Bachelor Thesis

Analysing the results of the New Zealand national hydrological model for estimating design floods

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Abstract

For use in design of bridges, levees and other civil structures design floods are needed. These floods can be estimated by hydrological models. The National Institute of Water and Atmospheric research is delivering efforts in improving flood modelling in ungauged catchments. A way of doing this is testing if the national hydrological model, TopNet, is fit for use on ungauged catchments on a national scale.

To answer whether or not TopNet is fit for flood estimation in ungauged catchments, the mean annual floods have been analysed at first. For evaluation the relative bias and the root mean square relative error were used. Furthermore, the time series of TopNet and observations were statistically compared mean ranks, variance and distribution.

Because of the vast difference in geology in New Zealand spatial patterns in model performance are to be expected. To evaluate this expectation, the model error and statistical tests are visualised on maps and summarised per island.

Explanations for model behaviour are investigated. This is done by calculating Spearman's correlation coefficient for catchments characteristics. Another effort to explain checking whether or not TopNet simulates the flood event at the same dates.

Lastly TopNet is compared to the empiric model currently in use and its recently improved version. To do this the relative bias and Root Mean Square Relative Error are compared. Another performance parameter is introduced, the Root Mean Square Weighted Error. This parameter weights the errors by using both the observation and model record lengths.

TopNet has a significant error in estimating mean annual floods. The maps and comparison between islands did not show any clear spatial patterns nor significant differences between areas. No strong correlation between catchment characteristics and error can be found. The channel area, slope and elevation however have the strongest correlation to the error. The TopNet model seems to do a decent job at the timing of the flood events for about half of the cases. Comparison with the empiric models points out that TopNet in its current state produces worse results. All in all, TopNet is promising and may after improvement be a better way for flood estimation in ungauged catchments than using an empiric model but in its current state it is unfit.

Acknowledgements

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First of all, I would like to thank my supervisors for guidance and help during the project. Daniel Collins provided me great guidance and even protected me from doing too much research while reporting had to be done. Markus Pahlow for the guidance during the project and help in structuring my thesis. Furthermore, I would like to thank Roddy Henderson and Christian Zammit for providing me with data and the help and advice to do my research.

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1. Introduction

Design flood estimates are needed in the undertaking of engineering works all over the world. Without these estimates the possibility exist expensive structures like roads and bridges could be damaged or destroyed by floods. In 2015 alone the damages caused by floods was over 100 million New Zealand dollar (ICNZ, 2015). Design floods can be based on observation data. The problem however, lies in the fact not all rivers have gauging stations or these gauging stations have not been in place long enough to get sufficient data. This is where flood modelling comes into play. Models can be used to estimate river flows.

With over 180,000 km of rivers in New Zealand, many of them remain ungauged. The New Zealand government currently uses design floods estimated by McKerchar and Pearson (1989). This is an empiric model that mainly uses the area of a catchment. The National Institute of Water and Atmospheric research (NIWA) is doing efforts and is revaluating design floods for ungauged catchments. One of their approaches is updating the model by McKerchar and Pearson by employing more catchment characteristics and gauging data. Another approach is to evaluate the possibility of using the national hydrological model TopNet (Bandaragoda et al., 2003) on a national scale. TopNet is a distributed rainfall runoff model. This thesis will focus on the results of TopNet.

1.1. Study Objective and research questions

This study will look into the usability of the TopNet model to estimate design floods in ungauged catchments in New Zealand. The performance of the model will be evaluated both statistically and spatially. The spatial evaluation is done because differences in performance between regions is expected. The TopNet model will be compared to the 1989 empiric model and its improved version. Furthermore, the possibility of extrapolating the TopNet results into design floods will be evaluated. To achieve this objective, the following questions will be answered.

1. How well do the TopNet results match the observed mean annual flood data?
2. Which extreme value distribution can be fitted to the observations and TopNet results?
3. Are there any differences or spatial organisation in the goodness of fit between regions?
4. What parameters may explain patterns of model fit?
5. How well does TopNet perform compared to performance of the 1989 empiric model and its recently improved version?

1.2. Outline of Report

The structure of the report is as follows. In chapter 2 the study area will be described and some background information will be given. Subsequently chapter 3 will focus on the data used in the report. The TopNet model and empirical models and their records will be explained. Followed by an explanation of the spatial catchment characteristics. Chapter 4 will explain the methodology used to performed and the theoretical background surrounding it. In chapter 5 the results of the analysis will be given. These results will be discussed in chapter 7. Finally, the research questions will be answered in chapter 7.

2. Study area

The study area is the entirety of New Zealand. A map with the regions of New Zealand can be found in figure 1. The islands of New Zealand include vast differences in geography. This ranges from volcanic plateaus on the northern isle to the mountain range on the southern isle. Such major differences in geology have a major influence on the hydrology.

New Zealand's freshwater comes from precipitation. The prevailing Westerlies drive moist air up and over the Southern Alps. This leads to an annual precipitation over 10 meters on the region just upwind of the crest. The areas Canterbury and Otago see as little as 300 mm of rain each year. The northern island is affected by the depressions forming in the North Tasman Sea. The clouds that form because of warm sea temperatures near the Queensland coast and jet streams flow towards the northern isle (John Harding et all, 2004).

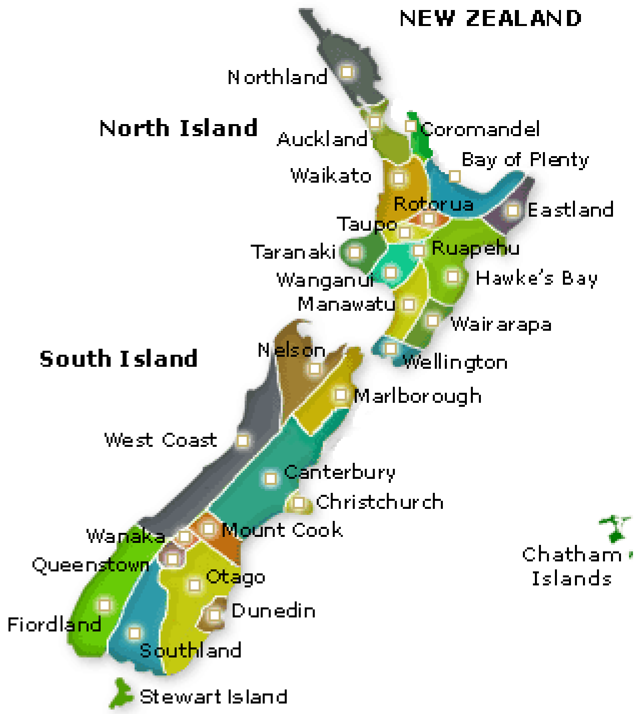


Figure 1 Map of New Zealand by region

3. Data

This section will start by introducing the national hydrological model TopNet. Secondly the empirical model by McKerchar and Pearson (1989) and the revised model will be introduced. Followed by the observation records and the selection process. Lastly this section will go into the available catchment parameters and spatial variables available.

3.1. TopNet

TopNet is a distributed hydrological model that consists of two fundamental components: simulating the water balance over a number of sub-catchments throughout a river basin, and routing streamflow from each sub-catchment to the basin outlet. TopNet is currently being used to evaluate impact on land use changes and effects of climate variability on hydroelectricity generation and water resource availability. The model divides water storage into five components: canopy storage, snowpack storage, aquifer storage, soil storage and overland flow storage by using state equations flows between these storages and the river are modelled. A schematic representation of the physical process modelled by TopNet is seen in figure 2. This figure is a simplification of the model and does not include all storage components. A detailed description of these storages and of the movement of water between these storages and the state equations are described by Clark et al. (2008).
While TopNet may be applied at the catchment and national levels, the national level is uncalibrated. For this thesis the uncalibrated TopNet simulations from 1973 to 2013 are used. This includes hourly flows for all Strahler order 3 reaches in New Zealand.

