horizontal. Ibbitt (1971) considered that for forested areas (some 40 percent of New Zealand) the moisture stored by a tree canopy is distributed through a considerable vertical distance, and that for this reason the evaporating surface is greater than the equivalent plan area. Using a mathematical model of interception for a scrub-type vegetation, he arrived at a multiplying factor of 1.16 times the potential evapotranspiration as calculated by the Thornthwaite method.

J. L. Taylor (pers. comm.) drew a map of potential evapotranspiration contours, and by planimetering this Toebes (1967) arrived at an average value for New Zealand of 660 mm. This method did not allow greatly for altitudinal differences or for the findings of Jackson or Ibbitt, and could be in error. Another problem is that the actual evapotranspiration, especially in the eastern parts of New Zealand, is invariably less than the potential evapotranspiration. J. D. Coulter (pers. comm.) calculated the actual evapotranspiration for 124 stations in New Zealand using the Thornthwaite water balance method. He assumed a uniform 75 mm water-holding capacity for the entire country and subsequently drew an isoplethal map.

Planimetering these maps gives values for the actual evapotranspiration as follows:

North Island	633 mm	
South Island	573 mm	
New Zealand	599 mm	(2)

The maps are based on varying lengths of records, with a typical length of about 10 years. Again, they do not include many data from the high country and therefore do not allow greatly for altitude and aspect, and the same comments apply as to the findings of Jackson and Ibbitt. Also, the assumption of a uniform water-holding capacity of 75 mm is considered to be somewhat on the high side.

The estimates are the best available on a nation-wide basis, and no great improvement can be expected in the short term by pursuing techniques as outlined. Baumgartner and Reichel (1970) stated that the most reliable method for the estimation of the evaporation (evapotranspiration) is $P-Q$. They stated that climatological evaluations by techniques such as the Thornthwaite or heat-balance methods are less precise, since computations cannot deal with the differentiated condition of soil moisture/texture and vegetation form at the earth surface. W. B. Morrissey (pers. comm.) considers that in the high-precipitation area of New Zealand the possible errors in measuring either P or Q are much greater than in estimating E by any method.

Runoff

The first actual runoff estimate for New Zealand was made by Toebes in an unpublished thesis in 1963. This study considered runoff in the individual hydrological regions based on streamflow data available at that time. The runoff values calculated are:

North Island	1071 mm
South Island	1733 mm
New Zealand	1449 mm

The records were short and for some regions data from similar regions were used to obtain average values.

More recently Toebes (1972) produced a map of surface water resources for New Zealand on a scale 1:1 000 000, on which 12 isohyds* are given between 5 and 340 l s^{-1} km^{-2}. He has calculated, using this map, the average annual runoff for all significant rivers (367) flowing into the sea. Summing these runoff values gave the following:

North Island	1052 mm	
South Island	1808 mm	
New Zealand	1481 mm	(3)

This work was based on information from some 200 gauging stations for which records existed for a length exceeding 4 years with an average length of close to 10 years, supplemented by correlation studies based on low-flow gaugings and in some cases on estimates of $P-E$. He stated that one-third of the value of the North Island and one-half of that of the South Island is based on actual records at the mouths of major rivers, and the total estimates – considering the integrated nature of a discharge record – must be regarded as reasonable.

The problem of accuracy is associated more with the length of records rather than with areas with no records. Short records were sometimes corrected with reference to the rainfall normals, but this procedure can be hazardous because there may be insufficient gauges in catchments to determine the average annual catchment rainfall. Typical streams arising in steep country such as Tongariro National Park, Mt Egmont or the South Island Alps have, for a 10-year record, a coefficient of variation of about 15 percent. Normals are not likely to give greatly different values in such cases, but in other areas short records may be most misleading, as is illustrated by the average annual runoff for varying periods for the Kaituna River at Lake Rotoiti outlet, the longest record in New Zealand:

1906–1966 (60 years):	1097 mm
1937–1966 (30 years):	1119 mm

* An isohyd is defined here as a line joining points of equal specific discharge on rivers and streams with catchment areas $\geqslant 50$ km^2. It is a line bounding a given area within which the average annual specific discharge of streams or rivers (or tributaries of these) varies within the limits of specific discharge shown on the map legend for that particular area.

1947–1966 (20 years): 1155 mm
1952–1966 (15 years): 1195 mm
1957–1966 (10 years): 1222 mm
1962–1966 (5 years): 1359 mm

Considering the close agreement between the runoff estimates of 1963 and 1972, made by different methods, some confidence may be placed in the runoff component of the revised water balance.

