METHODS OF OBTAINING HYDROLOGICAL EVIDENCE ON CLIMATE CHANGE

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In New Zealand hydrological data are classified in five broad categories: water resources, channel stability, floods, catchment condition, and suspended sediment or erosion measurements. A description of how the collection of data has been planned has been given elsewhere (Campbell 1960). The classification will assist the collection of evidence relating to climate change since confirmatory or contradictory evidence may be shown up by study of the different kinds of data.

The methods which can be used will depend on the observer having a good understanding of the meaning and interpretation of each kind of data and the subject is accordingly dealt with here in each separate category.

WATER RESOURCES

The data most commonly used to catalogue water resources are those of average annual discharge. This is the discharge which, if maintained uniformly throughout the year, would equal total precipitation less total evapotranspiration.

Such data give a more direct indication of climate than do other forms of hydrological data because they are relatively free from storm effects. Also, since the mean annual flow is reduced by increases in evaporation, they may occasionally indicate temperature changes as well as total precipitation. In mountainous areas of New Zealand, however, rainfalls are commonly from 100 to 300 in. and annual evapotranspiration (usually 25 to 30 in.) is not a very large influence.

Modern data on average annual discharges are available mainly from sites with relatively high discharges where the power potential is considerable.

Catchments with the highest discharges, as now measured (Ministry of Works 1962) are:—

Hutt River at Kaitoke	136 in.
Lake Pukaki	112 in.
Cobb River	99 in.
Motu River at Houpoto	96 in.
Lake Te Anau	94 in.
Buller River at Berlins	82 in.

Higher discharges undoubtedly occur in some un-measured rivers but most catchments will show lower discharges. Additional data covering all areas are now being obtained from a developing network of regional stations, and are being published in the Hydrology Annual as they become available.

The best prospects of finding evidence on mean annual flows of the past will probably be at lakes which, when large in relation to catchment area, greatly modify the influence of floods. In the Rotorua-Taupo area the absorbent deep pumice soils are an additional help in smoothing out the influence of floods. Records of lake levels in this area can therefore be interpreted to indicate the average annual discharge and hence the annual rainfall. The major fluctuations of Lake Rotorua over the period 1934–1962 (Fig. 1) show certain broad changes: rising levels 1934–38, low levels 1938–44, rising levels to 1952, and sustained high levels since then. These changes correlate reasonably with the cumulative departures of rainfall for the region given by Finkelstein (1963).

Evidence of the past existence of swamps or high water tables will be useful in much the same way as data on lake levels. It will, however, always be necessary to have present-day hydrological data at the same site to evaluate correctly the various factors.

In addition there will be slight possibilities of obtaining evidence on average annual discharges in rock-bound gorges, where the level of water surface for the average annual discharge is approximately on the line swept clear of vegetation.

