GIS V: Capstone Project - Report

A Weighted Flow Accumulation Model of Sheep and Cattle Contribution to Fecal Contamination in the Bay of Poverty and Gisborne Region

Luke Irza

Background:

A city located on the rural east coast of New Zealand's North Island. Gisborne is known for its extensive beaches, summer tourism, Māori culture, and industries. As of 2013, 46,656 people live in the Eastern Cape (4). In current national trends, Gisborne remains on average, the most economically underdeveloped population in New Zealand (5). As of 2012, agriculture, forestry, and fishing were the largest industries of the region. These represented 16.2% of the total GDP for the region, and 5.2% of New Zealand as a whole. Between 2011 and 2012, sheep, beef cattle and grain farming grew by 14.1% and sheep and cattle farming remain the largest employer in the region (6).

In 2010, the Gisborne regional council commissioned a study into the suitability of East Coast locations for the aquaculture of several economically significant species grown in New Zealand (1). Aquaculture is a valuable industry for New Zealanders. In 2011, exports of green-lipped mussels, salmon, and oysters amounted to $298 million NZD, with 73% and 6% of that export value coming from green-lipped mussels, *Perna* canaliculus, and the Pacific oyster, *Magallana* gigas, respectively (2). The East Cape was seen as a promising candidate for the establishment of an aquaculture industry because of its extensive and depopulated coastline, and estuarine environments that can provide nutrients for productive aquaculture (1). However, this study states that the benefits of the river plumes loading the water with nutrients could be outweighed by sedimentation and the risk of fecal contamination (1). The authors postulate that the high levels of fecal contamination are primarily due to the large numbers of grazing livestock such as sheep and cattle in the catchments of the East Cape's hydrological systems, specifically the Waiperoa River and Turanganui rivers which empty into Poverty Bay [1].

Project Objective:

The purpose of this project is to produce a simple weighted flow accumulation model to explore the accumulation of fecal bacteria from sheep and cattle in the catchments which drain into Poverty Bay and other estuaries along the East Coast. More advanced models are being developed by policy makers to provide valuable information for a management plan of water quality of Poverty Bay and other waters influenced by significant river plumes from the East Coast region [12, 15]. Improvement in fecal bacteria levels to a point where aquaculture can be established could provide the region with a significant economic boost. In the Marlborough Sounds, where about 80% of New Zealand's aquaculture is undertaken, marine farming provides over 1500 full time equivalent jobs and New Zealand Aquaculture Industry as a whole is forecasting a $1 billion dollar export revenue by 2020 [3]. In region where water near shore water was otherwise found to be conducive to bivalve culture [1], establishment of a shellfish aquaculture industry could provide a significant boon to the local economy.

Literature Review

Literature review and inspiration for this project began upon reading *Assessment of the East Cape Marine Water Quality and Implications for Aquaculture* [1]. The authors of the report postulate that the major source of the bacteriological contamination that makes the area unsuitable for shellfish aquaculture comes from non-point pasture grazing. The purpose of this project is to explore the modeling of this contribution using a weighted flow analysis.

Research into the data needed and methods to use was continued from the final project in GISIV, where a weighted flow analysis was used to determine amount of runoff that came from vineyards in a portion of Gisborne. In this analysis, Lab 3 of GISIV *Terrain Analysis Using Model Builder* was a significant resource for the methods and data acquisition [()]. In addition to Lab3, the web article *Using ArcGIS Hydrology Tools to Model Watershed-Level Non-Point Pollution Management Strategies* is is a valuable resource for those using ArcMap and ESRI software [(13)]. This web article provides a detailed tutorial and sample analysis for performing a weighted flow analysis model. However this tutorial does not analyze Fecal Indicator Bacteria loads in the watershed. To address this, further review was conducted. The following research questions were considered:

1). How do fecal bacteria travel from grazed pasture into waterways and how can this be modeled and quantified?

2). Do different farm and grazing animals have different contributions of FIO (fecal indicator bacteia)? If so, what are the relative populations and contributions in the Gisborne region?

3). Which factors increase the delivery of FIOs to streams, rivers and oceans?

In 2015, Stats NZ places the numbers of grazing livestock in the Gisborn Region at 1,740,515 animals. Of these, 0.74% and 14.66% of those are deer and cattle respectively. The remaining, 84.60% of animals are sheep [(14)]. Research performed in Southland (most southwest region in New Zealand), found that though sheep produce less manure than cattle, their manure is higher in fecal coliform bacteria. The report cites that a study of a catchment in Otago (south east South Island) estimates a loss of 8.6 x 10^9 *E. coli* per hectare per year when grazed by sheep [(8,11)] and with an annual rainfall of 1172 mm/yr [(11)]. Similiarly, the article addresses the different possible fates for FIO's (Fecal Indicator Organisms). All seven of the literature sources reviewed refer to the accepted fates of FIO's and the effects that contribute to their survival [(7-13)]. It is known that increases in rainfall and runoff greatly increase the bacterial load in waterways [(1, 7-13)]. However, it is not agreed how much is contributed from surface runoff, and how much through groundwater. A masters thesis from the University of Portland cites data that FIOs rarely make it below the first 2cm of soil [10], however, other papers and reviews have used subsurface waters as an FIO in their models [7,9,12]. It is generally agreed that the majority of non point source FIOs come from surface runoff [7-13], with rainfall significantly increasing the turbitdity and microbial burden of a catchment [8]. Turbid waters help increase the survivability of FIOs by reducing exposure to UV light [1,7-13], though relatively clear waters with a low NTU can still be contaminated [7].

Based off of the literature, *E. coli* and other FIO's in runoff and waterways from non-point source pollution are subject to three main groups of forces that determine their load. For this project these are designated "additive", "subtractive", and "vector", based on how they would be modeled. Additive forces are the sources of FIOs. These are wild and livestock sources of fecal bacteria. Subtractive forces are those that remove FIOs. These amount to deposition and death, and are contributed to by a number of factors [9]. In the SPARROW hydrological model, developed by the USGS, this reduction is described in large rivers according to the equation: [15]

$$Reduction\ (\%) = e^{d\left(-0.048\ Q^{-0.77}\right))}$$

Where d = distance upstream (km); Q = stream discharge (m^3/s)

Vector forces are those that increase or diminish the transport of FIOs into the waterways and promote their survival. These include rainfall, subsurface seeps and an increase in water turbidity [9].

Data

The following data were used for this project and their metadat is summarized in this table:

Purpose	Layer	Publication Info	Time Period Data are Relevant	Spatial Coordinate System	Data Type	Resolution (raster)
Elevation	NZDEM_SoS_v1-0_07_East Cape_gf.asc	University of Otago - National School of Surveying	19 July, 2011	NZGD2000 / New Zealand Transverse Mercator 2000	DEM	15m
Elevation	NZDEM_SoS_v1-0_11_Gisborne_gf.asc	University of Otago - National School of Surveying	19 July, 2011	NZGD2000 / New Zealand Transverse Mercator 2000	DEM	15m
Elevation	NZDEM_SoS_v1-0_10_Napier_gf.asc	University of Otago - National School of Surveying	19 July, 2011	NZGD2000 / New Zealand Transverse Mercator 2000	DEM	15m
Average Annual Rainfall	average-annual-rainfall-1972-2013	New Zealand's Environmental Reporting Series: The Ministry for the Environment and Statistics New Zealand	1972 - 2013	NZGD2000 / New Zealand Transverse Mercator 2000	Raster	5109.878467m
Gisborne Region Polygon	nz-territorial-authorities-2012-yearly-pattern.shp	Statistics New Zealand	2012	NZGD2000 / New Zealand Transverse Mercator 2000	Vector Polygon	N/A
LandCover	Land_cover_database_v4_0_class_orders	New Zealand's Environmental Reporting Series: The Ministry for the Environment and Statistics New Zealand	2012-2013	NZGD2000 / New Zealand Transverse Mercator 2000	Vector Polygon	N/A
Livestock Numbers	livestock-numbers-19942015.csv	Statistics New Zealand	1994-2015	N/A	CSV	N/A
Basemap	ESRI Ocean Basemap	ESRI	N/A	N/A	Map	N/A

Due to system constraints, and for convenience of analysis, the raw downloaded data was processed before any analysis steps could begin. First, the Gisborne Polygon was exported from the nz-territorial-authorities-2012-yearly-pattern.shp file by definition query. The nationwide 15m DEM from the University of Otago School of Surveying is available for download in a series of mozaic datasets. To get full coverage of the Gisborne Region, three of these mosaics had to be downloaded as .asc file. These were converted into raster datasets and merged into one raster. The average annual rainfall raster was resampled to a15m cell size by Nearest Neighbor to match the elevation rasters. Finally the Gisborne Polygon was used to clip the elevation raster, the annual rainfall raster, and the landcover rasters. The process can be visualized with the flochart (**Figure 1**). Basemaps were made for the three finished datasets (**Maps 1-3**).

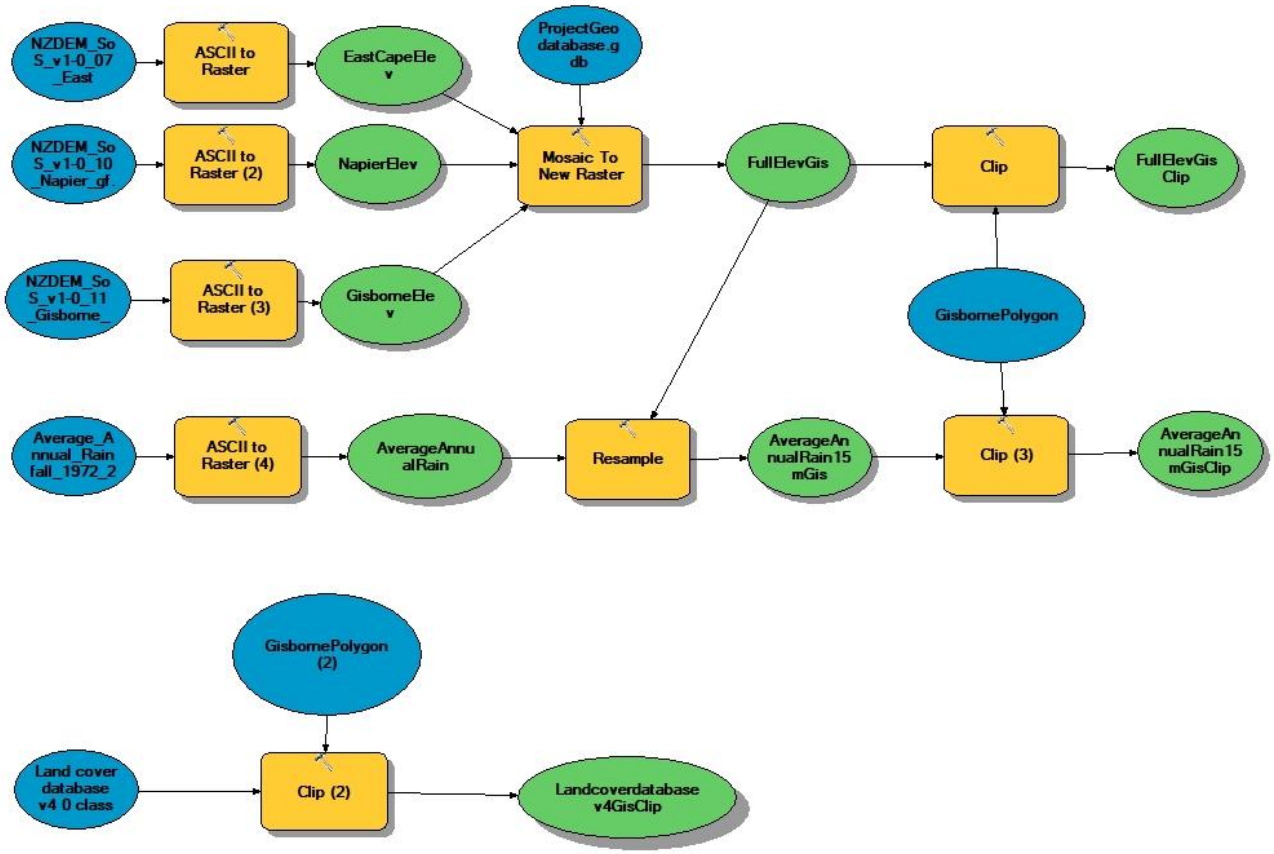


Figure 1: Preparation of the data for analysis

To perform map algebra using the landcover data, a raster with Boolean values for Exotic grassland land cover had to be generated. This was done by first using a defintion query to export the Exotic grass polygons from the landcover data as a new ExoticGrasslandcover layer. The Erase tool was used on the Gisborne Polygon layer to create a polygon layer of “NotExoticGrass”. A new common short field was created in the “ExoticGrassCover” and “NotExoticGrass” polygon layers. This field was named ‘ExoticGrass’ and given the value of 1 in the “ExoticGrassCover” attribute table, and 0 in the “NotExoticGrass” attribute table. Then the two layers were merged into one feature class and converted into a raster using the values for the ExoticGrass field. The resulting raster, “BooleanExoticGrassRas” has 1 and 0 values to denote whether the landcover is Exotic Grass or not, respectively. The entire process is shown in **Figure 2**.

