A Development and Application of GIS in Whanganui Catchment Based River Environment Classification System

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Dedication

This thesis is lovely dedicated to my Mother and Father

Bao Zhen Cao and Guan Jun Zhai

Abstract

This thesis concerns a development and implementation of Geographical Information System (GIS) for the New Zealand Whanganui catchment, based on a new methodology for river environment classification systems in New Zealand. The Ministry for the Environment (MfE) and National Institute of Water and Atmospheric Research (NIWA) are developing this system with assistance from regional councils. The river habitat classification is sometimes called river "ecotyping". It describes the process of dividing rivers into similar or different physical classes based on the habitat requirements of the plants and animals that live there (Murray McLea, 1999). This project focuses on generating a Digital Terrain Model (DTM) for the Whanganui river catchment to determine Whanganui catchment boundaries and a series of hydrology parameters such as catchment patterns and channel slopes, etc. It comprises layers of elevation, rainfall, geology, land-cover and additional ecotyping related attributes for classification of each arc of the Whanganui River.

There are five sections in this thesis.

The first section introduces the basic concept of hydrology in environmental and ecological aspects. It reviews the hydrology model with GIS and DTM. It also briefly describes the river environment classification system ---- ecotyping methodology. Finally, it describes the aims and achievements of this project.

The second section focuses on the ARC/INFO software environment, using different ways to generate the DTMs and present criteria that will be used to test and analyse the accuracy of DTMs. Also the Whanganui catchment and catchment boundaries will be determined.

The third section focuses on the river analysis. The main target is to test whether the 1: 50000 topographic data can be used to determine the channel slope and channel sinuosity for river sections other than reaches (Snelder et al. 1999).

The fourth section describes the method of using ecotyping parameters and classification rules to classify each arc of the river into a database. These rules are introduced in the article "Further development and application of a GIS based river environment classification system" (Snelder et al. 1999).

The last section as a conclusion of the thesis will summary the achievements, the methodology of the processing and the results of the application of this research.

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Chapter 1

Introduction

In recent years, people have had an enormous interest in the application of Geographical Information System (GIS) in hydrology and water resources. This is increased by the growing public sensitivity to environmental quality and management. The GIS technology has the ability to capture, store, manipulate, analyse and visualize the device sets of geo-referenced data. On the other hand, hydrology is inherently spatial and distributed hydrologic models have large data requirements. Therefore the integration of hydrology and GIS is quite natural.

1.1 Hydrology in environmental and ecological areas

In the environmental continuum, water plays a central role and brings soil and air closer together. Water shapes the landscape and it turns into water vapour. It sustains the ecological continuum. Therefore, hydrology is the core of environmental and ecological continua. As a science in its own right hydrology may partly be ascribed to the role that it plays in addressing a range of environmental and ecological problems and being a critical component of the environmental and ecological continua. It is the environmental and ecological problems and growing public concern for their solution that places increasing demands on hydrologic models (Singh V.P. and Fiorentino M., 1996).

1.2 Hydrologic modeling with GIS and DTM

A computer model provides an abstract method for representing a real system. Computer based hydrological models use mathematical expressions to represent the physical processes by which water moves through a catchment. These models are valuable tools; they can help us to understand basic hydrological principles, to reconstruct past events, predict future conditions and to assess the effect of human activities on a river's flow.

Hydrologic modelling from the simple analytical models at the end of the 1950's to now is becoming increasingly global, both in terms of spatial scale and depth of treatment. It has been developed in many ways and the distributed watershed model is one of them. This research will use it in the ARC/INFO software.

Watershed modelling is the greatest application of GIS in hydrology. Special concern for resource management and environmental quality requires the application of distributed models. These distributed-parameter models hold data intensively for multiple types such as hydrometeorology, topography, land use, soil, geology, stream flows, etc. Much of this data is often used to identify a hydrologic unit. This is very complex and cumbersome. Therefore GIS, as a spatial data analysis and manipulation tool, is required. In recent years, using GIS have obviously dedicated much effort to the development of distributed hydrological models. It is able to analyse large quantities of distributed geo-morphological information (Singh V.P. and Fiorentino M., 1996).

For example, Schumann (1993) discussed the development of conceptual semi-distributed models and estimation of their parameters with the aid of GIS. Mourad Bellal et al (1996) coupled GIS with a distributed hydrological model for studying the effect of various urban planning options on the rainfall-runoff relationship in urbanized watersheds (Mourad B.and Xavier S, et al., 1996).

The knowledge of distributed landscape topography, provided by Digital Terrain Models (DTM), (Ebner and Eder, 1992) is the basis of a series of automatic procedures that are able to derive drainage network structures at the appropriate scale of information and to support hydrological modelling. These procedures allow the derivation of traditional watershed parameters resulting in a set of useful information for a detailed description of the landscape morphology (Quinn et al., 1991).

The spatial distribution of topographical and geo-morphological features of catchments and of drainage networks is relevant for determining the spatial variability of some hydrological phenomena.

Such phenomena are usually analysed with hydrological distributed models, which require some parameters. The most important parameters are: catchment area, topographic form, slope and aspect for catchments. The quantification of these parameters is not only tedious and time consuming but expensive and difficult to update when accomplished either manually or using conventional methods. The conventional methods to store hydrological data separately and update the information have been cumbersome and expensive. Now the GIS technology can provide a means for merging spatial and attribute data into computerized database systems allowing input, storage, retrieval, overlay, analysis and tabulation of geographically referenced data. For example, the United Kingdom's Thames Water Authority uses GIS for keeping their up-to-date inventory of the existing water supply network, maintaining demographic and economic databases, assessing flood and pollution damage and also keeping a trace for real time on-line forecasting (Singh V.P.and Fiorentino M., 1996). The conventional or manual methods cannot implement these issues completely.

GIS, with some hydrology models have developed greatly. For example, Olivern and Maidments (1999), rainfall-runoff model for routing spatially distributed excess precipitation requires a flow direction matrix for the calculation of unit hydrographs over sub-watersheds. The ANSWERS model (Beasely et al., 1980) uses a flow direction matrix and a river segment network as inputs, although the procedure to obtain a network that matches the flow directions is not completely automated (Joao and Walsh, 1992). The TIPMODEL (Beven and Dirkby, 1979) is a physically based, topographically driven flood forecasting model which uses flow directions to compute the topographic index. The extraction of flow direction from a DTM has been studied by various researchers (Quinn et al., 1991) and (Wolock and McCabe, 1995). It allows the prediction of distributed soil moisture status on the basis of spatial indices which depend on slope and cumulative upslope area derived by flow pathways (Quinn et al., 1991).

The Geomorphic Instantaneous Unit Hydrograph-GIUH (Rodriguez-Iturbe & Valdez, 1979, and others) is a commonly used method for determining the rainfall-runoff response of catchment, which uses Horton's ratios in order to calculate its characteristic parameters. Horton's ratios can be determined from digital channel networks derived from DTM.

DTMs and GIS have been used in urban storm water modelling by Djokic and Maidment (1991). An application of DTM to delineate drainage and compute hydrologic characteristic was implemented (Wiche. 1992). The rainfall-runoff model utilizes a river network obtained from a DTM (Cabral et al., 1991) and other models such as SLURP (Kite, 1995) and PRMS (Leavesley and Stannard, 1995) use sub-watersheds as calculation units (Leavesley, G.H.and Stannard, L.G., 1995). Finally, HYDROTEL (Fortin et al., 1995, 2001) directly uses a direction matrix, a river segment network and associated sub-watersheds as inputs (Fortin, J.P. et al., 2001).

All these models, and others, could benefit from various levels of the GIS technology. The GIS models have been developed sufficiently for the analysis of hydrological characteristics.

1.3 River resource and river management problems in New Zealand

The complexity of water right issues has grown faster than public understanding of river processes and river ecology. Although New Zealand has numerous rivers, assigning rights to use water has become something of a balancing act. Increasing recognition is being given to the needs of resident biota and to the aesthetic and recreational values of rivers. At the same time, however, hydro-power stations must continue to operate; farmers must continue to irrigate; demands from domestic water users must be met (Kilbirnie, 1989). So providing a balance between the conflicting goals of resource use and the development and safeguarding of environmental values is very important.

We have qualitative information about river ecosystems. For example, we know that periphytons (simple plants such as algae) are near the bottom of the aquatic food chain. They are the food supply for aquatic invertebrates, e.g., insects. Invertebrates in turn are fed upon by fish. However, river managers need to be able to quantify the relationships. Then they can predict how proposed alterations to river conditions affect the river ecosystem.

Therefore, developing a comprehensive river classification system that divides rivers into various classes based on their physical, chemical and biological characteristics is very important. Such a classification must also be applicable between rivers. Without such a system, river managers have difficulty in judging whether experience gained from one river may be used to predict what will happen in another (Kilbirnie, 1989).

1.4 River Environment Classification System (ecotyping methodology)

On behalf of a consortium of regional councils and the Ministry for the Environment (MfE), the National Institute of Water and Atmospheric Research (NIWA) is developing a system of river habitat classification to support water resources and river management. There are four levels or scales in the system, which are regional scale, catchment/sub-catchment scale, valley segment scale and river reach scale (see the Figure 1-1).

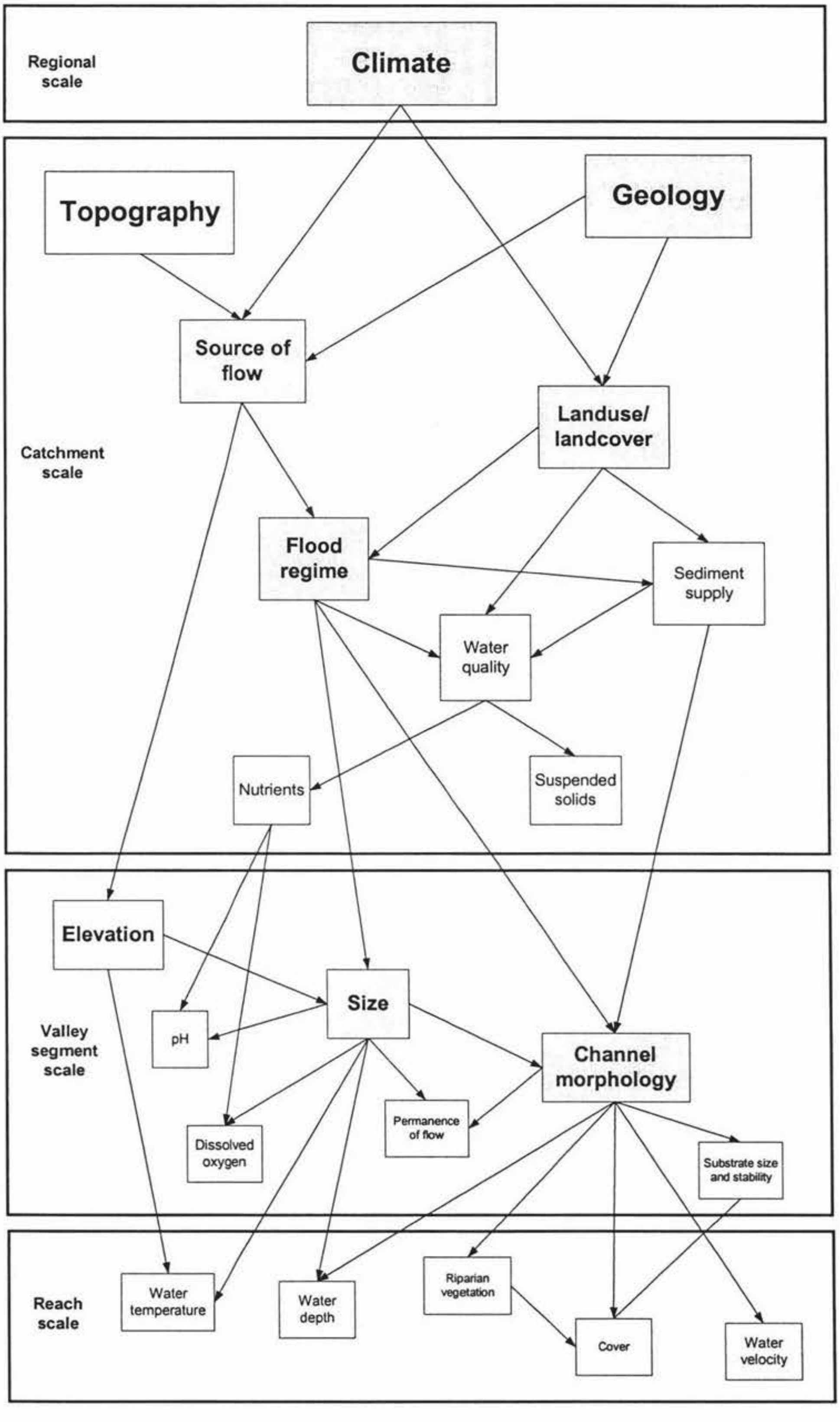


Figure 1-1 Physical variables affecting habitat in rivers (Snelder and Clarke, 1998)

The regional scale classifies the rivers on the basis of similarities in their climate. The catchment scale classifies the river catchments (and sub catchments of a single river system) on the basis of similarities in their source of flow, geology, land use and flood variability. The valley segment scale classifies the rivers on the basis of similarities in their elevation, size and morphology. The reach scale is the stretch of river between tributary junctions. GIS has been used to calculate reach slope and sinuosity (Snelder *et al.*, 1999). However it is not clear that slope and sinuosity are necessarily constant over a reach. One of the objectives of this research is to determine whether slope and sinuosity can be calculated over a non-reach based division of the river and used in an ecological classification.

This project concerns the development and implementation of a GIS based river environment classification system in the Whanganui River catchment in New Zealand.

1.5 The project requirement

- To build a DTM for the Whanganui River catchment from the 20 metre contours featured in the NZMS260 series topographical maps. The DTM will need to be sufficiently hydrologically accurate to determine sub-catchments.

- From the DTM, determine catchment boundaries, drainage patterns, channel slopes and channel sinuosity to any point in the Whanganui River catchment.

- Using both the catchment scale and valley segment scale and a further subdivision based on a contour intervals, data is then processed by applying the ecotyping method classification rules to derive a classification for each arc. The completed classification is summarized in tables in a database for each classified arc.

1.6 Method and issues

This research will use ARC/INFO software to achieve the requirements above.

- The DTMs were generated by digitized 20 m interval contour lines as well as spot heights and break-lines (such as streams) from a 1:50000 scale topographical map using a triangular irregular network (TIN) model in the ARC/INFO environment.

- Whanganui River catchment patterns and catchment boundaries are determined from the TIN model by using distributed watershed models – hydrology processing in ARC/INFO environment.

- How to determine the channel slope and channel sinuosity base data on 1:50000 topographic maps is an issue which will be discussed in this reasearch.

  - To test whether it is possible to achieve this by basing data on inter-contour slope rather than reach scale.