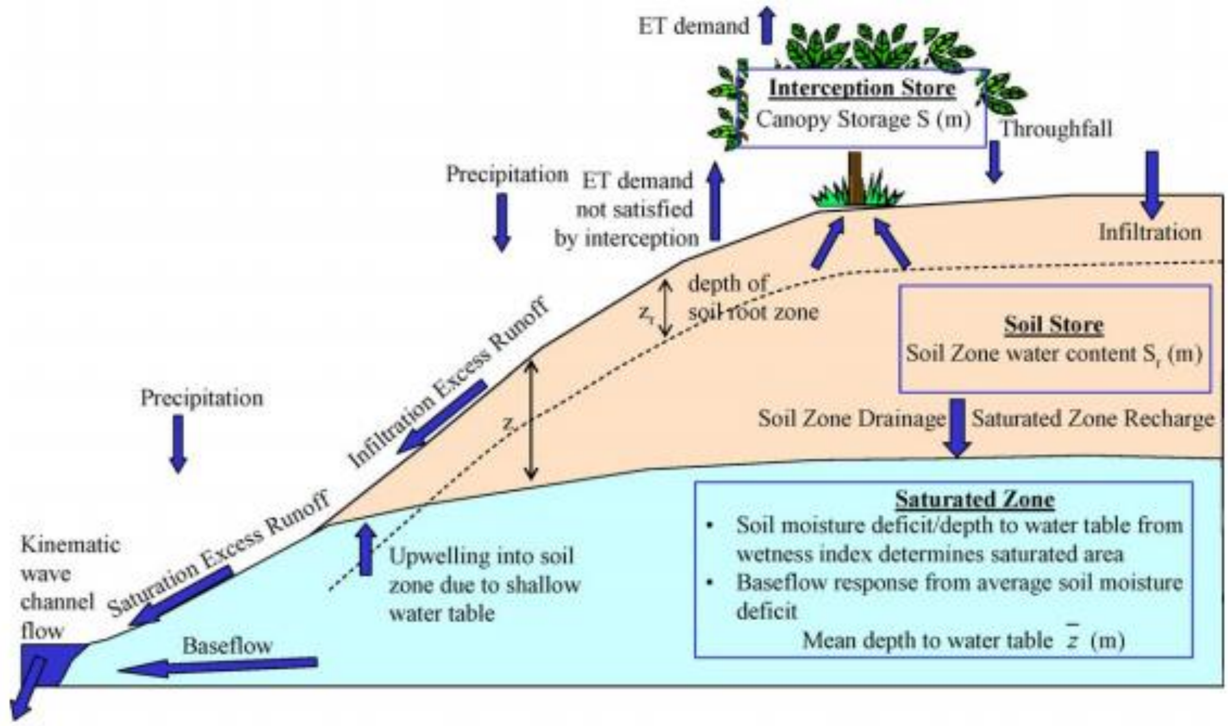


Figure 2 Schematic of the physical processes represented by TopNet (Bandaragoda et al., 2004)

3.2. Empiric model McKerchar and Pearson

McKerchar and Pearson (1989) developed an empiric regression model based on the catchment area (A). The least squares straight line for mean annual flood ($\bar{Q}$) versus catchment area was fitted on log-log paper. This resulted in the function:

$$\bar{Q} = 2.04A^{0.808} \text{ (1).}$$

Using this estimator and a map of mean annual rainfall contour maps were created for $2\bar{Q}/A^{0.8}$ to estimate mean annual flows in ungauged areas. This model was based on 275 sites with a record length of 10 years or more. The maps resulting from this model were digitalised and are currently being used to estimate design floods in ungauged areas.

3.3. Revised model

NIWA is developing a new empirical model for New Zealand using additional data gathered since 1989, split by island, and employing a larger suite of catchment and climatic characteristics than the crude model based on area. For a detailed explanation of characteristics used see section 3.5. Catchment characteristics and spatial variables. Catchment area and mean annual precipitation are fundamental variables, as are those describing the geology and physiography although the best selected variables depend on the island. This resulted in the following equations:

$$\overline{Q_N} = 1.52 \cdot 10^{-8} A^{0.84} P^{2.53} G_{SR}^{0.09} H_{4,5}^{0.14} H_{6,8}^{-.25}, \qquad (2)$$

$$\overline{Q_S} = 2.41 \cdot 10^{-4} A^{0.88} P^{1.41} S^{0.4} H_{6,8}^{-0.13} E^{-0.54}. \qquad (3)$$

Where A is the catchment area, P is the mean annual precipitation, G_{SR} is the fraction of the catchment with the top layer of the area being surficial rock, S being the average slope of the catchment, H being the hydrological indices per catchment derived from the Empirical Longitudinal Flow Model (Schmidt et al., 2009) and E being the catchment elevation.

The residual errors of this composite model will be interpolated and contours will be formed for applying corrections to the empirical model. This last step however has not yet been performed and thus the data without this correction will be used in this thesis.

3.4. Observation records and selection

NIWA manages most gauging stations in New Zealand. The data from these gauging stations can be used to compare to model results. The catchments used in for analysis were selected by three main criteria to ensure the natural flows has not been influenced. This is needed because the TopNet model is not designed to work with extraction of water or changes in catchment characteristics. The three criteria are no controlling of flow by the use of dams or levees, no extraction of water for the use of irrigation have to take place and there can be no vast changes in the use of landscape that influence the infiltration and time of concentration. By means of this process 609 gauging sites were selected for model evaluation.

These 609 are comparable to the TopNet model. Some of these sites however have to be ruled out by two selection criteria and due to errors in the linking process. This first criterion is catchment size. Due to the limitations of TopNet catchments having an area of under 7 km^2 cannot be used. This led to the exclusion of 76 sites. The second selection criterion was the record length of the observations within the time frame of the TopNet run from 1973 to 2013. In statistical analysis longer records make for a more accurate prediction or evaluation but the amount of sites is of great importance too. To not exclude too many sites it was decided to exclude 45 sites with seven or less years of available gauging records between 1973 and 2013.

Linking the gauging data to the TopNet was done by using station ID and the reach number in TopNet. The problem however is that these links are not perfect and in some cases multiple gauging sites are linked to the same reach. Where possible these gauging records were combined into one longer time series. This could not be done for two sites. One of these sites consisted of the records of two gauging stations in the Ohau river at Rongomatane. The data of these stations overlapped for multiple years but the flows differed several magnitudes, the records that were several magnitudes lower are assumed to be incorrect for a river this size and thus were eliminated. Leaving the records of only one gauging station. The other conflicting gauging stations were in the river Otara. Due to the differences in flow and a large overlap in the time series these two sites could not be combined. The shortest gauging records were left out of the analysis. Finally, due to a mismatch the records of Mangatawhiri at Moumoukai North were left out. The area in TopNet misrepresented the area covered by this flow recorder by 300%. This led to TopNet overestimating flows at this site and greatly affected the values for model performance. The elimination process left 485 sites for use in analysis.

3.5. Catchment characteristics and spatial variables

For the use of improving the 1989 model NIWA collected catchment characteristics. These characteristics were transformed for the use in the regression analysis of the improved model. Because of these efforts the characteristics are suitable for correlation analysis. The characteristics are categorised according to theme in: general, climate, storm and ecology. Other characteristics are fractions of the catchment containing the following themes: geological rock type, vegetation type, soil properties, soil textures and hydrogeological index. A detailed categorisation by theme can be found in Appendix A Catchment characteristics.

4. Method

This section will describe the evaluation methods used in this study. Because of the incomplete gauging records and focus on mean floods the use of several evaluation methods (e.g. Nash-Sutcliffe coefficient) is hard or impossible. Therefore, this section will start by explaining what performance estimators are used and why. Next statistical tests for further evaluation are chosen. Afterward, this section will explain the extrapolation of floods and assesses the usability of TopNet in flood frequency analysis. This will be followed by the spatial analysis of the data and investigation of model fit. Finally, comparison methods are discussed.

To compare the TopNet results as good as possible there will be made a distinction between the TopNet records that have corresponding observations available and the full length of records for both the observations and the 40 years of TopNet. Doing so will give us an indication of the robustness of the TopNet mean annual floods.

4.1. Evaluating model performance

As a first approach of evaluating the performance of TopNet all the annual maxima of the 485 selected sites from both TopNet and the observed data are summarized in log-log-scatterplots. Because of the great range in flows other scales are not sensible. These log-log-scatterplots will be made both using all the yearly maxima and the mean annual flood per site. For all sites the mean annual flood ($\bar{Q}$) and relative error was calculated using the following equations:

$$\bar{Q} = \sum_{i=1}^{n} \frac{Q_i}{n}, \qquad (4)$$

$$\text{relative flood error} = 100\% \cdot \frac{\bar{Q}_{mod} - \bar{Q}_{obs}}{\bar{Q}_{obs}}, \qquad (5)$$

With $\bar{Q}_{mod}$ being the modelled flows and $\bar{Q}_{obs}$ being the observed flows.

Because the flows range from $0.25 \text{m}^3/\text{s}$ to $5000 \text{m}^3/\text{s}$ measures like bias and Root Mean Square Error (RMSE) would be influenced too much by the higher numbers. Therefore, it was decided to use relative performance parameters for this thesis. The first of these is equation 6, the relative bias (Bennett et al, 2013). The other two parameters are the Root Mean Square Relative Error (equation 7) and Root Mean Square Weighted Relative Error (equation 8) these are variations on the Mean Square Relative Error (MSRE) by Bennet et all (2013). The RMSRE uses a square root to negate the power of two for easier interpretation. The RMSWRE is a weighted version of RMSRE. This measure is introduced because there is a big difference in the record lengths across all sites. The geometric mean, m, of the length of both time series will be used for weighing of the results. As record lengths are the same the geometric mean is of course equal to both records lengths.

$$\text{Rbias} = \frac{1}{n} \sum_{i=1}^{n} \frac{y_i - \hat{y}_i}{y_i}, \qquad (6)$$

$$\text{RMSRE} = \sqrt{\frac{1}{n} \sum_{i=1}^{n} \left(\frac{y_i - \hat{y}_i}{y_i} \right)^2}, \qquad (7)$$

$$\text{RMSWRE} = \sqrt{\sum_{i=1} \left(\frac{y_i - \hat{y}_i}{y_i} \right)^2 \cdot \frac{m_i}{\sum(m)}}. \qquad (8)$$

To further compare the results, the higher order statistics need to be taken into account. The means, average and distribution of both datasets will be tested against each other. To compare the means, the Wilcoxon signed rank test will be used. The average will be tested using Levene's Test. Lastly to compare the overall distributions the two-sided Kolmogorov-Smirnov test will be used. All tests will be performed with a p value of 0.05. Ideally all these tests will conclude in the model data having the same means, averages and distributions.