WATER BALANCE

Using the values P, E and Q as given in (1), (2) and (3), which are the most recent estimates, the water balance can be stated as follows (in mm):

$$P = E + Q + \Delta S$$

North Island	$1645 = 633 + 1052 - 40$
South Island	$2375 = 573 + 1808 - 6$
New Zealand	$2059 = 599 + 1481 - 21$

or, in km^3:

North Island	$188.7 = 72.6 + 120.7 - 4.6$
South Island	$357.4 = 82.2 + 272.1 - 0.9$
New Zealand	$546.1 = 158.8 + 392.8 - 5.5$

The catchment areas used are as follows: North Island, 114 682 km^2; South Island, 150 501 km^2; New Zealand total, 265 183 km^2.

EQUILIBRIUM CONDITIONS OF THE WATER BALANCE

The water balance, in spite of the apparent satisfactory closure, only indicates the magnitudes involved. Apart from inaccuracies in the estimates of the water balance components, the data for the various elements do not cover equal periods. Assuming that the rainfall normals for 1921–1950 do represent the average rainfalls up to the present, the water balance as presented here could be regarded as valid as an average for about 10 years, but a somewhat different water balance must be expected when data that cover equal periods become available. The storage element, although relatively small, is probably realistic and shows the imbalance of the system.

Although a hydrological system, by definition, shows a long-term dynamic equilibrium, actual equilibrium conditions in a large system such as New Zealand are not likely to occur. Kalinin (1968) considered that the global hydrological system as a whole never arrives at an equilibrium. He suggested that the 1.2 mm/year rise of the ocean level in recent times supports the assumption that there is a lag of several thousand years between variations in climatic conditions and the corresponding variation of the ocean level.

Orvig (1970) stated that the world sea level showed a rise of about 0.2 m for the 50 years ending in 1940 and a 40 percent decrease in rate of rise since then. Szesztay (1970) considered that the rise may be caused partly by the exploitation of groundwater aquifers which are not being recharged. He also concluded that the world ocean and the global hydrological system have no short-term or long-term equilibrium. Their static and dynamic characteristics (mean ocean level, extent of polar ice caps, or the total amount and distribution of the long-term average precipitation and evaporation) are always moving with immense inertia and extremely long time lags towards newer quasi-equilibrium conditions. These conditions are changing much more rapidly than the processes themselves, and are governed by a multitude of interrelated feedback effects within and outside the hydrosphere.

It is prudent to assume that the New Zealand system is not in an equilibrium condition in either the short or long term. Real data suggesting such a postulate are not available, but a consideration of volumes of storage and residence times of water in New Zealand may indicate the magnitudes involved.

STORAGE VOLUMES AND RESIDENCE TIMES

Ephemeral Snow

This is an extremely variable element in New Zealand and is most unlikely to have any effect on the water balance unless periods less than a year are considered. The maximum volume may be estimated as covering half the South Island with an equivalent water depth of 100 mm; this gives 7.7 km^3. Such a snow volume is not likely to persist for more than a few days on the average.

Permanent Snow and Ice

P. W. Anderton (pers. comm.) estimated the storage in permanent snow and ice as 50 km^3, with a surface area of 850 km^2. Sixty percent of this is contained in the 12 largest glaciers, with a surface area of 450 km^2. This, according to Anderton (in press) would disappear in about 800 years if the present climatic conditions continue. Forty percent is contained in about 500 small glaciers, with a surface area of 400 km^2, and would deplete to a negligible volume in about 100 years. The average annual depletion for the large glaciers is $(60\% \times 50)/800 = 0.0375$ km^3 or 83 mm over 450 km^2, and the depletion for the small glaciers $(40\% \times 50)/100 = 0.2$ km^3 or 500 mm over 400 km^2.

Interception Storage

G. J. Blake (pers. comm.) considers the maximum interception storage in New Zealand to be 7 mm or 1.8 km^3. The actual storage varies greatly throughout the year and would probably have no effect on the water balance unless very short periods are considered. The depletion of interception storage may be regarded as equal to water evaporation, i.e. about 750 mm per year.

Lakes

Lake storage is considerable in New Zealand. Toebes (1972) listed the important lakes and gave the total volume as 405 km^3. The total surface area is 3058 km^2, indicating the considerable depths of New Zealand lakes. Ignoring the outflow by rivers at high levels and seepage, and assuming that the waters are not mixed, depletion is by evaporation only at an approximate rate of 750 mm/year. The assumption that lake waters are not mixed may be incorrect, and lake outflows may have to be considered also.

Channel Storage

An estimate of volume of 13.3 km^3 can be arrived at by assuming a typical drainage density of 10 km/km^2 and an average channel cross section of 5 m^2.The outflow of New Zealand rivers has been calculated at 1481 mm (over the total area of New Zealand).