  - To test whether 1: 50000 topographic data is adequate for this purpose.

- Using overlay technology in both ARCVIEW and ARC/INFO environment to comprise the layers of elevation, rainfall, NZLRI (New Zealand Land Resources Inventory) geology, land-cover data and additional attributes that are based on ecotyping which relates to hydrological and water quality parameters and the classification to derive a classification rule for each arc of study area in the database.

- How to handle and compute these huge datasets of the Whanganui River catchment (which is a 7100 km^2 area with about 81073 arcs) is a big issue. It becomes our main focus during this research process. The detail will be described in the following sections.

Chapter 2

Generating DTMs for Whanganui catchment and determining hydrology parameters

2.1 Digital Terrain Modelling

2.1.1 Introduction

A special technique for the representation of surfaces is known as Digital Terrain Modelling. A Digital Terrain Model is a numerical representation of a topographic surface. The model may consist of regularly or irregularly spaced elevation point samples and lines of known elevation values, either contours of significant terrain lines, such as ridges and stream lines, or a mosaic of local mathematical surfaces. The simplest way of storing a surface model is to use an altitude matrix, which is a continuous-value raster map. The raster model is used to represent a surface entity, which is in reality present at each x, y coordinate in space. But a regular grid structure may distort certain operations such as line of sight calculations. The matrix may be too coarse to capture very localized features, and their misrepresentation may cause major problems in data analysis. An alternative representation strategy has been developed, using a triangulated irregular network (TIN). TIN models allow extra information in areas of complex relief without the need for redundancy elsewhere in the representation (Peucker et al., 1978) and (Heil, 1979). An example of a study in which a TIN model has been used for a population density surface may be found in Sadler and Barnsley (1990). Figure 2-1 shows different methods, the altitude matrix model and TIN model for representing surface.

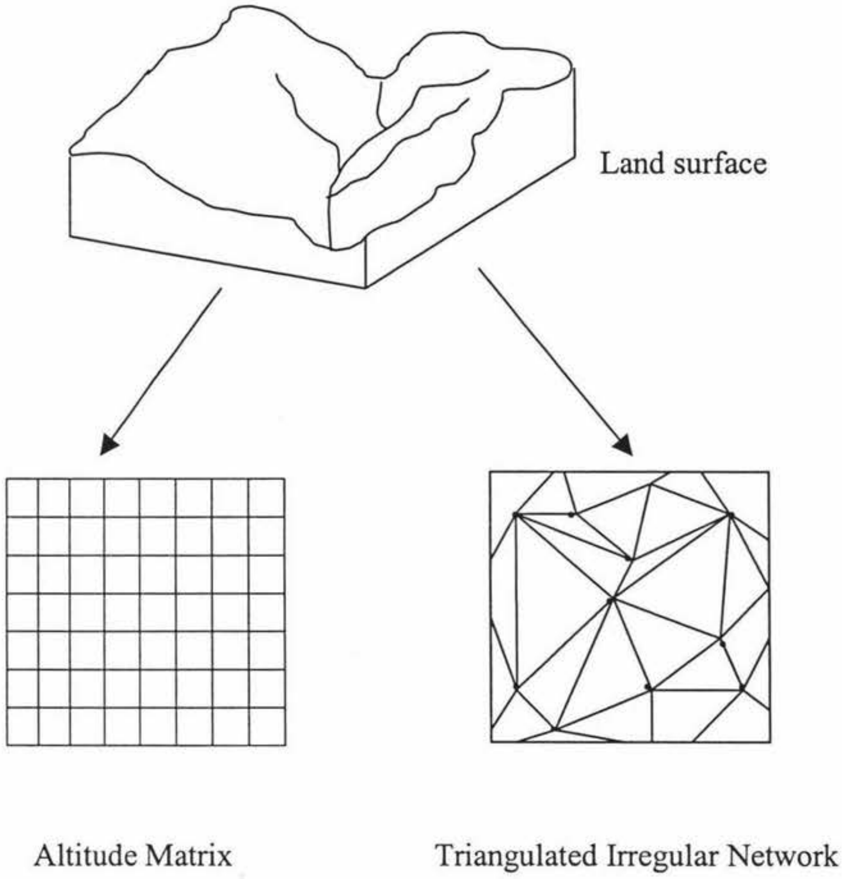


Figure 2-1 Altitude matrix and TIN methods for representing surface values

Both of the data models will be applied in different situations to achieve the targets of this research.

2.1.2 Data source for generating DTM

Data for DTM should be the observations about elevation and shape of terrain surface with particular attention to surface discontinuities (break lines) and special location (passes, pits, peaks, points of change, slope, ridges, stream channels etc.). This data can be collected using the following different techniques:

- Ground surveys;

- Photogrammetry using aerial photographs or satellite images;
- Digitizing existing maps;
- Scanning existing maps.

The choice of data source is dependent on a combination of many factors such as the range or extent of the study area, the precision and accuracy of DTM in relation to specific applications required, and time.

2.1.2.1 Ground surveys

This technique allows the creation of very accurate DTM, because surveyors can capture the elevation of discontinuities and special locations that are characteristic of the area under observation. But it needs time and therefore is usually applied to particular projects that involve small areas. Now a new technique called Global Positioning System (GPS) has been developed. GPS consists of a constellation of satellites, which transmit continuous time and position information, enabling users of GPS receivers to plot their positions on earth within metres of their true location.

2.1.2.2 Photogrammetry

This technique is suitable for big study areas. It uses aerial photographs or satellite images and suitable equipment to collect elevation data by implementing different sampling methods. The accuracy of DTM depends on the sampling method adopted.

2.1.2.3 Digitizing or scanning existing maps

In manual digitizing, topographic maps are positioned on a digitizing table and the digitiser cursor is used to trace contour lines or to pick elevation into contour points. In scanning, a topographic map is positioned in special equipment and an electronic detector moves across the map to produce a digital image.

Digital data sets have become available in most countries to satisfy a wide range of users. This data is produced by private and public organizations using the above-mentioned methods.

This project refers to the data sets of the Wanganui region that were supplied by New Zealand Aerial Mapping but they originate from Land Information New Zealand.

2.1.3 Methods for generating TIN

Once data has been collected using one of the previously mentioned methods, which can produce regularly or irregularly spaced data as shown before, it is necessary to build a model capable of approximating the surface behaviour.

The data structure of a TIN is based on two basic elements: sample points (nodes) with their x, y, z values and a series of edges joining these points (nodes) to form triangles. Nodes are connected to their nearest neighbours by edges, according to a set of rules. Left-right topology is associated with the edges to identify adjacent triangles. Triangles are constructed based on the input of mass points and breaklines, which provide the information and the constraints about the surface, such as the peak of a mountain, the floor of a valley, or the edge (top and bottom) of cliffs. By connecting points in these ways, a linear break in the surface can be defined. These are called breaklines (See Figure 2-2).

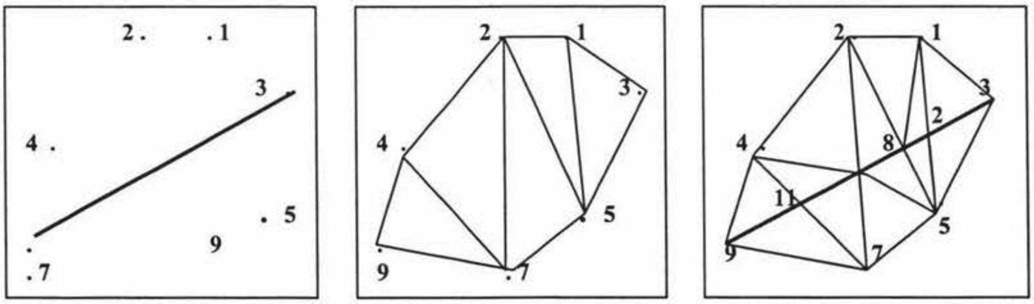


Figure 2-2 Breakline and relative modification of triangulation

Breaklines define and control surface behaviour in terms of smoothness and continuity. They have a significant effect in terms of describing surface behaviour when incorporated in a surface model. Breaklines can describe and enforce a change in the behaviour of the surface. Z values along a break line can be constant, or can vary throughout its length. Three types of breaklines can be employed to describe surface behaviour:

- Hard breaklines: These define interruptions in surface smoothness. They are typically used to define streams, ridges, shorelines, dams and other locations of abrupt surface change.

- Soft breaklines: These are used to ensure that known z values along a linear feature are maintained in the TIN.

- Faults: These represent interruptions in surface continuity. Geological faults are probably the most common type of fault. Faults have more than one z value for a given x, y location.

These triangles represent the terrain surface. The method allows the representation of areas with a complex topography using fewer points than an altitude matrix. It efficiently uses the information carried by sample points in terms of location and elevation (i.e. the elevation and location of triangle vertices are those of sample points), thus minimizing errors due to interpolation. In this project we use the contour line as the elevation, the location of height data as sample points, the river line and coastline data as the breaklines to create a TIN model.

2.2 Description of study area

The Whanganui River is the second-longest river in the North Island (after the Waikato River). The source of the Whanganui River is in the Mounts Tongariro and Ruapehu on the central volcanic plateau of the North Island of New Zealand.

It flows north initially, then turns west and south to enter the Tasman Sea in Wanganui City. The Whanganui catchment comprises approximately 7,100 square kilometres. Its length is approximately 320 kilometres. The average rate of discharge at its mouth is 211 cubic metres per second (see Figure 2-3).

North Island of New Zealand

Figure 2-3 Map to show the study area

2.3 The goals

- To build a DTM for the Whanganui catchment. The DTM should be sufficiently hydrologically accurate. We will use the DTM to create the following objects as the judgment criterion:

  - The Whanganui catchment profile: to check the river's main trend.

  - To determine the catchment boundaries and catchment patterns.

2.4 The available data

The dataset of two large areas, Taranaki and Waikato, are available which cover the Whanganui river catchment . They are listed as follows:

- The digitized 20 m interval contour line data,

- The digitized spot heights point data,

- The digitized river lines data,

- The digitized coastline data,

- The digitized river centre line data.

2.5 Problem definition

The most difficult and interesting aspect of this project is that there is a large study area (7,100 km^2) of Whanganui catchment. The data sets are huge e.g the contour data of the Whanganui river catchment alone is 81073 arcs. In handling the huge data for each step of the process of this research, the following problems are present:

- Space,
- Software limitation,
- Time.

These problems are a prime focus of this research.

2.6 Generate a TIN for Whanganui catchment

The following processes are implemented on ARC/INFO software environment.

We have contour line coverage, high point coverage, river line coverage, river centre line coverage and coastline coverage. All these cover the large areas of the regions of Taranaki and Waikato. The Whanganui river catchment is just a part of this. So in the next step we will cut out the Whanganui region from the two large areas of Taranaki and Waikato.

In the Taranaki and Waikato dataset coverage, contour coverage is the biggest dataset in the series. The arcs of Taranaki are 65793 and of Waikato are 64802 after removing pseudo nodes. How to extract Whanganui region from Taranaki and Waikato is the main issue at this stage. To avoid software limitation and disk space problems, we clip out 7 pieces of small coverage (4 pieces from Taranaki and 3 pieces from Waikato) then assemble them to one coverage. However this method is very time consuming, because to clip one piece of coverage needs half an hour to 4 hours depending on the size of piece. When these 7 pieces are put together to form one coverage, we get another problem: the data of each edge of each small coverage, which is to join with another piece should be edited, otherwise there will be errors in the arcs. Manual editing is needed to correct these errors. This is a huge miscellaneous task that cannot be automated but which must be undertaken to maintain the precision of data.

The idea is to keep the study area integrated. For this purpose we decide to clip out two large pieces of coverage. One is from the Taranaki area and other is from the Waikato area. Actually the data of the study area is too big and we also meet a software limitation problem. To solve this, the first thing we have to do is reduce the amount of data before clipping. So the contour data is grouped in different levels and is put into separate coverage, e.g. Taranaki coverage (65793 arcs) is divided into two groups and is put into two separate coverages: the contour lines (36708 arcs) with elevations equal and less than 400m and the contour lines (29085 arcs) with elevations greater than 400m. Waikato coverage (64802 arcs) is also divided into two groups and is put into two separate coverage: the contour line (29624 arcs) with elevations equal and less than 300m and the contour lines (35178 arcs) with elevations greater than 300m. Then each separated coverage is clipped successfully. A tolerance file is created for each separated coverage to keep the tolerance of edit, nodesnap, weed, grain and snap smaller. Finally they are put into one coverage. Then the pseudo nodes are removed. There are 81073 arcs in the final Whanganui region coverage.

The other related datasets of the Whanganui catchment such as river coverage, river center line coverage, high point coverage and coast line coverage can be easily clipped out from the Taranaki and Waikato coverage. Each of their two parts can be combined in one coverage.

So far we have the series of datasets of the Whanganui region. Using command CREATETIN with the contour line coverage, coastline coverage and high point coverage we can generate a TIN. After this a great deal of information can be derived from those TIN model, such as slope, aspect, watershed, catchment and channels. These hydrological terrain features are very important in hydrological modelling (Rieger, W. 1993). Next the accuracy of this TIN model needs to be tested before it is used.

2.7 Calculating river slopes from a TIN

As a surface that fixed the arcs of the river coverage in it, the TIN is used to create some profiles to perform this test. The results of these profiles show some ascending sections of river. That is not the right answer, because the rivers' trend should be down to the hill. Is the TIN not accurate? We do the following research to find the answer.

Can the TIN be used to extract river slopes? To test this five river arcs were taken at random and river profiles were created for these arcs from the TIN. A variety of different surfaces were tested.

(1) Using different TINs to test, because the different kinds of TIN may cause different results. There is detailed discussion about TINs in the section 2.1.3.

- TIN without breakline.

- TIN with breakline.

(2) Changing the resolution of the lattice to test, because a big lattice may lose detail data and cause poor results.

- Lattice of 30 * 30 metre DTM grid

- Lattice of 25 * 25 metre DTM grid

- Lattice of 5 * 5 metre DTM grid

(3) Generating a 'new' river coverage to test:

- Using the no sink DTM which is Lattice of 30 * 30 metre DTM grid was processed by the FILL function to generate a new river coverage. Using the certain same arcs (the position is the same with the original river coverage) fix them on the TIN to test.

There is a little difference in the profiles resulting from using the 20 m interval contour lines data. The main trend of the profile's line is ascending, perhaps because the interval of contour lines is too big. So in the next step we try using 5m interval contour lines to create a TIN as a surface to do the profile for the same arcs.

(4) Creating a TIN basic on 5m interval contour lines to test:

- Using LATTICETIN command to convert the 20m interval TIN to 5m interval contour lines then using it to generate a 5m interval TIN. There is still little difference in the results of using the new TIN as a surface to do a profile for same arcs. The profile's lines still tend to upwards. This is because the 5m contour was created by interpolation from the 20m contours.

