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AN ILLUSTRATION OF "AQUACODING" NEW ZEALAND WATERWAYS

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ABSTRACT

A logical coding system ("aquacoding") devised by A. G. Barnett for New Zealand waterways is presented. This system permits computer searches for all archived points either upstream or downstream of specified waterway locations. To illustrate how the aquacoding system works arbitrary criteria are selected and applied to aquacode water-level recording sites. Eighty per cent of water-level recording sites are allocated aquacodes by a combination of manual and computer-based techniques. Implications for future aquacoding arising from this illustration are discussed.

INTRODUCTION

New Zealand waterways have, in the past, been identified only by names and, in some cases, by numbers (e.g. river and tributary numbers, SCRCC, 1956; water-level recording site numbers, Walter, 1990). None of these identifiers indicate the connection between one part of a waterway and another. A coding system which allows immediate identification of upstream and downstream points of waterways would be useful, particularly for computer modelling of water quality and floods.

The present numbering system for water-level recording sites is not logical, e.g. in the Hutt River basin (Fig. 1), which is numbered 298, site 29808 is upstream of 29818, but 29809 is downstream of 29818. Even if the site numbers were reallocated more logically, there still remain the problems of inserting future sites, and catering for other points of interest on waterways (e.g. reaches, water quality monitoring sites, braids).

To overcome these difficulties, the "aquacoding" system was devised in the early 1980s by A. G. Barnett, for a water quality archiving software study (AQUAL, McBride and Shankar, 1989). The object was to provide unique codes for potential collection sites for water quality samples such that the spatial relationships between sites can be readily determined by computer. Points on New Zealand waterways can be allocated these "aquacodes" so that computerised upstream and downstream searches can be conducted and future aquacodes inserted without affecting earlier coding (see Barnett, 1987a, 1987b; Appendix D of McBride and Shankar, 1989). A system with similar purpose has been set up in Victoria, Australia (Nason *et al.* 1989). Other work in New Zealand on this topic includes a numbering system proposed by Woods (1983).

This paper presents a general outline of the aquacoding system, and discusses how it might be implemented for New Zealand waterways, particularly for water-level recorders.

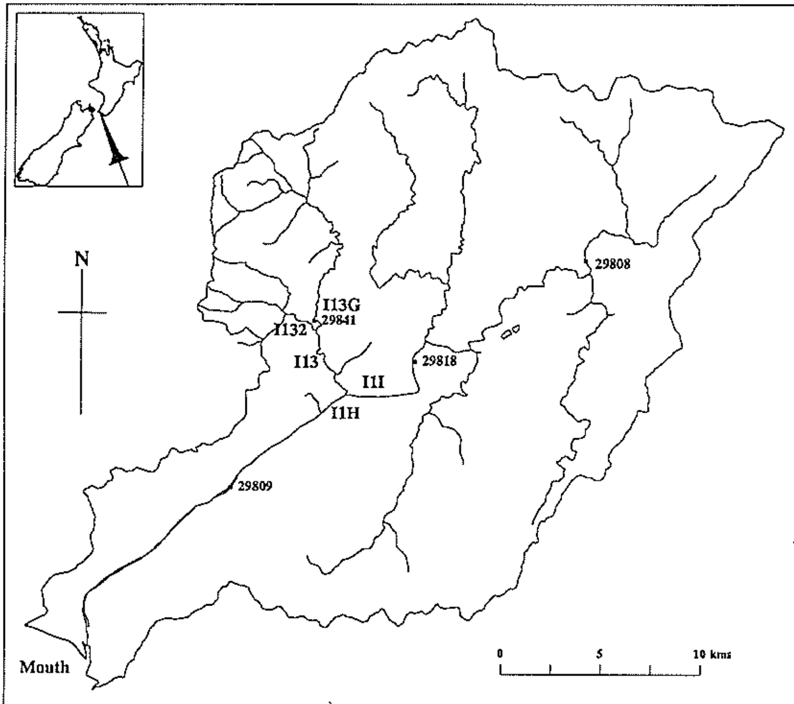

FIG. 1—The Hutt River and its water-level recording sites 29808, 09 and 18. The aquacode for this river is designated I1. The Whakatiki River (I13) tributary and water-level recording site 29841 are also shown.