4.2. Flood frequency estimation using extreme value statistics

Extreme rainfall events and the resulting flood can have a devastating impact on a country. They can take lives and cause billions of dollars in damages. It is important to have flood frequency statistics to designing flood control works but also for the design of other infrastructure such as bridges. The basic problem in flood frequency analysis is however the shortage of available information. The information is insufficient to define risks of extreme events happening. To address this problem, hydrologist use their practical knowledge and statistical techniques to estimate risks in the best of their ability. A common way of doing this is by fitting a frequency distribution to the available data. Previously, section 4.1. described using the two-sided Kolmogorov-Smirnov test to compare the distribution of samples. This test however does only compare and does not identify the distributions. This section will explain the Generalised Extreme Value distribution and the use of Probability Weighted moments to fit one of its distributions.

The physical origin of maximum flow values suggests that the distribution is likely one of the extreme value (EV) distributions. The cumulative distribution functions (cdf) of these largest of n independent variates with common cdf $F(Q)$ is simply $F(Q)^n$. For large n and many choices for $F(Q)$, $F(Q)^n$ converges to one of three extreme value distributions described by Gumbel (1958) based on the Gumbel, Fréchet and Weibull families also called GEV types I, II and III. The convergence, however, is too slow for this argument alone to justify any of these distributions as a model for annual maxima (Maidment, 2013).

The Generalised Extreme Value Distribution (GEV) is a general mathematical form that incorporates Gumbel's type I, II and III extreme value distributions for maxima. The CDF of this distribution can be written as:

$$F(Q) = \exp\left\{-\left[1 - \frac{\kappa(Q-\xi)^{\frac{1}{\kappa}}}{\alpha}\right]\right\} \quad \text{for } \kappa \neq 0. \quad (9)$$

For shape parameter $\kappa = 0$ the Gumbel distribution is obtained. The general shape of this formula is similar to the Gumbel distribution for $|\kappa| = 0.3$. The difference being that the right-hand tail is thicker for $\kappa < 0$ and thinner for $\kappa > 0.3$. Here ξ is a location parameter and α is a scale parameter.

With the use of the method of probability weighted moments (Arthur Greenwood et al. 1979) the shape, location and scale parameters of a time series can be estimated. PWM estimations are virtually unbiased parameter estimates with the added advantage of linearity and simplicity. Given a record of n annual maxima the PWMs based on the ordered sample $Q_1 < Q_2 < \cdots < Q_n$ are:

$$PWM_r = \sum_{j=1}^{n} \frac{\big((j-1)\,(j-2)\ldots(j-r)\big)Q_j}{n(n-1)\ldots(n-r)} \text{ for } r > 0. \quad (10)$$

The estimator for PWM_0 is the mean annual flood. For the GEV distribution the first three PWMs are algebraically related to the GEV parameters (Hosking et al., 1985):

$$\kappa = 7.8590c + 2.9554c^2, \qquad (11)$$

$$\text{where } c = \frac{(2PWM_1 - PWM_0)}{3PWM_2 - PWM_0} - \frac{\ln(2)}{\ln(3)}, \qquad (12)$$

$$\alpha = \frac{(2PWM_1 - PWM_0)\kappa}{\Gamma(1+\kappa)(1-2^{-\kappa})}, \qquad (13)$$

$$\xi = PWM_0 + \frac{\alpha(\Gamma(1+\kappa)-1)}{\kappa}, \qquad (14)$$

and $\Gamma(1+\kappa)$ is the Gamma function.

Comparison of the statistic Z (equation 15) with standard normal quantiles can be used to fit a GEV distribution. The standard normal quantile corresponding to a p-value of 0.975 is 1.96 and thus for values where $|Z| = 1.96$ the GEV type I distribution can be assumed. For $Z < -1.96$ GEV type II is a better fit and for $Z > 1.96$ GEV type III (Hosking et al., 1985). Once the distribution of the catchment is identified this distribution can be used to estimate the probabilities and magnitude of flood events.

$$Z = \hat{\kappa}\sqrt{\frac{n}{0.5633}}. \quad (15)$$

4.3. Investigating spatial patterns

To further analyse the results the spatial distribution of the previous result will be taken into account. Due to New Zealand's vast differences in geology, topography and climate, errors can be clustered, spread out or might be more common in certain areas. A way to investigate the possibility of this happening is to use GIS to visualise the statistics from the previous research question on maps.

The performance estimators and results of the statistical tests are linked to polygons representing the shape, area and location of the catchment. After linking the data to the polygons the data is categorised by error class and shown on maps. Doing this gives a good indication of the spatial distribution of error. A spatial analysis with the use of GIS software however is not possible because the polygons used contain several overlapping areas and have gaps between borders. This means possible spatial patterns have to be analysed by eye and cannot be quantified. The variables that will be laid out on maps are the error in mean annual flow, the results of the statistical test of section 4.1, the GEV distribution types for both TopNet and the observations.

Secondly, the difference between the northern and southern islands will also be looked at. This will be done for both the TopNet error and GEV distributions. The fractions of catchments belonging to certain error classes and distribution types will be evaluated.

4.4. Explanation of model fit

To identify potential weaknesses in TopNet the relative error in mean annual flow (equation x) will be related to spatial variables. These spatial variables include catchment characteristics like area, length and slope but also what fraction of the catchment containing various geological properties, vegetation types, mean plant-soil properties, soil textures and hydrogeological indices. For a table containing all variables see and explanation see section 3.5. and Appendix A.

To find correlations between TopNet performance and these catchment characteristics a statistical measure is needed. This measure can be used to determine which sets of data are correlated and the strength of this correlation. The measure chosen is Spearman's rank order correlation coefficient. This is a nonparametric test which means that there are no assumptions made for the distribution of the datasets. Spearman's rank order correlation coefficient ρ_S for data which includes ties is calculated by the following equation:

$$\rho_S = \frac{1 - \frac{6}{n(n^2-1)} \sum_i D_i^2 - \frac{1}{2}\left(T_x + T_y\right)}{\sqrt{(1-T_x)\left(1-T_y\right)}}, \qquad (16)$$

$$\text{where } T = \frac{1}{n(n^2-1)} \sum_k t_k\left(t_k^2 - 1\right), \qquad (17)$$

$$D_i = r_x - r_y\,. \quad (18)$$

For tied ranks the means are taken and D_i, the difference in ranks is calculated. T is calculated for both sets and t_k being the number of tied pairs. Using the t-distribution a p-value for this coefficient can be looked up. Coefficients will be calculated for both the whole island and each island on its own. The results will be ranked according to category and correlation strength. This list should form a good basis for calibrating TopNet and to form a better understanding of the model. Because of the use of ranks ρ_S is not affected by outliers or nonlinear functions. It has to be noted however that Spearman's rank correlation coefficient can only assess monotonic functions so data has to be altered accordingly.

Secondly the dates of the flood events will be taken into account. The difference in dates at which the maximum flows occur in TopNet and in the observations will be calculated and correlated to the error in flow. To further investigate the TopNet maxima for each reach within a 30-day timeframe of the real event are extracted. These differences in results will be evaluated.

4.5. Comparison with other models

To identify whether or not TopNet is a useful tool for estimating mean annual floods in New Zealand its performance has to be compared against other models. The model that is currently being used for design in New Zealand is the model by McKerchar and Pearson (1989). A revised model is currently being developed by NIWA. These two models however do not produce a time series but rather just a value for mean annual floods. The relative bias, RMSRE and RMSWRE (equations 6-8) will be the main comparison measures.

5. Results

This section will discuss the results of the analysis described in the methodology. Firstly, the focus will lay on the annual maxima of TopNet. Secondly the mean maximum floods modelled by TopNet will be evaluated for matching records and all available records. The section will continue by comparing the mean, variance and distributions of the results followed by fitting of Generalised Extreme Value distribution types. This is followed up by analysing the spatial organisation of the previously calculated statistics. Next parameters that might explain model fit will be identified. Lastly the models performance is compared to the empiric models.

5.1. Annual maxima

At first, all comparable annual records will be taken into account. The annual maximum TopNet flows are plotted against the observations (Figure 3). There is a general correspondence between modelled and observed floods. TopNet underestimates the annual maxima for 73.5% of the cases. Some outliers are clearly visible in the low flows. The negative value of -57% for the relative bias (Equation 6) might suggest an overestimation of results but this value is subject to cancelation of errors. Therefore, a better measure to look at is the Root Mean Square Relative Error (Equation 7). The value of 1630% indicates that the error in the results is significant.