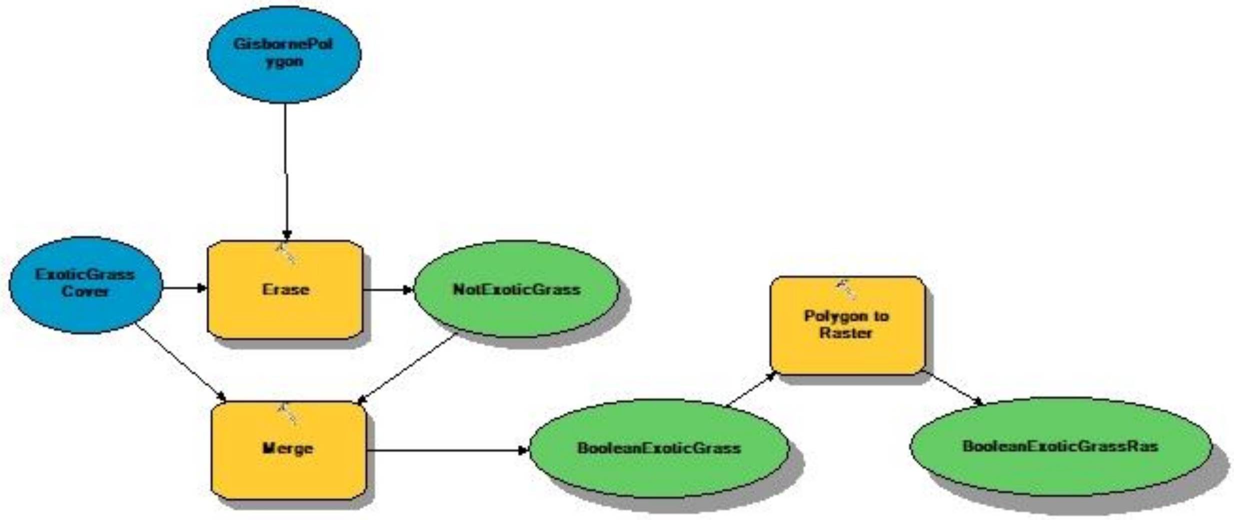
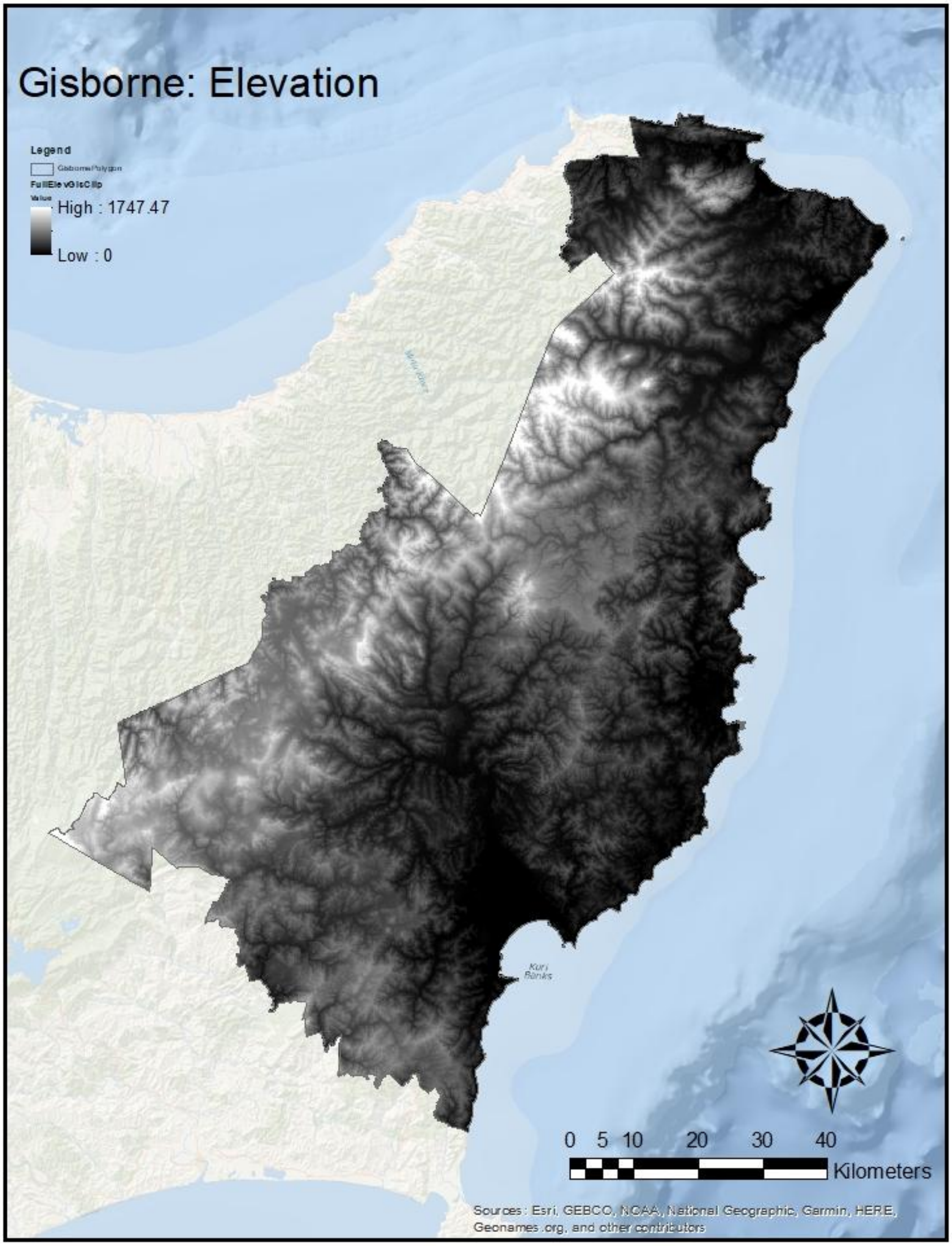
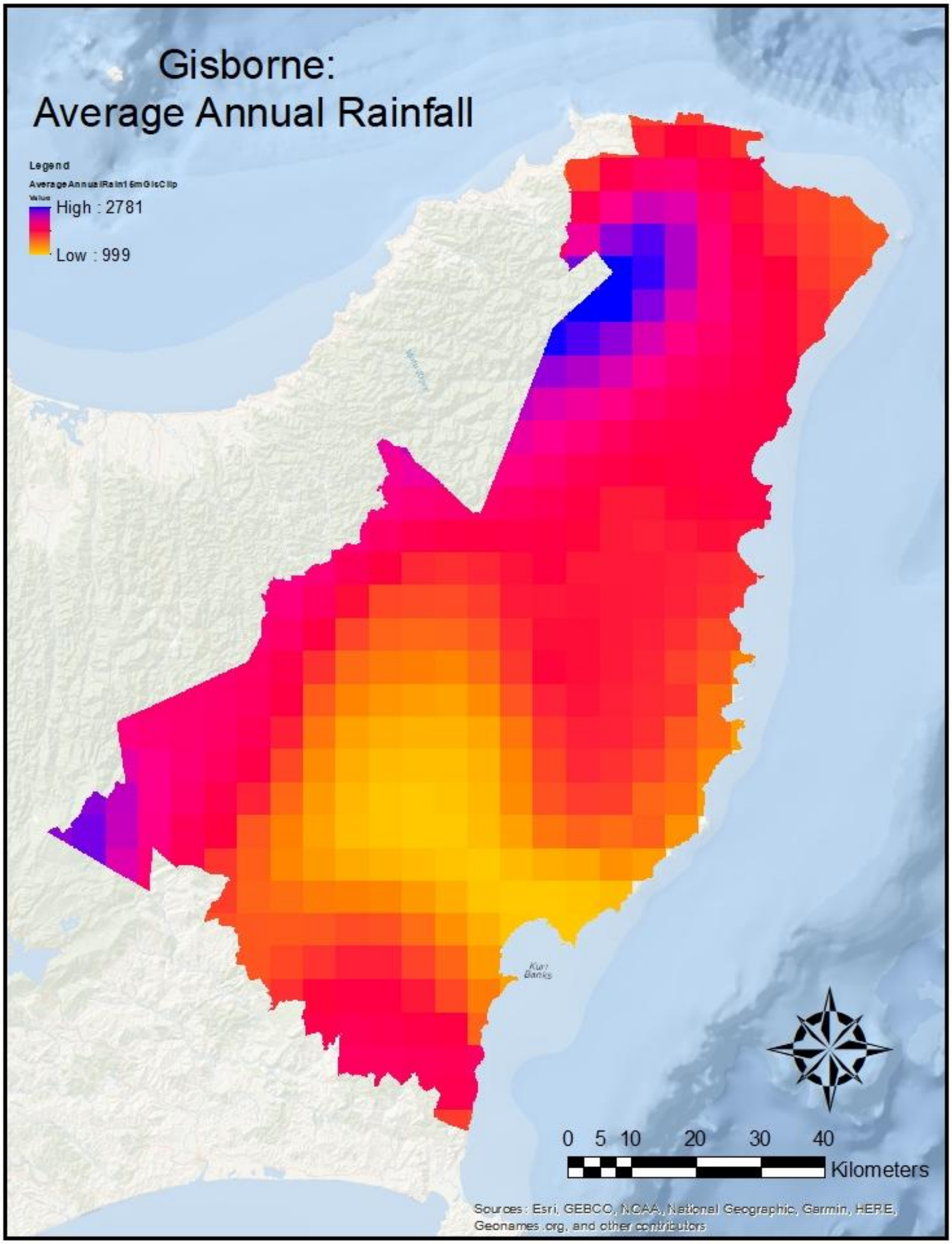


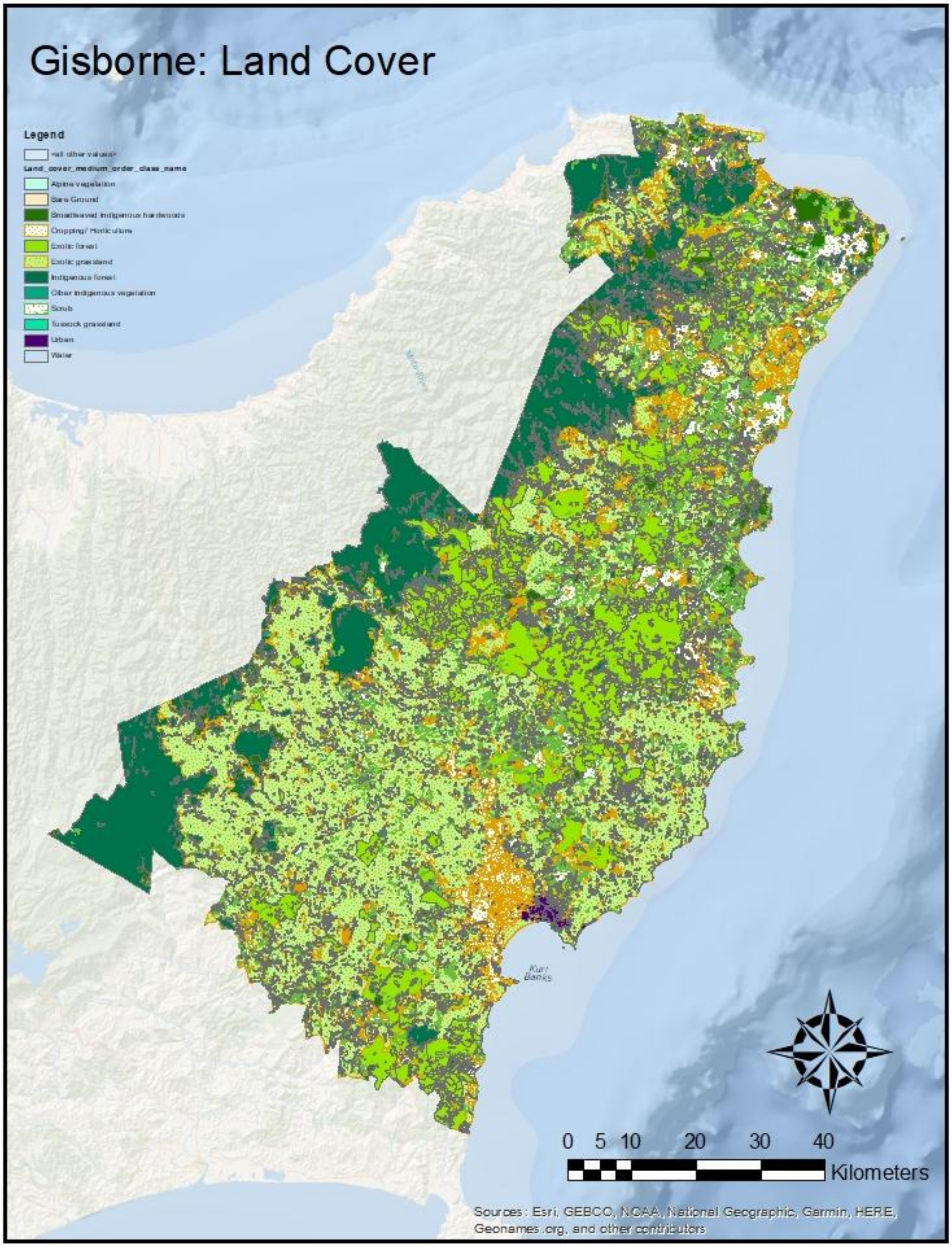
Figure 2: Generating a Boolean raster of a single land cover type. The new field was added before the Merge step using the Field Calculator.