THE AQUACODING SYSTEM

An aquacode consists of an alphanumeric sequence of characters, generated from left to right.

Digits and letters represent features as follows:

Digits — represent *complete* river systems, river main channels, river tributaries or lakes

Letters — represent *subdivisions* (termed zones) of the coast, rivers, river tributaries or lake perimeters. Each zone can be further subdivided until the required precision of location is obtained.

The coding process is systematic, beginning at the coast and then analysing the river system layout.

1. The Coast

The combined coastlines of the North and South Island can be split into 25 zones and labelled A to Y. Z is used for islands other than the North and South Island. Each coastal zone (say Y) can be subdivided into 25 sub-zones YA to YY. The subdivision may be repeated as necessary.

Thus, a coastal zone, or sub-zone, is defined by the letter(s) preceding the first digit of an aquacode.

2. The River

(a) At the Coast

Digits 1 to 9 are assigned directly to 9 major rivers to reduce the length of code required for a large number of sites. If an aquacode begins with a digit, it is immediately recognisable as being some part of that river system.

In all other cases, a particular river system is represented by the coastal zone code plus the first digit. The digit chosen roughly indicates the percentage distance along a coastal zone or sub-zone (in a clockwise direction) at which the river meets the sea. Thus, river M6 would intersect the coast 60% along coastal zone M.

River mouths may form convenient junctions between two sub-zones of a coastal zone. The two sub-zones are then defined using the key alphanumeric sequence:

ABCD1EF2GH3IJ4KL5MN6OP7QR8ST9UVWXYZ

Thus, there are two sub-zones between each digit, and four and six at the left and right ends respectively. Using the sequence, digit 6 lies between letters N and O; therefore river M6 would enter the sea between coastal sub-zones MN and MO. Similarly, river PK2 would intersect the coast between coastal sub-zones PKF and PKG. This sequence is used repeatedly in the aquacoding system when subdividing coastal zones and river reaches.

(b) Along the River

The main channel is identified from coast to source. This is then divided into 22 reaches, assigned the letters C for the most downstream reach to X for the furthest upstream. The letters A and B are reserved for estuaries, and Y and Z for special purposes, such as channels with braided patterns. Applying the key alphanumeric sequence, up to 9 major river tributaries may be given single digit codes and form the boundaries between river reaches. Which tributaries get single digit status depends on their location along the channel and their size relative to nearby tributaries. For example, the Hutt River catchment (Fig. 1) is assumed to be river I1. The Whakatiki River is a tributary entering the Hutt River at approximately 30% of the way from its mouth to its source. It could therefore be assigned the code 3. Thus, its aquacode would be I13, and it would enter the Hutt River at the boundary between reaches I1H and I1I.

The Whakatiki River (I13) could itself be subdivided into 22 reaches labelled C to X. The water-level recording site 29841 (Fig. 1) might be in sub-reach

G of I13, and hence it could be coded I13G if this level of resolution (i.e. 12 km / 22 = 500 m) is satisfactory, or I13GM (25 m) or I13GMC (1 m). The tributary of the Whakatiki River entering downstream of site 29841 (Fig. 1) could be coded I132, as it enters the Whakatiki River at around 20% of its length. I132 can be subdivided into 22 reaches C to X etc.

(c) Lakes

For lakes, the digit 0 is used for aquacoding. For example, if a lake is reach R of a river's main channel, the lake edge aquacodes begin R0, prefixed by the river aquacode. Lake-edge zones are coded anticlockwise around the lake, starting from its outlet, and are defined as being upstream and downstream of each other.

