DRAINAGE DENSITY REPRESENTATION ON WELLINGTON MAPS

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ABSTRACT

Drainage densities for samples of grid-square unit areas in NZMS 1 (1:63 360) and NZMS 2 (1:25 000) maps of the Wellington Peninsula are statistically compared with values derived from large-scale aerial photographs. The NZMS 1 and aerial photograph values correlate at a low level ($r=+0.41$), implying that actual drainage densities cannot be determined from the NZMS 1 maps. In the eight NZMS 2 maps, mean drainage density representation is 86 percent of the aerial photograph values, but variations of drainage density from square to square within each map are inadequately represented in most maps. Maps contoured on a multiplex instrument are shown to be relatively poor, and even the single map drawn on a Wild A6 instrument is less adequate than the maps contoured in the 1940s. Thus, it cannot be assumed that drainage density representation improves with technical advances in photogrammetry. It is concluded that no NZMS 2 map should be used for drainage density measurement without prior checking against aerial photographs or field reconnaissance data.

INTRODUCTION

Morphometric data derived from untested sources (and therefore of unknown validity) are, unfortunately, occasionally fed into sophisticated computer programmes, or otherwise used by hydrologists. The obvious example of such data is drainage density figures extracted from published topographic maps.

Drainage density (stream length per unit area) is usually the first to be quoted in any list of indices used in fluvial morphometry or drainage basin analysis. It is an indicator of the texture of dissection of a landscape and is clearly of importance to hydrology in, for example, the ratio of overland flow to throughflow in river discharge – particularly peak discharges.

A great number of drainage density measurements have been published from all environments where streams are present. Selby (1967) lists values ranging from 1.86 km/km^2 to 820 km/km^2. In

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quoting Selby's table of drainage densities, Doornkamp and King (1971, p. 32) state, however, that "these values are not entirely comparable for they have been measured in a variety of ways". Much of the potential utility of the index is not being realized because of lack of standardization and the fact that many authors do not attempt to evaluate the adequacy of stream representation in their source materials, usually published topographic maps. Some studies of map accuracy have been made (Coates, 1958; Eyles, 1966; Miller, 1953; Morisawa, 1957; Selby, 1967) and in no case have maps of scale smaller than 1:25 000 been found to represent adequately the smaller-order streams of the drainage network.

Not only are comparative studies difficult at present, but erroneous conclusions have been drawn from data extracted from unsuitable maps. An example is Horton's conclusion that "the bifurcation ratio is generally higher for hilly, well-dissected drainage basins than for rolling basins" (Horton, 1945, p. 290). It has since been shown that the bifurcation ratio is highly stable under a wide range of relief conditions.

No tests of the adequacy of stream representation on New Zealand 1:25 000 (NZMS 2) or 1:63 360 (NZMS 1) maps have been published. In a recent paper concerned with hydrological regions in Northland the authors state "for the determination of maximum channel order, bifurcation ratio, and drainage density, there was insufficient detail on NZMS 1 maps. Although aerial photographs were a source of extremely detailed drainage networks, their use on such large catchments proved to be impracticable. The method finally adopted was to use the NZMS 1 maps and draw in streams wherever the contours suggested. This method, although not producing absolute results, should give a good basis for comparison between catchments" (Blake *et al.*, 1970, p. 198).

The NZMS 1 series is multi-purpose in design with no special emphasis on stream representation, thus the assumption that drainage densities calculated from NZMS 1 maps will be proportional to the actual drainage densities is questionable and has prompted the present paper in which maps of the Wellington area are tested for accuracy against a stream map derived from vertical aerial photographs.

WELLINGTON MAPS

The area now under consideration is shown in Fig. 1 to be bounded to the east by Port Nicholson and the Hutt River, to the north by Porirua Harbour, and to exclude Wellington City, Tawa Borough, and Porirua City, where urban development has destroyed or masked the natural stream system.