It is clear that basing river slopes on any form of DTM derived from 20m contour intervals will not be satisfactory.

2.8 Hydrological terrain features derived from TIN

The following is a process presenting a methodology to determine the whole Whanganui catchment with its boundaries from the TIN model.

Figure 2-4 is a diagram to highlight the following steps of the process.

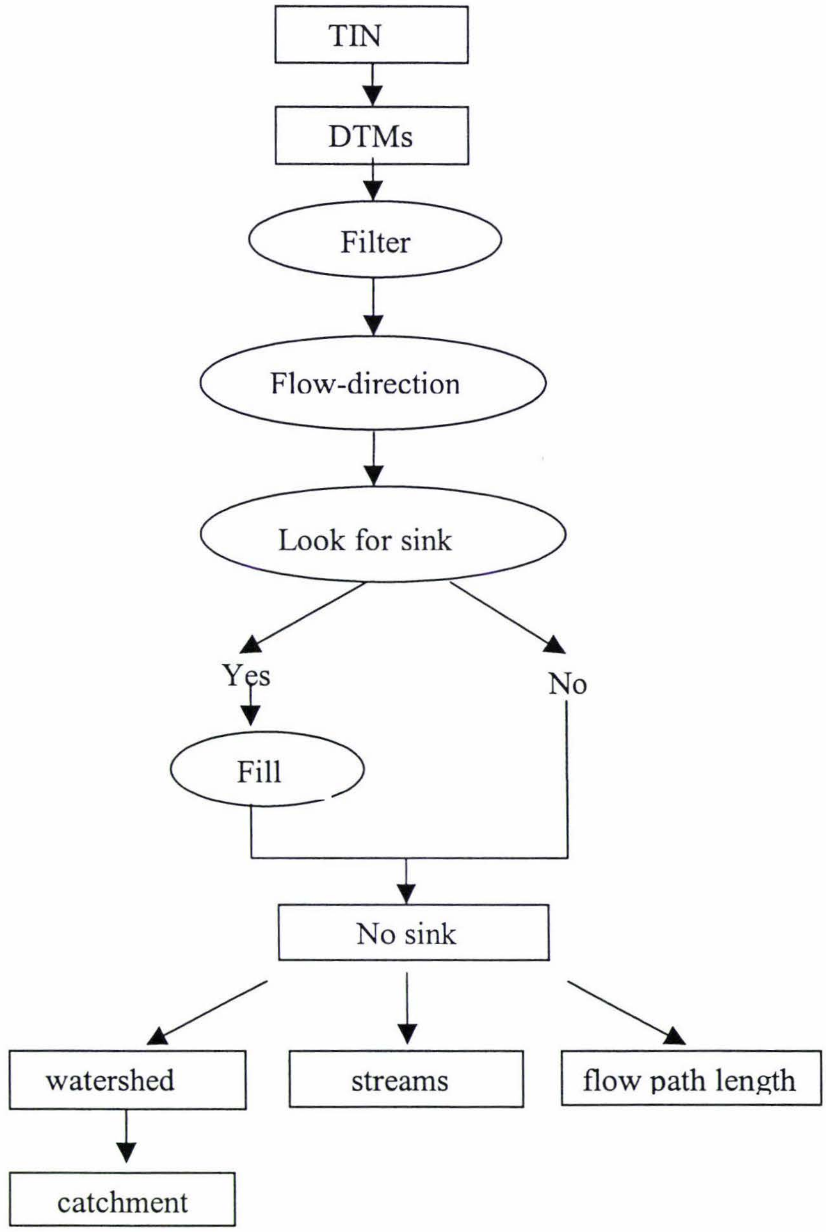


Figure 2-4A process of hydrological terrain features derived from TIN (Sourced from the ARC/INFO Version 3.2 help)

2.8.1 Creating DTMs and an application of a low pass filter

Because the ARC/INFO software just supplies the GRID function for data analysis, the following processes will be based on the ARC/INFO Grid System.

The function TINLATTICES will be used to convert the TIN mode to DTMs grid which has a 20 * 20 metre and 30 * 30 metre resolution for the two lattices coverage.

These two images look rough and much more angular. ARC/INFO supplies filtering processes to enhance image quality, such as clarifying detail, sharpening contrast, smoothing edges (Mather, P.M., 1987). In our case, a low pass filter is used to remove the high frequency components or noise, resulting in a smoothed image, and to reduce the spatial variability or detail in a continuously varying raster object (Mather, P.M., 1987).

A low pass filter is usually based on a moving average or median approach. The median is considered to be superior as the derived image is composed of original image values. The moving average is based upon the calculation of the mean value of a neighbourhood of pixels using a two dimensional matrix that is passed over an image. The calculated new z values can be derived by centring the specified 3*3 filter over each lattice mesh point. As the filter is passed over each mesh point, the centre mesh point is assigned the sum of the products of each surrounding mesh point z value and its corresponding operand in the 3 * 3 filter. Figure 2-5 is a sample of a low pass filter based on a moving average. This example is taken from GIS Dictionary - Search Results (Mather, P. M., 1987).

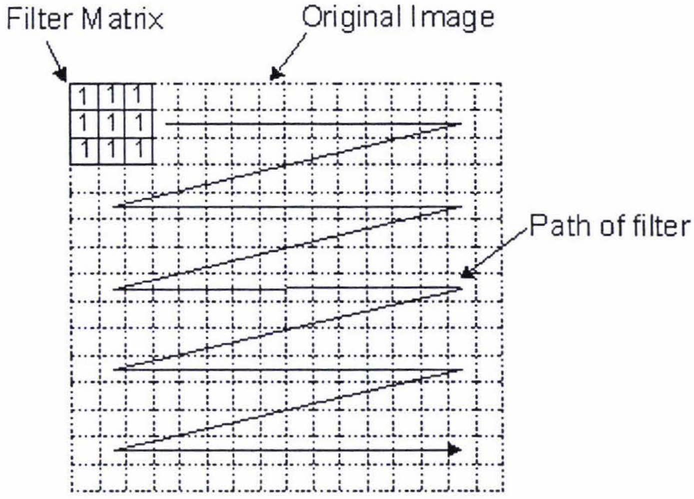


Image filtering using a filter matrix, showing the moving average filter passing over an image. Note that the cells at the edges of the image will not be recalculated. Instead, these cells are normally set to zero.

Figure 2-5 A low pass filter based on a moving average

2.8.2 Grid based flow direction patterns

There is a function in the ARC/INFO Grid System, which determines water flow direction over land surface terrain using the pour point model (David, R., 1993). The water from one grid cell is permitted to flow into one of the eight neighbouring cells (See Figure 2-6).

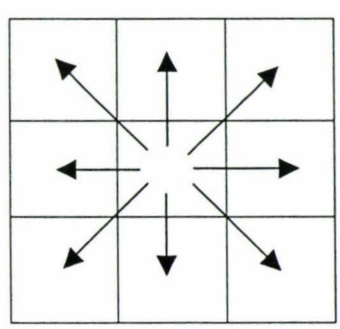


Figure 2-6 The flow direction over land surface terrain on grid cell

A grid of terrain elevations is shown in Figure 2-7.

78	72	69	71	58	49
74	67	56	49	46	50
69	53	44	37	38	48
64	58	55	22	31	24
68	61	47	21	15	19
74	53	34	12	11	12

Figure 2-7 A grid of terrain elevations

By determining the slope of the line that links the cells with each of their neighbouring cells, a grid of flow directions is created with one direction for each cell representing the direction of the steepest descent among the eight permitted choices. This grid is shown in Figure 2-8 as a set of arrows, but in fact it is stored in GIS as a grid of numbers where each flow direction has a unique identifying number. The example used here is taken from ESRI (1992).

↘	↘	↘	↓	↓	↙
↘	↘	↘	↓	↓	↙
→	→	↘	↓	↙	↓
↗	↗	→	↘	↓	↙
↘	↘	→	↓	↓	↓
→	→	→	→	↓	←

Figure 2-8 A grid of flow directions is shown as a set of arrows

In the Arc/Info package the water flow directions are calculated with the FLOWDIRECTION function. This function takes a surface as input and outputs a grid showing the direction of flow out of each cell. The direction of flow is determined by finding the direction of the steepest descent or maximum drop from each cell. This is calculated in the following way:

Maximum drop = change in z value / distance

In this formula, distance is determined between cell centres. For example, if a 3*3 window is considered, the central cell of this window has eight neighbours. If the cell size is 1, the distance between two orthogonal cells is 1 and the distance between two diagonal cells is the square root of 2 (1.4142) (Sole, A. and Valanzano) (see Figure 2-9)

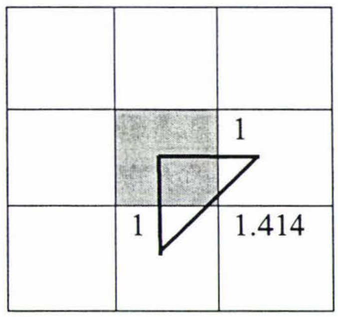


Figure 2-9 Distance between the cells of water flow direction

2.8.3 Sinks

In the natural world, water always flows in the direction of the deepest slope. In the grid DTM this direction is restricted to neighboring grid cells (4 or 8 neighbors), It must be decided into which cell the water will drain. This gap between the natural and DTM can lead to gross errors along larger slopes.

Errors in DTMs are usually classified as either sinks (pist) or peaks. A sink is surrounded by higher elevation values, and is also referred to as a depression or pit. This is an area of internal drainage. Some of these may be natural, e.g. in glacial or karsts areas (Mark, 1988). Many sinks are imperfections in the DTM.

A sink can happen in the following cases:

- If all neighbors are higher than the processed cell, the processed cell is a sink and has an undefined flow direction.

- If two cells flow to each other they are sinks and give an undefined flow direction.

- If a cell has the same change in Z value in multiple directions it is a sink and has an undefined flow direction.

If all of the cells have an undefined flow direction, the value for that cell in the output flow direction grid will be the sum of those directions. e.g. if the change in z value is the same both to the right (flow direction = 1) and down (flow direction = 4) direction, the flow direction for that cell will be 1 + 4 = 5. Cells with undefined flow direction can be flagged as sinks by using the SINK function in Arc/Info package.

A spike or peak is an area surrounded by cells of lower value. These are more common natural features, and are less detrimental to the calculation of flow direction.

There are often errors in the data of sinks and peaks due to the resolution of the data or rounding of elevations to the nearest integer value (See Figure 2-10).

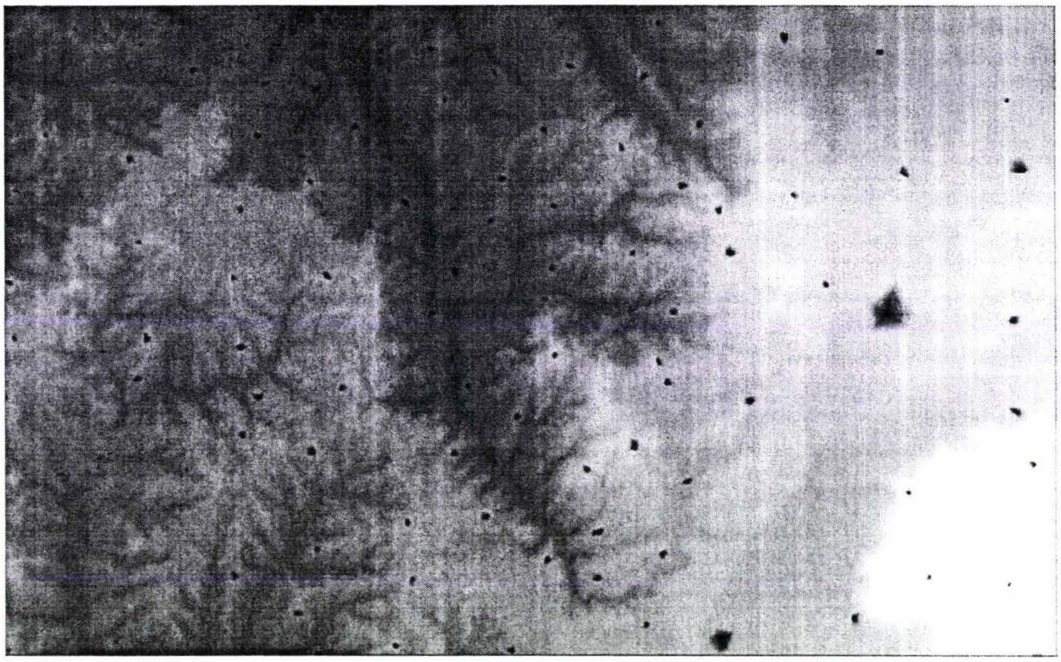
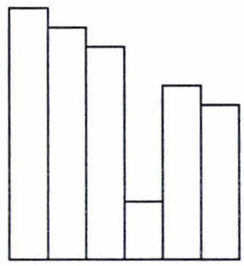
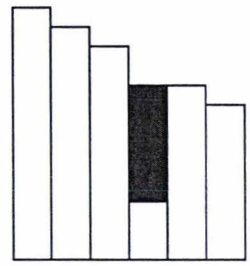


Figure 2-10 Sinks in the low pass filtered shaded relief is from the 30 metre lattice DTM.

2.8.4 Fill

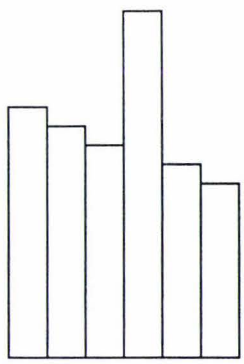
Errors in the data of sinks and peaks, especially sinks, should be removed before attempting to derive any surface information. Sinks, as areas of internal drainage, may cause undesirable results when flow direction is calculated. In Arc/Info, the FILL function is used to remove or fill sinks. After using the Fill function, all sinks in the Figure 2-10 will be removed. The Figure 2-11 shows the process of the filling function.

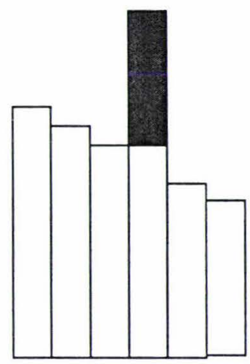




Profile view of a sink before FILL

Profile view of a sink after FILL





Profile view of a peak before FILL

Profile view of peak after FILL

Figure 2-11 The process of FILL function

2.8.5 Catchment

After filling the sink errors in the DTM, the basin function can delineate catchment within the analysis window by identifying ridge lines between catchments. The function BASIN analyses the flow-direction grid to find all sets of connected cells that belong to the same catchment. The catchments are created by locating the pour points at the edges of the analysis window (where water would pour out of the grid), then, just like sinks, identifying the contributing area above each pour point. Figure 2-12 shows the result of a grid of the Whanganui catchment.

Figure 2-12 Whanganui catchment derived from the TIN model

This result of the Whanganui catchment derived from the TIN model is intuitively correct. To prove this completely, a further test is carried out by tracing the Whanganui River structure from its source.