Unlike NZ Meteorological Service grid references, aquacodes do not define exact spacial *locations.* Their purpose is to allow determination of spatial *relationships.* For example, tributary stream AS35 enters river AS3 upstream of tributary AS32 and downstream of reach AS3Q (from the key alphanumeric sequence), but the exact location of AS35 is not inferable.

EXAMPLE OF AQUACODING

System Specifications

As an example of implementing the aquacoding system it was necessary to (somewhat arbitrarily) specify New Zealand coastal zones, nine major rivers, and criteria for selecting the main channel of any river.

Initially Barnett (1987a) defined the boundaries between the 25 coastal zones using the old (pre-October 1989) catchment authority boundaries. For this illustration of the aquacoding system, political boundaries have been arbitrarily ignored, and the letters spread evenly around the North and South Islands, retaining Z for other islands. The coastal zones are shown in Figure 2 and are each approximately 300 km long.

The major rivers which do not need a coastal zone were chosen on catchment area (to the sea) alone. If two were in one coastal zone (e.g. Buller and Grey Rivers in coastal zone Y in Figure 2) then only the larger was given a single character river code (hence Buller is 6 and Grey is Y1). The major rivers with their aquacodes are given in Table 1 and shown on Figure 2.

In this illustration the key aquacode sequence has not been adhered to for the single letter coastal zones and the nine major rivers, e.g. major river 2 (Waikato) does not define the boundary between coastal zones F and G (Hawkes Bay) etc. To have done this (if it were possible) would only have the advantage of presenting an elegant system; the disadvantages would have meant a combination of widely varying coastal zone lengths and some minor rivers defined as major rivers.

Selection of the main channel of a river in this example was assisted by considering stream-lengths and Strahler (1964) stream-orders, both available from Department of Survey and Land Information (DOSLI) digitised maps at scale 1:250000. Moving from the downstream boundary of a river, defined by either the coast, an estuary, a lake or the river's confluence with a larger river, the first part of the main channel is taken as the path which leads to the first upstream confluence. Here the sums of stream-lengths upstream of each branch