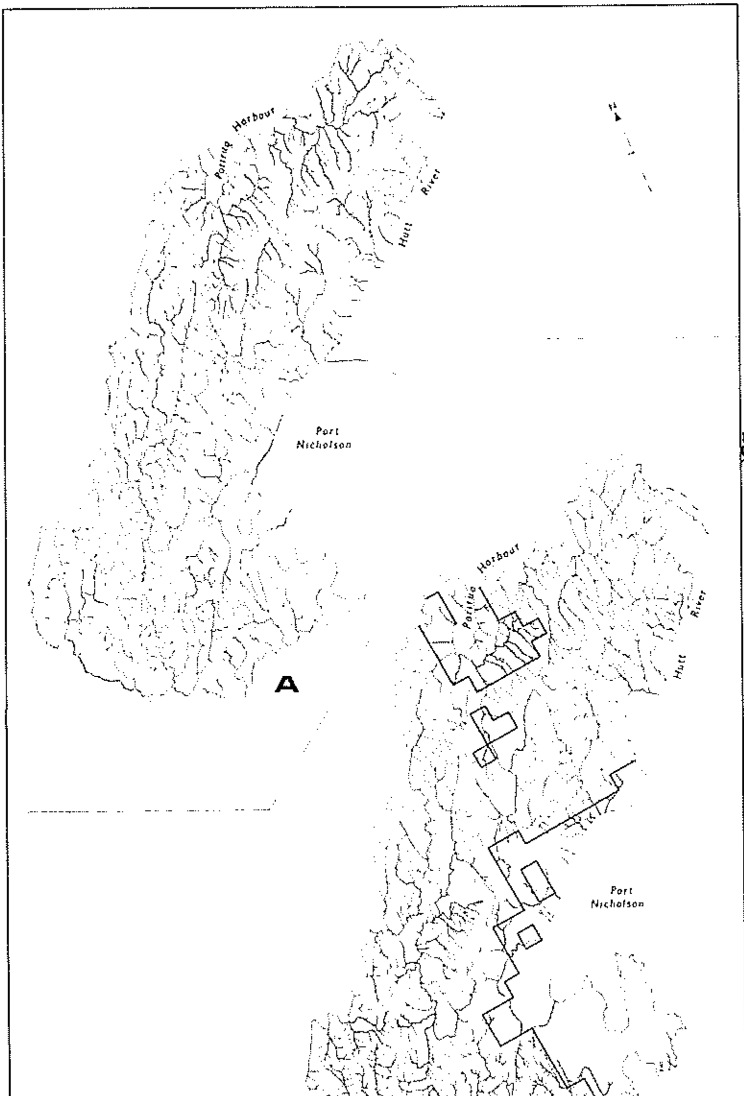

FIG. 1 — Two stream network maps of the Wellington area: (A) from the aerial photograph map compiled by the writer; (B) from NZMS 1 sheets N160 and N164. The streams in A are order 3 or higher (Strahler, 1952).

The area is represented on two NZMS 1 and on eight NZMS 2 sheets contoured by a variety of methods (Table 1). Sheets N160/6 and N160/9 have not been published and were used in plan-print form.

TABLE 1 — Topographic maps of Wellington.

Sheet	*Scale*	*Contour interval (m)*	*Date of publication*	*Method of contouring*
N160	1:63 360	30	1965	multiplex
N164	1:63 360	30	1967	ZD 15
N160/5	1:25 000	15	1942	ZD 15
N160/6	1:15 840	15	–	multiplex
N160/8	1:25 000	15	1943	ZD 15
N160/9	1:25 000	15	–	Wild A6
N164/1	1:25 000	15	1942	ZD 15
N164/2	1:25 000	15	1952	ZD 15
N164/4	1:25 000	15	1941	ZD 15
N164/5	1:25 000	15	1965	ZD 15

C. A. Cotton, in his series of papers on the Wellington landscape, several times mentioned topographic maps and was quite certain that they could not be used for detailed measurements. For example, referring to NZMS 1 sheets he states "this map, though useful for location and for altitudes, affords less help than might be expected. Because of the small scale it naturally fails to show with any approach to accuracy the details of an extremely fine-textured erosional relief" (Cotton, 1956, p. 762). And again, "reliable measurements for the determination of drainage density cannot be made in New Zealand, at any rate in the southern part of the North Island, on the available topographic maps, because the contour lines on these are smoothed, the minor details of landform being neglected" (Cotton, 1964, p. 349).