2.9 Generalizing the river centre line coverage

The river centre line coverage of the Whanganui catchment region, which is the main body of the river, was initially digitised by multiple-line feature coverage. Before tracing process the first step of the analysis for this stage is to change the multiple-line feature to single-line feature. This process is called generalization.

The river center line coverage generalization is a process to extract and reduce or eliminate unimportant features, simplify lines and boundaries, combine area features, and resolve conflicting information from reality or source maps. It makes a map more explicit to display a specific theme at a smaller scale, while meeting cartographic specifications and maintains the representative integrity of the mapped area. Generalization involves a great deal of human analysis of the geographic data and decisions. It is very difficult to fully automate this process. A digital generalization technology has been developed for decades. However, a set of universal rules has not existed that explicitly defines how generalization should be performed. Traditional generalization adopts a manual process, which is extremely subjective and time consuming (Mark, D.M., 1988).

However, in this project we adopt manual generalization. A single-line related to the INFO file of multiple-lines is put into the middle of the double-lines. Then the multiple-lines are deleted. This process is time consuming.

After generalizing the river centre line coverage, this coverage is combined with the river line coverage, which is a tributary of the river, to create a new river coverage by using the PUT or GET command with the arc snap on 250 m. Figure 2-13 shows the new river coverage.

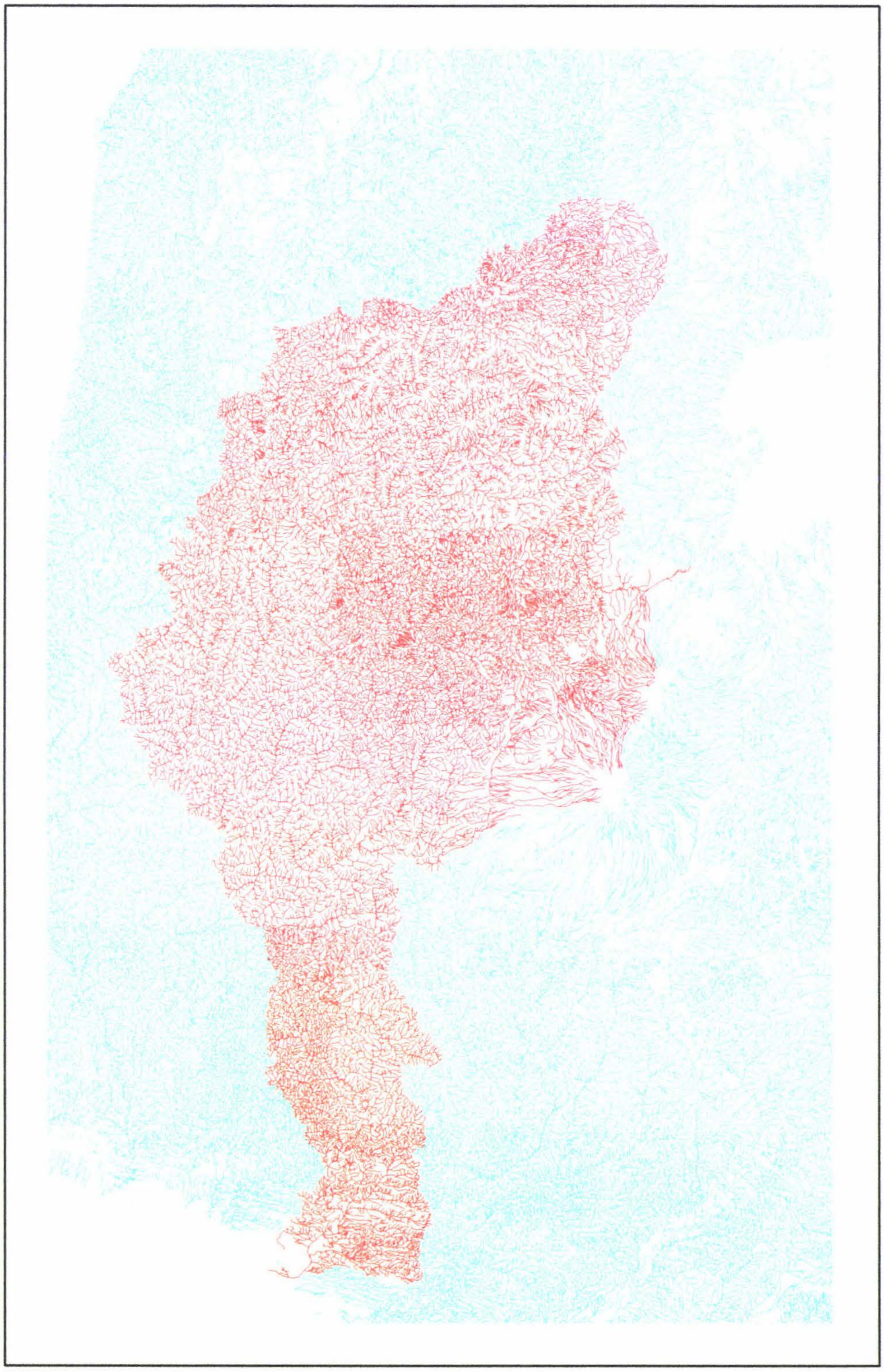
Map Scale 1:1050000

Figure 2-13 A new river coverage after generalizing

2.10 Tracing the new river coverage

The TRACE function organizes a network to create a selected set of arcs and nodes that flow into and/or out of an origin node or nodes. By using the TRACE function all arcs connected to the endpoint or point of discharge of the Whanganui River can be identified (Davis, K., 1999). The function TRACE DIRECTION identifies the flow direction of each selected arc and creates its flow-direction-file where flow is from the from-node to the to-node of the arc. The other arcs that are not in the flow-direction-file are oriented in the opposite direction. So after using the TRACE command, two selection files can be created, one is an outflow-direction-file that contains arcs oriented (in terms of digitised direction) away from the node location, and another is an inflow-direction-file that contains arcs oriented towards the node locations. When the flow direction has been established, the path resources will be found, which build flow network and travel along all connected arcs that belong to them, by using the trace <both > option (ARC/INFO software version 7.2.1 help).

Figure 2-14 is a result of using the TRACE function on the new river coverage with both options. The red arcs indicate the whole Whanganui River catchment. The black arcs do not belong to this catchment. Comparing this trace result with the Whanganui catchment pattern (see Figure 2-12), you can see that they are exactly the same. This result proved the TIN model has been generated successfully. TIN is adequate to define catchments.



Map Scale 1:1050000

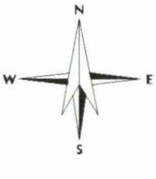


Figure 2-14 By using the TRACE function, the whole Whanganui River catchment (red lines) is extracted from the new river coverage

Chapter 3

Channel slopes and sinuosity identification

Up to now, boundaries and drainage patterns have been determined from the TIN model of the Whanganui River catchment. In the next step we will trace the Whanganui River drainage to advance prove the TIN's accuracy and figure out the channel slopes and the channel sinuosity for all points of the Whanganui River catchment by using basic information from the 1:50000 topographic maps.

3.1 The goals

- Testing whether it is possible and adequate to use the data base of 1: 50000 contour to carry out the channel slope and channel sinuosity rather than the notion of the reach scale.

- Calculating the channel slopes for each arc of the Whanganui River catchment.

- Calculating the channel sinuosity for each arc of the Whanganui River catchment.

3.2 The data sources

In this chapter, the data to be analysed are based on the Whanganui region dataset coverage, which was clipped from that of Taranaki and Waikato (refer to section 2.6.2). We also have created the DTMs and the data, which were determined from the DTMs.

- The DTMs of Whanganui catchment based on the TINs which were created and data which were extracted from the DTMs.

- The contour line coverage of the Whanganui region.

- The river line coverage of the Whanganui catchment region.

3.3 The methods of this approach

As mentioned previously, to save more space, processing time and reduce the amount of data to avoid a software limitation problem, it is very important and necessary to reduce the size of each dataset of the Wanganui region coverage. So extracting only the Whanganui catchment pattern from each data set is essential. Whanganui catchment boundaries are used as the background, the Whanganui catchment contour coverage is clipped out from the whole contour line coverage.

3.3.1 Calculating the channel slope

The channel slopes between the upstream and downstream nodes of the valley segment can be calculated by dividing the elevation difference (between the upstream and downstream nodes of the each arc) by length along the channel. The channel sinuosity between the upstream and downstream nodes of each arc can be calculated using length along the channel divided by straight line distance between the nodes for any point of the river catchment (Snelder, T., et al., 1999).

The river coverage does not have a height attribute in its node attribute table. However, the contour coverage has its elevation attribute in its arc attribute table. In order to figure out the elevation of each node in the river coverage, an idea is adopted to use the overlay technology putting the contour and river coverage together to create a contour-river coverage, which can give the elevation (height value) for each intersection node. There are three kinds of different nodes, which will be defined in this overlaid coverage: An example to explain the three different kinds of nodes will be shown in Figure 3-1. The brown lines are the contours and the blue lines are the rivers. The type of the nodes A and B are 0, the type of the nodes C and D are 1 and the type of the nodes E, F and G are 2.

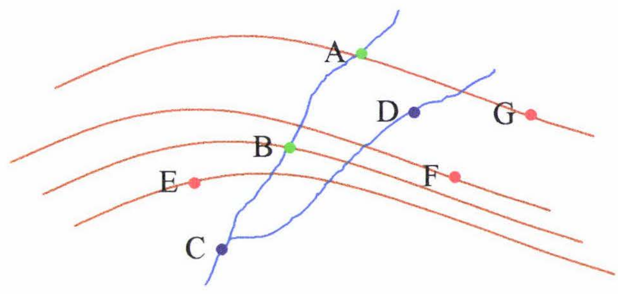


Figure 3-1 Three different kinds of nodes in the overlaid coverage.

- Type 1: The nodes of the river coverage.

- Type 2: The nodes of the contour coverage (the elevation as the height value).

- Type 0: The nodes of the contour coverage overlaid with the nodes of river coverage.

The height value of nodes of Type 1 and Type 0 will be calculated. Detail of the method will be displayed in the following sections. After the height value of each node has been figured out, the channel slope can be calculated. The process detail is shown below (see Figure 3-2).

The following is a diagram that gives an outline structure of this process.

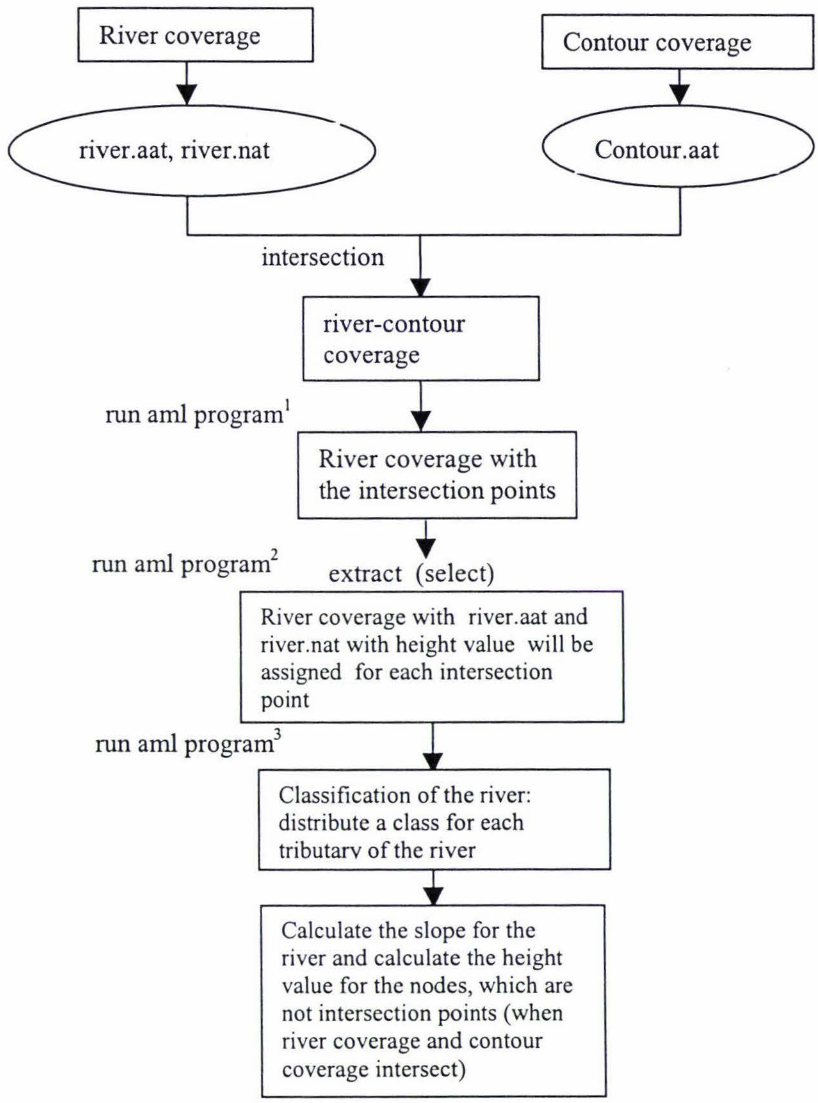


Figure 3-2 Outline structure of the process of calculating the channel slope (1: Appendix 1; 2: Appendix 2; 3: Appendix 3)

3.3.1.1 Identifying an elevation of the type 0 intersection points in the river.nat

Both river coverage and contour coverage have their INFO file. Using the command BUILD with the LINE and NODE operations can create the arc attribute table (aat) and node attribute table (nat) for the two coverages. The following process will distribute the elevation value from contour.aat into the river.nat:

- Adding item *type* for all of the river.aat, river.nat, the contour.aat, and the contour.nat of each coverage.

- Assigning value 1 to the *type* column of river INFO file and value 2 to the *type* column of contour INFO file.

- Adding item *elevation* for river.aat and river.nat.

- Assigning -9999 to these elevation columns, to differentiate null.

- Using *intersection* technology in putting the two coverages together. During this process, in order to avoid software limitation problems, space problems and to save time, first each contour coverage and river coverage is separated into five small pieces. Overlaying each of the relavent pieces of the contour coverage and the river coverage by using INTERSECTION command. The process followed works for each small piece of contour-river coverage, which means the same processing will be repeated four times.

- A node attribute table (nat) and an arc attribute table (aat) for intersection coverage are built.

- The river coverage is extracted from the contour-river coverage by using SELECT command. Then using the BUILD command with the LINE and the NODE operation, a new arc attribute table and a new node attribute table are created. There are three groups of value in the *type* column. (see the Figure 3-1) The value 1 indicates the nodes which are not intersection points. They are the original river features and their elevation columns keep value -9999. The value 2 indicates the nodes which are the original contour features and their elevation columns keep their original values. The value 0 indicates the nodes that are intersection points of the river coverage and the contour coverage when they are overlaid. The values of elevation columns are shown as 0.