Map 1: Gisborne Region Elevation in meters.



Map 2: Gisborne Region average annual rainfall in millimeters



Map 3: Gisborne Region land cover symbolized categorically.

Methods

Most of the steps for the procedure were lifted from the source *Using ArcGIS Hydrology Tools to Model Watershed-Level Non-Point Pollution Management Strategies*(13). Additional help came from Lab 3 of GIS 4, and the formulas for raster calculations were adapted from "A Farm-scale *E.coli* model for Gisborne District Council"(15).

The process begins with a series of hydrological modeling steps to generate a stream network from the Elevation raster (**Figure 3)**. In this process, a Flow Distance raster is created using the data from the Flow Direction raster. This will be used in the calculations for the decay of *E. coli* over distance. Additionally, the stream polyline is useful for generating riparian buffers. For example, a scenario in which fences exclude the grazing livestock from the water's edge could be considered, and is a common mediation method examined (7,8,10,10).

To create a layer that represents the initial source of *E.*coli, an average density of grazing livestock was determined using the landcover data and the livestock census data. This was performed under the following assumptions: 1). Grazing livestock will be contained within the Exotic grassland land cover. 2). These Exotic grasslands are mixed livestock operations, typical of New Zealand (11) 3). The ratio of different species of grazing animals represents the average for the region. To calculate animal density the following equation was used:

$$Density = \frac{Total\ \#\ of\ livestock}{cells\ of\ ExoticGrass}$$

Based off of Gisborne agricultural data, a typical pasture is about 15% cattle and 85% sheep. Deer are present, although fairly negligible with a percentage of 0.70% of the grazing animals overall (14). Different animals produce different levels of *E.coli* in their feces, with sheep producing more than cows, however, sheep defecate less (8,15). The intial *E.coli* for each cell is therefore given by the following equation:

$$I = D(0.15(C) + 0.85(S))$$

Where D = Density of animals; C = *E.coli* deposited by cattle per day; S = *E.coli* deposited by sheep per day; and I = Initial *E.coli* available in a cell per day.

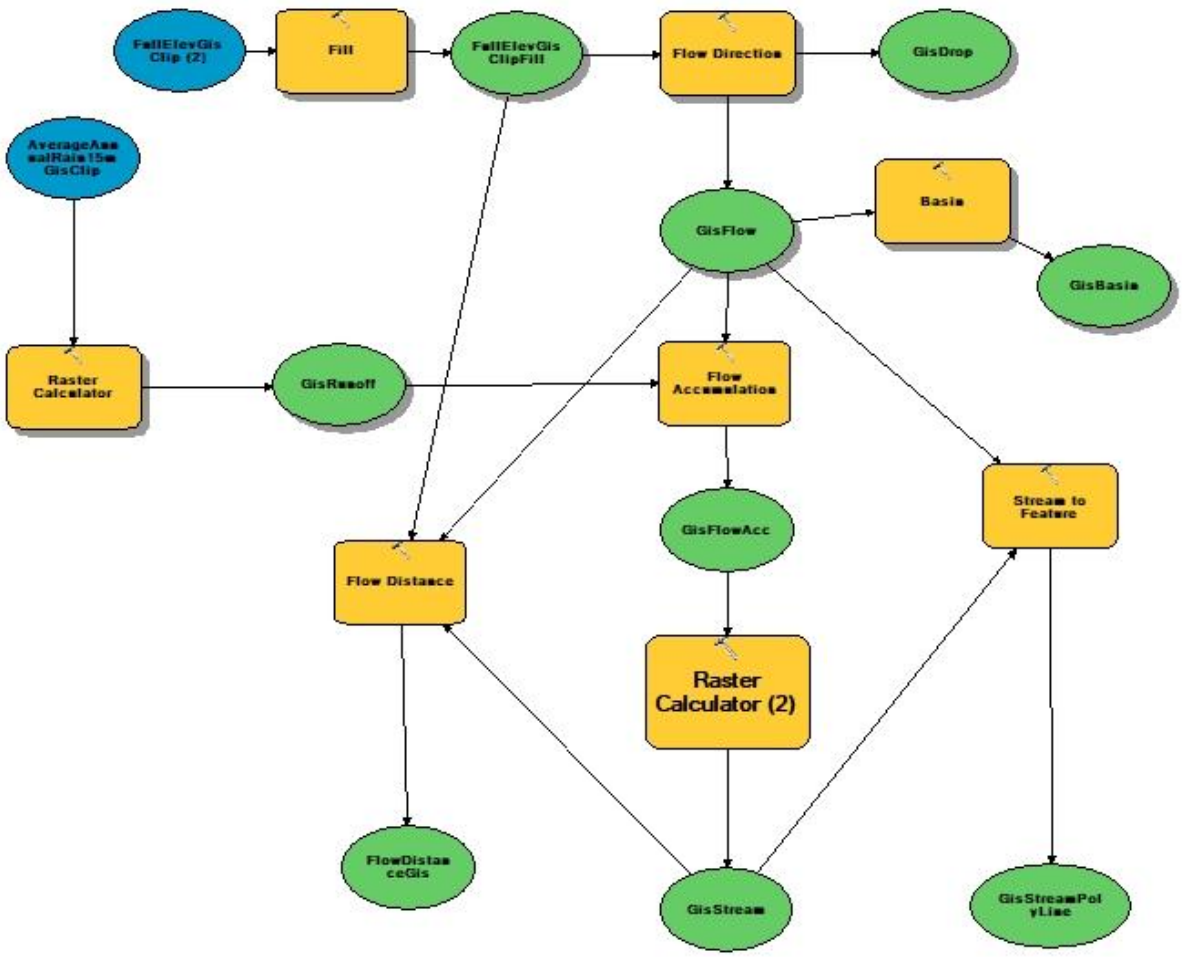


Figure 3: Process to derive the Flow Accumulation, Stream Networks, and Flow Distance rasters.

In this model, the "additive" forces are represented by the initial livestock density, and *E.coli* deposition. The generated watershed rasters provide information for the "vector" forces and the Flow Distance raster and decay equation provide for the "subtractive" forces. To begin the final analysis, the raster of initial E.coli concentration is diminished according to the decay equation that was mentioned above:

$$Reduction\ (\%) = e^{d(-0.048\ Q^{-0.77})}$$

Distance values are supplied by the Flow Distance Raster. Stream flow is given by the equation *Q = VA* where *V* = the velocity of the water and *A* = the area of the cross section of the flow[16]. Since velocity of the water is not available data, the runoff raster will be used instead to describe the water accumulation in millimeters. This is the height and 15m (the length/width of one side of a raster cell) is the width of the cross section. Negative slope is assumed to be proportional to the water velocity, so the equation can define Q as:

$$Q = cS(15R)$$

Where *S* = slope; *R* = Accumulated runoff in meters; and *c* = is a constant with units (m/s) that relates slope to velocity.

When combined, the result of the analysis is a map that describes the accumulated E.coli in each cell along the watershed accounting for die-off and levels of flow throughout the catchment. This is called the viable *E.coli* (**Figure 4**).

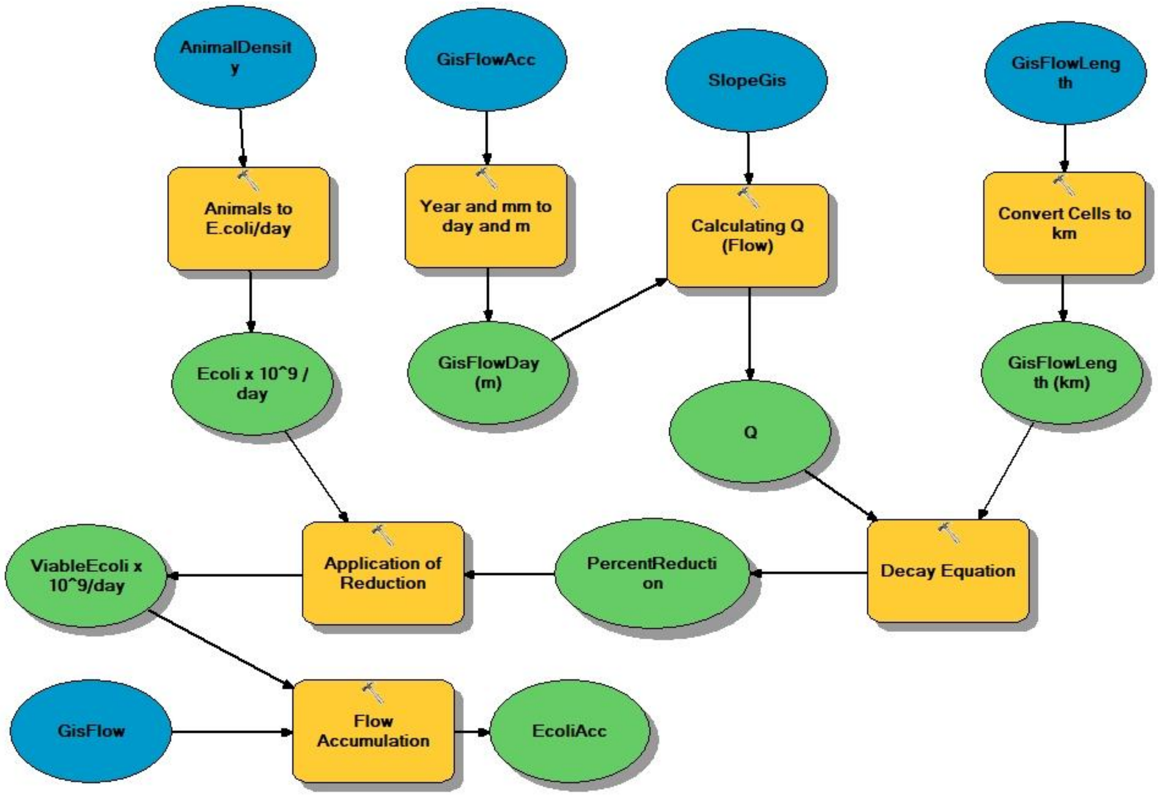


Figure 4: Calculation of the number of viable *E.coli* per cell.

Now that viable E.coli is determined for each cell in the analysis area, it is possible to determine the accumulation of E.coli downstream. This is done by running another flow accumulation analysis, as seen in **Figure 3**. This flow accumulation uses the ViableEcoli raster as a weight and the result is the accumulation of E.coli in each cell. By dividing the E.coli accumulation raster by the previously calculated Flow Accumulation raster, which uses Runoff as a weight, it is possible to predict the concentration of *E.coli* per unit volume of water in each cell (**Figure 5)**. This can be compared with the Gisborne District Council's measurements at each site.

For safe shellfish production and harvest, median fecal colifom of the water around the shellfish must not exceed 14 cfu/100 ml and the E. coli concentrations within the shellfish themselves must not exceed 230 cfu/100 ml.Also, less than 10% of water quality samples can exceed a faecal coliform concentration of 43 cfu/100 ml [1].