One of the variables which can influence map accuracy is, of course, the character of the topography to be mapped, particularly its texture of dissection. Cotton often described the Wellington landscape as "extremely fine-textured" or "feral" but only documented this by the single estimate of actual drainage density as being "at least as high as 25" (15.5 km/km^2) (Cotton, 1964, p. 349). This contrasts markedly with the maximum value of 10.9 km/km^2 and the mean value of 6.8 km/km^2 obtained from grid-square unit areas by the present writer using photographs of similar scale to those used by Cotton.

STREAM CHANNEL DEFINITIONS

A basic difference in the definition of what constitutes a stream channel is apparent here. This illustrates another general reason for most published drainage density data not being comparable; different rules of thumb exist about whether or not channels are present in gully thalwegs and how far headward to extend channel traces. This problem is particularly important for the Wellington landscape, which contains many 'fossil gullies'. "Most of the gullies of finely dissected hillslope reliefs of possibly precryergic date, and more certainly gullies eroded in intercryergic ages, have thus been

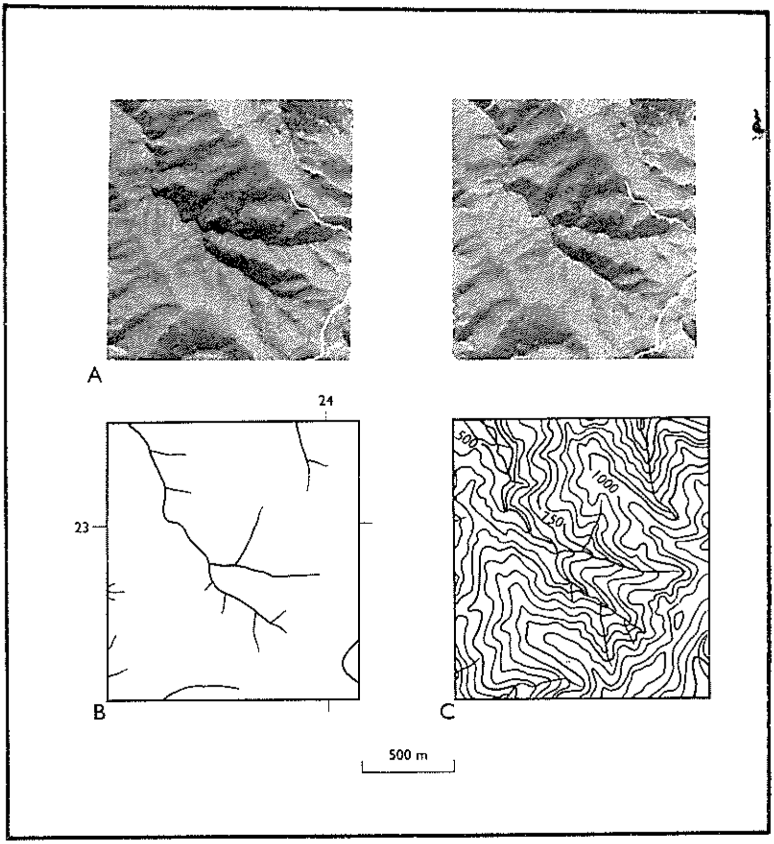

FIG. 2 — (A) Stereogram of typical Wellington hill country, 'feral' in the sense of containing sharp-crested ridges, yet with a relatively low density of active stream channels. (B) The stream pattern inferred from the stereogram. (C) The contour representation on sheet N164/1 and the inferred stream pattern (contours in feet).

eliminated throughout the Wellington district. Innumerable hillslope gullies have been completely infilled and so concealed" (Cotton, 1957, p. 420).