- Next, all 0 values are replaced with corresponding contour height values, using an AML program (see Appendex I).

  AML stands for Arc Macro Language. Macros are used in GIS as in any other program, to simplify the process and to perform calculations and other activities that otherwise would be too time consuming.

3.3.1.2 Analysing the AML structure of Appendix I

This is an algorithm (in pseudo code) to approach the intersection elevation to replace the 0 value.

```
Tables
Select intersection-coverage.nat
Reselect type = 0 and elevation = 0 or type = 2 and elevation = 0
Unload file1 using column intersection-coverage#
/* this file1 is a text file
/* make a read file using unload file1
&do &while records of read file = 0
select intersection-coverage.aat
reselect form-node# = record
aselect to-node# = record
reselect elevation  > -1   /*We have assigned elevation = -9999,
                             when type = 1. This command will
                             just chose the record type = 2 and
                             type = 0
unload file2 using column elevation
read the elevation from file2
   Select intersection-coverage.nat
   Reselect intersection-coverage# = record
```

```
Calculate elevation = file2' s elevation
&return
```

3.3.1.3 Assigning a class number for each arc of the river coverage

Now, just the nodes with the type 1 need to be defined for the elevation of the river coverage. These nodes are original data in the river coverage that do not contain any height information. They are also related to a large number of irregular data. However, the AML program based on the use of the GIS network to find out the path of each arc is the main line to approach this issue. First, it should be made sure that all the data has a consistent flow direction. Then the rivers main trend and each tributary are assigned class numbers (e.g. 1, 2, 3,...). The principle by which the class numbers for the river are assigned is to use the GIS network to find the longest river from the sea. It is assumed to set the base level and has the lowest identifier (class 1). Node heights are calculated for this longest river first. Tributaries to this river have their base level set by this river. Each lower order tributary has its base level set by the next tributary up the order. An AML program is used (See Appendix II).

3.3.1.4 Analysing the AML structure of Appendix II

This is an algorithm (in pseudo code) for assigning a class number for each arc of the river coverage

```
Tables
Add item class for the river.aat and the river.nat
Add item direction for the river.aat
Quit

/* populate direction item outflow = 1 inflow = 2
Arcplot environment
```

Trace river coverage

calculate downstream direction = 1

calculate upstream direction = 2

Quit

Arcedit environment

Flip all upstream direction

Save

/* manual select start node and store this record number

edit feature nodes

&sv startnodeid

/* select dangle arcs and set them as a variable

&sv numcon

/* select fnode for each dangling arc, find path to start node, keep the longest path

if variable numcon = 0 /* means there is no dangling arcs

else,

call findnode

/*do sub-program of main program called findnode to find each

/*nextnode id which is not startnodeid. Then use network to find /*paths between startnode and each nextnodes using another /*program which is inside sub-program findnode

call findpath, and

call redolongpath

/*to find and keep the longest path, then process and return back to /*main program.

&sv clas = 0 /* set a variable clas and give it an initial value 0

call setclass

/* do subclass program, called setclass, to assign a value for all /*arcs on the longest path, then return to main program

select class = variable clas

put newcov

/* a coverage which hold all arcs which have an assigned class

call tidyup

/* do subclass program, called tidup, to delete the arcs which /*hold class number in the original coverage.

/*arcpolt environment

netcover clear /* delete and reset the network

quit

/*arcedit environment

edit river coverage

&return

3.3.1.5 Calculating the slope and identifying the elevation of the non-intersection type 1 points in river.nat

Once the elevation of each type 2 or type 0 node is available and the class number for each arc of the river main trend and tributaries is assigned, the elevations of the type 1 nodes will be calculated. Then the slope of each arc can be calculated. The basic method is:

Calculating the slope of each arc by using the command PATH to find the path, which is from the elevation of the start node to the elevation of the next node. Normally the difference of the start height to the next height of the elevation of the nodes is 20 metres, because we use the 20 metre contours as the basic unit. So the formula will be:

slope = (N – S) / path

N is a next height elevation;

S is a start height elevation.

Here "path" is from start height node to furthest next height node along the same class.

Figure 3-3 is an example that explains each variable of the formula.

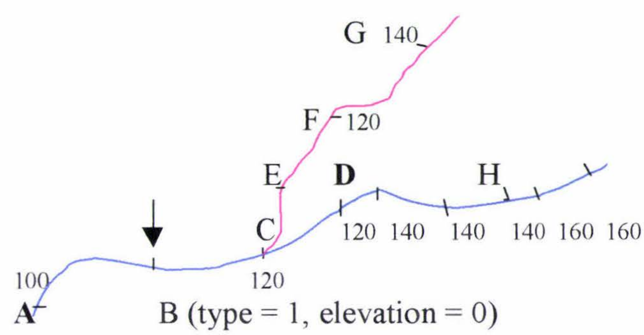


Figure 3-3 A part of the river with different classes

This is a part of the river with two tributaries. It is assigned by different classes e.g. the classes with all blue arcs are 9 (A, B, C, D and H in Figure 3-2), the classes with purple arcs are 10 (E, F and G in Figure3-2). The class number of intersection nodes always belongs to the smaller number of the class. For example on node C, its class number is 9.

The node A is the start height with elevation 100. The node D is the next height with elevation 120 (it is the same class on A and is the furthest node with elevation 120m). The path is between node A and node D. So the slope from A to D can be calculated. However, we assume all the arcs between node A and node D the same slope. The start node followed will be D and the next node will be H and so on.

Once the slope of each arc has been calculated, it can be used together with the path between each arc to calculate the elevation of each node with type 1 (e.g. node B). The formula is:

elevation = (slope * path (which is from node A to node C)) + start node's elevation (the elevation of node A is 100).

Under this principle an AML program is written to perform the process. See Appendix III: An AML program to calculate the slope of each arc and elevation of the nodes with type 1.

3.3.2 Analysing the slope result

After running the AML program, the slope of most arcs and the elevation of each node have been assigned. However, some arcs haven't got the correct slope. There are two main issues, which need to be identified:

a. The slope of most dangle arcs is null.

b. Some arcs have negative slope.

There are some factors causing these two errors:

In Issue a, for each tributary (any different levels), if the end of the node is type 1, its elevation is 0. The slope of the end of the arc will be null. Because in the AML program of the Appendix III, the elevation of the variable next node is defined as

If *&sv nextheight = &sv startheight + 20,*

Then AML process to be continue,

If *&sv nextheight <> &sv startheight + 20,*

such as, Issue a,

nextheight = 0, and type = 1,

The program will display 'end of the class'. So the slope value of these arcs will be null. Then the program will process next number class of arcs.

In Issue b, there are many situations to cause the negative slope. In the AML program of the appendix III, each arc is defined as downstream if it is a start node, and upstream if it is the next node. But, in the real world, sometimes the river direction shows as a loop. Sometimes the river crosses a hill. The 20m interval contour line cannot describe them in much details. In these cases the next height may be lower than the start height. Also in the watershed of different level of tributary, the next height may be lower then the start height. So the slope will be negative if using the formal calculation method for slope in the AML program of Appendix III. There is an example to show the one situation in the Figure 3-4. The river flows from node A to node E, crossing contour line 420, 400, 380 and 360. The river slopes between C and D, D and E are negative.

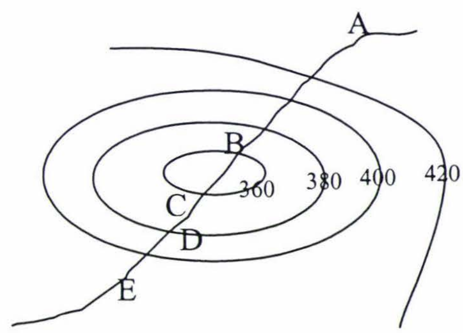


Figure 3-4 An example to show the negative slopes

In order to solve these problems, an advanced approach is needed. An AML program is written to assign slope value to dangle arcs of type 1 and to recalculate the arc's slope if the slope is negative.

The principle of this AML is to look for the height values of the fnode (&sv %height0%) and the tnode (&sv %height1%) of each arc in the negative slopes:

if the value %height0% = 0, then

the arc might be dangling.

Else,

if %height0% - %height1 > 0% or

height0% - %height1 < 0, then

the slopes of the arc will be recalculated (a arc length divided by the different of a height value).

Else, look for the number of arcs which, are

tnode# = %fnode% (the arcs are same class)

if no any arc belong this situation, then

this arc is dangling arc,

the slope value of the dangling arc is same as its connected of same class arc.

Else,

The slope will be recalculated.

The details of this AML program are shown in Appendix VI.

3.3.3 Calculate the channel sinuosity

The sinuosity of the channel is a very important attribute and criterion in identifying the channel type of the valley segment scale in the ecotyping methodology. See Figure1-1 Physical variables affecting habitat in rivers.

Valley segment scale is identified in ARC/INFO system as an arc from upstream to downstream of each node. The sinuosity of the channel between the upstream and the downstream of each node of the valley segment, which essentially are f-node and t-node of each arc are calculated by using their length along the channel divided by the straight line distance between the nodes (Snelder T.,et al., 1999). Figure 3-5 is an example that shows the method of calculating the channel sinuosity.

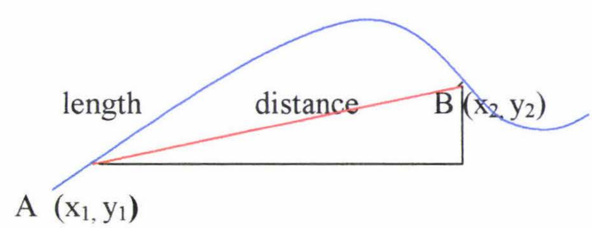


Figure 3-5 The relationship between the length and the distance of the arc from node A (x_1, y_1) to node B (x_2, y_2)

The method to calculate the channel sinuosity is:

Sinuosity = length / distance

or, extract the coordinate value of the nodes A and B.

Sinuosity = path (from nodes A to nodes B) / $\sqrt{(x_2 - x_1)^2 + (y_2 - y_1)^2}$

Based on this principle, an AML program is written to implement a calculation of the channel sinuosity for each arc in the Whanganui catchment. See Appendix V: an AML program to calculate channel sinuosity.

All those results have proved that the river slopes and sinuosity can be calculated from inter contour stretches of the river. However there is another issue- the river may be cut down into gorges, which are not revealed by 20 meter contour.

Chapter 4

Implementation of the river habitat classification in GIS database

4.1 Introduction

The habitat classification of rivers is a tool that subdivides the river system into units based on the similarities and differences in a range of physical variables. These physical variables are termed controlling variables. They are divided by four spatial scales, regional scale, catchment scale, valley segment scale and reach scale. See the Figure 1-1. Each spatial scale is defined by some controlling variables that represent the habitat ranges for different biota. It has been developed by NIWA for MfE to provide a river environment classification system of dividing rivers into habitats in relation to the ecological values that the river supports such as plants (periphyton and macrophytes), invertebrates, fish and birds is called ecotyping methodology (Snelder, T., 1998).

4.2 The targets of the project identification

The river habitat classification requires the development of appropriate GIS databases.

- On the catchment scale, the layers of elevation, rainfall, geology and land-cover data will be implemented to identify each arc of the Whanganui river.

- On the valley segment scale, the channel slope and channel sinuosity will be used to identify the channel type for each arc of the Whanganui river.

- Both the catchment scale and the valley segment scale data are processed by applying the classification rules, which are defined by Snelder et al., (1999).

- The completed classification is summarised in a database with each unique, classified arc.

- These database tables will be joined as a set of attributes on the GIS layer to represent the river's channel network.

4.3 Data sources

- The habitat classification requires some controlling varables to represent different spatial scales, such as elevation, slope, and sinuosity. These can be found in the Whanganui River coverage with its INFO file. They are ARC/INFO file format.

- Other controlling variables of habitat classification, such as the geology and land-cover, derived from a digitized NZLRI (New Zealand Land Resource Invertary) and LCDB (Land Cover Data Bases) data that are stored as polygons. They are the shape file format which is a layer in the ARCVIEW environment.

- A digitized polyline annual rainfall layer. This is a shape file format in the ARCVIEW environment.

4.4 Procedures

- Step 1: The current data exists in two different software environments and has a different format. They need to be converted to the same data format for further analysis and classification.

- Step 2: Use GIS overlay technology to extract the data required by this project.

- Step 3: Classify each arc in the database based on the rules for each controlling variable of habitat classification.

Details follow:

4.4.1 the arcs' elevation identification

After running the AML programs mentioned in the previous sections, the elevation value is created in each node of the Whanganui River coverage, which is held in its node attribute table. However, no arc between any two nodes has an elevation value to be identified. It means there is no elevation feature in the arc attribute table of the Whanganui River coverage. In order to implement the river environment classification (river habitat classification), an elevation value has to be assigned to each arc. There are two nodes in each arc that are called from-node (fnode#) and to-node (tnode#). In this project, each arc will hold the same elevation value as that in its to-node (tnode#). To approach this issue, an AML program has been written. However, this processing will take 13 days to run, because the whole Whanganui River coverage has 132919 arcs! Is there any other way to achieve it more efficiently and more intelligently? Instead, a relational database operation, relate, is adopted to achieve this target. The related common items links the river's node attribute table (nat) and arc attribute table (aat) to assign the elevation value (the elevation of tnode#) of the nat to corresponding arc record in the aat. Because of this computing process in the relate environment, there is no need to enter ARCEDIT or TABLES to read the data and to judge or calculate the data. It is very fast. To achieve the target just takes a few minutes.

4.4.2 A new river coverage with database creation

Now, the current data is in the two different environments and has different data formats. It has to be put in the same environment before any analysis. For convenience, the Whanganui River coverage will be converted from the ARC/INFO environment into a shape file for use in ARCVIEW environment.

4.4.2.1 The geocoding system identification

The river coverage displays as a layer in the ARCVIEW environment. For the analysis, the following layers have to be registered to the same position in the river layer: NZLRI (New Zealand Land Resource Invertary) layer, LCDB (Land Cover Data Bases) layer and rainfall layer. All of them through a common coordinate system ------ New Zealand Projection.

4.4.2.2 Overlay technology implementation

Topological map overlay technology creates new features and attribute relations by overlaying the features from two or more input map layers. Features from each input layer are combined to create new output features. Attributes of each input feature are combined from the two or more input layers to describe each new output feature, thus the new attribute relationships are created (Escobar, F., *et al.*, 2001).

In this project, intersection line on polygon technology is implemented. Line on polygon searches overlay a polygon on a set of lines and output shows those lines contained in the polygon in which the relationship is computed for line on polygon searches. During the overlay process, lines are broken at the boundaries of overlaid polygons and the polygon becomes an attribute of the line segment (Williams, D., and Summer, R., 1995).