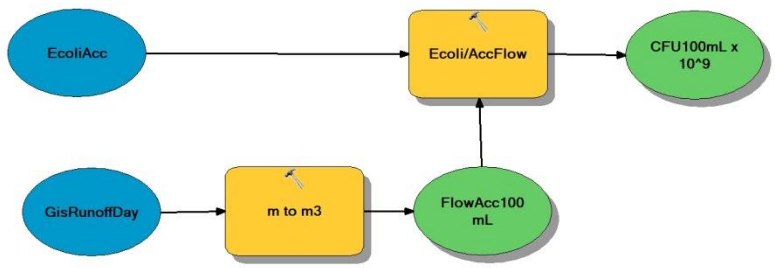


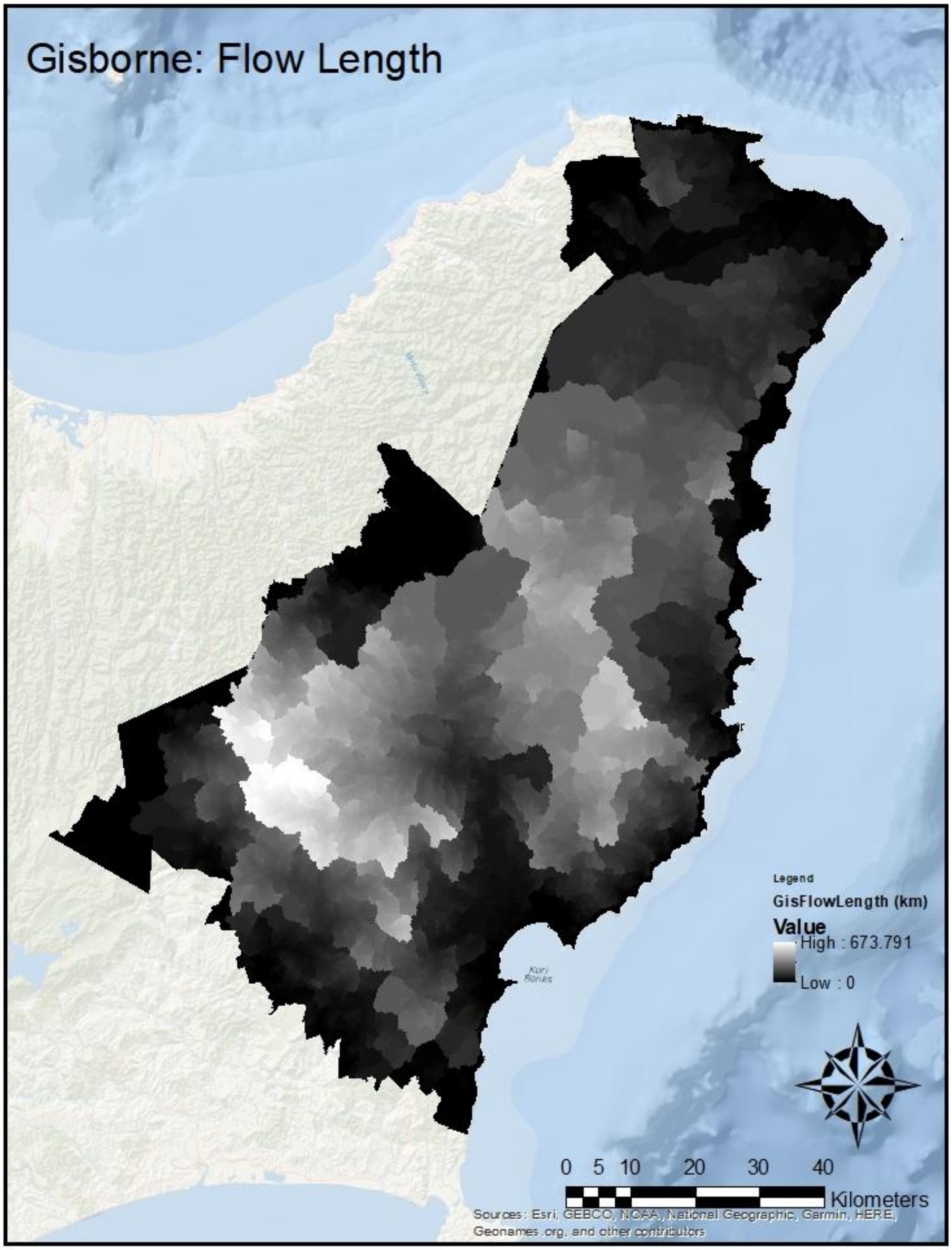
Figure 5: Determination of the concentration of *E. coli* for each cell.

Analysis and Results:

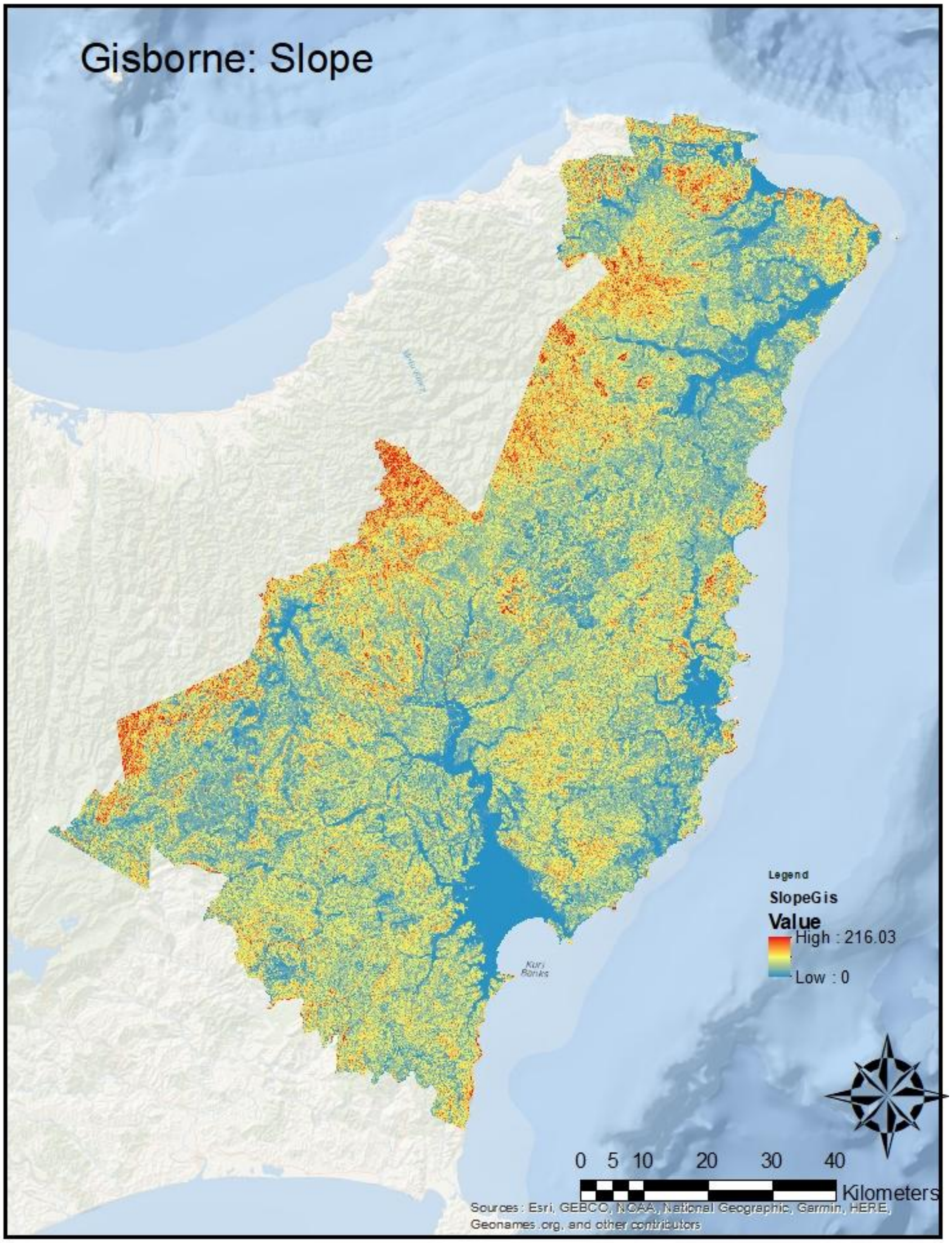
The results of the analysis are a series of maps that characterize the predicted concentration of grazing-animal sourced *E.coli.* Flow length (**Map 6**) gives the distance of each cell along the flow network from the outlet. This is an important factor in the decay equation, since *E. coli* are more likely to be subtracted by death or deposition the farther they travel along the stream network.

Slope is the stand-in for flow velocity in this model, and notice how the slope reduces rapidly into the Bay of Poverty Flats (**Map 5**). A steeper slope increases the flow rate of a stream, and subsequently the survival rate of the bacteria.

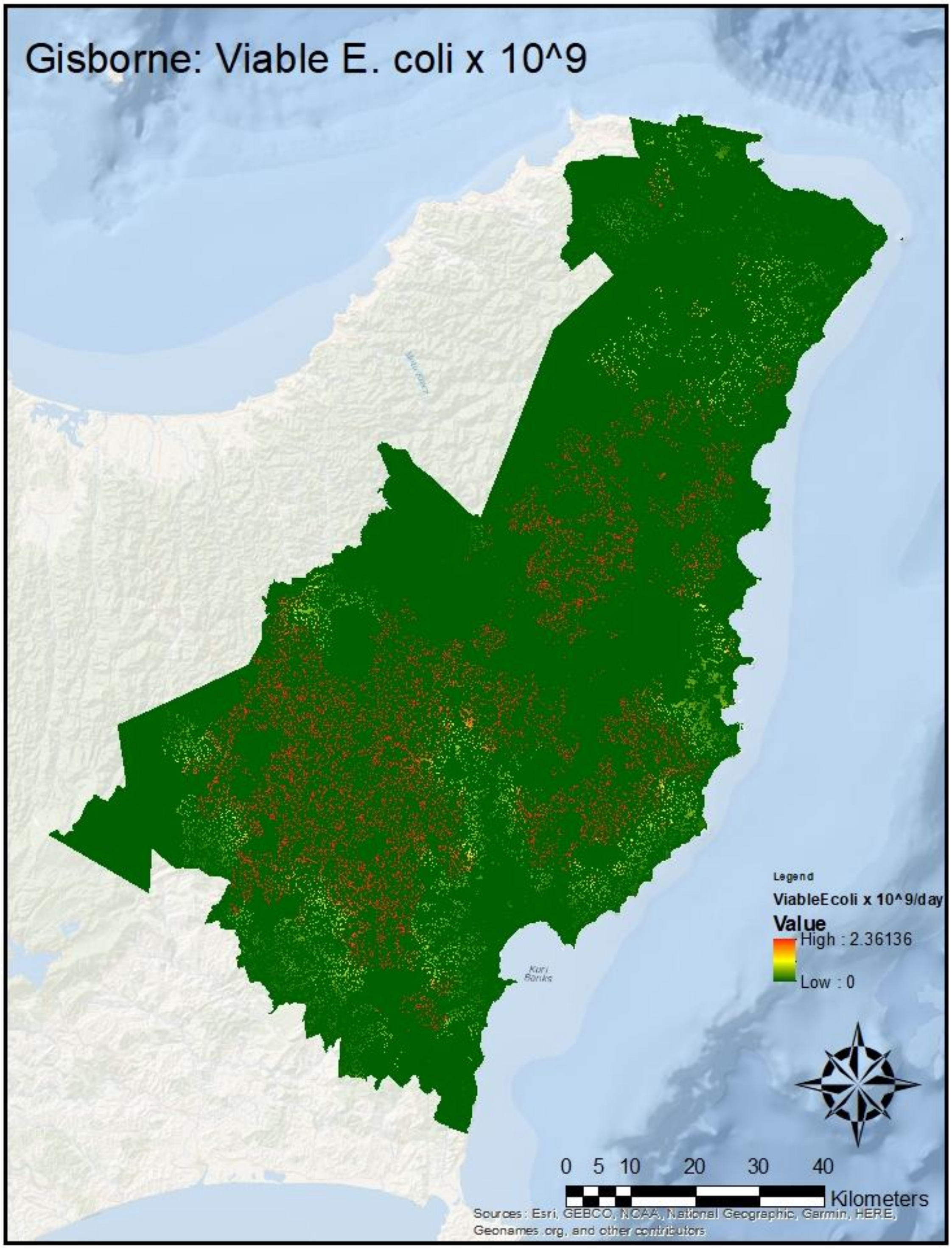
It was expected to see *E. coli* concentrations that are highest in the higher elevations closest to deposition. Mapping shows that the concentration of *E.coli* increases in areas close to the location of deposition. These cells have less flow accumulated, and high initial values. High concentrations, shown in red, are all over the interior elevations where grazing is prevalent (**Map 7**). Outside of areas of deposition, high concentrations of the bacteria are seen in only the largest tributaries.