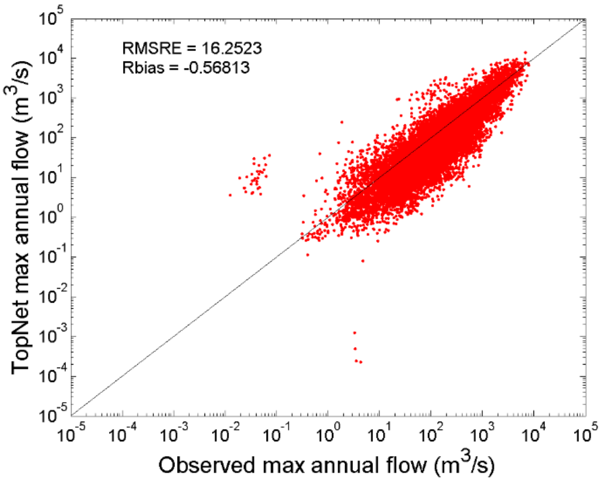


Figure 3 Observed maximum annual flow vs TopNet max annual flow

5.2. Mean annual flood prediction

The goal of this thesis is however to see if the model is suitable to estimate mean annual floods (equation 4). Figure 4 and 5 show the TopNet and observed means in scatterplots, figure 4 plots only the matching records while figure 5 takes the mean of the full time series at each site. When using the means, the results are closer to the 1:1-line and the spread seen using all annual maxima per site (figure 3) is greatly reduced. These visual observations are backed up by the relatively low values for Rbias and RMSRE being 20% and 86% for the matching records and 19% and 87% for the full record lengths, respectively.

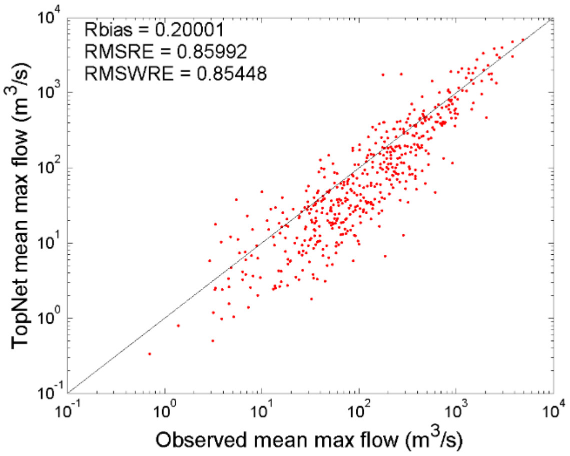


Figure 4 Observed mean max flow vs TopNet mean max flow using only matching records

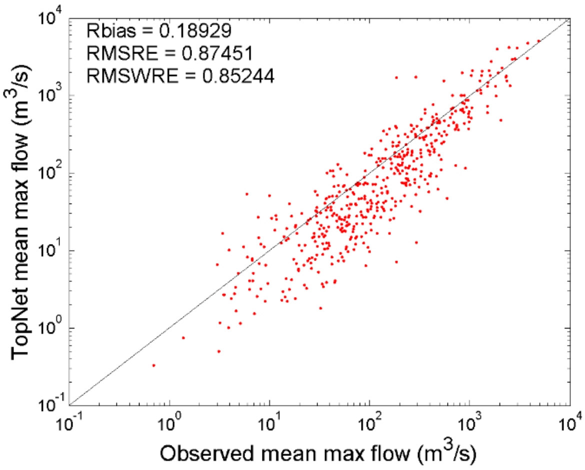


Figure 5 Observed mean max flow vs TopNet mean max flow using full record lengths

The relative error per site calculated (Equation 5) and summarised in Table 1. The underestimation of mean flows is clearly visible. Only a small difference between matching records and full record lengths is visible.

Table 1 Relative error in mean max flow

Error	Matching records	Full record lengths
>100%	28	30
75% - 100%	9	5
50% - 75%	15	16
25% - 50%	18	23
0% - 25%	48	53
-25% - 0%	80	73
-25% - -50%	92	88
-50% - -75%	116	122
-75% - -100%	79	75

5.3. Statistical comparison of mean, variance and distribution

To follow up these results the higher order statistics were taken into account too. These are also used indicate the usability of the model. The means, variances and distributions of the TopNet results were compared to the observations. This was done using Wilcoxson's Signed Rank test, Levene's test and the two-sided Kolmogorov-Smirnov test. The results of these tests can be found in table 2. These tests cannot be performed on datasets of different lengths so only the matching records have been taken into account. This table shows 79% of the results pass Wilcoxon's signed rank test which indicates the means of these datasets have a different ranking. This result is in line with the large relative errors in the TopNet results. The results of Levene's test show that 45.7% of all sites have the same variance. Lastly the Kolmogorov Smirnov test points out that for 74.3% of all sites TopNet models max annual flows that have the same distribution as the observed flows.

Table 2 Summary of results Wilcoxson's Signed Rank test, Levene's Test and the two-sided Kolmogorov Smirnov test for TopNet vs Observations

Amount of cases	**Wilcoxon's Signed Rank test for Means**	**Levene's Test for Variance**	**Kolmogorov-Smirnov Test for Distribution**	**All tests combined**
Statistically the same	101	214	360	3
Statistically different	384	271	125	483

Using the Z statistic (equation 15) the GEV distributions of the sites are determined and can be found in table 3. This table shows TopNet tends to predict more series belonging to the GEV II-distribution than the gauging data indicates. Using the whole 40 years of TopNet this behaviour is even clearer this can be seen in table 4.

Table 3 Summary of GEV distributions TopNet vs Observed for matching records

		TopNet matching records			
		GEV I	GEV II	GEV III	
Observed	GEV I	262	113	11	**386**
	GEV II	28	46	0	**74**
	GEV III	20	5	0	**25**
		310	**164**	**11**	**485**

Table 4 Summary of GEV distributions TopNet vs Observed for full record lengths

		TopNet full lengths			
		GEV I	GEV II	GEV III	
Observed	GEV I	225	154	1	**380**
	GEV II	28	49	0	**77**
	GEV III	22	6	0	**28**
		275	**209**	**1**	**485**

5.4. Spatial patterns in relative error

Figure 6 shows a map of the errors in the mean maximum flow TopNet produces. The map shows that the areas where TopNet underestimates the data (blue areas) are spread out evenly across of the entire country. It can be seen that on the eastern part of the north island there is a small cluster of regions where TopNet overestimates the flows. Upon closer inspection and not taking area into account however this pattern vanishes. The volcanic plateau just south of the middle on the northern island the flows are underestimated. These maps have also been viewed by multiple hydrologist at NIWA who are experienced in working with the New Zealand geography. This points out the distribution of the error might be random.

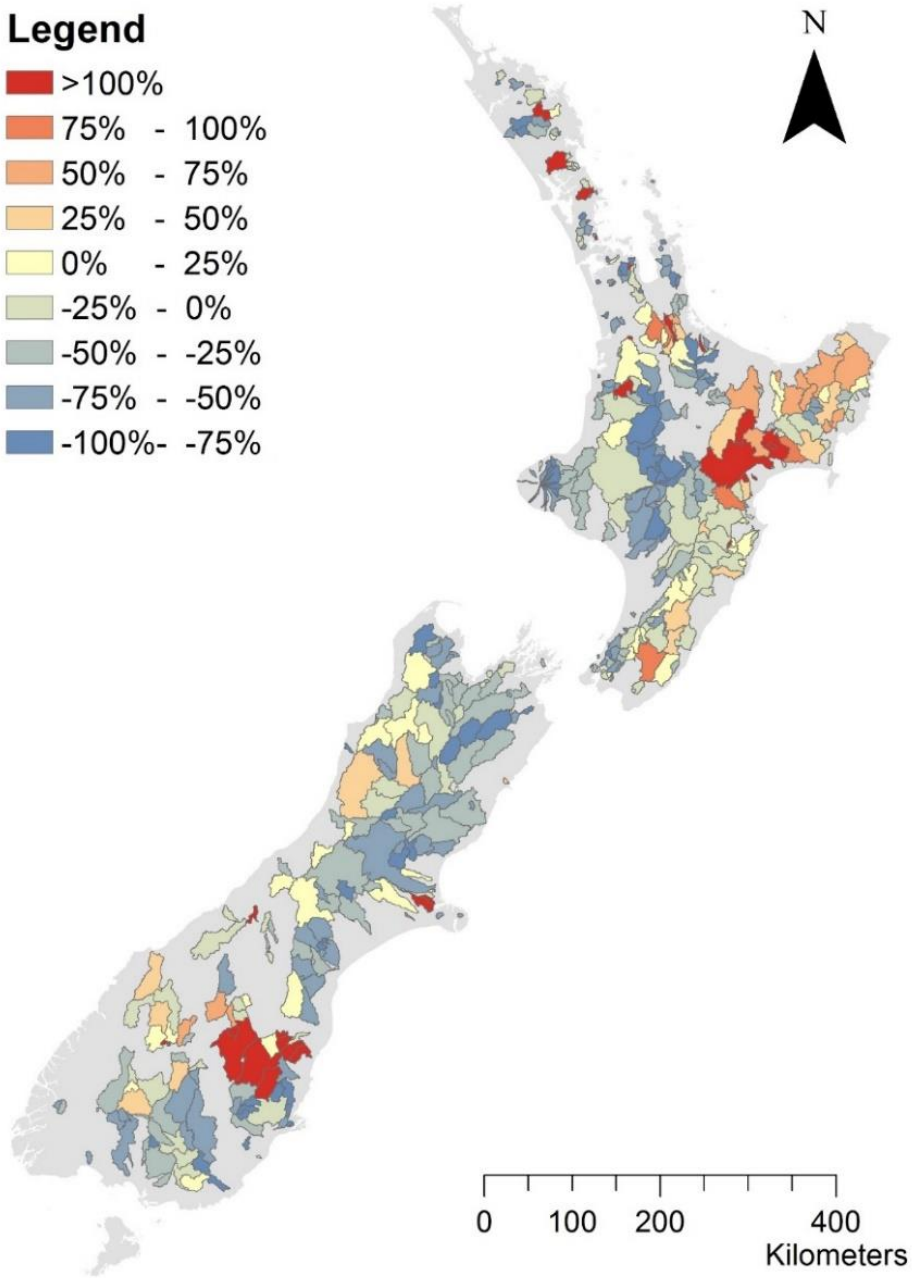


Figure 6 Map of relative error in TopNet using matching records

To reinforce the observations made by looking at the map the mean errors split by island and displayed in Table 5. As seen in this table the spread in error ranges of the northern and southern islands is similar. This stands true for both matching records and full record lengths.

