GIS techniques for developing a habitat classification for rivers

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ABSTRACT

Under the Resource Management Act (1991) water managers are required to promote the sustainable management of natural resources, which involves safeguarding the life supporting capacity of water and ecosystems. To help water managers give practical effect to the concept of life supporting capacity, the Ministry for the Environment (MfE) and a number of regional councils are working collaboratively to develop a system of habitat classification for rivers. This system forms part of the Environmental Performance Indicators (EPI) program and aims to be a tool for planning also. Habitat classification involves sub-dividing river systems into units based on the similarities and differences in a range of physical variables. The underlying principle is that the physical variables chosen determine the habitat and hence the bio-physical attributes of specific parts of rivers. Such systems are extremely useful tools for integrated water resource management as they assist with developing spatially explicit management objectives and setting environmental criteria. This paper presents a physically based river habitat classification system and describes the Geographical Information Systems (GIS) techniques implemented to provide data for this framework.

Keywords and phrases: river habitat classification, Geographical Information Systems

1.0 INTRODUCTION

The need for a river habitat classification system in New Zealand arose from work carried out by the Ecoclassification Working Group (EWG) (Rutherford *et al* 1997), which is facilitated by Ministry for the Environment (MfE). The EWG was formed to develop an environmental management framework for rivers including a method for developing a core set of environmental indicators to report on the ‘ecological health’ of rivers. Work currently being done in Australia and the United Kingdom similarly recognises the need to classify river systems in some way in order to monitor stream health and quality (see for example Ladson *et al* 1996, Ladson *et al* 1997, Walley *et al* 1999, Young *et al* 1999).

The river habitat classification scheme described in this paper is a hierarchical classification system. It is designed to be extremely flexible so that it can be used to help manage a wide range of issues using scales that are specifically derived for each issue. The scheme is based on physical variables that are readily available in GIS format at both the catchment and valley segment scales. The valley segment scale identifies river channel units that are homogeneous at a scale of hundreds of meters, while the catchment scale incorporates the entire upstream area draining directly into the valley segment. A further scale, the reach scale, is derived from information that is gathered in the field and does not involve GIS analysis.

The objective of the GIS component of this piece of work was to assign a classification to each stream segment in a river network. This classification is based on a number of variables, sourced from readily available databases, such as the New Zealand Land Resources Inventory (NZLRI) (Newsome 1992), draft regional land use databases (LCDB) (supplied by Ministry for Agriculture and Forestry), elevation data, rainfall data, flow statistics, and channel characteristics. Classification rules are applied to the variables, providing a coarse model of interconnections between the dominant environmental variables. This is useful for examining cause and effect relationships constraining expectations of bio-physical conditions.

The GIS work described in this paper was carried out using ARC/INFO 7.1 and ArcView 3.0a (ESRI 1992).

2.0 RIVER HABITAT CLASSIFICATION METHODOLOGY

The river habitat classification scheme has been developed using a top-down approach, with the physical variables at each scale being a subsidiary outcome of interactions at higher levels in the hierarchy. In addition each subordinate hierarchical level describes a smaller spatial scale.

2.1 REGIONAL SCALE

The regional scale relates to six climatic regions defined for New Zealand. Climate (temperature) data is not included in the GIS analysis because this analysis is carried out at a sub-regional scale, and therefore there is no variation in climate data within each area that the river habitat classification has been applied to. However climate at regional scale illustrates the hierarchical nature of the classification, as it is an important controlling factor for lower order classes. In particular source of flow, a catchment scale variable, is a subsidiary outcome of climate, the regional scale variable.

2.2 CATCHMENT SCALE

The catchment scale incorporates the entire upstream catchment area from a given point in the river network. Variables defined at the catchment scale may have an influence on a part of the same river further downstream. For example a river with a “glacial mountain” source of flow may retain the characteristics associated with this source of flow at the mouth of the river, even though the river flows through hill and lowland catchments and has tributaries with these sources of flow. Similarly geology and landuse are defined as catchment scale variables.

2.3 VALLEY SEGMENT SCALE

The valley segment scale refers to the local catchment of a river reach, excluding the contributing upstream catchment. Variables at this scale have a local impact on the classification of a river reach and include morphology, river size and elevation.