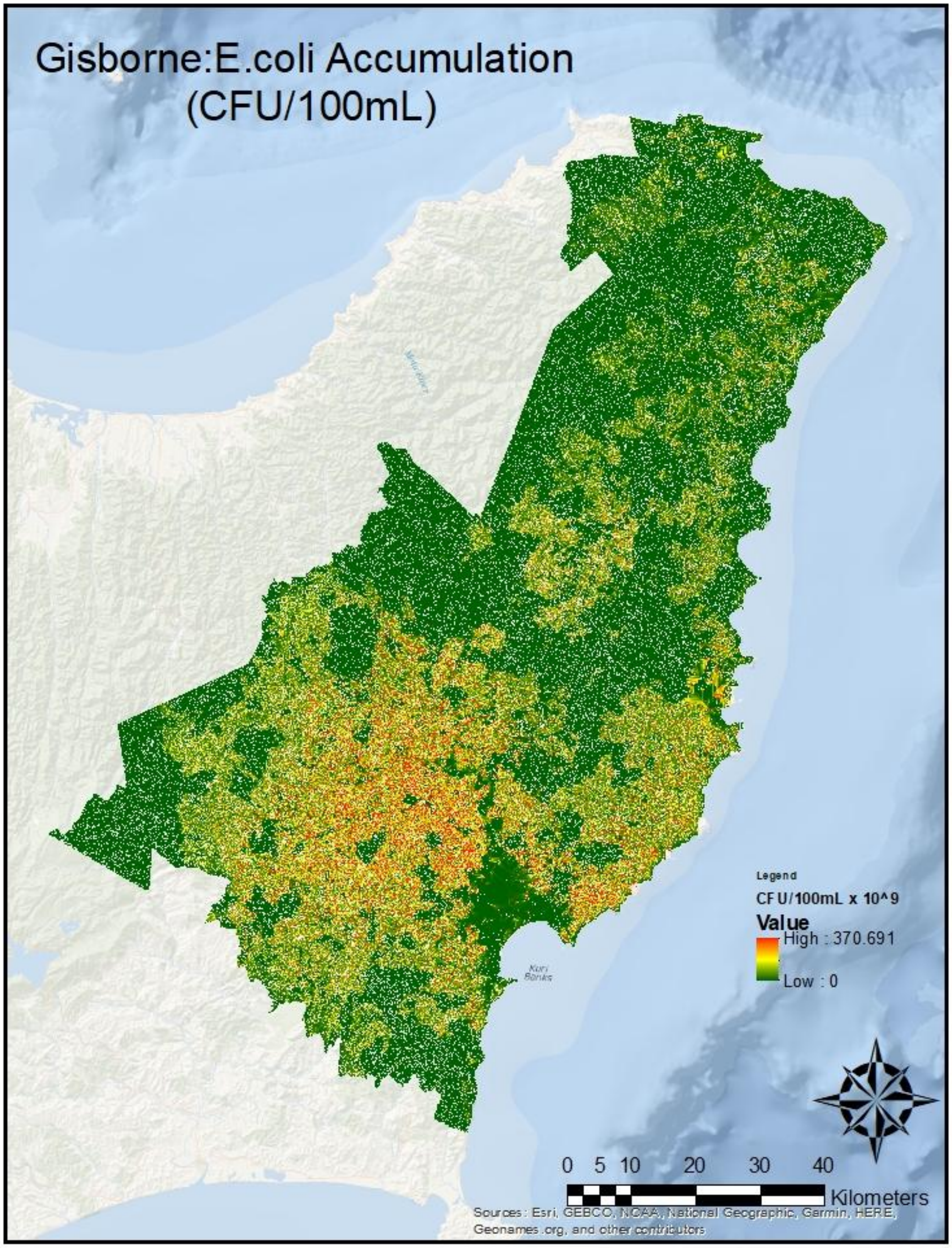
Map 4: This is a map of the relative flow length of the cells in the Gisborne Region in km. Flow length measures the distance of the cell from the outlet at the edge of the map along the flow direction raster. This is a measure of how far 'upstream' a cell is, and is the value *d* for the decay equation.



Map 5: The slope values for the Gisborne Region. Notice the predominance of the Bay of Poverty Flats.



Map 6: The viable *E. coli* shown in this map refers to the average number of *E. coli* predicted for each cell in a day that will wash to the pour point of a basin. In other words, this is the number of *E.coli* adjusted with the application of the decay equation.



Map 7: This map shows the anticipated concentration of *E.coli* in each cell in CFU/100mL. This was found by dividing the Accumulated *E.coli* raster by the Flow Accumulation raster. A series of unit transformations brought the values into CFU/100mL.

Comparison of the model with existing data:

According to the data in the Cawthorne Institute's assessment [1], the average outflow of the Waipaoa River is between 14.85 and 41.51 m^3/s. This can be converted to 1.28×10^6 and 3.59×10^6 m^3/day. Examination of the equivalent outflow in cells in the Flow Accumulation Raster place this value at 1.61×10^6 m^3/day, or 18.66 m^3/s (**Figure 6**). This is within an order of magnitude, and quite close to the values quoted in the report.

The Gisborne Regional Council performs regular sampling of rivers and streams for Fecal Coliforms. A quick comparison was performed using the Council Sampling locations. Though locations are generally sampled on the coast and sea, there are few monitored freshwater sites. One of these sites is the popular Rere Rockslide on the Wharekopae River, and there is extensive data on this location. By lifting the GPS coordinates from Google maps, a point can be placed on the stream network, and compared to the data from the council. The Rere Rockslide has an average *E.coli* level of 268 MPN/100mL, according to Council data that goes back to 1995 [17]. According to the model, the site can expect an accumulated value of 1.85×10^9 CFU/mL, much, much higher than the measured value. Another measured point at the mouth of the Taruheru River is much lower than the values in the model (**Figure 7**). Since the flow rate appears to be consistent with measured values, it appears *E.coli* deposition estimates or survival values are significantly overestimated.

The model does not accurately predict the *E. coli* concentrations, however, even then it is limited to predicting discharge values. The next step would be to implement the model in the marine environment of the Bay of Poverty. This presents challeges, as the effects of salinity, dilution, currents, etc., add more uncertainty to the model. Probably the best approach is to focus on policy that controls bacteria levels at the river outflows, and assume a reduction of the Bay in kind.

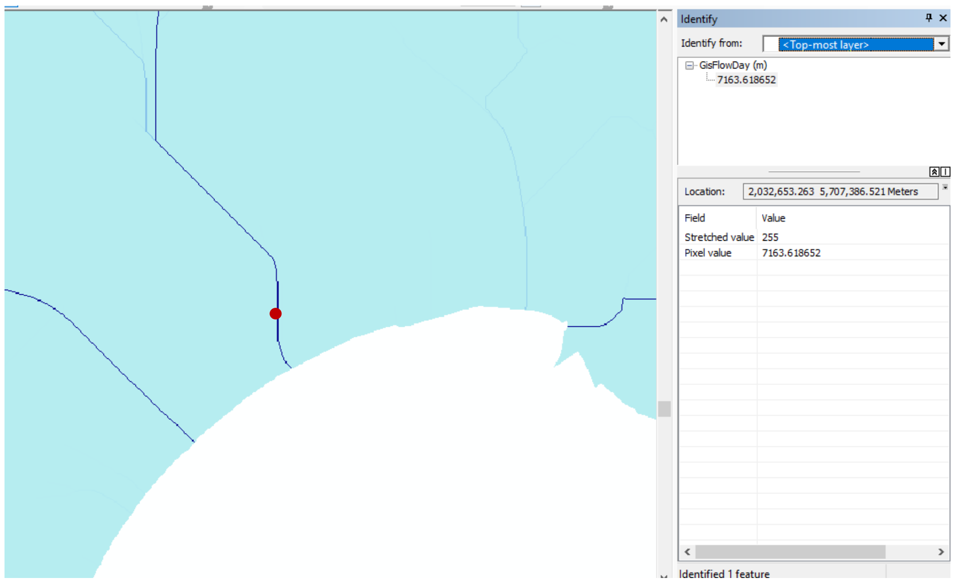


Figure 6: The average value of the accumulated flow in meters of precipitation at the outflow of the Waipaoa River in one day. Using the area of each cell (15 m^2) it is possible to determine the volume.

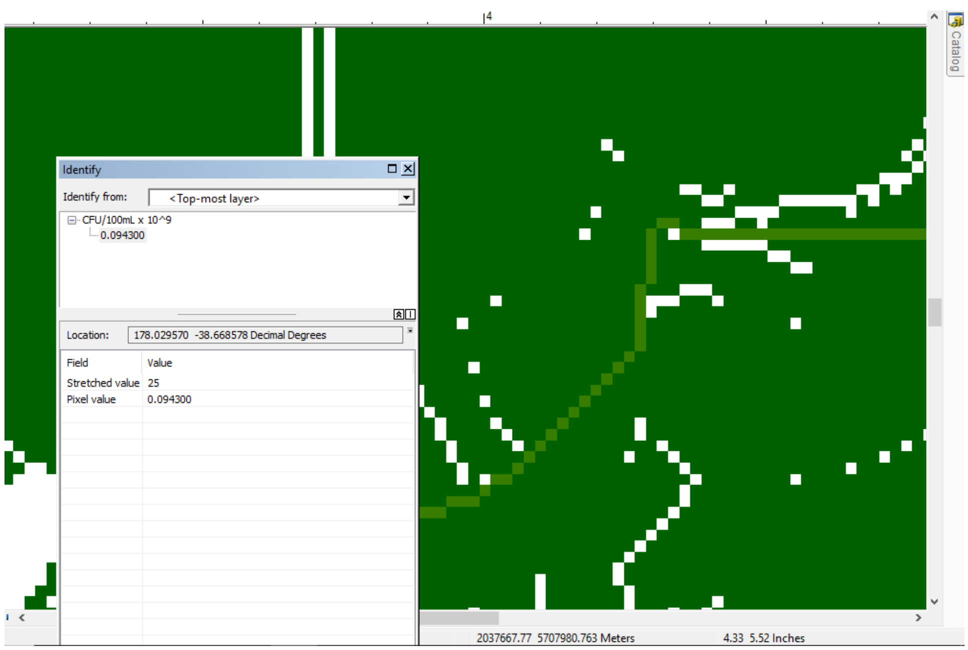


Figure 7: Taruheru Bridge CFU/100mL never exceeded 10,000 in the past 6 months. The model gives a value of 9.34 x 10^7 CFU/100mL.

Additional Analysis:

The next steps would be to refine the equations and calculations so that they better reflect the values sampled by the Gisborne District Council. Instead of estimating Q, it would be ideal to have flow rate data for the stream network. This would remove a lot of uncertainty from the model. Machine learning is a powerful anfd cutting-edge tool that could be implemented to find best fit equations.

Stream fencing requirements are a commonly proposed mitigation policy. Using the stream polylines, it would be possible to create a buffer of a specified width and use that to clip out any surrounding pasture. This would simulate implementation of an effective stream fencing policy. The percent mitigation could be determined and then evaluated with sampling at outlets, and within the Poverty Bay. For ideal median CFU/mL values for shellfish production to be achieved, an approach that uses modeling to evaluate the most effective and cost effective mitigation techniques upstream is an invaluable tool, and work should continue on this.

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Metadata:

Title	**Livestock numbers, 1994–2015**
Type	Dataset
Subject	stocks, animals
Source	StatsNZ
Description	Livestock numbers reflect changes in the number of farmed beef and dairy cattle, deer, and sheep across New Zealand. Livestock farming is a widespread land use in this country. It is important to monitor livestock numbers, because concentrated numbers, or large increases in numbers, can affect the indigenous biodiversity, soil health, and water quality. File contains total livestock numbers by region for each year over the period 1994–2015
Variables	- Variable_Annual_Jun: • Total dairy cattle (including bobby calves) • Total beef cattle • Total cattle • Total sheep • Total deer - Region - Year - Number: numbers of animals
Rights	Creative Commons Attribution 4.0 New Zealand
Publisher	New Zealand's Environment Reporting Series: The Ministry for the Environment and StatsNZ
Coverage	National, 1994–2015
Identifier	FW17/016
Language	New Zealand English
Issued	27 April 2017
Environmental reporting topic	Resource use and management, and other human activities
Environmental reporting category	National indicator
Environmental report	Our fresh water 2017
Relevant measure on the Environmental Indicators, Te taiao Aotearoa website	Livestock numbers

Other data and reports which relate to this measure	
Methodology (collection & analyses)	Livestock numbers come from the Agricultural Production Census (APS) and Agricultural Production Survey conducted by StatsNZ with the Ministry for Primary Industries. The population of the current (as of 2002) census and survey is all those people or businesses registered for goods and services tax (GST threshold is $60,000 from 2010; between 2002 and 2010, the threshold was $40,000) and classified by StatsNZ's Business Frame as being engaged in horticulture, cropping, livestock farming, or exotic forestry operations. Annually, approximately 30,000 of the total 70,000 businesses involved in agricultural, horticultural, or forestry production are selected to participate in the survey, with a full census every five years. We present data back to 1994; however, caution is advised interpreting results because the APS changed its questionnaire design and farm coverage between 1994 and 2002. Between 1994 and 1996, the APS population included businesses registered for GST and recorded on StatsNZ's Business Frame as being engaged in horticulture, cropping, livestock farming, or forestry. This population covered smaller farming units than the current APS.
Limitations to data & analysis	The accuracy of the data source is of high quality. No agricultural survey was conducted in 1997 and 1998. The APS population in the 1999 iteration was AgriQuality New Zealand's national database, AgriBase. Agribase covered all units recorded as holding livestock and/or engaging in grain/arable cropping. In 2002, the population was changed back to StatsNZ's Business Frame with the higher $60,000 GST threshold.
Changes to time series	The 2004–15 deer figures are not directly comparable with those from 2002 and 2003. StatsNZ estimates an undercount of about 70,000 deer at 30 June 2002, and 50,000 at 30 June 2003.
References	Agricultural production statistics: June 2015 (final) http://www.stats.govt.nz/browse_for_stats/industry_sectors/agriculture-horticulture-forestry/AgriculturalProduction_final_HOTPJun15final.aspx

A free fully assessed 15 metre digital elevation model for New Zealand

Joshua Columbus, Pascal Sirguey and Robert Tenzer

A digital elevation model (DEM) is a fundamental data layer in any geographical information system (GIS). It has many uses and is required for a number of applications such as hydrological, environmental and climate modelling, geoid/quasi-geoid computations, or the ortho-rectification of satellite imagery. Several countrywide DEMs already exist in New Zealand. They have been produced by private companies, Crown Research Institutes, overseas institutions and enthusiast users.