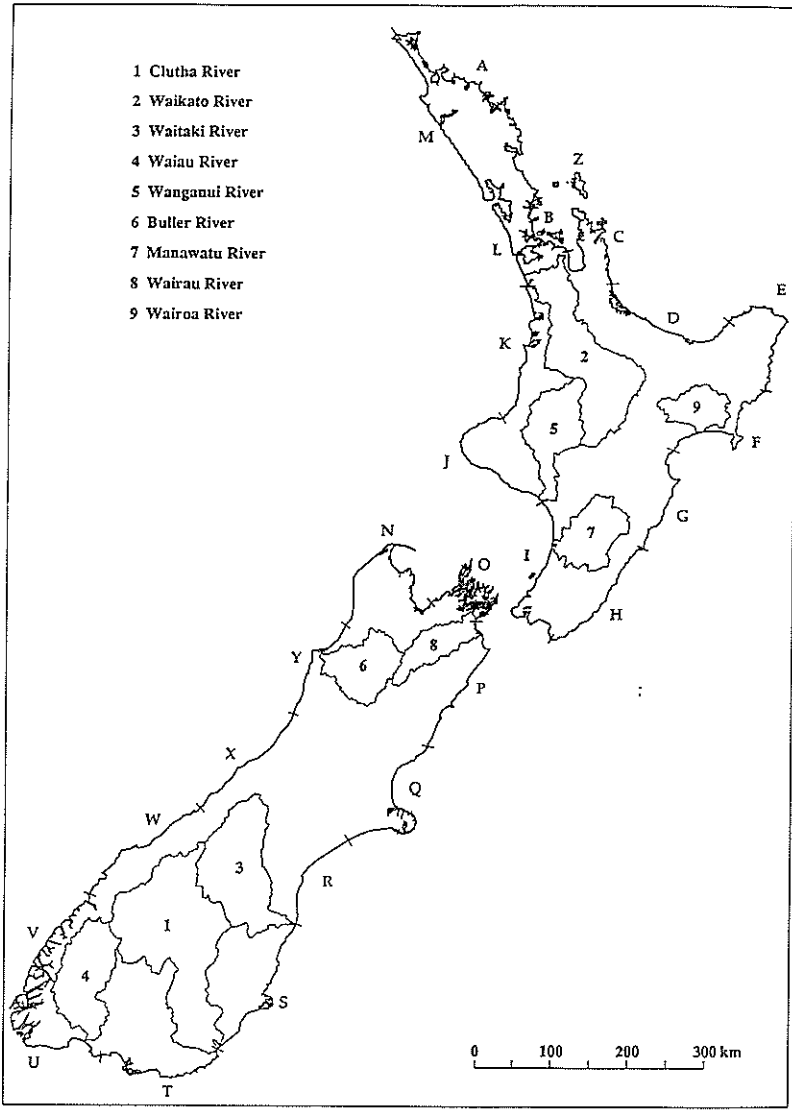

FIG. 2—The New Zealand coastal zone aquacodes and nine major rivers used in this illustration. Coastal zones are delimited at the left bank of river-mouths when rivers define boundaries, e.g. Waikato River and coastal zones K and L.

TABLE 1—Major rivers for aquacoding determined by catchment area. Catchment areas to the sea from M. J. Duncan (pers. comm., 1990).

River Name	Catchment Area (km^2)	River Aquacode
Clutha	21100	1
Waikato	14500	2
Waitaki	12000	3
Waiau (Southland)	8200	4
Wanganui	7130	5
Buller	6480	6
Manawatu	5970	7
Wairau (Marlborough)	4190	8
Wairoa (Hawkes Bay)	3680	9

entering the confluence are compared. The main channel route is decided if one sum is less than 70% of the larger sum, i.e. the branch with the much larger sum is taken as part of the main channel. Otherwise, the appropriate path for the continuation of the main channel is the branch which has the greater sum of upstream stream-orders multiplied by stream-lengths. This approach was used as a surrogate for comparison of upstream catchment area, which would have required much more effort to compute. The main channel is completely specified when the last confluence has been considered.

Major tributaries off any reach were selected using Strahler stream-orders as surrogates for catchment area. A major tributary can be defined as a tributary having stream-order either equal to or one less than the reach it enters at their confluence. At the same time, the spacing of tributary junctions along the reach should be considered. For example, if a major tributary is specified as 4, the key sequence forces the downstream and upstream sub-reaches to be J and K. Selection of 9 or fewer major tributaries should therefore consider both their relative size and their spacing with respect to the key alphanumeric aquacode sequence.

Aquacoding Water-level Recording Sites

A computer algorithm was devised along the lines described in the previous section, and used to aquacode water-level recording sites using DOSLI databases of river networks derived from 1:250000 topographical maps and geographic information software (POLAR, U. Shankar, pers. comm., 1990). Networks with complications, for example lakes or braids, were manually coded up to a point where the upstream drainage pattern could be handled by the computer algorithm.

For this example water-level recorder site aquacodes were defined by resolving site reaches to a length of about 10 m. For sites on lakes, lake sub-zones were defined to approximately 10 m. Site aquacodes thus became long, particularly for sites on tributaries of tributaries of rivers. Length of aquacodes is addressed in the Discussion section.