3.0 GIS METHODS

Many of the tasks applied to produce a river habitat classification system can be easily solved using ARC/INFO (ESRI 1992) commands and processes. However in some instances a more involved approach is needed, combining GIS tools with programs to process text files and databases.

3.1 GIS METHODS USED IN THE RIVER HABITAT CLASSIFICATION PROCESS

The classification process involves five broad steps, each encompassing a number of GIS and programming tasks. These steps are:

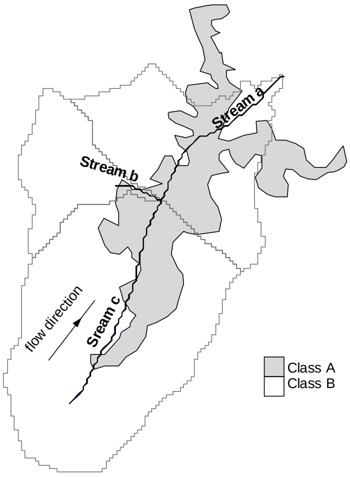
1. Generate a Digital Elevation Model (DEM) at an appropriate resolution
2. Generate a hydrologically correct river network
3. Assign data to river network segments
4. Classify the data
5. Produce GIS output

The technical processes contributing to the third step, assigning data to river network segments, are described in the following section. Step 2, generating a hydrologically correct river network from a DEM, is discussed in section 3.4.

3.2 ASSOCIATING DATA WITH STREAM SEGMENTS

Associating various characteristics with stream segments in a river network can be accomplished in a variety of ways, depending on the nature of the characteristics. Three common ways of representing data in GIS are polygons for discontinuous classes (for example land use polygons), grid cells for continuous data (such as elevation and rainfall) and scattered point data (for example data from water-level recorder sites). All data need to be processed in such a way that they can be directly related back to a single stream segment.

Characteristics represented by polygons can be associated with stream segments in three different ways (Figure 1). In the first method, the percentage of the stream length running through each polygon class is calculated (Table 1a). This method is useful for classifying the effects of local geology or landuse at the valley segment scale. However stream segments are not only affected by the class immediately beneath or alongside the stream, but by the classification of the entire watershed. As Hynes (1975) concluded, “in every respect the valley rules the stream”. Therefore in most cases it is appropriate to overlay polygons on polygons (Table 1b).



Stream	Length (m)	Class A (%)	Class B (%)
a	1,625	45	55
b	439	69	31
c	2,061	49	51

Table 1a: Percentage of stream in class by length

Stream	Area (km^2)	Class A (%)	Class B (%)
a	1.61	32	68
b	0.72	4	96
c	3.13	19	81

Table 1b: Percentage of stream in class by watershed area

Stream	Area (km^2)	Class A (%)	Class B (%)
a	5.46	21	79
b	0.72	4	96
c	3.13	19	81

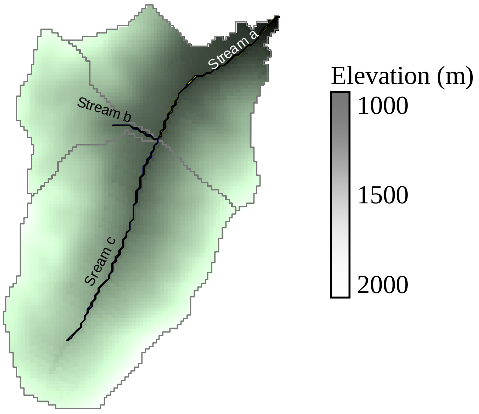
Table 1c: Percentage of stream in class by accumulated watershed area

Figure 1: Methods of associating polygon classes with stream segments

In addition the entire upstream catchment (accumulated catchment), not just the local watershed, may have an impact on a stream segment (Table 1c). In this example the watersheds of streams b and c form the upstream catchment of stream a. In each of these methods the importance of Class A and Class B differs, potentially resulting in different classifications of the stream segment depending on the rules applied.