Table 5 TopNet error in mean max flow by Island

	Southern Island		Northern Island	
TopNet error	**Matching records**	**Full lengths**	**Matching Records**	**Full lengths**
>100%	7%	8%	5%	5%
75% - 100%	1%	1%	3%	1%
50% - 75%	2%	2%	4%	4%
25% - 50%	4%	3%	4%	6%
0% - 25%	10%	12%	10%	10%
-25% - 0%	15%	15%	17%	15%
-25% - -50%	23%	22%	16%	15%
-50% - -75%	24%	25%	24%	25%
-75% - -100%	14%	13%	18%	17%

5.5. Spatial patterns in results statistical tests

The results of the statistical tests have also been laid out on maps (figure 7). Spatial patterns are hardly visible in these maps. It can however be noted that areas where the relative error is high the means do not pass Wilcoxon's Signed Rank test. Furthermore, table 6 shows the percentages of catchments that pass tests or not. This table also shows little difference between islands. These results were to be expected because the no patterns in relative error were found either.

Table 6 Results of statistical tests by Island

Amount of cases	**Wilcoxon's Signed Rank test for Means**	**Levene's Test for Variance**	**Kolmogorov-Smirnov Test for Distribution**	**All tests combined**
North Island				
Statistically the same	21%	42%	73%	1%
Statistically different	79%	58%	27%	99%
South Island				
Statistically the same	21%	47%	76%	1%
Statistically different	79%	53%	24%	99%

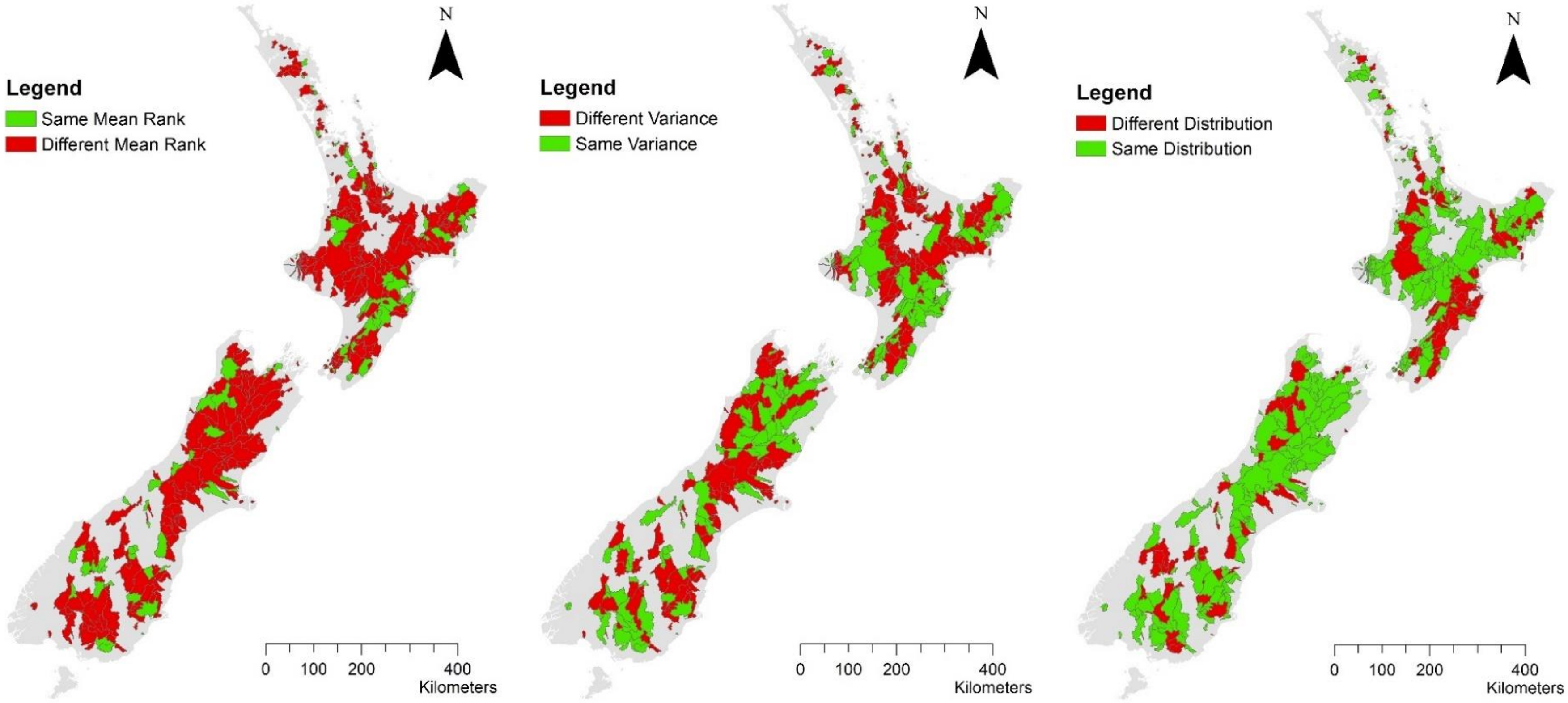


Figure 7 Maps of the results of the statistical tests

5.6. Spatial Patterns in Extreme Value distributions

Next the spatial distributions of the GEV types (section 4.2.) for the full record length is laid out on maps to look at these regions. These maps can be found in figure 8. For the maps using only the matching records see appendix B. As shown before TopNet generates values which distribution can be described by the GEV type II distribution. Unlike the errors in flow however patterns in GEV types seem to be present. Regions where the distribution fit to the GEV Type II distribution are mostly located on the eastern sides of both Islands and seem to be more frequent in the South Island. The percentages of this occurring can be found in table 7. The observations also point out that catchments in the south eastern regions of the South Island have maximum flows fit to GEV type II. GEV type III catchments are few and far between in the observations and even fewer in TopNet. There are too few catchments to see a pattern occurring.

Table 7 GEV distribution types

	Observations		TopNet Match		TopNet full	
	NI	SI	NI	SI	NI	SI
GEV I	80,1%	75,7%	65.0%	62.4%	49.7%	60.9%
GEV II	13,1%	20,1%	32.3%	36.0%	50.3%	38.7%
GEV III	6,7%	4,2%	2.7%	1.6%	0%	0.3%

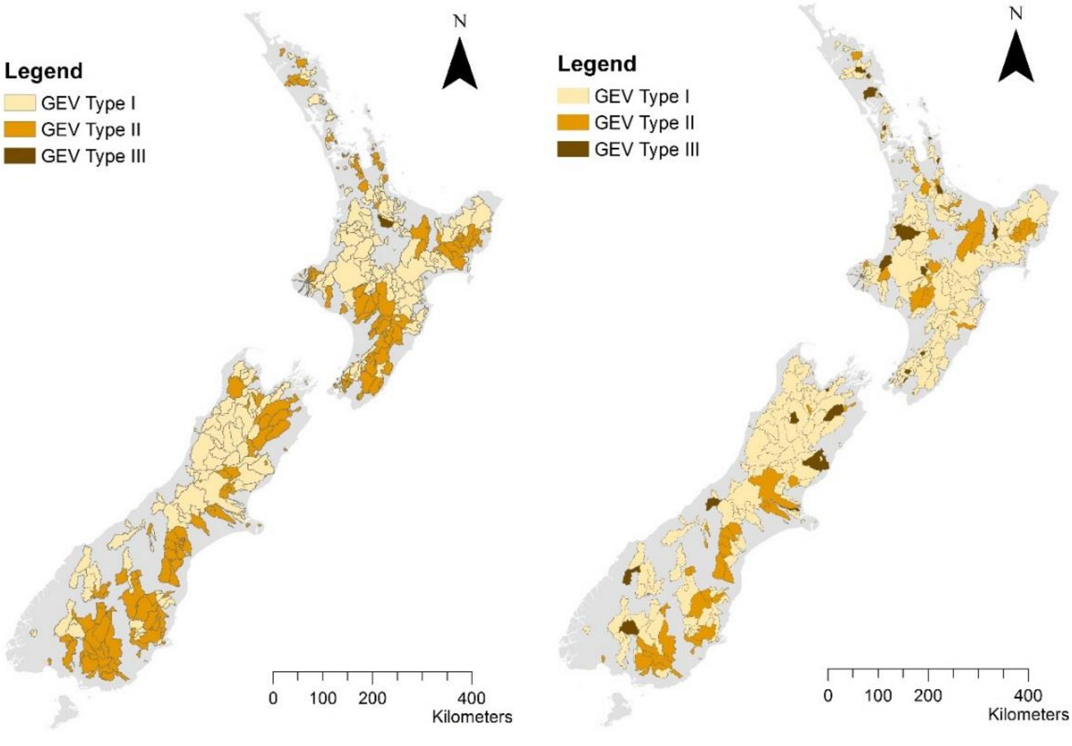


Figure 8 Maps of GEV distribution types for TopNet (left) and Observations (right) using full record lengths

5.7. Model fit correlations

To find patterns in model fit of TopNet spearman's correlation coefficient (equation 16) is calculated for relative error (equation 5) to catchment characteristics (section 3.5.). The correlation coefficients are ranked according to the absolute value of ρ_S. The top five correlations are shown in table x. The five highest correlated catchments characteristics are channel slope, channel length, catchment area. All other coefficients are grouped by type and can be found in Appendix C. The three characteristics that have strongest correlations to the error are characteristics that are essential for most hydrological models and are thus not surprising. The other two characteristics High fractions of surficial rock and large bodies of water also have a big influence in flow rate of rivers.