Fig. 2 shows a number of partly infilled gullies which are gently concave in cross section and are 'fossil' in the sense that they do not now contain active stream channels. Cotton may have included some of these gullies in his estimate of drainage density. The present writer follows Melton's definition of a stream channel as being "a permanently clearly defined trench or trough clearly showing evidence of scour by channel (linear) flow and bounded by valley sides sloping towards the channel axis" (Melton, 1957, p. 1).

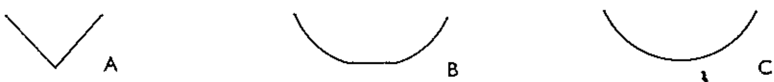

FIG. 3 — Valley cross sections: A and B contain active stream channels, C does not.

Figs. 3(A) and 3(B) show the cases in which a stream channel is present; there must be a discontinuity of cross-sectional slope at the gully thalweg. Stream channels thus defined were measured from 1:16 000 aerial photographs by means of a mirror stereoscope with a magnification attachment of factor three. This method was adopted because the vegetation over most of the area studied is grass or open scrub and the ground surface could be easily seen, and there was little accelerated rill or gully erosion. Ravines on the sea cliffs bordering much of the south and west of the area were specifically excluded.

PHOTOGRAPHIC MAP

The photographic stream map was built up from stereopairs, with the stream pattern being traced on a transparent overlay for the left-hand photograph of each pair to give a strip covering each east–west flight run. Each channel was at this stage represented by two traces. East–west corrections for altitudinal and radial scale changes were effected by drawing each channel midway between the two initial traces. North–south corrections were similarly made from the overlapping portions of successive transparent strips. The grid from the NZMS 2 map series was then placed on the final map to allow the scale variations which still remained to be accommodated in length and area measurements.

This method gave stream representation within the limits of accuracy of length measurement (dividers set at 0.1 inch, 2.5 mm).

STATISTICAL METHOD

Drainage density values derived from the 1:63 360 and 1:25 000 topographic maps were compared separately with values based on the photographs (Table 2).

TABLE 2 — Comparison of map and aerial-photograph drainage densities (km/km²) for a sample of 20 unit areas on each of N160 and N164.

	N160		*N164*	
	Mean	*Standard deviation*	*Mean*	*Standard deviation*
Photo.:	7.45	0.845	3.56	0.683
Map:	3.77	0.434	6.05	0.960

A random sample of 20 unit areas each consisting of four adjacent grid squares was chosen from each of sheets N160 and N164. Stream channels were inferred from contour notches, measured, and drainage density values calculated for each unit area. Map representation ranged from 39 percent to 79 percent of the actual drainage density values for the 40 unit areas, mean representation being 51 percent on sheet N160 and 59 percent on sheet N164.

Fig. 4 shows the relationship between map and photograph drainage density values, the product-moment correlation coefficient (r) being $+0.41$. Though this is statistically significant,* it has little predictive value. The coefficient of determination (r^2) of 0.17 indicates that only 17 percent of the variation in photograph drainage densities is reflected by the map values. Sheets N160 and N164 must therefore be considered as completely unsuitable for drainage density calculations.

TABLE 3 — Comparison of map and aerial-photograph drainage densities (km/km²) for 1:25 000 sheets.