Characteristics represented in grid format are usually continuous data such as elevation or rainfall (Figure 2). Again the data may be useful at both local (valley segment) and accumulated (catchment) scales (Table 2a). For example, the average elevation of a local watershed may reflect local temperature. An example of using accumulated watersheds combined with an elevation grid is the calculation of the proportion of flow from a mounatin source (originating above a certain elevation).

In some instances spot elevation can be used, that is, the value of the elevation grid directly below a certain point of the stream segment. For example, the spot elevations of the downstream node (Table 2b) and the upstream node of a stream segment can be used to calculate the local slope of the stream segment.



Watershed	Average elevation (m)
Stream a	1,502
Stream b	1,734
Stream c	1,714
Stream a accumulated (entire catchment)	1,654

Table 2a:Elevation of stream segments by average catchment elevation

Elevation of downstream node (m)
1,022
1,297
1,297

Table 2b: Elevation of stream segments by downstream node

Figure 2: Methods of associating continuous grid data with stream segments

A third data format is scattered point data, for example, data from recorders used for collecting flow statistics. In order to associate values with all stream segments, these data need to be interpolated spatially in some fashion. One method supported by ARC/INFO is kriging, which interpolates a lattice from a set of variably spaced points, with various interpolation options.

3.3 PROCESSING GIS OUTPUT

A combination of Arc Macro Language (AML), Delphi and Fortran programs were used to process the raw output from GIS processes into a format appropriate for the classification database. For example a Unix Fortran program was used to calculate values for accumulated (catchment scale) data, based on a relationship between stream segments defined by their upstream and downstream nodes. Processing grid based data can be time consuming in AML, so in order to process complicated grids such as rainfall weighted by elevation bands, text files representing grids were processed using Fortran.

3.4 DEVELOPING A RIVER NETWORK AND WATERSHEDS

Before all these attributes can be applied to stream segments, a river network needs to be developed that identifies individual channel components at an appropriate level of resolution, and their associated watershed boundaries. The method used here is to derive both a river network and watersheds based on a Digital Elevation Model (DEM), using ARC/Info's in-built hydrological processing functions.

The finer the resolution of the DEM, the more accurate the resulting river network will be. The DEM used in this project is a 30m grid, derived from 20m contour data. The key to controlling the level of resolution of the river network is to specify the minimum contributing area of each watershed. Trial and error showed that a threshold of 0.45km^2 (500 grid cells) produced a river network that closely approximated the resolution of the digitised network at 1:50,000.

Comparing a river network produced in this way with a digitised river network (or with a paper-based map) reveals that in steeper areas the DEM-based river network is much more accurate. However in flat areas the DEM-based river network can be displaced a fair distance compared to the digitised river network. This is because there is not enough resolution in the DEM in flat areas to force the streams into their correct channels (Figure 3).

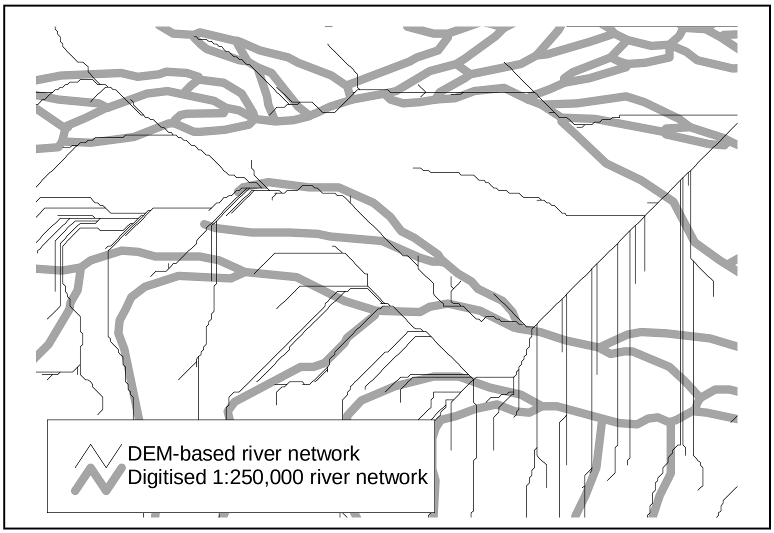


Figure 3:Comparison of DEM-based river network and digitised 1:250,00 river network

The solution applied to correct this problem was to "burn in" river channels digitised at 1:250,000. A number of ARC GRID processes were applied to the elevation DEM, resulting in the elevations of the cells which lay under a digitised river channel being lowered by 25 metres. In addition a buffer of cells was created on each side of the river channel, and these cells were gradually lowered by three metres. The net result was a gradual lowering of elevation towards the river channels with a sharper drop at the actual channel. The resulting DEM was then used to derive a new river network (Figure 4).