The intersection of the river layer (lines), with the NZLRI layer (polygon) and LCDB (polygon) has created a new river layer with INFO file that has not only the original items (columns) but also all the items of both NZLRI and LCDB.

Because rainfall data is polyline file format, the intersection command cannot be used before changing it to polygon file format. In this case, manually editing polyline data to polygon is required. It is the basis for adding some polyline to join the rainfall line together then assigning a new rainfall value for each polygon. The new rainfall value of each polygon is the average value of the original two neighbor polyline rainfall values. Then the rainfall (polygon) data is overlaid to the new river layer by using the intersection again.

Now, the new Whanganui River layer with its database owns all information required by this project. This is:

- river elevation data,
- channel slope data,
- channel sinuosity data,
- NZLRI (New Zealand Land Resource Invertary) data,
- LCDB (Land Cover Data Bases) data,
- annual rainfall data.

In the next step the data needs to be classified based on the rules of each controlling variable as suggested by Snelder, T., et al. (1999). To implement this classification in the relational database operation - Relate will be use in the ARC/INFO environment. Thus, converting the new river layer in the ARCVIEW environment to the new river coverage in the ARC/INFO environment by using SHAPARC command to processes.

4.5 Implementation of the river environment classification

In this section, an implementation of the river environment classification theory in the Whanganui River coverage will be described, based on the rules of the classification for each controlling variable which is refered to in *Testing a system of river environment classification ------ stage 1. Further development and application of a GIS based river environment classification system* by Snelder, et al (1999).

4.5.1 Rules for classifying Geology

In this project the geological data of the Whanganui catchment is from the NZLRI. The principle of classification has been used from the top rock categories. However, when the top rock is a highly erosive material such as loess, base rock is allowed to be used as a part of the classification. In this case, the classification of catchment geology combines the erosive top rock category and the dominant base rock category.

Not all of the rock type categories provided by the NZLRI are 'biologically' relevant. The NZLRI categories therefore have been grouped into 'ecotyping' geological categories as shown in the Table 4-1. It is a table of geological categories used by the environment classification that classifies the geological categories of NZLRI used by the ecotyping classification.

Table 4-1 A table of geological categories used by the environment classification (refer to appendix of NZLRI categories for key)

Ecotyping Category	Rock_code	NZLRI Category (Whanganui catchment)	Notation
Acidic Igneous	Va	Kaharoa and Taupo ashes , Lapilli, Taupo and Kaharoa breccia and volcanic alluvium, Breccias older than Taupo breccia	Kt, Lp, Tp, Ft
Alluvium and Sand	Al	Undifferentiated floodplain alluvium, Gravels, Sands - windblown	Al, Gr, Wb
Basic Igneous	Vb	Scoria, Lahar deposits, Ngauruhoe ash, Tarawera Ash and Lapilli, Rotomahana Mud, Ultramafics	La, Ng, Ta, Rm
Gneiss	Gs		
Hard Sedimentary	Hs	Argillite, Argillite - crushed, Greywacke	Rr, Ac, Gw
Lime Stone	Ls	Limestone	Li
Loess	Lo	Loess	Lo
Miscellaneous	Mi	Othertop/ Otherbase	
Mix Igneous	Vm	'Soft' volcanic rocks, Lava, ignimbrite and other 'hard' volcanic rocks, Ashes older than Taupo Pumice	Vo, Mo
Peat	Pt	Peat	Pt
Plutonic	Gn	Crystalline intrusive rocks	Gn
Soft Sedimentary	Ss	Mudstone or fine siltstone - massive, Mudstone or fine siltstone - banded, Mudstone or fine siltstone - jointed, Mudstone - bentonitic, Sandstone or coarse siltstone - massive, Sandstone or coarse siltstone - banded, Conglomerate and breccia, Unconsolidated to moderately consolidated clays, silts, sands, tephra and breccias Us	Mm, Mb, Mj, Me, Sm, Sb, Us

4.5.2 Rules for classifying land cover

Land cover is one of the controlling variables in the catchment scale in the river environment classification. Its data is available from Land Cover DataBases (LCDB). Table 4-2 The land cover categories used by the ecotyping classification show the land cover categories used by the ecotyping classification.

Table 4-2 The land cover categories used by the ecotyping classification

Ecotyping Category	Veg_code	LCDB Groups
Pasture	P	Primarily pastoral
Tussock	T	Tussock
Scrub	S	Scrub
Exotic forestry	EF	Planted forest
Wetlands	W	Coastal wetlands, inland wetlands
Urban	U	Urban, urban-open space, mines, dumps
Indigenous forest	IF	Indigenous forest
Misc	M	Coastal sands, mangroves, riparian willows
Bare Ground	B	Bare ground

4.5.3 Rules for classifying elevation

Elevation, as a controlling variable, has been used to represent the location of the valley segment within the catchment. The valley segment scale indicates and constrains the local topography and controls the potential size and morphology of the river channel. Elevation is also an important criterion element to control and distribute rivers of ecology. Each valley segment has been classified according to elevation by calculating the average elevation above sea level for each reach. In Table 4-3 the elevation categories of the valley segment control variable show the classification of the valley segment elevation.

Table 4-3 The elevation categories of the valley segment control variable

Ecotyping categories (elevation_code)	Elevation above sea level
A	0 –20 m
B	20 – 100 m
C	100 – 1000m
D	1000+ m

4.5.4 Channel types classification rules

Snelder, T., et al. (1999) have developed a classification for New Zealand channel types by using the strength factors, which reflect and control the river channels such as channel slope (channel gradient), channel sinuosity percent, channel in alluvium and braiding index.

'The most difficult class to distinguish in an objective way is the entrenched stream or river, such as those flowing across the tertiary mudstone country between the Rangitikei and Whanganui Rivers. Their character reflects not just hydraulic/geomorphic processes in the channel itself but the immediate geological surroundings' Snelder, et al. (1999). In particularly, the criteria for the allocation of a stream or river to the entrenched categories needs further testing. However, it is possible to make sub-types from other principle types. See Table 4-4 Channel type categories for use by the classification to find the channel type categories that were created by using ecotyping method. This table is quote from Snelder, et al. (1999).

Table 4-4 Channel type categories for use by the classification

Channel type	Description
Cascade	A cascading stream has a very steep gradient (0.08-0.15), is confined by adjacent valley walls, and flows over bed material which is of cobble and boulder size and which is not organised into distinguishable bed forms. Bedrock outcrops in the bed and banks are frequent. The water tumbles over the bed material in jets and falls, with many small pools among the boulders.
Step-pool stream	A step-pool stream has a steep gradient (0.03-0.065) and is characterised by the presence of periodic accumulations of cobbles and boulders that create steps or falls in the longitudinal profile. They are separated, at a spacing of 1-4 channel widths, by pools or runs which contain finer (gravel and cobble) bed material. The channel perimeter is largely composed of alluvial material; bedrock outcrops are infrequent. Nevertheless, the stream is confined by the valley sides, and there is limited development of terraces or floodplain.
Plane cobble/	A plane bed stream or river has a moderate gradient (0.005-0.03), and

gravel bed stream or river	looks like a continuous riffle. The bed is composed predominantly of cobble and gravel (boulders may be present), and is largely featureless, with little sign of rhythmic bedforms such as steps, bars or riffles. The channel is relatively straight, and may be confined or unconfined by the valley sides. However, the banks – which are composed predominantly of alluvial material which is resistant to lateral erosion – constrain the flow from migrating laterally and developing alternate bars/riffles.
Riffle-pool stream or river	A riffle-pool stream has a moderate gradient (0.002-0.015), and during normal low flow has a regular sequence of gravel/cobble riffles (alternate bars or "skew shoals"). These are separated, at a spacing of 5-15 channel widths, by pools and runs in which the bed is predominantly gravel, with occasional cobbles and patches of sand. The high flow channel has a low sinuosity (<1.1), but the flowing water during normal low flow winds across the alternating gravel bars, and the pools tend to be at the toe of the banks, and elongated. The channel is bordered by Holocene terraces or a currently active floodplain, possibly with occasional bedrock outcrops and probably with a continuous cover of willow trees. The banks are resistant to erosion, so that they limit lateral migration of the channel; the channel therefore is relatively narrow and deep.
Semi-braided gravel bed river	The semi-braided gravel bed river has a moderate to steep gradient (0.004-0.03), depending on the size of the bed material and its location between the headwaters and the sea. During low flow there are one or two main channels, and backwaters and discontinuous channels which mark the location of former high flow channels. The channel divergences, confluences, bars and riffles are somewhat irregularly distributed across a wide active bed, and the river has an appearance of instability and recent change. The channel may be bordered and somewhat confined by Holocene terraces or a currently active floodplain, but is actively eroding its banks, particularly where the low water channels impinge on the foot of the banks.
Braided gravel bed river	A braided gravel bed river has a moderate to steep gradient (0.004-0.03), depending on the size of the bed material and its location between the headwaters and the sea. There are at least two, and up to ten or more, low flow channels which are separated by extensive areas of gravel bar and gravel sheets. The individual braids feature riffles, pools, and runs similar to those in a riffle-pool channel, but the frequent confluences and divergences add an extra level of complexity. The active channel as a whole appears unstable, although there may be extensive areas of gravel which are becoming vegetated. The channel margins are composed of Holocene or Recent alluvium and are being eroded by the river in many locations, so that the channel is laterally confined to only a limited extent.
Entrenched stream or river	The entrenched stream or river has a relatively narrow and deep channel that is incised into the terraces and valley fills across which it flows. It commonly has a pronounced meandering course, but can have a gradient anywhere between 0.0005-0.01, depending on proximity to the sea and local geologic conditions. Even at low flow, water covers the full width of the bed; the composition of the bed reflects catchment geology, but commonly is fine gravel and silt, although there are occasional bedrock outcrops in the channel bed, and even small

	waterfalls. The channel is strongly confined by terraces and valley walls.
Freely meandering river	The freely meandering river has a low gradient (0.0001-0.001), and a relatively narrow and deep channel that winds across a floodplain composed of silt and sand that the channel has itself deposited. It is only locally confined by terraces or valley walls, and is actively eroding its banks and migrating laterally. Willows and other channel control works may prevent the channel's natural tendency to migrate. The bed is composed of silt, sand, and fine gravel, and alternate bars and pools are associated with the bends and crossings of the meander pattern.
Tidal river	The tidal river is in most respects similar to the freely meandering river, with a sinuous course and a relatively deep and narrow channel. However, it shows the additional influence of the regular ebb and flow of the tide, and the gradient is very low (<0.0001). The bed and banks are generally composed of mud, silt and sand. In northern North Island, the channel may be stabilised by mangroves.
Channelised stream or river	The distinguishing characteristic of a channelised river is that it has been modified or created by human agency. It is generally straight, with a regular cross-section, and is relatively narrow and deep. The gradient is likely to be in the range 0.0001-0.001, with concrete weirs to maintain a low gradient, although it is possible to have very high gradient, channelised torrent courses. Bed and bank material may be artificial, including rock rip-rap and concrete.

There are two factors, the braiding index and the percent channel of alluvium, that are omitted in the following classification because the Whanganui River has very little braiding and the percent channel of alluvium is not relevant to this project.

In this project there are two factors to concentrate on, which reflect and control the river channel type such as channel gradient and channel sinuosity. See Table 4-5 Channel type categories with channel gradient and sinuosity for channel type categories.

Table 4-5 Channel type categories with channel gradient and sinuosity

Ecotyping Channel type	Channel_code	Channel gradient	Channel sinuosity
Cascade	CG	0.065-0.15	<1.1
Step-pool stream	SG	0.03-0.065	<1.1
Entrenched plane cobble/ gravel bed stream or river **or** Non entrenched plane cobble/ gravel bed stream or river	EP	0.005-0.03	<1.2
Entrenched riffle-pool stream or river **or** Non entrenched riffle-pool stream or river	ER	0.002-0.015	<1.4
Semi-braided gravel bed river	SBR	0.004-0.03	<1.2
Braided gravel bed river	BR	0.005-0.015	<1.1
Entrenched stream **or** river	ES	0.0005-0.01	No limits
Freely meandering river	FM	0.0001-0.001	>1.4
Tidal river	TR	<0.0005	No limits
Channelised stream **or** river	CH	No limits	Normally <1.1

4.5.5 Implementation of the classification rules

Based on the classification rules of each controlling variable, for the classification of these variables in the database, the relate operation is still an efficient method. The relate environment has been discussed in section 4.5.1.

Implementing the channel type classification is different with geology, land cover and elevation. Like the ecotyping classification described in section 4.6.4, for channel type categories, some values of the criteria for categories have overlapped each other. For example channel type ES and FM have some overlapping paths. The types CH and CG, SG and BR have overlapped and so on. We cannot implement the channel types classification by using RELATE like other controlling variables described before. There are a series of SELECTION commands in the ARC/INFO, which can be used to achieve this target.

Up until now, in the Whanganui River arc attribute table, the geology is classified as 12 categories in the rock_code. The land cover is grouped as 9 categories in the veg_code. The elevation is classified as 4 categories in the elevation_code The channel type is classified as 10 categories in the channel_code. The environment classification will combine these four controlling variables. Writing an AML program to process this target is difficult and complex. A simple and efficient method is implemented as follows:

- Working on the TABLES.

- Adding an item called ecotype.

- Using REDEFINE to define four columns, rock_code, veg_code, elevation_code and channel_code, as one combined column called ecotype. Then taking ecotype as one item in the Whanganui River arc attribute table. This ecotype combined column like small sub-table to record all information of these four controlling variable categories in the database.

- Using FREQUENCY to create a ecotype lookup table. The combination of the rock_code, veg_code, elevation_code and channel_code will be figured out. The final classification results are 719 ecotyping groups. Please see Figure 4-1.