Sheet	*No. of grid squares*	*Map drainage density*		*Photo. drainage density*	
		Mean	*Std. dev.*	*Mean*	*Std. dev.*
160/5	6	5.83	0.92	5.82	0.82
160/6	15	5.17	1.08	8.48	1.16
160/8	15	7.10	0.58	7.11	1.24
160/9	15	5.92	0.71	7.48	1.18
164/1	15	5.06	0.79	5.35	1.13
164/2	15	6.10	0.72	5.94	1.16
164/4	13	4.11	0.79	4.78	1.54
164/5	15	5.46	0.77	6.21	1.26
overall:	109	5.60	1.16	6.47	1.69

* All statistical tests use the 0.01 level as the critical level of significance.

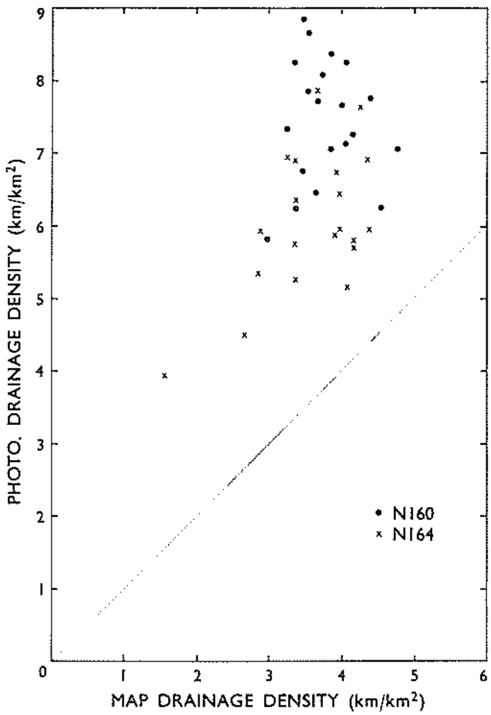

FIG. 4 — Scatter diagram of NZMS 1 and photograph drainage densities for a random sample of 40 units.

A second sample of grid squares was chosen randomly from the 1:25 000 maps (Table 3). In sheets N160/5 and N164/4 all the grid squares which included no sea were measured. The overall mean representation of drainage density on the maps is 86 percent of the value derived from the aerial photographs. An F test established that the mean value of 5.60 km/km^2 was significantly less than the mean 6.47 km/km^2, but similar testing on the individual maps revealed that significant differences between mean map and photograph values occurred only in sheets N160/6 and N160/9. The grid squares from these two sheets show up clearly in Fig. 5. The overall product-moment coefficient (r) is shown in Fig. 5 to be $+0.53$. This is substantially improved to $+0.74$ by the exclusion of sheets N160/6 and N160/9, but even then predictability of map drainage density values is only $r^2 = 0.55$, meaning that for individual grid squares only 55 percent of the variations in drainage density of the photographs is reflected by map-square grid values. The maps