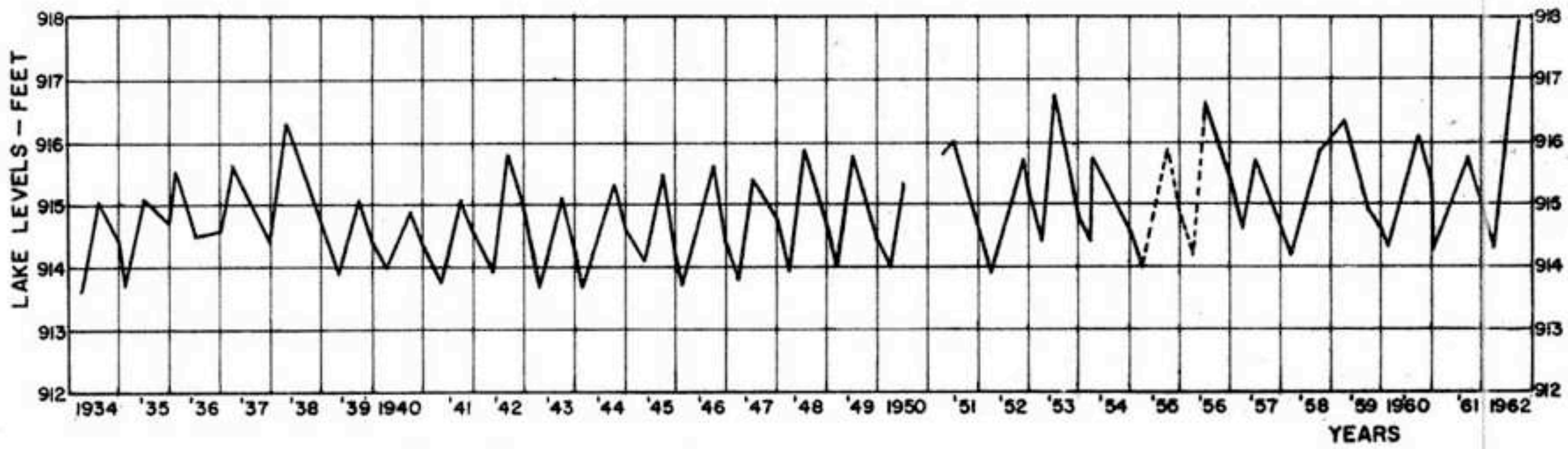

FIGURE 1. High and low levels for Lake Rotorua for the years 1934–1962.

FLOODS

Data on flood discharges indicate the magnitude of large storms rather than annual rainfall or its seasonal distribution. Further, if there is evidence of larger floods in the past, for the study of climate it is necessary to consider the probable cause of these larger storms.

In mountainous areas the largest storms will always be associated with severe orographic effects and therefore large floods may indicate high winds.

In all catchments, however, whether mountainous or of easy slopes, higher storm intensities will be associated with higher temperatures. The kind of variation to be expected may be seen in modern studies of the range of probable storm intensities from North to South of New Zealand as given by Seelye (1947). For example, daily rainfalls to be expected once in 100 years are 9.55 in. in Whangarei and 3.10 in. in Invercargill.

It is often said that large flood discharges may be due to lack of vegetation or generally poor condition of the catchment. This, however, is a misconception as it is only on quite small catchments that readily measurable changes in flood magnitude will occur as a result of changes in catchment condition (Campbell 1963). There may also be similar misconceptions about the extent to which melting snow contributes to great floods in New Zealand: few catchments are large enough for this to become a major factor.

Direct evidence of flood sizes will always be hard to find, but in rock-bound gorges lines of flood debris may be found in sheltered coves from which an approximate estimate of flood magnitude may be made (Toebes & Morrissey 1961). Such direct evidence is always likely to be scanty and a doubtful basis for firm conclusions.

Indirect evidence of flood sizes obtained from observations on stream channels is likely to provide a much more reliable source of information, and is described in the section on channel stability. The data necessary for this purpose are, however, only now being classified and observed in New Zealand.

Flood data cannot be interpreted as evidence of the precipitation causing floods without fully understanding the influence of other factors, notably catchment slope and shape, soil and cover, and intensity of precipitation. A method of estimating floods, which evaluates the effect of each factor, has been developed for New Zealand conditions by the Ministry of Works (1961).

In New Zealand, data on floods are published annually by the Soil Conservation and Rivers Control Council, and a summary by Parde (1960) has compared the flood characteristics of New Zealand catchments with those in other parts of the world.

CATCHMENT CONDITION

As a hydrological term, catchment condition refers mainly to flood-producing characteristics. The principal variable factors are soil and vegetation, and for flood estimation purposes a preliminary range of values applicable to various soil-cover complexes has been given by Campbell (1962).

Quantitative measurements defining catchment condition are possible, but recently introduced methods are as yet supported by little data.

CHANNEL STABILITY

Data on channel stability relationships in New Zealand are few but some measurements and provisional definitions have been made by Campbell and Caddie (In press).

The three primary items in channel stability measurements are dominant discharge, bed particle size, and channel characteristics including cross-section shape and slope. The first task is to establish the inter-relationship of these primary items, and then to study various aspects of channel behaviour; the radius of bends forming the channel alignment is of particular interest.

For geomorphic studies all these data are valuable, but for obtaining evidence on climate they are useful only as a means of deducing flood discharges and hence estimating the probable intensity of precipitation. For this purpose data on bed particle size are a guide, but quantitative flood discharges cannot be estimated unless the depth of flow and the water surface slope are also known.

Data on channel curvature are more useful. Provided they are derived from areas where channels have formed in incoherent alluvium, the channel curvature is not greatly affected by slope and may be used to deduce the "channel forming dominant discharge". Until more complete New Zealand data are available the relationship given by Grant (1948) provides a satisfactory method for deducing dominant discharge:

$$R = 1/6 \ \sqrt{Qr},$$

where R = radius of curvature in chains; Qr = dominant discharge in cusecs (commonly taken as a flood having a recurrence interval of 2 years); from which

$$Qr = 36\,R^2.$$

From the dominant discharge determined in this way, climatic data in terms of a rainfall factor can be derived using the formula given by Campbell and Caddie (1962).