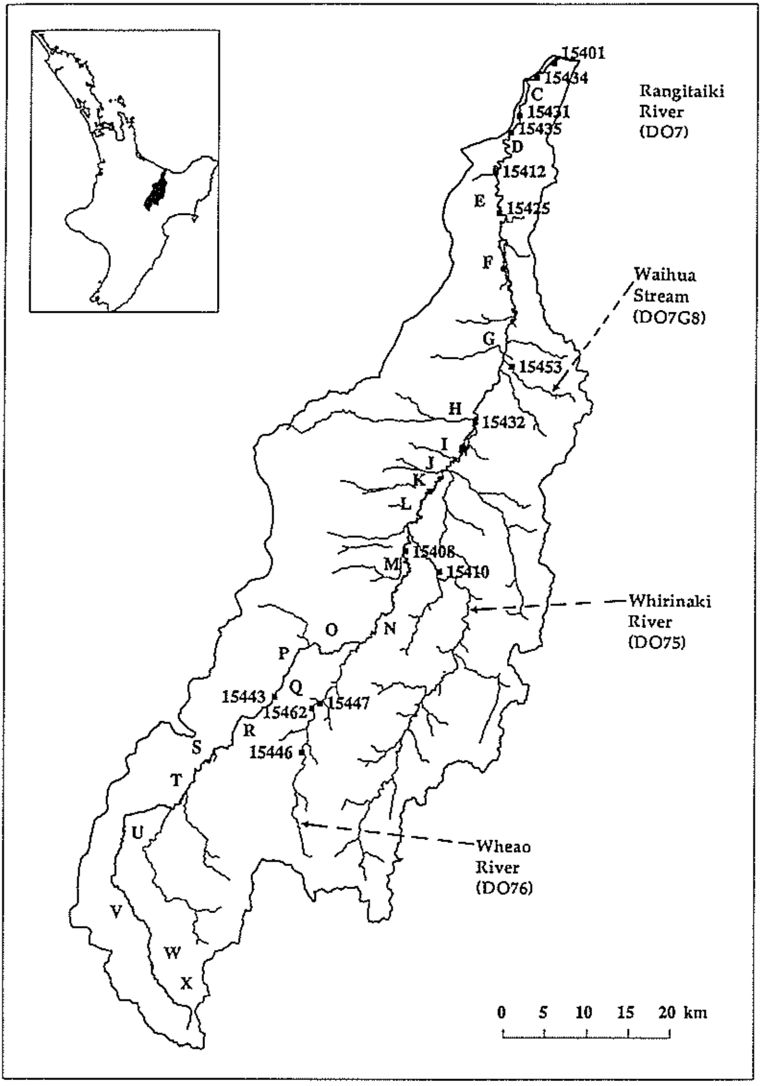

FIG. 3—Rangitaiki River catchment, Bay of Plenty, showing Strahler (1964) second and higher order streams from 1:250000 scale and water-level recording sites. The 22 aquacode reaches of the main channel are labelled. Their exact boundaries are only defined at major tributaries 5 and 6 — the remainder are not required for the present illustration. Similarly, only tributaries 5 and 6 required definition. Aquacodes for water-level recording sites are given in Table 2.

As an illustration, Figure 3 shows the Rangitaiki River catchment which discharges into Bay of Plenty, North Island. Water-level recording sites are marked on the map with their site numbers. The Rangitaiki River was aquacoded DO7 since it intersects the coast 70% of the way along coastal sub-zone O, in coastal zone D. The main channel of the Rangitaiki River (bold) heads up beyond its confluences with the Whirinaki and Wheao Rivers. The Whirinaki River is defined as major tributary 5 (i.e. DO75) and the Wheao River is major tributary 6 (i.e. DO76). Back downstream in main channel reach G, Waihua Stream is aquacoded as major tributary 8 entering this reach (i.e. DO7G8). Once the water-level recording sites are identified as being in specific reaches on these rivers and streams, then sub-reaches and sub-sub-reaches are further identified for each site to ensure the site reach lengths are of the order 10 m. The aquacodes for each site are given in Table 2.

Some tributary streams to reaches DO7K, L, and M (in the centre of Fig. 3) go underground before reaching the Rangitaiki River. These streams can be coded as either entering a groundwater system or as entering the river. In the case of the former, Barnett (1987a) gives further ideas on coding groundwater systems, including using lower case letters.

TABLE 2—Aquacodes for water-level recording sites on the Rangitaiki River.