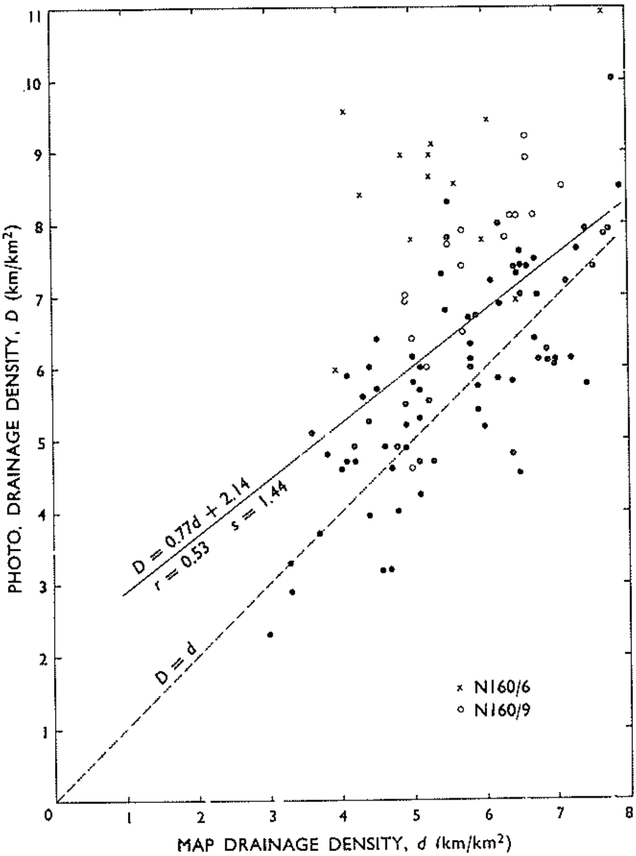

FIG. 5 — Scatter diagram and linear regression for 109 sample NZMS 2 grid squares, drainage densities being measured from the maps and aerial photographs.

(other than N160/6 and N160/9) can therefore be used to obtain mean drainage density values for large areas, but not to obtain satisfactory drainage density figures for areas as small as the 914-m (1000-yd) grid squares. This is emphasized by the fact that in seven of the eight sheets the standard deviation of drainage densities is less than the corresponding photograph drainage density standard deviations (Table 3). In five sheets (160/8, 160/9, 164/2, 164/4, 164/5) according to a z test this difference between standard deviations is significant, implying that most sheets tend to be insensitive to changes of drainage density within the map area (Fig. 6). It must therefore be concluded that the 1:25 000 maps cannot be used for anything other than a crude estimate of mean drainage density over a large area.

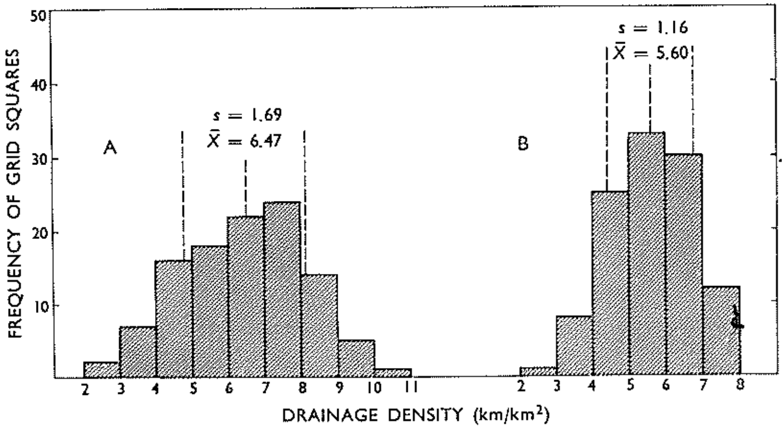

FIG. 6 — Histograms of drainage density values measured from the sample of 109 grid squares. (A) Photograph values; (B) NZMS 2 values.

REASONS FOR MAP INADEQUACY

There appear to be four main reasons for the inadequacy of Wellington contour maps in representing drainage density. The most obvious concerns the scale and contour interval of the maps. The amount of detail possible in a 1:63 360 map is limited and this, coupled with the contour interval of 30 m (100 ft) and the amount of inter-contour relief in the landscape makes it unreasonable to expect any approach to complete stream representation in the two NZMS 1 maps. This is also true to some extent in the 1:25 000 maps with their contour intervals of 15 m (50 ft). The recently published maps also suffer in comparison with those published in the 1940s (Table 1) in that fewer stream channels are marked with blue lines. This reflects a policy change in the Lands and Survey Department towards representation of more cultural detail in maps.

The character of the landscape will also influence map representation of streams. This factor is illustrated in Fig. 7, where mean contour spacing is assumed to be inversely proportional to the average slope of the grid square concerned. The difference between photograph and map drainage densities correlates significantly with average slope at $r = -0.40$, implying that map representation of drainage density improves as average slope increases, and therefore as contour spacing decreases. Thus, sheet N160/6 which contains the greatest under-representation of drainage density also has the smallest average slopes. This sheet covers the area just south of Pauatahanui Inlet where the landscape includes many flat-floored aggraded valleys and low convex interfluves and yet has a relatively high drainage density.