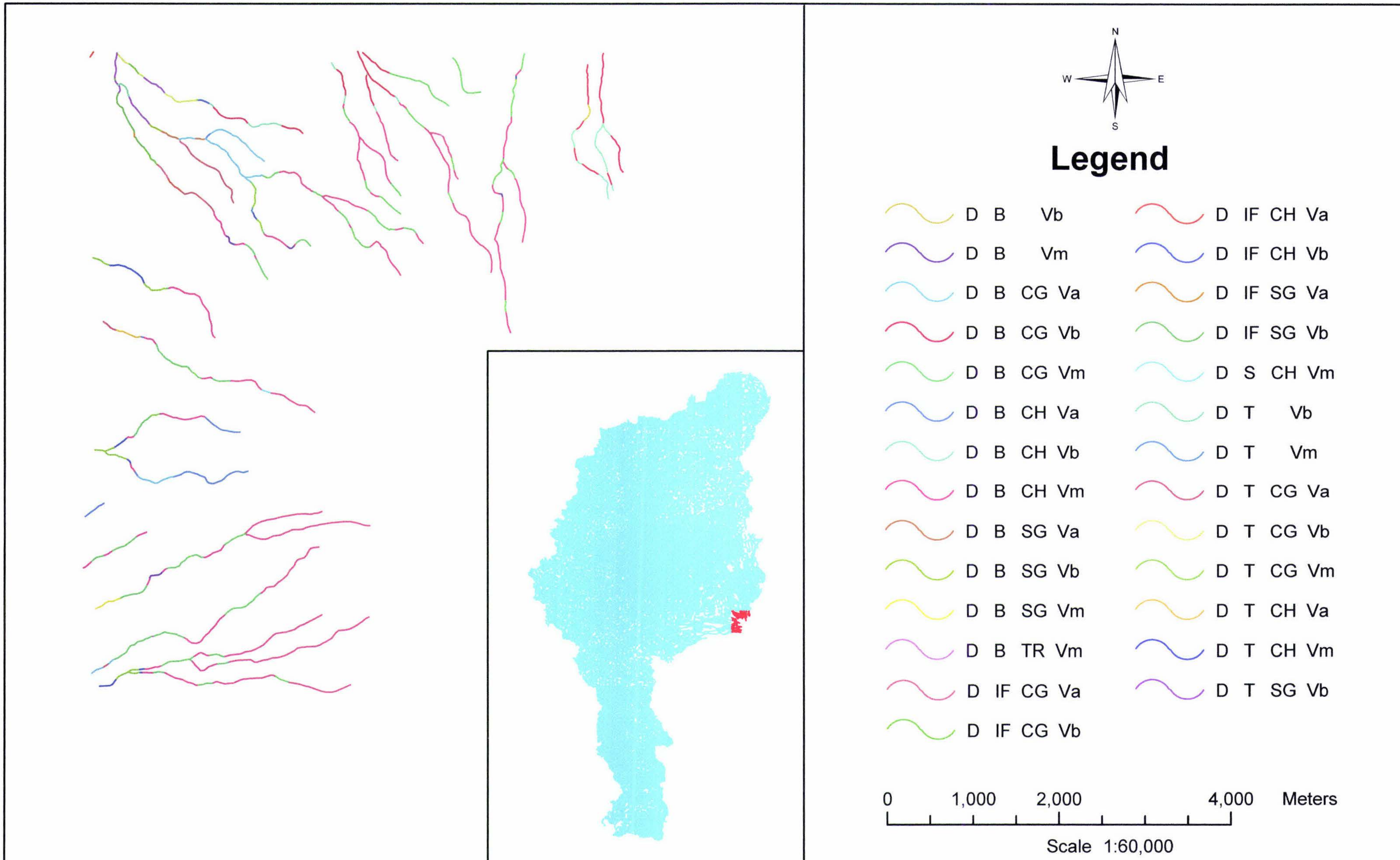


Figure 4-1 Ecotyping Classes of the Whanganui River Catchment

Chapter 5

Conclusions

This project is an application of GIS on Whanganui River catchment based river environment classification system developed by Snelder et al., 1998. It uses the original 1: 50000 digital topographic data to create the TIN model of the Wanganui region, generate the Whanganui catchment, calculate the other hydrological elements such as channel slope and channel sinuosity and create a database to implement the river habitat classification system. These results will be used in ecotyping research in the Whanganui River. The methodology used in this project can also be used in any other related research.

This thesis has introduced and proved some of the basic concepts involved in this research. Some methods, algorithms and structures of AML programs for the approach of each target have been illustrated in different sections.

5.1 The project achievements

This project successfully created a TIN model of the Whanganui catchment by using 1: 50000 topographic data. In order to test the accuracy of the TIN model, a series of processes have been performed:

- From the TIN, different kinds of the profiles are generated to test the river's trend and slope, but the results show the river has an ascending trend. What caused this wrong result is that the TIN is created by digitized 20 m interval contour line data. For the natural river these interval contour lines are too big.

- After filling the sink errors in the TIN, a catchment of Whanganui has been determined successfully.

- By tracing the river coverage, the Whanganui rivers pattern is created. This pattern is exactly the same as the Whanganui catchment that has been determined from the TIN.

This project successfully calculated the other hydrological elements such as channel slope and channel sinuosity using 1: 50000 topographical data. This result proves that it is possible and adequate to base data on 1: 50000 topographical maps to calculate the channel slope and channel sinuosity rather than the reach scale.

This project successfully implemented in the Whanganui catchment, the river habitat classification system developed by Snelder et al., 1998.

5.2 Methodologies

In particular, the project refers to a big study area and contains a huge dataset. During the analysis and processes, all steps should be considered simultaneously to avoid the problems of the software limitation, disk space and time consumption. Each step attempts to use the best method and achieve its approach automatically.

Using 1: 50000 topographical data to generate the DTM of Whanganui catchment, many ways were tried to reduce the data size. Eventually, an ideal method was found and adopted in this research, which could keep the Whanganui catchment integrated. The contour data of the Taranaki area and the Waikato area is separated to different elevation levels. From it, the Whanganui catchment is extracted. These different elevation level pieces are put into one coverage. The detail is discussed in chapter 2.

A series of AML programs were written to approach the target of automatically calculating the channel slope and channel sinuosity. The appendix shows these AML programs. The algorithms and structures of these AML programs are discussed in chapter 3.

The implementation of the river environment classification is based on the classifying rules of each controlling variable. The relational database operation that is a related environment is built to approach this target. Finally a combined column called 'ecotype' was redefined, as one item in the Whanganui River arc attribute table. This 'ecotype' item consists of the classified elevation, the geology, the land cover and the channel type. The details are discussed in chapter 4.

5.3 Applications

The outcomes of this research are used by the river environment classification systems (ecotyping project), being developed by the Ministry for Environment (MfE) and National Institute of Water and Atmospheric Research (NIWA).

The methods used in this project, the algorithms and the AML programs can be used not only in the Whanganui River research, but also in any other river research with related issues.

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Appendix I

An AML program: To identify an elevation of the intersection points in the node attribute table of the river.

```
/* An AML to identify an elevation of the type 0 intersection
points
/* in the wanrvcont.nat

tables
select wanrvconta.nat
reselect type = 2 and elevation = 0
unload wtestfile wanrvcont#   /*testfile1 is a text file

&sv closestat = [close -all]
&sv amlunit = [open wtestfile openstat -read]

&sv record = [read %amlunit% readstat]
&do &while %readstat% = 0
    select wanrvcont.aat
    reselect fnode# = %record%
    aselect tnode# = %record%
    reselect elevation > -1
    unload wtestfile2 elevation # init
    &sv amlunit1 = [open wtestfile2 openstat -read]
    &sv elev = [read %amlunit1% readstat]
    &sv closestat = [close %amlunit1%]

    select wanrvcont.nat
    reselect wanrvcont# = %record%
    calculate elevation = %elev%

list

&sv record = [read %amlunit% readstat]
&end

&sv closestat = [close %amlunit%]

&return
```

Appendix II

An AML program: To assign a class number for each arc of the river coverage.

```
/*An AML to assign a class number for each arc of the river
coverage (wanrv)
/* routine to find longest river
/* Aug 00

copy cwanrv wanrv


additem wanrv.nat wanrv.nat class 4 5 b
additem wanrv.aat wanrv.aat direction 4 5 b
additem wanrv.aat wanrv.aat class 4 5 b

/* populate direction item outflow = 1 inflow = 2

arcplot
mape wanrv
arcs wanrv
trace direction wanrv odfile1 # *
readselect odfile1
calculate wanrv line direction = 1
nselect wanrv line
calculate wanrv line direction = 2
q

/* select outflow arcs and flip them

arcedit
edit wanrv
de arcs arrows
ef arc
select direction = 1
flip
save
q

build wanrv line


/* select start node, select dangling arcs, find number of arcs

arcedit
edit wanrv
de arcs nodes
draw
ef node
select
&sv startnoderecno = [show select 1]    /* store recno of starting
node
&sv startnodeid = [show node %startnoderecno% id]
```

```
ef arc
select dangle
&sv numcon = [show number selected]  /* puts no of arc selected
into numcon

/* select fnode for each dangling arc, find path to start node,
keep longest path


&if %numcon% = 0 &then
    &type 'No dangling arcs'
&else
    &call findnode

&sv clas = 0 /* &sv clas = 1
&call setclass
select class = %clas%
put newcov1
&call tidyup

/* select nodes with class x

&sv cdan = 1
&sv holdclass = %clas%

&do &while %cdan% <= 1000000  /* count each selected startnode
  ef node

  select class = %holdclass%
  &sv numcon1 = [show number selected]
  &if %numcon1% > 0 &then
     &do
       &sv flag = 0
       &call selfind
     &end
   &else
     &do
       &sv flag = %flag% + 1
       &if %flag% > %clas% &then
           &sv cdan = 100000000
        &else
           &sv holdclass = %holdclass% + 1
        &end

&end  /* end of do while (loop)

&return


&routine findpath

arcplot
netcover wanrv route init
impedance length length
path %nextnodeid% %startnodeid% end 1
&sv allpath = [substr [show path 1] 11]
&if %i% = 1 &then
   &do
      &sv testpath = %allpath%
```

```
      &sv longnode = %nextnodeid%
   &end
&else
   &do
      &if %allpath% > %testpath% &then
         &do
            &sv testpath = %allpath%
            &sv longnode = %nextnodeid%
         &end
   &end

&return

&routine redolongpath

/* re-establish longest path

arcplot
netcover wanrv route init
impedance length length
&type %longnode% %startnodeid% here1
path %longnode% %startnodeid% end 1
q

&return

&routine setclass

/* set class to next class for all arcs on longest path

&sv clas = %clas% + 1
&sv noarcs = [show route.route 1 narcs]
&sv c = 1
&do &while %c% <= %noarcs%
   &sv arcid = [show route.route 1 arc %c%]
   select $recno = %arcid%
   calculate class = %clas%
   &sv nodes = [show arc %arcid% nodes]
   &sv fncoox = [extract 1 %nodes%]
   &sv fncooy = [extract 2 %nodes%]
   ef node
   coordinate keyboard
   select
   %fncoox% %fncooy%
   coordinate cursor
   calculate class = %clas%
   ef arc
   &sv c = %c% + 1
&end
save


&return

&routine tidyup

delete
save
```

```
/* reset network
arcplot
netcover clear
q
&sv testpath = 0
/* reset arcedit
quit
/*clean wanrv wanrv # # line
build wanrv node
arcedit
edit wanrv
de arcs nodes
draw


&return

&routine selfind

&sv noderecno = [show select 1]
&sv startnodeid = [show node %noderecno% id]

&sv coos = [show node %noderecno% coordinate]
&sv xcoo = [extract 1 %coos%]
&sv ycoo = [extract 2 %coos%]
&type %xcoo% %ycoo%
ef arc
select dangle
/*reselect class = 0
&sv numcon = [show number selected]  /* puts no of arc selected
into numcon

/* select fnode for each dangling arc, find path to start node,
/* keep longest path


&if %numcon% = 0 &then
  &do
   &type 'No dangling arcs'
   &sv cdan = 100000000
  &end
&else
  &do
    &call findnode
    &call setclass
    select class = %clas%
    put newcov
    y
    &call tidyup
    &sv cdan = %cdan% + 1

  &end

&return

&routine findnode

&sv i = 1
&do &while %i% <= %numcon%
```

```
   &sv arcrecno = [show select %i%]
   &sv nodes = [show arc %arcrecno% nodes]
   &sv fncoox = [extract 1 %nodes%]
   &sv fncooy = [extract 2 %nodes%]
   ef node
   coordinate keyboard
   select
   %fncoox% %fncooy%
   coordinate cursor
   &sv nextnoderecno = [show select 1]
   &sv nextnodeid = [show node %nextnoderecno% id]
   ef arc
   &if %nextnodeid% <> %startnodeid% &then
      &do
         &call findpath
      &end    /* end of if do
   &sv i = %i% + 1
   q
&end  /* end of do loop
&call redolongpath

&return
```