Table 8 Top 5 strongest Spearman correlations

Catchment characteristics	Spearman's rho	p-value
Channel slope	-0.344	5.76E-15
Channel length	0.271	1.21E-9
Catchment Area	0.268	2E-09
Water Land Cover	0.252	1.87E-08
Surficial rocks	0.215	1.69E-06

5.8. Offset in time

To further investigate the results, the dates of these high flow events will be looked at. This information can indicate whether or not TopNet models the same flood event as the observations. In Figure 9 a histogram of the time difference between the maximum flood events in days. In 47.8% of the cases TopNet predicts the flood with a maximum offset of 10 days in 37.3% of the cases TopNet has an offset of only 1 day or less.

To see if the absolute difference in date is correlated to the error in flow these values were plotted and Spearman's correlation coefficient was calculated. With a ρ_S of -0.185 and a p-value of $3.93*10^{-5}$ there is a weak correlation between the difference in date and the error.

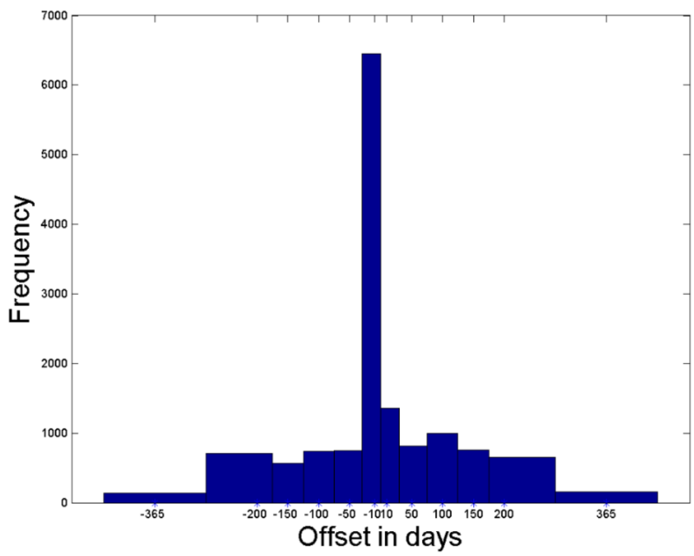


Figure 9 Histogram offset in days of maximum flow event

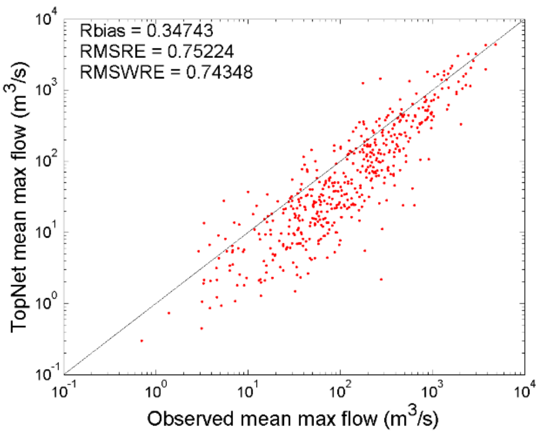
The TopNet maxima within 30 days of the real event were extracted from the results to see whether or not these values were significantly different. Because the time frames in which the maxima can be found are limited, the maxima extracted will either be lower or equal to the previous results. This is backed up by the error shown in table 9 and figure 10 and as expected the relative bias is lower for these results. The effects on the RMSRE and RMSWRE however are less predictable by a shift in maxima. These values (table 10) are both significantly smaller than the regular TopNet results. This might suggest that the rainfall input of TopNet is wrong but can also be caused by other faults in TopNet.

Table 9 Relative error in TopNet for matching records and matching records extracted in a 30-day timeframe

Error	TopNet	TopNet 30 day frame
>100%	29	16
75% - 100%	9	10
50% - 75%	15	11
25% - 50%	18	18
0% - 25%	48	28
-25% - 0%	80	65
-25% - -50%	92	87
-50% - -75%	116	132
-75% - -100%	79	119

Table 10 Comparison parameters for TopNet for matching records and matching records extracted in a 30-day timeframe

	TopNet		TopNet 30-days timeframe	
	Matching records	Full Length	Matching records	Full Length
Rbias	0.2000	0.1893	0.3474	0.5294
RMSRE	0.8599	0.8745	0.7522	0.7401
RMSWRE	0.8545	0.8524	0.7435	0.7299



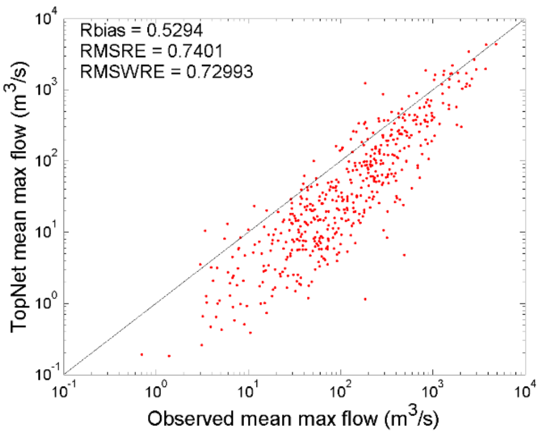


Figure 10 Observed mean maximum annual flood vs TopNet for matching records (left) and full record lengths (right) extracted in a 30-day timeframe

5.9. Comparison

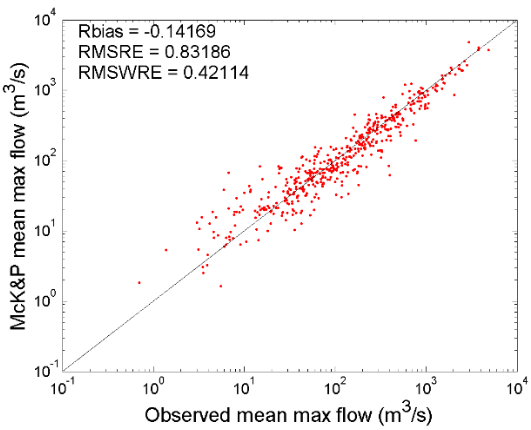
For comparing the model to the ones currently in use and its improved version a good understanding of the model is needed, see chapter 3 for a description of the models. The mean annuals errors of both other models are calculated for all sites. A summary of the results in table 11. It can be seen that the McKerchar and Pearson (1989) model has most of its annuals within a -25% to 25% error margin where the TopNet results are mostly in the -25% to -75% margin. The values for the improved model also tend to underestimate the flows. It has to be taken into account however that error correction will be applied to the revised model but was not yet available in time for this research.

Table 11 Summary of Relative Errors in models

Error	TopNet all	McKP	"Improved" McKP
>100%	30	40	67
75% - 100%	5	17	20
50% - 75%	16	17	28
25% - 50%	23	42	34
0% - 25%	53	101	77
-25% - 0%	73	145	95
-25% - -50%	88	81	97
-50% - -75%	122	38	64
-75% - -100%	75	4	4

Looking at the scatter plots of these models in figure 11 in comparison to figure 4 and 5, it can be seen that the spread of results is substantially larger within TopNet. McKerchar & Pearson's model does a better job but there are several large outliers. The improved version of McKerchar & Pearson has a bigger spread but doesn't have the big outliers, this can of course be expected of a model that has been calibrated using longer record lengths. Table 12 gives the relative bias, RMSRE and RMSWRE (equation 6-8). It is shown by the RMSRE and RMSWRE that TopNet is a worse estimator than the improved model.

The RMSWRE of the McKerchar & Pearson however is not a good parameter for model comparison as it was based on less sites this causes the geometric mean to be 0 for these sites and the error will be ignored in the calculation.