There is, however, no relationship between residual drainage density and average slope for grid squares within sheet N160/6 (Fig. 7), which leads to a consideration of the two other factors tending to cause differences from map to map. The first of these is the method of contouring and the second can be termed 'operator variability'.

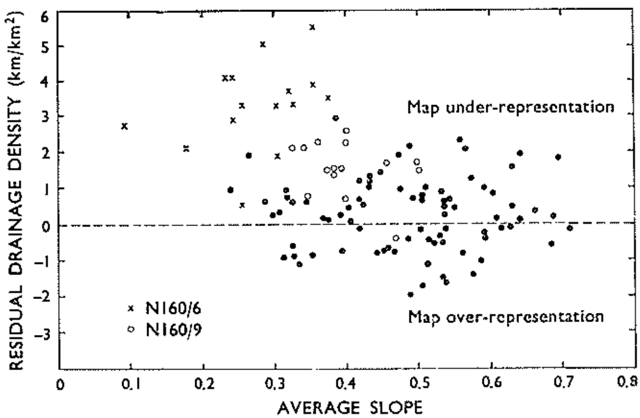

FIG. 7 — Residual drainage density (photograph value less map value) for each of the 109 grid squares in the NZMS 2 sample plotted against average slope for each square (Wentworth, 1930).

Three different photogrammetric procedures have been used to contour the NZMS 2 maps of Wellington (Table 1). All the sheets actually published (including N164/5, the 1965 edition of which merely repeated the contour pattern of an earlier edition) were contoured in the 1940s by use of an early photogrammetric instrument called the ZD 15. Planimetric control was achieved by radial line plots, and altitude control by aneroid barometric surveys in the field. The advantage of the ZD 15 instrument seemed to be the direct ink tracing of streams on to large-scale (1:15 840) photographs under the stereoscope mirrors. Sheet N160/6 was contoured on a multiplex instrument and sheet N160/9 on a more sophisticated Wild A6 machine. The Wild A6 allows for more precise contouring than the multiplex, in which plotting is done from enlarged stereoprojected images which reduce the clarity of the aerial photographs.

Drainage density representation on the single sheet contoured by multiplex was much poorer (Table 3) than on any other sheet; to check whether or not this was coincidental, unpublished plan prints of sheets 160/5 and 160/8 contoured by multiplex were procured and measurements taken for the 21 sample grid squares. The mean drainage density of 5.52 km/km^2 was found by an F test to be significantly lower than the 6.74 km/km^2 for the same squares in the published maps. This supports the view that representation of small streams is likely to be poor on maps contoured by the multiplex method.

Operator variability is obviously the most difficult factor to assess. Wide differences of interpretation are possible in the representation of minor features such as small streams while still conforming to general specifications that heights be accurate to within one half the contour interval of the map. The quality of an instrument operator's work may also vary with health, experience and other factors affecting his concentration. The impressive accuracy of drainage density figures from the old maps may be in part due to this second group of factors. The present-day operator is usually younger than his predecessors and may have had only a short period of training with emphasis on output rather than on selective interpretation. He has little time to spend on appreciation of the landscape he is depicting. Although overall accuracy of modern maps is high, this lack of awareness must result in omissions such as the fine details of the drainage pattern.

CONCLUSIONS

While this paper considers only the two NZMS 1 and eight NZMS 2 maps of the Wellington area, there is no reason to suppose that either these maps or the landscape are unique, and the following general points can therefore be made concerning calculations of drainage density:

1. 1:63 360 NZMS 1 maps should not be used at all.
2. Adequacy of stream representation on NZMS 2 maps does not necessarily improve with technical advances in photogrammetry.
3. Multiplex-derived maps are likely to be suspect.
4. Drainage-density changes over the areas covered by individual NZMS 2 sheets tend not to be fully represented.
5. No map should be used without at least a pilot check of stream representation against aerial photographs, or field reconnaissance data.

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