Despite the multiplicity of DEMs, these products generally involve fees, restrictions of use, and sometimes a lack of documentation and quality assurance limiting their use. In addition, their spatial resolution, processing method, and assessment protocol are sometimes unsatisfactory or obscure. Difficulty of access and poor documentation results in many users still processing DEM layers for custom extents as they see fit, therefore adding to the inconsistency of data available.

This founded the need for a free publicly available countrywide DEM that would be transparent in its creation and assessment, as well as convenient for various applications and users. To achieve this, the resulting DEM not only required a sound, well documented processing method and thorough accuracy assessment, but it also needed to be presented in a format consistent with existing datasets of national importance in order to facilitate its usage.

This task was undertaken at the National School of Surveying, University of Otago. This article reports on the preparation and assessment of NZDEM SoS v1.0, a 15-m spatial resolution DEM for New Zealand. The quality of this product is then compared with two other nationwide DEMs.

Context

Source of data

The principal source of topographic data in New Zealand is the LINZ NZTopo database. This supplies a seamless coverage of the 1:50,000 scale topographic mapping of the country in industry standard digital format – the Environmental Systems Research Institute shapefile. The topographical heights data available in the LINZ database were obtained by a stereo photogrammetric approach using aerial photographs.

All of the data is projected on the New Zealand Transverse Mercator 2000 projection and is accurate to within certain tolerances. The database specifications state 90 per cent of all the well-defined points are within ± 22 metres planimetrically and ±5metres vertically. The contour lines, which are of 20 metres equidistance, are within ±10 metres in elevation. The errors in the position of the data result from errors inherent in the map production processes. This includes the cartographic principles of generalisation and displacement, and also errors in the digitising processes used to convert analogue data to a digital format.

Additional considerations

A clear understanding of how the final product would be presented in terms of spatial resolution and extent was required before the DEM could be created.

Spatial resolution

It was considered desirable to create a DEM with a spatial resolution as fine as possible, while ensuring its relevancy and practicality. A spatial resolution of 15 metres was chosen. It is believed that the 20 metre contours in the NZTopo database make such an interpolation relevant while ensuring that the final product would keep a reasonable size. In addition, this provides a desirable improvement compared to DEMs currently available for the country such as Geographx: 20m, Landcare: 25m, SRTM: 90m.

Spatial extent

The final product needed to be a user friendly database which could be related to easily and be consistent with existing datasets of national importance. In addition, the size requirements of a high resolution DEM of New Zealand was considered to be a potential obstacle in terms of future distribution. This justified the strategy to provide NZDEM_SoS_v1.0 as a set of individual but seamless tiles.

The LINZ Topo250 topographic map series was chosen as a practical reference. The Topo250 series contains 30 maps of 180 km by 120 km which seamlessly cover the entire country barring two maps which overlap some regions as shown in Figure 1.

Each map is easily distinguishable and can be uniquely identified by a map number and name. The only map to be excluded from the series in this project was Chatham Islands Map 31 as it was located outside the study area. Using the Topo250 series as the method of presentation for the final product was believed to have advantages.

- First, by being a LINZ topographic map series, it is already well documented and easy to relate to. This is a big assistance in helping to create an easy to use database which suits many users.
- Second, the extent of one map creates a raster file size of approximately 350 mb, allowing the data to be handled and transferred efficiently.
- Finally, the map extents are divisible by 15 making the interpolated raster grids correspond exactly with each map without distortion.

Users also have the option of selecting only certain areas of the country if desired and therefore are able to save on load times and storage space.

Method

Topographic interpolator

The topographic data available in the LINZ database contains features such as contour lines and height points and these needed to be interpolated to create the DEM raster grid. There are various methods of interpolation, each having their own advantages and disadvantages. Inverse distance weighed, Kriging and Spline interpolation are some such methods. ANUDEM is a specific topographic interpolator that aims to generate a hydrologically correct DEM by removing spurious sinks in the surface.

ANUDEM accommodates data points by means of a 2-D thin plate smoothing spline. The regularity of the spline is controlled by a user-defined roughness penalty that permits sharp changes occurring between slopes and valley floors to be accommodated while minimizing interpolation artefacts. ANUDEM was selected to be the method of interpolation for NZDEM_SoS_v1.0, along with a roughness penalty of 0.5 and 40 iterations, as this was proven to produce a DEM with competitive accuracy and limited artefacts compared to various other methods.

Process

Due to the sheer size and extent of the project the DEM could not be made in one stage. Being limited by the computer hardware available, the DEM was created in 150 tiles with each tile overlapping adjacent tiles by 6,000 metres. This overlap allowed mosaics of the tiles to be formed later in the creation process without negatively affecting the bounding areas of each tile. To create each tile, the 'Topo to Raster by File' tool in the 3-D Analyst extension of the ArcGis v9.3 software suite was used. This tool is in effect the ANUDEM v4.6 topographic interpolator for which a script was written in VBScript to fully automate the process.

Mosaics were created for every Topo250 map using only the created tiles required, thus saving on heavy computation times. Next, artefacts of the spline interpolator in flat areas such as lakes and sea, required correction. A mask containing all lakes of known elevation and the ocean was created. A conditional test using this mask was run over each mosaic to replace the interpolated values with the known elevation. The output raster was clipped at the same time to the extent of the respective Topo250 map. Finally, the tiles were exported to a GeoTIFF file format and named appropriately. The final product of this process was a database of smaller DEMs representing the Topo250 map series which could be seamlessly positioned together to create a high resolution countrywide DEM.

Accuracy assessment

Check points

The complete LINZ geodetic database was acquired (retrieved in January 2011) for the purpose of obtaining check points (CP) to assess the accuracy of NZDEM_SoS_v1.0 by statistical methods. The database, which contains over 100,000 geodetic survey marks of various accuracies and reliability, had to be filtered to ensure only a high standard of CPs were used in the assessment. A geodetic mark was considered eligible, if it matched the following criteria –

- It is located within the study area.
- It has a positive elevation in NZVD2009.
- It is of coordinate order 9 or lower, that is ±5 metres both planimetrically and vertically.
- It is more than 15 metres from any height point used in the interpolation process in order to avoid bias in the assessment.

All marks with heights in terms of the ellipsoid or one of the 13 major levelling datums from around the country were able to be converted to New Zealand Vertical Datum 2009 (NZVD2009) using the LINZ online conversion tool. All other marks in the database with heights on minor or unknown datums were ignored. To limit any direct bias between the creation and assessment of the DEM, marks within 15 metres of a height point used by the interpolation were also removed. A group of 42,090 geodetic marks were eligible to be selected as check points.

To create a strong statistical accuracy assessment of NZDEM_SoS_v1.0, a robust and acceptable sampling strategy of CPs was required. It was essential the CPs were randomly chosen but also that they maintained a distribution of heights that matches that of the terrain. This would allow the final selected CPs to be representative

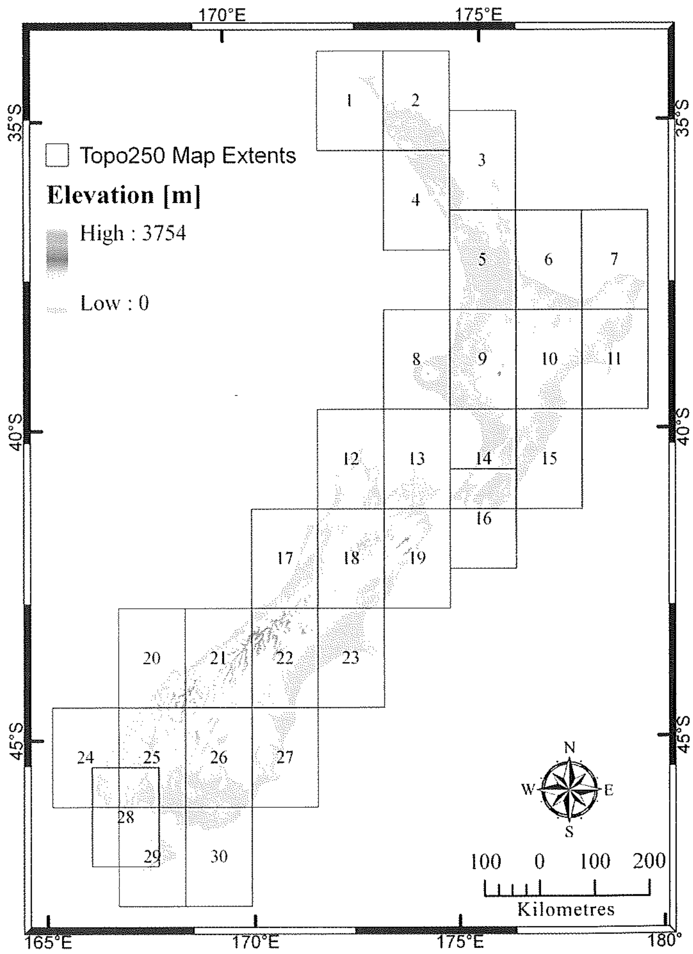

Figure 1. LINZ Topo250 topographic map series

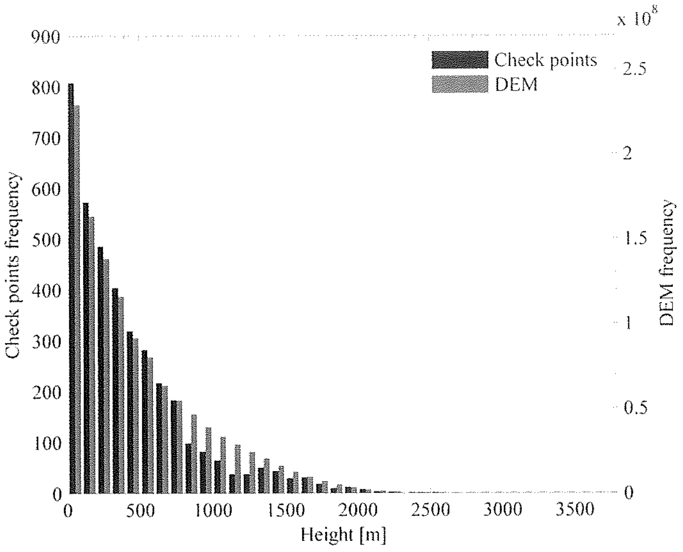

Figure 2. Frequency distribution of CPs heights relative to the DEM's heights.

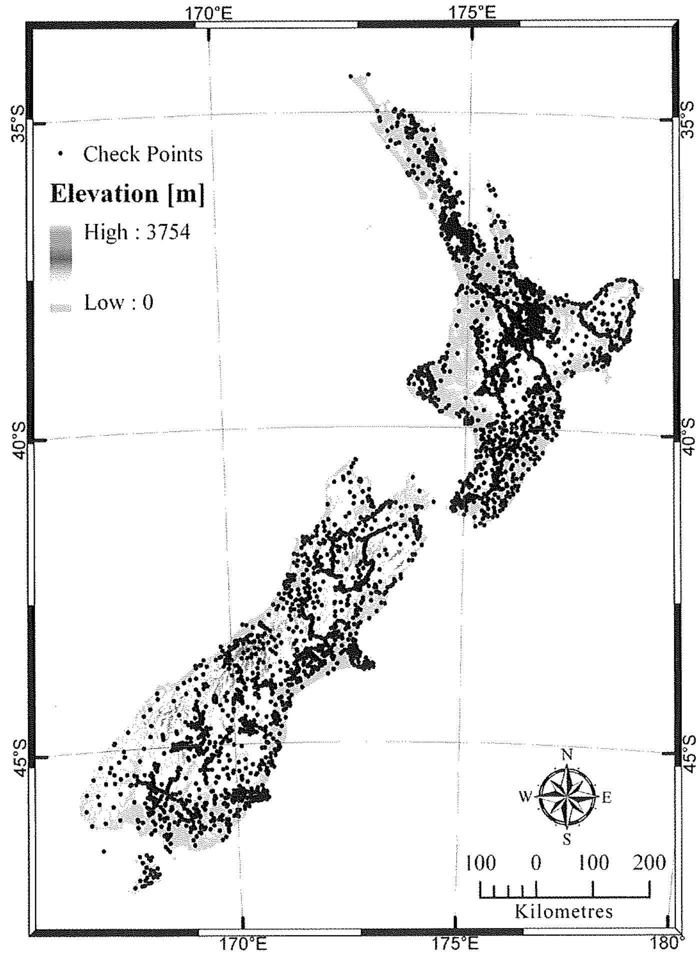

Figure 3. Spatial distribution of check points over the study area.

of the terrain being assessed. A minimum distance of 1500 metres between selected CPs was implemented to minimize the spatial correlation between survey marks too close to each other, while creating an even distribution over the country.