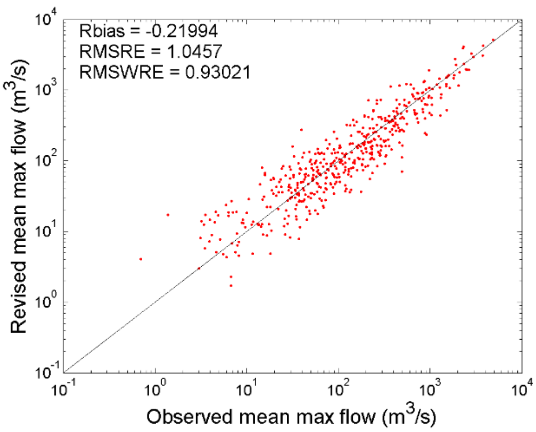


Figure 11 Observed mean maximum flow vs McKerchar and Pearson mean maximum flow (left) and Revised mean maximum flow (right)

Table 12 Summary of of comparison parameters

	TopNet matching records	TopNet full length	McKP	Improved McKP
Rbias	0.2000	0.1893	-0.1417	-0.2199
RMSRE	0.8599	0.8745	0.8319	1.0457
RMSWRE	0.8545	0.8524	0.4211	0.9302

Looking at the map of the McKerchar and Pearson model (figure 12) spatial patterns are not recognizable overestimations of mean flows seem to occur spread around both islands but on different places than they do in the TopNet results. The revised model has clustering of error and this is mostly on the North Island.

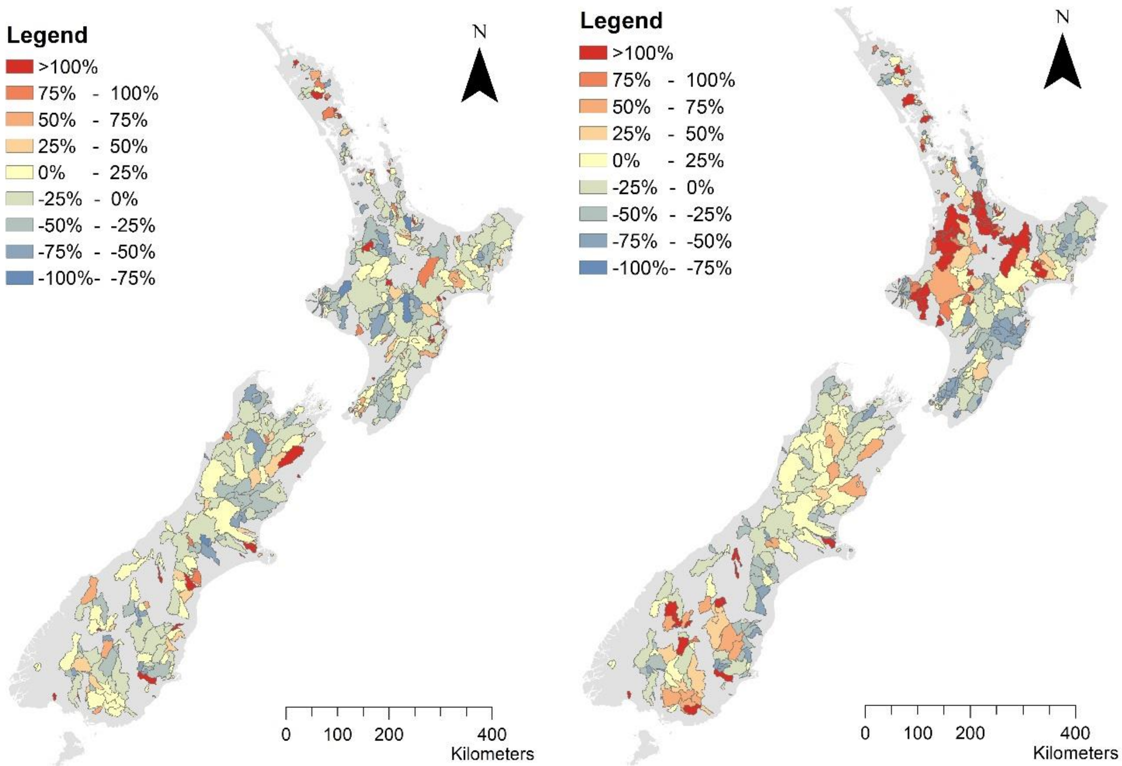


Figure 12 Maps of relative error in McKerchar and Pearson (left) and revised (right)

6. Discussion

The uncalibrated national hydrological model TopNet is able to predict the mean annual flood but suffers from quite large errors, both positive and negative. The relative bias (equation 6) and Root Mean Square Relative Error (equation 7) being 20% and 86% for the matching records and 19% and 87% for the full record lengths, respectively. The error in TopNet for the full record length is a bit higher this however is to be expected when flood events outside of the simulated years are taken into account. Statistical tests show that only 21% of the means are the same rank of the observations, 44% of the flood records have the same variance and 74% of the sites are from the same distribution. Only 3 sites however pass all these tests. This means that the TopNet model in its current state is not a good estimator for mean annual flood.

To extrapolation these mean floods for use in water works the Generalised Extreme Value Distribution is used. The records statistically fitted to Type I, II or III. This process has been performed on the TopNet results as well as the observed data. For 64% of the sites in TopNet fit to the same GEV type when the matching records are taken into account. This percentage goes down to 56% when the full length of records of both the observations and TopNet are taken into account. This is likely caused by the occurrence of observed extreme flood events outside TopNet's scope of 40 years.

To further understand the results, the results were laid out on maps and analysed. Spatial patterns in the model behaviour are hardly present in the data this can clearly be seen on maps. Neighbouring catchments can have vastly different errors. There is also no distinction between the north and South Island, the spread in relative error is the same on both islands. A difference in fit for both island was expected due to the differences in geology. The Northern Island has had more modelling issues in other projects. Mapping the results of Wilcoxon's signed rank (fig 7) test has a similar pattern to the map with relative error this is to be expected because means with big errors rarely have the same rank. Patterns in the results of Levene's test and the two-sided Kolomogorov-Sminrov test are not found. A pattern in GEV distributions however is clear, a higher percentage of catchments on the South Island fit to the GEV type II distribution than on the North Island. Most of these catchments are in on the eastern side of the island in the regions Canterbury, Otago and Southland. This pattern is also shown by in the TopNet results although there are more catchments fitting to GEV type II and the area they cover is larger and spreads more towards the north.

To get a further understanding of the results, the errors in TopNet are correlated to spatial variables of the catchments. With the help of Spearman's correlation coefficient, ρ_S (equation 16), it is shown that the errors have a moderate correlation with the catchments channel slope, channel length and area. The values for ρ_S of these variables are -0.344, 0.271 and 0.268. Meaning steeper slopes correlate to smaller errors and longer rivers and bigger areas correlate to bigger errors. These are standard model parameters in all runoff models and are expected to be a cause of errors especially in an uncalibrated model. The error also correlates to the percentage of land that is covered by surface water and surficial rocks with values of ρ_S being 0.252 and 0.215 respectively. Most of the geological properties have high correlations to the error. Where soil texture and storm characteristics do not seem to have big correlations to the error at all.

Having looked at the spatial parameters the timing aspect will also be taken into account. The annual maxima modelled in TopNet only lines up with the date of the real event in 47.8% of all cases. This can be caused either by errors in TopNet or the rainfall input. The offset in date of flood events has no strong Spearman correlation to the error neither does it have a strong correlation to any of the spatial variables. Using the dates of the real events and extracting TopNet maxima within a 30-day timeframe does improve the relative bias, RMSRE and RMSWRE (equations 6-8) by about 10% this however is of no great significance as there are less errors over 100% which influence these parameters.

To put TopNets results into perspective simulations have been compared to the empirical model designed by McKerchar and Pearson (1989) and the revised empirical model. The RMSRE of this model has been recalculated including the newly obtained gauging records. The TopNet RMSRE is comparable to the McKerchar and Pearson model. TopNet does however gives significantly lower means for a lot of catchments. The RMSWRE is significantly lower for McKerchar and Pearson but this is mainly due to the fact sites which were not included in their own research have been excluded as the geometric mean for record length is 0 at these sites.

The revised model has a higher RMSRE compared to TopNet meaning its results are more spread out, in this case this applies to both positive and negative errors in flood. The results from the revised version however are not final and will improve by the use of error-correcting contours. In the current state of both models the TopNet results underestimate the floods but have a smaller spread. It should also be noted that spatial patterns of model fit are clear in the revised model results. The North Island has a worse fit compared to the South Island.

7. Conclusions

To conclude this thesis, the research questions will be answered.

1. How well do the TopNet results match the observed mean annual flood data?

TopNet simulations have a general correspondence with the observed mean annual floods. They do however generally underestimate the observations and have a big spread. And the mean ranks, variance and distributions of these simulated values do not match the observations well.

2. Which extreme value distribution can be fitted to the observations and TopNet results?

The distribution of the TopNet results do generally fit to the same general extreme value distribution type as the observations do. The TopNet results however fit to the GEV type II more often than the observation data.

3. Are there any differences or spatial organisation in the goodness of fit between regions?

No spatial organisation in the goodness of fit in the TopNet results has been found. Neither was a difference in goodness of fit between islands. The GEV distributions types however do have a spatial pattern. TopNet results with GEV type II distributions occur mostly on the eastern side of both islands and are more prevalent on the South Island.

4. What parameters may explain patterns of model fit?

Parameters that may explain model fit are channel slope, channel length, catchment area, the fraction of the catchment covered by water and fraction covered by surficial rocks. These variables have the strongest correlations to the error in mean flood. When improving the TopNet model these parameters and their effect on the results should be looked into. TopNet does show a significant increase in performance when extracting maxima within 30 days of the observed peak. This indicates that the timing in the model or the rainfall input is wrong.