Site No.	Site Name	Aquacode
15401	Rangitaiki at Thornton	DO7CEG
15408	Rangitaiki at Murupara	DO7MHK
15410	Whirinaki at Galatea	DO75DSW
15412	Rangitaiki at Te Teko	DO7DUC
15425	Rangitaiki at Te Mahoe No 2	DO7EMH
15431	Rangitaiki at Edgecumbe Br	DO7CSI
15432	Rangitaiki at Kopuriki	DO7HKX
15434	Rangitaiki at Reynolds	DO7CJP
15435	Rangitaiki at 4 km below Te Teko	DO7DDP
15443	Rangitaiki at Waitaharua Road	DO7QCM
15446	Wheao at Falls	DO76MQC
15447	Wheao at Wairaro Road	DO76ICD
15453	Waihua at Gorge	DO7G8EDC
15462	Wheao at Powerhouse	DO76IOC

Just on 80% of New Zealand's water-level recording sites were aquacoded and are listed in Walter (1990). Coverage of the country was reasonably uniform (Table 3). All codes from the computer algorithm were checked manually to correct any mistakes resulting from errors in the data-base. The remaining 20% of uncoded water-level recording sites are mainly on small streams, lakes, irrigation races etc, which were not depicted on the 1:250000 scale database.

TABLE 3—Number of water-level recording sites aquacoded for each district in New Zealand, where the districts are defined in Walter (1990).

District	Number of water-level recording sites	Number of sites aquacoded
Northland[1]	142	131
Waikato	160	102
Bay of Plenty	228	193
Hawkes Bay	122	82
Wellington	88	69
Manawatu–Wanganui	139	119
Taranaki	45	45
Nelson	118	92
Canterbury[2]	206	150
Otago	141	125
Southland[3]	75	73
West Coast	82	62

[1] Excludes Great Barrier Island
[2] Excludes Chatham Islands
[3] Excludes Stewart Island

Barnett (1987b) describes software written for running upstream and downstream searches on archived aquacodes using the POLAR geographic information software (U. Shankar, pers. comm., 1990). Hence for 80% of New Zealand's water-level recording sites, upstream and downstream searches can now be performed. For other waterway features (e.g. water quality sampling points, locations of bridges, power stations, water treatment plants etc), their aquacodes would need to be allocated and entered onto a POLAR archive before searches could be made.

There is no difficulty aquacoding new water-level recording sites and inserting them into the existing aquacode archive created for this illustration. For example, a new site on the Rangitaiki River (Fig. 3) 100 m upstream of its confluence with the Waihua Stream can be aquacoded DO7GSQ, since the Waihua Stream is DO7G8 and GSQ is upstream of G8.

There still remain complex aquacoding problems, some of which were encountered and dealt with using Barnett's (1987a) suggestions, e.g. water diverted from one river system to another. Most of the problems, including distributaries and braids, can be addressed using Barnett (1987a).

DISCUSSION

The illustration presented in the previous section made arbitrary choices for specifying the aquacoding system. Other options should be considered by future aquacode users before implementing the system for their own purposes or adopting national conventions. Some options and related issues are discussed below. Further discussion is recommended by water groups such as NZ Hydrological

Society, IPENZ Technical Group on Water, Water Supply Disposal Association etc.

Coastal Options

It is difficult to set up an elegant lay-out of New Zealand coastal zones and the 9 major rivers. Options for selecting coastal zones are either to use regional (political) boundaries or use a scientific basis. Political boundaries, although subject to obsolescence, do reflect some consensus on regional identity which is clearly defined and widely accessible. Further, they represent the demarcation between coastal administrative zones, so a large proportion of aquacode searches are likely to be based on regional criteria. The fact that boundaries will no doubt change at some future time, making aquacode usage based on obsolete regions less convenient, may not rule out regional usage. Scientific bases for coastal zone lay-outs include spreading the letters out according to coastline length (as used in this paper), catchment area feeding the coastline, or demographic population.