A MATLAB script was written to select the CPs. The script selected marks at random while constantly ensuring the minimum distance criteria was met. The script continued selecting points until either enough points were collected to represent the terrain, or until there were no more points left which passed the criteria.

The graph in Figure 2 shows the frequency distribution of the final CPs heights relative to the created DEM's heights. The spatial distribution of the final CPs is displayed on the map in Figure 3. After the script selection and some minor rational investigating, a final collection of 3,791 accurate and reliable CPs remained to be used in the accuracy assessment.

Standard statistical measures

The quality of a DEM is a relative concept that is assessed in accordance with its intended use. To describe the ability of a model to produce reliable observations Willmott et al (1985) recommended the use of several measures to allow reliable conclusions about the performance. Given a set of control points of known elevation, the modelling error $\varepsilon_i = P_i - O_i$ between the height P_i predicted by the DEM at the point i and the observed height O_i can be computed. The mean error (μ_ε), the mean absolute error (MAE), and the root mean square error (RMSE) often form the core of goodness-of-fit measures and model assessment. The performance of these standard statistical methods, that is, μ, σ, RMSE and MAE) for NZDEM_SoS_v1.0 are shown in the table on page 19.

Contour bias

In the context of assessing DEMs, Wise (2000) argued that standard statistical measures based on a limited sample of CPs such as the RMSE are too crude to assess fully the quality of DEMs, because they fail to indicate gross errors. In the search for additional metrics that would be suitable to measure the quality of DEMs, Carrara et al. (1997) pointed out that the interpolated heights should be uniformly distributed between the elevations of two bounding contours. In other words, when interpolating from 20 metres contour lines, 20 per cent of the point heights should lie within ±2 metres of a contour elevation.

Within this context, Carlisle (2002) showed that some interpolators create DEMs where point elevations tend to be close to those of contour lines used as the primary source for the interpolation. Such artefacts can result in a more or less severe flattening of the output surface as it crosses the contour. This is sometimes readily visible by the typical terracing effect in a hill shaded DEM. Carlisle (2002) proposed to quantify this effect by means of the contour bias criterion that represents the proportion of points that lie within 10 per cent of the height of a contour line. Any substantial increase in contour bias from the ideal 20 per cent could therefore be interpreted as a lesser quality interpolated surface. This contour bias was found to be 27 per cent for the NZDEM_SoS_v1.0 as shown in the table on page 19. This non ideal contour (i.e., >20 per cent) can be partially explained by the fact that relatively flat areas are more susceptible to contour bias.

Comparison

A comparison of NZDEM_SoS_v1.0 with two existing countrywide DEMs was undertaken to gain a better understanding of its relation to existing datasets. A 20-m DEM created by Geographx Ltd and a 25-m DEM created by Landcare Research were used for the comparison. The same metrics used in the initial accuracy assessment were calculated for the additional two DEMs. This involved using the exact same set of check points and methods of calculations to allow the various metrics to be compared directly using a common reference. The final results of the comparison show NZDEM_SoS_v1.0 is an improvement on both existing datasets. All of the metrics used displayed this improvement except for the contour bias which remained in a similar category to the Landcare Research DEM. The computation of confidence intervals for each metric is yet

Results of the accuracy assessment for each DEM

Statistics	NZDEM_SoS_v1.0 (15-m)	Geographx DEM (20-m)	Landcare Research DEM (25-m)
μ_ε [μ]	-2.1	-2.3	-2.5
σ_ε [μ]	6.8	7.1	7.6
MAE [m]	5.1	5.5	5.6
RMSE [m]	7.1	7.5	8.0
Max Absolute Error [m]	53.2	54.2	55.9
Contour Bias [%]	27.4%	40.5%	27.3%

to be completed in order to demonstrate the significance of the improvements achieved by NZDEM_SoS_v1.0.

Summary

NZDEM_SoS_v1.0, a digital elevation model covering the whole of New Zealand at a spatial resolution of 15 metres, was created to accommodate the need for a transparent, free and publicly available DEM. The DEM was created to correspond exactly with the LINZ Topo250 topographic map series. The 30 various maps allow smaller regions to be obtained individually but also fit together seamlessly to create a full countrywide DEM.

These maps create a user friendly database which is efficient in the handling and transferring of data. An accuracy assessment was undertaken using a statistically robust set of check points which minimized any bias from influencing the final results. Standard statistical methods and the contour bias criterion were able to be used to assess the quality of the DEM and obtain a direct comparison with two existing DEMs of New Zealand. The results from this comparison exhibit a visible improvement of NZDEM_SoS_v1.0 in terms of quality that comes in addition with a finer spatial resolution.

Joshua Columbus is currently an honours student at the School of Surveying, University of Otago and conducted this research within a summer bursary programme.

Pascal Sirguey received a MSc degree in structure dynamics from the Ecole Centrale de Lyon, France, in 2001. After a brief career in the industry, he completed a PhD in remote sensing at the School of Surveying, University of Otago, in 2010 where he has been a lecturer since 2008. He teaches remote sensing, photogrammetry, and spatial analysis.

Robert Tenzer completed his PhD studies in 1999 (STU Bratislava) and in 2008 (CVUT Prague). He joined the School of Surveying as a lecturer in 2009. His research area is physical and satellite geodesy, geophysics, and geodynamics.

A full list of references is available on request – Editor

Industry scholarship gives Tamehana Wickliffe a career boost

A survey cadet from Downer NZ in Hamilton is one step closer to achieving his career goals, after receiving a $10,000 National Diploma Scholarship for Maori. Tamehana Wickliffe was awarded the scholarship by InfraTrain New Zealand through its Te Poutama Kaiahumahi programme. The programme is run in partnership with Te Puni Kokiri and aims to strengthen the skills and qualifications of Maori working in the civil infrastructure industries.

Tamehana Wickliffe with InfraTrain Chief Executive Philip Aldridge and Dr Pita Sharples.

The scholarship will enable Tamehana, who is of Ngati Hako, Pae Ahi, Ngati Tara Tokanui and Ngati Tamatera descent, to study for a National Diploma in Surveying.

InfraTrain has awarded a total of 18 National Diploma Scholarships since it started working with Te Puni Kokiri in 2008. The latest winners, including Tamehana and several civil engineering cadets, were presented with their scholarships in Auckland recently by the Minister of Maori Affairs, Hon Dr Pita Sharples.

Speaking at the presentation, Dr Sharples said, 'It really is wonderful to be back again to present more Scholarships and recognise the ongoing success of Te Poutama Kaiahumahi. The winners represent the aspirations we want to stimulate within the wider Maori workforce. That is of a skilled, talented and highly qualified workforce realising its potential.'

Dr Sharples continued, 'What is great about the Te Poutama Kaiahumahi programme is that the benefits flow two ways. On one hand, Maori staff improve their skills and gain qualifications which improves their job and promotion prospects. On the other hand, employers will gain higher productivity and efficiencies.'

InfraTrain Chief Executive Philip Aldridge added, 'InfraTrain congratulates Tamehana and all of the scholarship winners. The applications were of an extremely high standard, and we were impressed by their motivation and commitment to their chosen careers. We expect great things from them in the future.'

Statistics New Zealand ANZLIC Metadata Template

Identification

Title	Territorial Authorities 2012
Date	1 November 2010 (publication)
Language	eng
Character Set	Uft8
Abstract	This dataset is the definitive set of territorial authority boundaries for 2012 as defined by the Local Government Commission and/or the territorial authorities themselves but maintained by Statistics New Zealand (who are the custodian). A Territorial Authority is defined under the local government act 2001m as a city or a district council. There are now a total of 67 territorial authorities in New Zealand. This updated total reflects the amalgamation of the seven territorial authorities (Rodney District, North Shore City, Waitakere City, Auckland City, Manukau City, Papakura District and Franklin District) into one new Auckland Council in 2010. Territorial authorities are the second tier of local government in New Zealand, below regional councils. The 67 territorial authorities comprise: 12 city councils, 53 district councils, the Auckland Council and the Chatham Islands Territory. Six territorial authorities (Auckland Council, Nelson City Council, Gisborne , Tasman , and Marlborough District Councils) also perform the functions of a regional council and thus are known as unitary authorities. Chatham Islands Territory undertakes only some of the functions of a regional council, and is therefore not a unitary authority. Territorial authority districts are not subdivisions of regions, and some of them fall within more than one region. Taupo District has the distinction of straddling the boundaries of four different regions. Territorial authorities are based on communities of interest and road access and administer local roading and reserves, sewerage, building consents, the land use and subdivision aspects of resource management, and other local matters. Territorial authorities are defined at meshblock and area unit level. The 2012 digital pattern includes the following territorial authorities:

Territorial Authority Code	Territorial Authority Name
001	Far North District
002	Whangarei District
003	Kaipara District
011	Thames-Coromandel District
012	Hauraki District
013	Waikato District
015	Matamata-Piako District
016	Hamilton City
017	Waipa District
018	Otorohanga District
019	South Waikato District
020	Waitomo District
021	Taupo District
022	Western Bay of Plenty District
023	Tauranga City
024	Rotorua District
025	Whakatane District
026	Kawerau District
027	Opotiki District
028	Gisborne District
029	Wairoa District
030	Hastings District
031	Napier City
032	Central Hawke's Bay District
033	New Plymouth District
034	Stratford District
035	South Taranaki District
036	Ruapehu District
037	Wanganui District
038	Rangitikei District
039	Manawatu District
040	Palmerston North City
041	Tararua District
042	Horowhenua District
043	Kapiti Coast District
044	Porirua City
045	Upper Hutt City
046	Lower Hutt City
047	Wellington City
048	Masterton District
049	Carterton District
050	South Wairarapa District
051	Tasman District
052	Nelson City
053	Marlborough District
054	Kaikoura District

055	Buller District
056	Grey District
057	Westland District
058	Hurunui District
059	Waimakariri District
060	Christchurch City
062	Selwyn District
063	Ashburton District
064	Timaru District
065	Mackenzie District
066	Waimate District
067	Chatham Islands Territory
068	Waitaki District
069	Central Otago District
070	Queenstown-Lakes District
071	Dunedin City
072	Clutha District
073	Southland District
074	Gore District
075	Invercargill City
076	Auckland
099	Area Outside Territorial Authority

The following have been significant changes to the territorial authority boundaries:

Year	Changes
1989	New Zealand's local government structural arrangements were significantly reformed by the Local Government Commission in 1989. There were 205 territorial local authorities: 28 cities, 78 boroughs, 67 counties, 31 districts and 1 town district, as well as a multitude of ad-hoc authorities such as pest control boards, drainage boards, catchment boards, and domain and reserve boards. These were replaced by 74 territorial local authorities, 15 of which were cities and 58 districts. The exception was Chatham Islands County which retained its county status.
1990	Invercargill proclaimed a city.
1992	Nelson-Marlborough Regional Council abolished by a Local Government Amendment Act. Kaikoura District was transferred to the Canterbury Region. Nelson City, and Tasman and Marlborough districts became unitary authorities.
1995	The Chatham Islands County was dissolved and

	reconstituted by a specific Act of Parliament as the "Chatham Islands Territory", with powers similar to those of territorial authorities and some functions similar to those of a regional council. This included the addition of territorial sea, a coastal buffer extending to 12 nautical miles from the coastline.
1995	Tasman District boundary extended to agree with the Tasman Region boundary at the 12 mile limit.
1998	Not Applicable category changed to Area Outside Territorial Authority
2004	Tauranga District changed to Tauranga City
2006	Banks Peninsula District merged into Christchurch City as a result of a Local Government Commission decision following a 2005 referendum.
2010	Auckland Council established under the Local Government (Tamaki Makaurau Reorganisation) Act 2009. Rodney District, North Shore City, Waitakere City, Auckland City, Manukau City, Papakura District and Franklin District territorial councils and the Auckland Regional Council were abolished to become a unitary authority known as the Auckland Council. The area now consists of one city council (with statutory provision for three Maori councillors), four urban local councils, and two rural local councils: • Rodney local council lost Orewa, Dairy Flat, and Whangaparaoa but retained the remainder of the old Rodney District. The split areas as well as the old North Shore City formed a Waitemata local council. • Waitakere local council consists of the old Waitakere City as well as the Avondale area. • Tamaki Makaura consists of the old Auckland City and Otahuhu (excluding CBD) • Manukau local council consists of the urban parts of the old Manukau City and of the Papakura District. • Hunua local council consists of the entire Franklin District, much of which was previously in the Waikato Region, along with rural areas of the old Papakura District and Manukau City. • The entire Papakura District was dissolved between urban and rural councils.