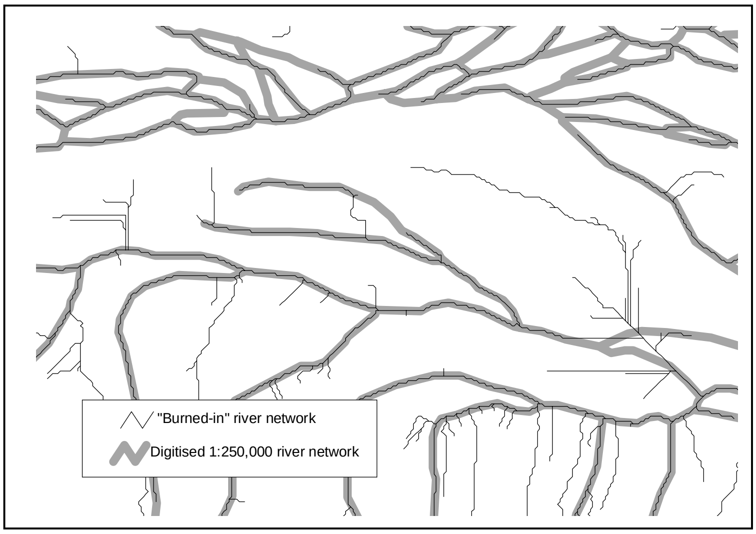


Figure 4: Comparison between digitised 1:250,000 river network and generated "burned-in" river network.

This "burned-in" river network tends to follow the digitised 1:250,000 river network a lot more closely, especially in flatter areas, such as braided river channels. The resulting classification will thus be much more closely aligned with existing digitised river networks, with additional detail representing a finer scale of resolution. In addition the "burned-in" river network remains hydrologically correct, while still following most of the channels of braided rivers.

The classification of a river as braided or otherwise was also defined as an input into the classification system. In the Canterbury region, this was done by creating buffers around rivers classed as braided on a 1:250,000 river network supplied by Canterbury Regional Council. Our "burned-in" river network was then overlaid on these buffer polygons, with overlapping stream segments being classed as braided.

Similarly the presence of lakes and a measure of the effect of lakes on downstream reaches was incorporated by flagging stream segments identified as representing lake locations.

Although "burning in" improves the river network used in the classification, the "burned in" network may still differ significantly from the true location of the network at the finer scale, i.e. in places where the 1:250,000 network is not present. Although classifications produced based on this river network will be correct, it may be difficult to directly apply the results to an actual river if its location is significantly different to the digitised river. It is proposed that in future applications a 1:50,000 river network will be used for "burning in", further reducing this source of error.

3.5 CLASSIFICATION RESULTS

Results were summarised in tables in a database before the classification rules were applied, resulting in nine classification variables which apply at a range of scales. These classification variables are the variables described in section 2 above. For example source of flow, a catchment scale variable, is classified as one of "glacial mountain", "mountain", "hill" or "lowland". These classifications are calculated based on cumulative total rainfall within elevation bands in the upstream catchment. If the majority of total rainfall in the upstream catchment occurs for example above 900m, then source of flow at that reach is classified as Mountain. The classification "glacial mountain" depends on the area of ice in the catchment.

Once the classification system has been applied, the results can be readily displayed and analysed using a Windows based GIS such as ArcView or ArcExplorer (freely available shareware with limited analysis capability). The resulting classification for source of flow in Canterbury is shown in Figure 5 below.