Soil Moisture

At the average value of water-holding capacity of 75 mm as assumed by J. D. Coulter (pers. comm.) the average volume of water stored in soils may be taken as 50 mm, or 13 km^3. The outflow may be taken as being equal to the average actual evapotranspiration of New Zealand, i.e. 600 mm.

Groundwater

Groundwater may be considered as that portion which appears as interflow and baseflow and as deep groundwater (below base level, i.e. mean sea level, of New Zealand).

Reilly (1965) calculated the volume of New Zealand above base level as 139 200 km^3. Assuming an average rock porosity of 1 percent, the amount of groundwater above base level may be calculated as 1392 km^3. The average outflow may be taken as 45 percent of the average runoff of New Zealand (Toebes, 1972). This neglects outflow by utilization of groundwater and recharge of deep groundwater because of pressure gradients.

Deep groundwater below mean sea level, assuming a similar porosity and depths to base rock of about 100 m as determined in coastal aquifers in New Zealand, could give a storage of 265 km^3. The loss by artesian outflow into the oceans and by utilization is not likely to be very great.

Biological Storage

The estimate by Volker (1970) of 1 mm depth for the continents is assumed to apply to New Zealand also. The average outflow is taken as for soil moisture.

Residence Times

The average rate of water exchange, or residence time of water in storage, may be calculated by dividing the volume in storage by the rate of outflow. The residence times so calculated show to what extent the inflow is damped by the storage and indicate the effect that the various storages have on the water balance of a given period.

The residence times have been calculated for all significant storages and are listed in Table 1. Considering that the water balance may have validity for an approximately 10-year period, it is obvious that ephemeral snow, interception storage, channel storage, soil moisture and biological storage could have no influence on the water balance because of the very short residence times involved. Also, permanent snow and ice, lakes and deep groundwater have such long residence times that their effect must be minimal. This leaves groundwater that is supplied to rivers as interflow and baseflow. The similarity of its residence time to the water balance period, coupled with the fact that it is the largest single storage, must lead to the postulate that variations in groundwater storage could have a significant effect on the water balance as presented here.

No data are available in New Zealand, but Ehrlich and Ehrlich (1972) stated that the water resources of the United States are being depleted twice as quickly as they are being recharged at present, and a withdrawal rate of 400×10^9 U.S. gallons per day is quoted. This would mean that the actual loss is two-thirds of this figure, or 368 km^3 per year. Taking the population of New Zealand as 1/70 of that of the United States, we arrive at an annual withdrawal rate for New Zealand of 5.3 km^3 or 20 mm per annum. The withdrawal rate in New Zealand is much less than that of the United States and may be no more than 10 percent or 2 mm, but even this volume is of significance in the water balance as presented here.

World residence times as given by Volker (1970) and Lvovitch (1970) have been listed in Table 1 also. The generally longer world residence times indicate in particular the extremely humid conditions of New Zealand as compared with overall world conditions, which include Antarctica, the Arctic and land near Arctic areas in the Northern Hemisphere.

TABLE 1 — Residence times for storages in New Zealand.

Storage	*Average stationary volume (km^3)*	*Average stationary volume per area covered (mm)*	*Average rate of outflow (mm/year)*	*Residence time*		*World residence time (years)*	
				(years)	*(days)*	*(Volker)*	*(Lvovitch)*
Ephemeral snow	7.7 (max.)	102	—	0.006	2	—	—
Permanent snow and ice	50	58 800	583	101	—	12 000‡	8 600‡
Interception storage	1.8 (max.)	7*	750	0.009	3	—	—
Lakes	405	132 500	750	177†	—		10
Channel storage	13.3	50*	1 481	0.033	11		0.032
Soil moisture	13.2	50*	600	0.083	30	1	1
Groundwater (baseflow)	1 392	5 250*	666	7.9	—	—	—
Deep groundwater	265	1 000*	—	—	—	10–300	5 000
Biological storage	0.27	1*	600	0.0017	6	—	—

* Over total area of New Zealand.

† Assuming lakes are unmixed.

‡ Includes Arctic and Antarctic ice.

CONCLUSIONS

From the study it may be concluded that in spite of possible large errors in estimates of precipitation, evapotranspiration and runoff in certain areas of New Zealand, the water balance as presented here gives a realistic estimate of the magnitudes involved. The storage volumes and residence times given for the various storages may show only the likely magnitudes involved, but at this stage they are a useful indication of the extent to which they affect the water balance.