To take a practical example: if, as has been suggested, the climate at Oamaru may once have been the same as the present climate at Hokitika, the ratio of past to present rain factors at Oamaru would be the same as that between the present factors at Hokitika and Timaru (3.7 : 1.5). The dominant discharge of streams at Oamaru would then have been 3.7/1.5 greater than today's values and the stable channel radius 1.57 times greater. From partly known relationships it can be concluded that stream beds would also have been different in other respects. The boulders transported could have been 25% larger than at present and streams would have run at flatter gradients, scouring at the upstream end of reaches and aggrading at the downstream end. Climatic changes should therefore produce noticeable landscape changes of which the best residual evidence is likely to be provided by channel curvature.

These effects will occur in channels draining catchments of considerable size, say of 10 square miles or more. On small catchments, say about 100 acres, the evidence of climate change could show up in another way, because the influence of catchment condition on the magnitude of flood runoff during storms is then severe (Campbell 1963). If the vegetation cover is for any reason lost, then much surface erosion is likely to take place producing rilling and substantial increases in stream density: these changes are likely to remain a permanent feature of the landscape.

SUSPENDED SEDIMENT AND EROSION

Sediment data will be available in various forms and their interpretation is likely to present more complex problems than occur in the interpretation of other hydrological data.

The standard measurement is of suspended sediment in flowing rivers, with results expressed as sediment rating curves. The gross changes which may occur when erodible catchments deteriorate are remarkable. Hundredfold increases may then be found. Moreover, unlike flood data, suspended sediment concentrations are not affected by the size of catchment.

Standard work now being developed will accumulate sediment rating data from which in due course the normal range of erosive characteristics for various soil cover complexes will be determined. This will give excellent opportunities for interpreting evidence from deposited sediments.

Meanwhile interpretation of data on sediment deposits presents a number of difficulties. It might be thought that increases in annual rainfall would automatically result in increases in sediment yields. This will be true wherever mudflows, mass earth movements and gullying occur, and these erosion forms are all fairly common in New Zealand. However, in more stable landscapes in the United States sediment yield is commonly at a maximum where annual rainfalls are in the range 10–14 in. (Langbein & Schumm 1958).

An example of careful tracing of sediment deposits has been published recently by

Croft (1962) in which an analysis is made of sediments in each of several deposits formed at various shorelines which existed during the recession of the Great Salt Lake. Opportunities for such useful studies may exist in New Zealand.

Sediment investigations clearly need a scale to give the approximate order of magnitude of total sediments transported by rivers. A suitable scale for general use in New Zealand catchments that are hilly to mountainous and with "fairly heavy rainfall" is:

TYPE OF CATCHMENT	TOTAL SEDIMENT TRANSPORT
Mainly hard rock. Large boulders common in stream beds.	1000 cu. yd. per sq. mile of catchment per annum.
Rock of intermediate hardness which breaks up readily in streams.	5000 to 10,000 cu. yd. per sq. mile of catchment annum.
Very soft rocks and many sources of fine materials, mudflows, etc.	50,000 to 100,000 cu. yd. per sq. mile of catchment per annum.

Surveys to measure actual accumulations in reservoirs and aggradations in river beds are being made and more accurate scales will be available in due course.

In the study of deposits of total sediment, allowances must be made for the ability of rivers carrying coarse materials to sort the sediments and to deposit most of the coarse sediments in a narrow belt while spreading fine sediments over a wider area. A hydrologist would suspect the probability of such a process in the Orari river sediments (Raeside 1948). Similar deposits have been observed by the author in the lower Tauherenikau, where several fingers of a delta system having coarse material on the old channels can be seen in an area where most of the sediments are quite fine. In such circumstances these coarse deposits probably form less than 25% of the whole quantity of sediment transported by the river.

CONCLUSIONS

Long term data on the Nile have been summarised by Hurst (1952). Even here, where observations of major fluctuations in river flow date back to 622 A.D., no very definite evidence can be found on climate change.

The conclusion is that direct opportunities will be few, but that hydrological studies will help to evaluate evidence of climate change obtained in other ways. For instance, modern hydrological data will show the inter-relationship of climate, catchment conditions, and erosive effects following which the sequence of events likely to result from any given circumstances can be deduced with confidence.

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