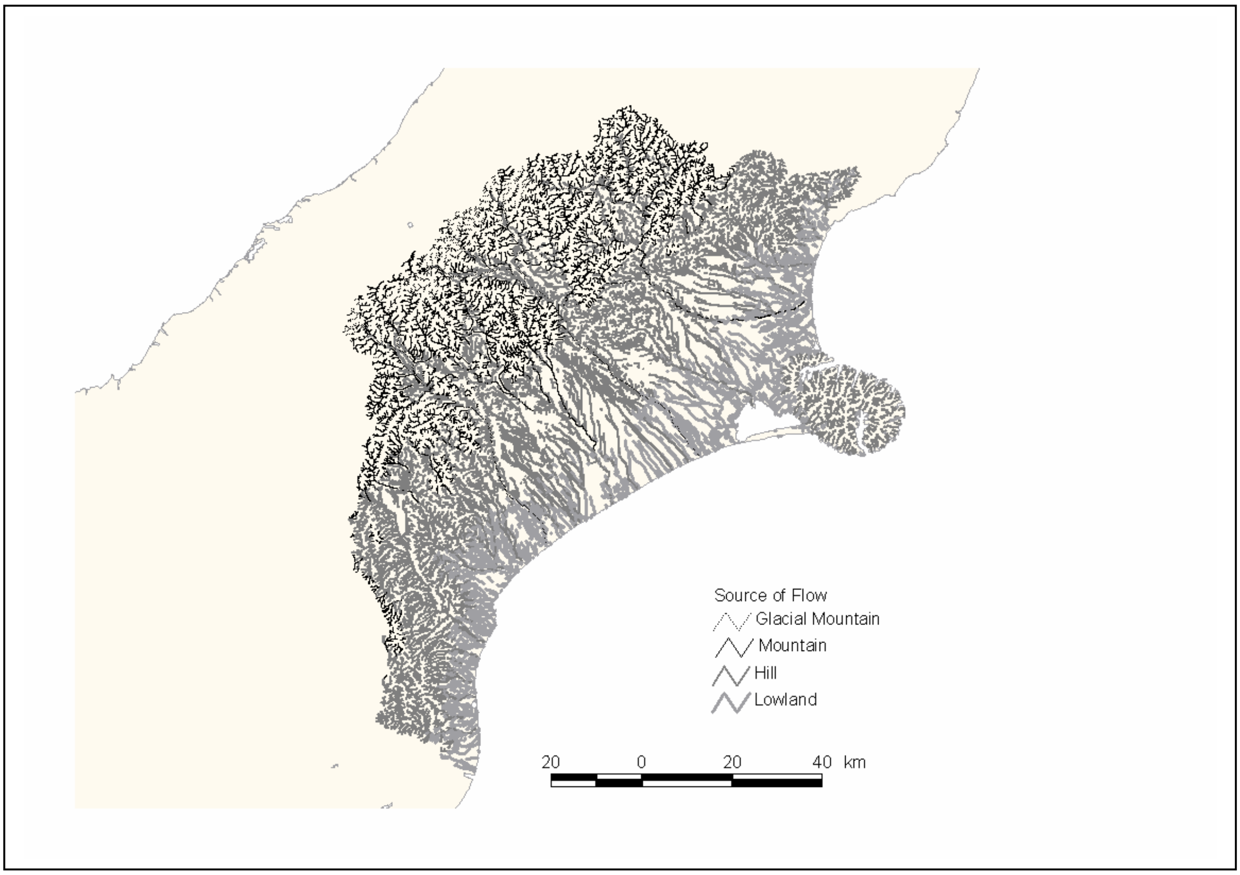


Figure 5:Classification of Canterbury rivers by Source of Flow

4.0 CONCLUSION

The database resulting from the river habitat classification scheme contains approximately 180 fields, which together describe temperature, source of flow, geology, land cover, flow variability, morphology, river size and elevation. Various levels of classification are achieved by successively aggregating subsequent classes. The classification is flexible and the categories in each controlling variable can be amalgamated to produce broader classifications. Classifications can therefore be described at differing levels of complexity, ranging from regional scale classified by temperature, through to valley segment scale incorporating all variables in the classification.

The next stage of this project is to test the classification with biological data. The river habitat classification system will then be used as a tool for resource management and planning purposes.

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