Appendix III

An AML program: To calculate the river slopes and identity the elevation of the non-intersection points in node attribute table of the river.

```
/* An AML to calculate the slope and identify the elevation of
the type 1 points
/* in the river.nat (the river coverage is called grivslope)
/* routine to find slopes on river
/* Aug 00

copy combcov2 grivslope

renode grivslope
additem grivslope.aat grivslope.aat slope 8 9 n 2

/* select startheight node and class

&sv startheight = 0
&sv nextheight = %startheight% + 20
&sv clas = 1

/* select start node and next node
arcedit
edit grivslope
de arcs nodes
draw
ef arc
select all
statistics
max class
end

&sv maxclas = [show statistic 1 1]
&sv test = 'true'
&sv startnoderecno = 0
&do &while %test% = 'true'

  ef node
  &if %startnoderecno% = 0 &then
   &do
    select box
    &sv startnoderecno = [show select 1]    /* store recno of
starting node
    &sv startnodeid = [show node %startnoderecno% id]

&sv clastest = true
&do &while %clastest% = true
&sv flag = 0
&sv test = true
&do &while %test% = true
  ef node
```

```
  &if %flag% > 0 &then
   &do
      &sv startnodeid = %longnode%
      &sv startheight = %nextheight%
      &sv nextheight = %nextheight% + 20
   &end

   select elevation = %nextheight% and class = %clas%
   &type %nextheight%
   &sv seln = [show number selected]
   &type %seln%

        &if %seln% > 0 &then
         &do
           &call findnode
           &call redolongpath
           &sv slpe = ( 20 / %allpath% ) * 100
           &type %allpath%
           /*&pause
           &call setslope
           &sv startnodeid = %longnode%
           &sv startheight = %nextheight%
           &sv nextheight = %nextheight% + 20
           &type %startnodeid% %startheight% %nextheight%

         &end
    &else
      &do
         &type 'End of class'
         &sv test = false
      &end
   &end      /* end do loop

&call carryon
&end  /* end do loop

&return    /*End AML


&routine findnode

&sv x = 1
&do &while %x% <= %seln%

   &sv nextnoderecno = [show select %x%]
   &sv nextnodeid = [show node %nextnoderecno% id]
   &call findpath

   &sv x = %x% + 1

&end  /* end of do loop


&return


&routine findpath

arcplot
```

```
netcover grivslope route init
impedance length length
path %startnodeid% %nextnodeid%  end 1

&sv allpath = [substr [show path 1] 11]

&if %x% = 1 &then
 &do
  &sv testpath = %allpath%
  &sv longnode = %nextnodeid%
 &end

&else
   &do
      &if %allpath% > %testpath% &then
         &do
            &sv testpath = %allpath%
            &sv longnode = %nextnodeid%
         &end
   &end
q

&return

&routine redolongpath

/* re-establish longest path

arcplot
netcover grivslope route init
impedance length length
path %startnodeid% %longnode% end 1
&sv allpath = [substr [show path 1] 11]

&type %startnodeid% %longnode%

q

&return

&routine redoshortpath

/* re-establish shortest path

arcplot
netcover grivslope route init
impedance length length
path %startnodeid% %shortnode% end 1
q

&return

&routine setslope
/* set slope to calculated slope for all arcs on path

reset no
edit grivslope
ef arc
&sv noarcs = [show route.route 1 narcs]
```

```
&type %noarcs%

&sv c = 1
&sv totlen = 0.0
&do &while %c% <= %noarcs%
   &sv arcid = [show route.route 1 arc %c%]
   select $recno = %arcid%
   /*&type [show arc %arcid% id]
   calculate slope = %slpe%
   &sv len = [show arc %arcid% item length]
   &sv totlen = %totlen% + %len%
   &type %totlen% %len%
   &sv nodes = [show arc %arcid% nodes]
   &sv fncoox = [extract 1 %nodes%]
   &sv fncooy = [extract 2 %nodes%]
   &sv tncoox = [extract 3 %nodes%]
   &sv tncooy = [extract 4 %nodes%]

   ef node
   coordinate keyboard
   select
   %fncoox% %fncooy%
   coordinate cursor
   &sv nid = [show select 1]
   &sv noid = [show node %nid% id]
   &sv elev = [show node %nid% item elevation]

   &if %noid% <> %startnodeid% and %noid% <> %nextnodeid% and
%elev% = 0.0 &then
     &do
      calculate elevation = ( ( %totlen% * %slpe% ) / 100 ) +
%startheight%
      &type %totlen% %slpe%
     &end
   &else
       &do
         coordinate keyboard
         select
         %tncoox% %tncooy%
         coordinate cursor
         &sv nid = [show select 1]
         &sv noid = [show node %nid% id]
         &sv elev = [show node %nid% item elevation]

         &if %noid% <> %startnodeid% and %noid% <> %nextnodeid%
and %elev% = 0.0 &then
            calculate elevation = ( ( %len% * %slpe% ) / 100 ) +
%startheight%
      &type %totlen% %len% %slpe% %startheight%
      &end


   ef arc
   &sv c = %c% + 1
&end
save


&return
```

```
&routine carryon

 &sv clas = %clas% + 1
 &type %clas%
 &if %clas% <= %maxclas% &then
     &do
      ef node
      select class = %clas%
      reselect type <> 1
      &sv numbsel = [show number selected]
       &if %numbsel% = 0 &then
         &call carryon
       &else
        &do
         statistics
         min elevation
         end
         &sv minelev = [show statistic 1 1]
         sel class = %clas% and elevation = %minelev%
         &sv seln = [show select 1]

         ef arc
         sel fnode# = %seln%
         &type %seln%
         &sv recno = [show select 1]
         &sv tnod = [show arc %recno% tnode#]

         ef node
         sel grivslope# = %tnod%
         &sv noderecno = [show select 1]
         &sv startnoderecno = %noderecno%
         &sv elev1 = [show node %startnoderecno% item elevation]
         &sv nodetype = [show node %startnoderecno% item type]
         &type %clas% %startnoderecno% %elev1%

         &sv test = 'true'
         &do &while %test% = 'true'
           &if %elev1% = 0 or %elev1% = %minelev% &then
            &do
             ef arc
             sel fnode# = %startnoderecno%
             &sv recno = [show select 1]
             &sv tnod = [show arc %recno% tnode#]

             ef node
             sel grivslope# = %tnod%
             &sv noderecno = [show select 1]
             &sv startnoderecno = %noderecno%
             &sv elev1 = [show node %startnoderecno% item
elevation]
              &if %elev1% <> 0 &then
               &do
                &type %clas% %startnoderecno% %elev1%
                &sv test = 'false'
               &end
             &end
```

```
        &else
          &sv test = 'false'
        &end

       &sv nodetype = [show node %startnoderecno% item type]
       &type %nodetype%
        &if %nodetype% = 1 &then
         &do
          sel class = %clas% and elevation = %minelev%
          &sv seln = [show number selected]
          /*&call findnode
          &sv startnodeid = [show node %startnoderecno% id]
          &sv elev1 = [show node %startnoderecno% item
elevation]
          &type %startnodeid% %elev1%
          &call findnode
          &call redolongpath
          &sv elev2 = [show node %nextnoderecno% item
elevation]
          &sv startheight = %elev1%
          &sv nextheight = %elev2%
          &sv slpe = ( ( %elev2% - %elev1% ) / ( %allpath% ) )
* 100
          &call setslope
          &type %elev1% %elev2%
          &type %allpath% %slpe%


          &sv startnodeid = %longnode%
          &sv startheight = %elev2%
          &sv nextheight = %elev2% + 20
          &type %startnodeid% %startheight% %nextheight%


              ef node
              select elevation = %nextheight% and class =
%clas%
              &type %nextheight% %clas%
              &sv seln = [show number selected]
              &type %seln%

              &if %seln% > 0 &then
               &do
                 &call findnode
                 &call redolongpath

                 &sv slpe = ( 20 / %allpath% ) * 100
                 &type %allpath%
                 /*&pause
                 &call setslope
                 &sv startnodeid = %longnode%
                 &sv startheight = %nextheight%
                 &sv nextheight = %startheight% + 20
                 &sv flag = 1
               &end
             &end

            &else /*nodetype <> 1
             &do
```

```
                  &sv startheight = [show node %startnoderecno%
item elevation]
                  &sv nextheight = %startheight% + 20

                  &sv startnodeid = [show node %startnoderecno%
id]
                  &type %startheight% %nextheight% %startnodeid%

                   select elevation = %nextheight% and class =
%clas%
                   &sv seln = [show number selected]
                   &if %seln% > 0 &then
                    &do
                     &call findnode
                     &call redolongpath

                     &sv slpe = ( 20 / %allpath% ) * 100
                     &type %allpath%
                     &call setslope
                     &sv startnodeid = %longnode%
                     &sv startheight = %nextheight%
                     &sv nextheight = %startheight% + 20

                     &sv flag = 1
                    &end
                  &end
                &end
            &else
             &do
              &type 'End of class'
              &sv test = false
             &end
            &end      /* end do loop


&return
```

Appendix IV

An AML program: To assign slope value to dangle arcs and to recalculate the slope of the arcs if the slope is negative.

```
/* An AML to assign slope value to dangle arcs of type 1 and to
/* recalculate the arc's slope if the slope is negative.
/* aml to set dangle slopes to connected arc slope
/* 17.9.01

arcedit
edit grivslope
ef arc
select unitslope = -1
selectput arcplot
arcplot
writeselect negatives grivslope arcs
&sv i = 1

&do &while %i% < 115 /*2047
 &sv id = [show select grivslope line %i% item grivslope#]
 &type %id%
 reselect grivslope line grivslope# = %id%
 &sv fnode0 = [show select grivslope line 1 item fnode#]
 &sv tnode0 = [show select grivslope line 1 item tnode#]
 q

 &sv arc1len = [show arc %id% item length]
 &sv class1 = [show arc %id% item class]
 &sv height0 = [show node %fnode0% item elevation]
 &sv height1 = [show node %tnode0% item elevation]
 &if %height0% = 0 &then
   /*&type Might be dangling arc
   &call case
 &else
   &if %height0% - %height1% > 0 &then
     &do
      &sv slp = %arc1len% / ( %height0% - %height1% )
      select grivslope# = %id%
      calculate unitslope = %slp%
     &end
 &else
  &do
   &sv type = 1
   &type %height0%
   &sv totlen = %arc1len%
   select fnode# = %tnode0% and class = %class1%
   &sv numsel = [show number selected]
   &if %numsel% > 0 &then
    &do
     &sv n = 1
     &sv repeat = 1
```

```
     &do &while %repeat% = 1
       &sv arcid%n% = [show select 1]
       &sv fnode%n% = [show arc [value arcid%n%] fnode#]
       &sv tnode%n% = [show arc [value arcid%n%] tnode#]
       &sv height%n% = [show node [value tnode%n%] item
elevation]
       &sv arclen%n% = [show arc [value arcid%n%] item length]
       &sv totlen = %totlen% + [value arclen%n%]
       &if %height0% > [value height%n%] &then
         &do
           &sv sth = [value height%n%]
           &sv slp = %totlen% / ( %height0% - %sth% )
           &type [value height%n%]
           &type %totlen%
           &type %slp%
           &sv repeat = 2
           &call process
         &end
       &else
         &if %height0% < %height1% &then
          &do
             &sv hei = [show node %tnode0% item elevation]
             &sv slpe = [show arc %id% item slope]
             &sv lenth = [show arc %id% item length]
             &type %height0% %height1% %slpe% %lenth%
             &sv ele = ( %lenth% * %slpe% ) + %hei%
             &type new elevation here
             &type %ele%
             &sv tnod = [show arc %id% item fnode#]
             ef node
             sel grivslope# = %tnod%
             &type %tnod%
             cal elevation = %ele%
             &if %ele% > %hei% &then
              &do
                &sv slp = %lenth% / ( %ele% - %hei% )
                ef arc
                sel grivslope# = %id%
                &type %id%
                cal unitslope = %slp%
                save
                &sv repeat = 2
              &end
             &else
              &do
               &sv slp = 0
               ef arc
               sel grivslope# = %id%
               cal unitslope = %slp%
               save
               &sv repeat = 2
             &end
            &end
         &else
         &do
           &sv oldn = %n%
           &sv n = %n% + 1
           select fnode# = [value tnode%oldn%] and class =
%class1%
```

```
          &sv numsel = [show number selected]
          &if %numsel% = 0 &then
             &do
               &type Problem here
               &return
             &end
          &end
      &end
     &end
    &else
      &do
          select tnode# = %fnode0% and class = %class1%
          &sv numsel = [show number selected]
          &if %numsel% = 0 &then
                &type Dangling arc

          &else
            &do
              &sv type = 2
              &sv height0 = [show node %tnode0% item elevation]
              &type %height0%
              &sv n = 1
              &sv repeat = 1
              &do &while %repeat% = 1
                &sv arcid%n% = [show select 1]
                &sv fnode%n% = [show arc [value arcid%n%]
fnode#]
                &sv tnode%n% = [show arc [value arcid%n%]
tnode#]
                &sv height%n% = [show node [value fnode%n%] item
elevation]

                &sv arclen%n% = [show arc [value arcid%n%] item
length]

                &sv totlen = %totlen% + [value arclen%n%]
                &if %height0% < [value height%n%] &then
                   &do
                     &sv sth = [value height%n%]
                     &sv slp = %totlen% / ( %sth% - %height0% )
                     &type [value height%n%]
                     &type %totlen%
                     &type %slp%
                     &sv repeat = 2
                     &call process
                   &end
                &else
                  &do
                     &sv oldn = %n%
                     &sv n = %n% + 1
                     select tnode# = [value fnode%oldn%] and
class = %class1%

                     &sv numsel = [show number selected]
                     &if %numsel% = 0 &then
                        &do
                           &type Have a look at it
```

```
                                   &return
                                &end
                           &end
                       &end
                     &end
                  &end
                &end
   &sv i = %i% + 1
   ef arc
   arcplot
   readselect negatives

&end    /* end of first do
q
save

&return

&routine process

select grivslope# = %id%
&do count = 1 &to %n%

   aselect  grivslope# = [value arcid%count%]

   &sv count = %count% + 1
&end

calculate unitslope = %slp%
&if %type% = 1 &then
   &sv sheight = [value height%n%]
&else
   &sv sheight = %height0%
&sv max =  %n% - 1
&do count = 0 &to %max%
    &sv num = %n% - %count%
    &sv extra = [value arclen%num%]
    &sv more = %extra%  / %slp%
    &sv nheight%num% = %sheight% + %more%
    &type [value nheight%num%]
    &sv sheight = [value nheight%num%]
&end

ef node
&do count = 0 &to %max%
    &sv num = %n% - %count%
    select grivslope# = [value fnode%num%]
    calculate elevation = [value nheight%num%]
&end

&return


&routine case

select fnode# = %tnode0% and class = %class1%
   &sv numsel = [show number selected]
   &sv classn = [show node %tnode0% item class]
   &type %classn% %class1%
```

```
  &if %numsel% = 1 and %classn% = %class1% &then
   &do
    &sv slp = [show arc %id% item slope]
    &type %slp%
    &sv height2 = ( %slp% * %arc1len% ) + %height1%
    sel grivslope# = %id%
    &type %id%
      &if %height2% > %height1% &then
        &do
          &sv slop = %arc1len% / ( %height2% - %height1% )
          cal unitslope = %slop%
        &end
       &else
         cal unitslope = 0
       &end
    &else
     &if %numsel% = 1 and %classn% <> %class1% &then
      &do
      sel grivslope# = %id%
      cal unitslope = -2
     &end
   &else /* if %numsel% <> 1
   &do
   &sv n = 1
   &sv repeat = 1
    &do &while %repeat% = 1
      &sv arcid%n% = [show select 1]
      &sv fnode%n% = [show arc [value arcid%n%] fnode#]
      &sv tnode%n% = [show arc [value arcid%n%] tnode#]
      &sv height%n% = [show node [value tnode%n%] item
elevation]
      &sv class%n% = [show node [value tnode%n%] item class]
      &sv arclen%n% = [show arc [value arcid%n%] item length]
      &sv arcslp%n% = [show arc [value arcid%n%] item slope]
       &if %class1% = [value class%n%] &then
        &sv n = %n% + 1
         &else
          &if %class1% <> [value class%n%] &then
           &do
              sel class = %class1% and unitslope = -1
              cal unitslope = -2
           &end
          &else
           &do
            &sv slp = [show arc [value arcid%n%] item slope]
            sel class = %class1% and unitslope = -1
            cal unitslope = %slp%
            &sv repeat = 2
           &end
         &end
       &end

 &return
```

Appendix V

An AML program: To implement a calculation of the channel sinuosity for each arc in the Whanganui catchment.

```
/* aml to calculate sinuosity for each arc
/* 8.8.2001
date

arcedit
&sv fname = [open sinuos openstat -write]
&if %openstat% <> 0 &then
  &do
   &type bugger%openstat%
   &return
 &end

edit grivslope
ef arc
select all

&sv i = 1
&do &until %i% = 141919
/* reselect $recno = %i%
&sv nodexys = [show arc %i% nodes]
&sv node1x = [extract 1 %nodexys%]
&sv node1y = [extract 2 %nodexys%]
&sv node2x = [extract 3 %nodexys%]
&sv node2y = [extract 4 %nodexys%]
&sv hypo1 = ( %node1x% - %node2x% ) ** 2
&sv hypo2 = ( %node1y% - %node2y% ) ** 2
&sv hyposum = %hypo1% + %hypo2%
&sv hypot = [sqrt %hyposum%]
&sv len = [show arc %i% item length]
&sv sin = %len% / %hypot%
&sv writestat [write %fname% %i%,%sin%]
&type %i% %sin%
&if %writestat% > 0 &then
  &do
     &type bugger%writestat%
     &return
  &end
&sv i = %i% + 1

/* select all
&end
[close -all]
quit
date


&return
```