As at 1st July 2007, Digital Boundary data became freely available.

Topic category	Boundaries
Spatial representation type	vector

Extent

Description	Twelve mile New Zealand territorial limit

Geographic Box

West bound longitude	165.905646
East bound longitude	179.855610
North bound latitude	-33.826584
South bound latitude	-47.841491

Extent

TEMPORAL	
Description	Data represents Territorial Authorities polygons dissolved since 1990
Begin date	1991-01-01
End date	2013-01-01
Access Constraints	None. Data is freely downloadable from the Statistics NZ website.
Use constraints	These conditions of supply apply to all users of Statistics New Zealand digital boundaries effective 1 July 2007. **Permitted uses** Statistics New Zealand must be acknowledged as the source of the boundaries. **Uses not permitted** Users are not permitted to change the accuracy of the boundaries and supply them to another party. **Liability** While care has been used in compiling these boundary coordinates, Statistics New Zealand gives no warranty that the data supplied is free from error. Statistics New Zealand shall not be liable for any loss suffered through the use, directly or indirectly, of any information, product or service.
Use limitation	
Maintenance and update frequency	The meshblock pattern and associated hierarchies are maintained on a regular basis. An annual pattern is made available for each year up to 2012.
Date of next update	December 2012.
Update scope	Dataset

Point of Contact

Organisation name	Statistics New Zealand
Position name	GeoStatistical Analyst
Role	Point of Contact
Voice	03-964 8700
Facsimile	03 964 8379
Delivery point	Statistics House The Boulevard, Harbour Quays
City	Wellington
Administrative area	
Postal code	6140
Country	New Zealand
Electronic mail address	geography@stats.govt.nz
Linkage	http://www.stats.govt.nz/browse_for_stats/people_and_communities/geographic-areas/download-digital-boundaries.aspx

Distribution Info

Distribution format	ESRI Shape MapInfo Tab
Distribution version	1.0
Online resource linkage	http://www.stats.govt.nz/browse_for_stats/people_and_communities/geographic-areas/download-digital-boundaries.aspx
Online resource description	Web page for downloading the digital boundaries which the Territorial Authorities is part of the bundle of boundaries/geographies StatsNZ makes available

Reference system info

Title	New Zealand Transverse Mercator 2000 (NZTM2000)
Date	1 July 2001
Edition	

Code (page 128 of Guidelines)	19971

Data quality info scope

Hierarchy level	Dataset
Description	New Zealand Territorial Authority Boundaries

Lineage

Statement (general explanation of the data producer's knowledge about the lineage of a dataset)	Territorial authority boundaries are based on the meshblock pattern and comprise of whole area units. Non-alignment of meshblock and cadastral boundaries are one of a number of reasons for meshblock boundary adjustments. Other reasons include requests from local authorities, Local Government Commission, Electoral Representation Commission and to make Census of Population and Dwellings enumeration processes easier. Once all changes are prepared, Statistics NZ then passes the requests for changes to the meshblock pattern onto LINZ for the electronic changes to take place. To Derive the area unit boundaries clipped to the coastline, meshblock polygons were dissolved to include or exclude land/water attributes attached to each meshblock. From the meshblock pattern, higher geographies, including the 2011 territorial authority pattern were dissolved using the dissolve tool in the Arc GIS suite to create multiple output datasets.
Description (detailed description of the level of the source data)	The original points representing the meshblock boundary pattern were digitised in 1991 from 1:5,000 scale urban maps and 1:50,000 scale rural maps. The magnitude of error of the original digital points would have been in the range of +/- 10 metres in urban areas and +/- 25 metres in rural areas. Where meshblock boundaries coincide with cadastral boundaries the magnitude of error will be within the range of 1–5 metres in urban areas and 5 - 20 metres in rural areas. This being the estimated magnitude of error of Landonline. The creation of level 1 meshblock boundaries for 2012 digital pattern and the dissolving into other geographies/boundaries were outsourced to Sinclair Knight Merz (SKM) and were created by the following processes using ESRI software. 1. Import data from the supply format of ESRI Shapefiles to an ESRI

	Geodatabase. 2. Clip layers for the Area Unit, Territorial Authorities, Regional Council, Urban Areas, Wards and meshblock regions, creating two output datasets ("High definition boundaries", and "High definition boundaries –clipped to the coastline") 3. Run Topology Checks on all data 4. Run attribute checks 5. Export supplied and created data to MapInfo format 6. Quality Assurance of delivery files 7. Dissolve the meshblocks layer into layers for area unit, territorial authority, regional council, urban area, ward and community board. Level 1 is exactly as exists in Landonline i.e. no points are removed and co-ordinates are retained at 1mm accuracy. The following quality checks were applied to the meshblock pattern: **Translation of ESRI Shapefiles to ESRI geodatabase dataset** The meshblock dataset was imported into the ESRI Geodatabase structure that is required to run the ESRI topology checks. Topology rules were set for each of the layers. **Clipping of Layers to Coastline** The supplied shapefiles were then clipped to the coastline. The coastline was defined as features within the supplied land_water12_region with codes and descriptions as follows: **11**- Island – *Included* **12**-Mainland – *Included* **21**- Inland Water – *Included* **22-** Inlet – *Excluded* **23**- Oceanic – *Excluded* **33**- Other – *Included.* The clip was completed using ArcGIS 10 and FME. *Note- for the Chatham Islands, 22-Inlet was included as this gives a full clip of the data for the main island. An inlet feature covers much of the main island in the group.* **Topology Checks** A tolerance of 0.1 cm was applied to the data, which meant that the topology engine validating the data saw any vertex closer than this distance as the same location. This is the smallest tolerance possible in this software and for this projection. A default topology rule of "Must Be Larger than Cluster Tolerance" is applied to all data – this would highlight where any tiny features with a width less than 0.1cm exist. No errors were found for this rule. Two topology rules were applied specifically within each of the layers in the ESRI geodatabase – namely "Must Not Overlap", "Must Not Have Gaps". These both check a layer upon itself. **Must Not Overlap** This process checks for any areas that overlap another feature from the same layer and produces an error where an overlap is found.

	Must Not have Gaps This process checks for any voids between or within features in the same layer and produces an error if found. **Topology Checks Results:** There were no real errors in either the gap or overlap checks for the mb11_region layer supplied, and none for any of the created datasets. For the gaps test, the most outer polygons are always reported as an error, and this was the only error reported for all cases. **Scripted Process - Spatial overlay correct** A script was created going through the following process: each of the dissolved layers was cycled through, taking each polygon feature and checking that the meshblock features with the same code have the exact same overall spatial boundary. No errors were found. **Export to MapInfo Format** The data was supplied to SKM in ESRI Shapefile – these were exported to MapInfo format using FME for delivery to Stats NZ. The original data was supplied in NZTM coordinates, and so no projection of data was required. **QA of Delivery Files** The ESRI delivery files were viewed in both delivery formats (ESRI and MapInfo) and had spot checks on data consistency and attributes performed. All data was then written to DVD and checked for readability. Statistics NZ is progressively realigning meshblock boundaries to cadastral boundaries and therefore the quality of the meshblock pattern has improved since 1991 when originally digitised. However, the accuracy of the digital meshblock pattern is dependent on the quality of the underlying survey information. **Dissolve meshblocks to higher levels** Statistics New Zealand then dissolved the ESRI meshblock shapefile to the higher levels, for both the full and clipped dataset. The dissolve tool was used to generate these datasets from the full meshblock dataset and the clipped to the coastline meshblock dataset.

Metadata

File identifier	
Language	eng
Character set	Utf8
Hierarchy level	dataset
Hierarchy level name	Dataset – meshblocks -2012
Date stamp	2012-01-01

Metadata standard name	ANZLIC Metadata Profile
Metadata standard version	1.1

Metadata author

Individual name	Sarah Cowell
Organisation name	Statistics New Zealand
Position name	GeoStatistical Analyst
Role	Point of Contact
Voice	03-964 8700
Facsimile	03 964 8379
Delivery Point	Statistics House The Boulevard, Harbour Quays
City	Wellington
Administrative area	
Postal code	6140
Country	New Zealand
Electronic mail address	geography@stats.govt.nz
Linkage	http://www.stats.govt.nz/browse_for_stats/people_and_communities/geographic-areas/download-digital-boundaries.aspx

Title	Land cover database v4 0 class orders
Abstract	Land cover describes the extent of vegetation, water bodies, built environments, and bare natural surfaces (eg gravel and rock) across New Zealand. Measuring the composition and changes in land cover can help us understand the pressures that different land uses are placing on the biodiversity and functioning of ecosystems. This data set relates to the "Land cover" measure on the Environmental Indicators, Te taiao Aotearoa website.
Reference date	21/10/2015
Language	eng-nz
Topic category	Environment
Geographic location	New Zealand
Temporal extent	2012–13
Legal restrictions	Creative Commons Attribution 3.0 New Zealand
Identifier	https://data.mfe.govt.nz/x/UbNmvS
Reference date type	Date of publication
Subject	surfaces, vegetation
Source	Landcare Research
Publisher	New Zealand's Environmental Reporting Series: The Ministry for the Environment and Statistics New Zealand
Resource point of contact	Analyst – Environmental Reporting, Ministry for the Environment
Environmental reporting topic	Vegetation and other land cover
Environmental reporting category	National indicator

Methodology (collection & analyses)	The New Zealand Land Cover Database (LCDB) is a national classification of land cover and land use mapped using satellite imagery. The LCDB uses satellite images to define polygons for areas with similar land cover types. The land use classifications for the polygons are then stored in a spatial database that can be used for mapping. We used Version 4.0, which covers mainland New Zealand and the nearshore islands but not the Chatham Islands. The LCDB has four major versions (1–4), correlating to the four summer survey periods – 1996/97, 2001/02, 2008/09, and 2012/13. The land cover classification was developed over the first three versions. Classification changes can be tracked to allow comparison between versions. The LCDB contains 33 classes of land cover. These classes were grouped into 13 medium-order classes according a classification provided by Landcare Research. Using this medium-order level classification provides a higher level of confidence in the allocation accuracy (eg for scrub). Refer to: https://data.mfe.govt.nz/table/2469-land-use-land-cover-classes-1996-2001-2008-and-2012/

Title	Average annual rainfall, 1972–2013
Abstract	Annual rainfall is the total accumulated rain over one year. Rain is vital for life, including plant growth, drinking water, river ecosystem health, and sanitation. Floods and droughts affect our environment, economy, and recreational opportunities. This dataset shows annual average rainfall across New Zealand for years 1972 to 2013. Annual rainfall is estimated from the daily rainfall estimates of the Virtual Climate Station Network (NIWA). This dataset relates to the "Annual average rainfall" measure on the Environmental Indicators, Te taiao Aotearoa website. Geometry: raster catalogue Unit: mm/yr
Reference date	21/10/2015
Language	New Zealand English
Topic category	Environment
Geographic location	New Zealand
Temporal extent	1972–2013
Legal restrictions	Creative Commons Attribution 3.0 New Zealand
Identifier	https://data.mfe.govt.nz/x/UEXef3
Reference date type	Date of publication
Subject	precipitation
Source	National Institute for Water and Atmospheric Research
Publisher	New Zealand's Environmental Reporting Series: The Ministry for the Environment and Statistics New Zealand
Resource point of contact	Analyst – Environmental Reporting, Ministry for the Environment
Environmental reporting topic	Rain, hail, sleet and snow
Environmental reporting category	Case study
Methodology (collection & analyses)	Annual rainfall is the total accumulated rainfall over a year. It is estimated from the daily rainfall estimates of the Virtual Climate Station Network (NIWA). Virtual climate station estimates are produced every day, for every 25km2 around the country. They use a statistical model to estimate the values between observations made at actual climate stations. This model uses

	information such as the pattern of annual rainfall to help with the estimations. (NIWA, Tait & Turner 2005; Tait et al 2006, Tait et al 2012). The New Zealand precipitation values in the Water Physical Stock – surface water components show the total precipitation. The maps in this case study highlight spatial and time variations. The accuracy of the data source is of high quality. References: NIWA (nd). Virtual climate station data and products. Accessed 3 June 2015 from www.niwa.co.nz. Tait, A, Henderson, R, Turner, R, & Zheng, XG (2006). Thin plate smoothing spline interpolation of daily rainfall for New Zealand using a climatological rainfall surface. International Journal of Climatology, 26(14), 2097–2115. Available from http://onlinelibrary.wiley.com. Tait, A, Sturman, J, & Clark, M (2012). An assessment of the accuracy of interpolated daily rainfall for New Zealand. Journal of Hydrology (New Zealand), 51(1), 25–44. Tait, A, & Turner, R (2005). Generating multiyear gridded daily rainfall over New Zealand. Journal of Applied Meteorology, 44(9), 1315–1323. Available from http://journals.ametsoc.org.