In selecting the 9 major rivers for single digit status, scientific bases seem appropriate, e.g. ranked according to catchment area (this paper), economic importance, number of water-level recorders, etc. Considering the range of options for coastal zones and major rivers, it is difficult to find a satisfactory combined choice, particularly if the key aquacoding sequence is to be satisfied.

For subdivision of each coastal zone, the allocation of letters A to Y to sub-zones and of the digits 1 to 9 should be considered. In this paper, most emphasis was placed on an even spread of the letters. This left some large rivers out of the first 9 of their coastal zone, e.g. Rangitaiki River (c 3000 km^2) was coded DO7; more emphasis on digit allocation would have resulted in a code of D6 or D7.

For upstream and downstream searching, which is the main advantage of aquacoding, coastal zone definitions are not important. Three digit river numbers presently in use (from SCRCC, 1956) could be used for river identification (e.g. 298 for Hutt, 154 for Rangitaiki, 434 for Waikato rivers, etc). However this often would lengthen aquacodes. If coastline position was considered important, a system which had no single digit (major) rivers would be a possible option. Again, aquacodes for these rivers would be lengthened.

River Options

The main channel of a river network could be selected using objective and/or legal options. An objective approach could entail moving upstream and successively choosing the branches with the greatest upstream catchment area, Strahler stream-order, or number of water-level recorders, etc. Rivers, however, are gazetted in law with official names. The continuation of a name along one branch could designate the main channel, and it could be undesirable for this channel to change aquacodes at a junction because an objective procedure defined some other channel as the main one. This would mean there was no longer a 1:1 correspondence between the common (and legal) meaning of a given river channel and the aquacode interpretation. Objective selection of the main channel could be applied only where the streams were too small to have gazetted names. Where given names are already in use, however, these would always take priority.

Selection of 9 or fewer major tributaries to the main channel is probably best done by considering jointly the spacing of tributaries and some objective measure of their size (catchment area, stream-orders, etc).

Aquacode Lengths

Resolution of aquacodes for waterways of interest (e.g. water-level recorders) dictates aquacode lengths. All sites in Table 2 are coded down to the sub-sub-reach level (i.e. all end with three letters), as many sites are closely clustered. Where there are fewer sites than primary reaches, as shown in Figure 3, it could be better to simply identify the reach. For example, site 15408 (Rangitaiki at Murapara) would become D7M, halving the length of DO7MHK (Table 2). The extra definition of the longer aquacode has very little advantage for existing sites, as the site location is still better expressed by map reference, and computer search algorithms would work exactly the same for D7M as for DO7MHK if there was only one site in that reach.

Aquacodes could therefore be kept to the minimum length needed to uniquely define existing sites. The typical aquacode lengths required for water-level sites would then be 3–5 characters.

Longer aquacodes more realistically represent actual reach sizes, and so make inserting new codes easier. The very existence of a site coded DO7MHK does not imply that the boundaries of all 484 (22 × 22) sub-sub-reaches of reach DO7M have been defined. So any subsequent user (e.g., one wishing to code a tributary of reach M), needs only to know the exact locations of the existing aquacodes on a map of the area, from which it is possible to infer general locations of undefined aquacodes (e.g. DO7M) in order to specify new aquacodes.

The lengths of aquacode used depends to a large degree on whether users wish to actually see and use them in the same way site numbers are used, or whether they are hidden behind computer panels as attributes of names or site numbers.

Aquacode Searching

Upstream and downstream searches for existing aquacodes can be performed using algorithms written by Barnett (1987a, b). Search procedures define a point of origin or base from which the search is to proceed. The location of this point on a water body can be defined as accurately as necessary by specifying a base aquacode. A series of aquacodes drawn from a database is then compared with the base aquacode and either upstream or downstream aquacodes are identified.

CONCLUSION

Using A. G. Barnett's aquacoding system for coding water-level recording sites, approximately 80% of New Zealand water-level sites were coded (listed in Walter, 1990). Arbitrary system specifications were assumed for this exercise. Further consideration of these options by potential aquacode users and water groups is recommended.

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