It is postulated that the hydrological system of New Zealand never reaches actual equilibrium conditions, and that a storage factor should always be considered in water balance calculations. It is concluded that groundwater above the base level in New Zealand is likely to be the storage contributing most to storage changes.

The hydrological system of New Zealand is somewhat unusual because of extremely humid conditions which lead, with the exception of the deep lakes, to short residence times.

ACKNOWLEDGMENTS

The assistance of Mr M. R. Willcocks and Miss J. L. Raven with computations, and the valuable remarks made by Mr W. B. Morrissey upon reading the manuscript are gratefully acknowledged.

The work described in this paper was carried out in the Water and Soil Division of the Ministry of Works, and permission to publish the paper was given by the Commissioner of Works.

REFERENCES

Anderton, P. W. (in press): The significance of perennial snow and ice to the water resources of the South Island, New Zealand. *Journal of Hydrology (N.Z.) 12* (1).

Baumgartner, A.; Reichel, E. 1970: Preliminary results of new investigations of world's water balance. In: *World Water Balance, Proceedings of the Reading Symposium.* Studies and Reports in Hydrology 11. UNESCO, Paris, vol. 3.

Ehrlich, P. R.; Ehrlich, A. H. 1972: *Population, Resources, Environment.* 2nd ed. Freeman, San Francisco. 509 p.

Fitzgerald, P. D.; Rickard, D. S. 1960: A comparison between Penman's and Thornthwaite's method of determining soil moisture deficits. *N.Z. Journal of Agricultural Research 3*: 106–112.

Flohn, H. 1970: Comments on water budget investigations, especially in tropical and subtropical mountain regions. In: *World Water Balance, Proceedings of the Reading Symposium.* Studies and Reports in Hydrology 11. UNESCO, Paris, vol. 3.

Ibbitt, R. P. 1971: *Development of a Conceptual Model of Infiltration.* Hydrological Research Progress Report No. 5. Ministry of Works, Wellington.

Jackson, R. J. 1967: The effect of slope, aspect and albedo on potential evapotranspiration from hillslopes and catchments. *Journal of Hydrology (N.Z.) 6* (2): 60–69.

Kalinin, G. P. 1968: *Problems of global hydrology*. Moscow. 376 p. (in Russian.) Quoted in *World Water Balance, Proceedings of the Reading Symposium*. Studies and Reports in Hydrology 11. UNESCO, Paris, 1970. vol. 1. p. 103.

Kidson, E. 1932: *Mean Annual Rainfall Map of New Zealand*. N.Z. Meteorological Office, Wellington.

Lvovitch, M. I. 1971: *The Water Balance of the Continents of the World and the Method of Studying It*. Academy of Sciences of the USSR, Moscow. IUGG Assembly, 1971.

Morrissey, W. B. 1970: A review of hydrology in New Zealand. In: *Proceedings of the N.Z. Water Conference*. Part 1. p. 13.1–13.14.

Morrissey, W. B. 1972: Water resources of Egmont-Taranaki. Paper presented N.Z. Hydrological Society Symposium, Hamilton, 1972.

National Water and Soil Conservation Organization (in press): *Hydrological Research Report No. 28, Glaciology 1969–71*. Ministry of Works, Wellington.

Orvig, S. 1970: The hydrological cycles of Greenland and Antarctica. In: *World Water Balance, Proceedings of the Reading Symposium*. Studies and Reports in Hydrology 11. UNESCO, Paris. p. 41–49.

Pardé, M. 1966: Flow regimes of New Zealand rivers. *Journal of Hydrology (N.Z.) 5* (1): 2–19.

Reilly, W. I. 1965: The mean height and hypsographic curve for New Zealand. *Journal of Geology and Geophysics 8* (1): 128–139.

Rodda, J. 1971: *The Precipitation Measurement Paradox – The Instrument Accuracy Problem*. WMO/IHD Report No. 16. WMO, Geneva. 42 p.

Seelye, C. J. 1945: *Maps of Average Rainfall in New Zealand*. N.Z. Meteorological Office, Wellington. 16 p.

Szesztay, K. 1970: The hydrosphere and the human environment. Paper presented IASH Symposium, Wellington, 1970.

Toebes, C. 1967: The place of hydrology in New Zealand's economy. *Journal of Hydrology (N.Z.) 6* (2): 57–59.

Toebes, C. 1972: The surface water resources of New Zealand. Paper presented XII N.Z. Science Congress, Palmerston North, 1972.

USSR Committee for the IHD 1967: *Water Resources and Water Budget of the USSR Area*. Leningrad.

Volker, A. 1970: Water in the world. Paper presented IASH Symposium, Wellington, 1970.