5. How well does TopNet perform compared to performance of the 1989 empiric model and its recently improved version?

TopNet is a worse fit to the observations than the model by McKerchar and Pearson (1989). TopNet has a bigger error due to under prediction of floods. The results are better than the revised version due to less spread in the results.

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Appendix A Catchment characteristics

This section describes the catchment characteristics of section 3.5. Catchment characteristics and spatial variables.

The general characteristics include:

- Catchment area;
- Channel length;
- Channel slope;
- Channel distance to coast;
- Centroid northing;
- Centroid easting;
- Catchment elevation;

The climate characteristics from the Freshwater Ecosystems geo-database (FENZ) (Department of Conservation, 2016) include:

- Mean annual precipitation;
- Mean annual temperature;
- Mean annual evaporation;

Storm characteristics per catchment include:

- Storm intensity and depth variables for x-minute storms with a return period of 2 or 5 years;
- Storm depth of a time of concentration (toc) storm.

Ecological characteristics and fractions of catchment containing:

- Plant rooting depth;
- Plant water availability;
- Shallow macroporosity;
- Deep macroporosity.

Fractions of catchment containing geological rock types categorised in:

- Surficial rock;
- Weak sedimentary rock;
- Strong sedimentary rock;
- Igneous rock;
- Metamorphic;
- Other.

Fraction of catchment containing vegetation categorised in:

- Unvegetated;
- Water land cover;
- Artificial land cover;
- Marsh;
- Grass/crop;
- Shrub;
- Forest;
- Shrub and forest.

Fraction of catchment containing soil textures categorised in:

- Skeletal;
- Not soil;
- Loamy;
- Bedrock;
- Sandy;
- Clayey;
- Silty;
- Organic soil.

Hydrological indices per catchment derived from the Empirical Longitudinal Flow Model (Schmidt et al., 2009) categorised in:

- Hydroindex 0
- Hydroindex 1-3
- Hydroindex 4-5
- Hydroindex 6-8

Appendix B GEV distribution maps using full record lengths

This section includes the maps of the fitted GEV distributions using the full record lengths for both the observations and TopNet.

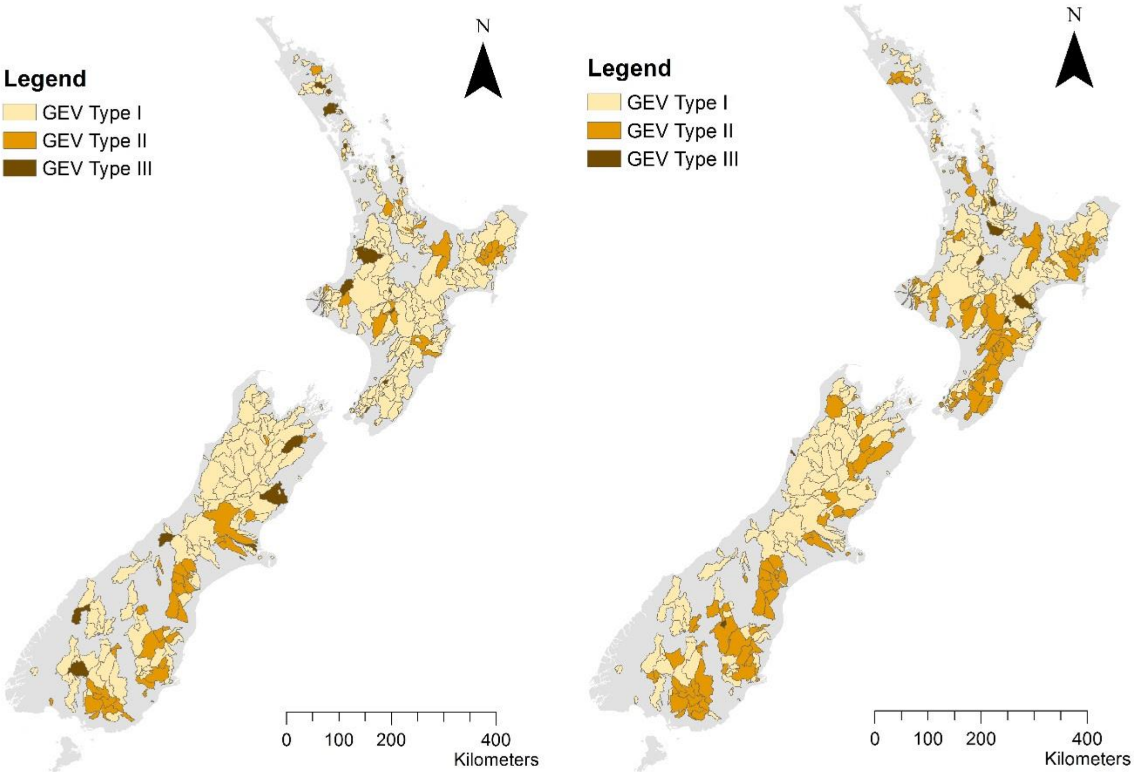

Figure 13 GEV distributions for Observation (left) and TopNet (right) using full record lengths

Appendix C Rank correlations with catchment characteristics

This table gives the Spearman's rank correlation coefficient (equation 16) for mean annual flood error (equation 5) and catchment characteristics and spatial variables. These values are organised by category and ranked by their absolute ρ_S, p-values greater than 0.05 have been marked red.

Table 13 Spearman's rho for catchment characteristics and spatial variables split by whole country North Island and South Island

	Whole Country		North Island		South Island	
	ρ_S	p-value	ρ_S	p-value	ρ_S	p-value
Catchment characteristics						
Area	0.268	2.00E-09	0.309	5.46E-08	0.193	7.66E-03
Channel length	0.271	1.21E-09	0.296	1.98E-07	0.207	4.35E-03
Channel slope	-0.344	5.76E-15	-0.457	1.05E-16	-0.129	7.79E-02
Channel distance to coast	0.064	1.57E-01	0.008	8.89E-01	0.159	2.86E-02
Centroid Easting	0.118	8.96E-03	0.379	1.37E-11	-0.150	3.97E-02
Centroid Northing	-0.043	3.48E-01	-0.067	2.47E-01	-0.029	6.92E-01
Catchment slope	0.069	1.27E-01	0.144	1.29E-02	-0.029	6.93E-01
Catchment elevation	-0.019	6.76E-01	-0.073	2.09E-01	0.107	1.42E-01
Annual precipitation	-0.118	9.02E-03	-0.221	1.20E-04	-0.083	2.59E-01
Freshwater Ecosystems geo database						
FENZ slope	0.071	1.18E-01	0.145	1.23E-02	-0.026	7.19E-01
FENZ precipitation	-0.098	3.12E-02	-0.217	1.67E-04	-0.025	7.31E-01
FENZ temperature	0.019	6.68E-01	0.060	3.04E-01	-0.122	9.47E-02
FENZ evaporation	0.014	7.61E-01	0.045	4.36E-01	0.012	8.68E-01
FENZ flow	0.219	1.08E-06	0.261	5.13E-06	0.160	2.74E-02
Storm characteristics						
Time of Concentration T-5 storm	-0.208	3.64E-06	-0.303	1.03E-07	-0.094	2.00E-01
Time of Concentration T-2 storm	-0.207	4.43E-06	-0.309	5.46E-08	-0.082	2.63E-01
Storm depth T-5 storm	0.190	2.59E-05	0.245	2.01E-05	0.141	5.31E-02
Storm depth T-2 storm	0.181	5.72E-05	0.228	7.15E-05	0.145	4.65E-02
Intensity 10 minute T-2 storm	-0.108	1.74E-02	-0.221	1.26E-04	-0.046	5.31E-01
Intensity 10 minute T-5 storm	-0.108	1.77E-02	-0.224	9.59E-05	-0.013	8.57E-01
Intensity 20 minute T-2 storm	-0.099	2.91E-02	-0.206	3.45E-04	-0.048	5.14E-01
Intensity 20 minute T-5 storm	-0.098	3.14E-02	-0.209	2.80E-04	-0.012	8.69E-01
Intensity 30 minute T-5 storm	-0.091	4.41E-02	-0.190	9.98E-04	-0.048	5.15E-01
Intensity 30 minute T-2 storm	-0.087	5.43E-02	-0.188	1.17E-03	-0.010	8.88E-01
Intensity 1 minute T-2 storm	-0.075	1.01E-01	-0.159	6.18E-03	-0.044	5.49E-01

Intensity 1 minute T-5 storm	-0.069	1.30E-01	-0.150	9.83E-03	-0.018	8.01E-01
Intensity 2 minute T-2 storm	-0.066	1.46E-01	-0.147	1.13E-02	-0.011	8.81E-01
Intensity 2 minute T-5 storm	-0.057	2.09E-01	-0.125	3.17E-02	-0.001	9.91E-01
Intensity 72 minute T-5 storm	0.032	4.81E-01	0.001	9.80E-01	0.073	3.18E-01
Intensity 48 minute T-5 storm	0.030	5.07E-01	-0.001	9.92E-01	0.070	3.38E-01
Intensity 72 minute T-2 storm	0.029	5.17E-01	-0.013	8.28E-01	0.079	2.82E-01
Intensity 48 minute T-2 storm	0.027	5.49E-01	-0.014	8.09E-01	0.075	3.07E-01
Intensity 6 minute T-2 storm	-0.025	5.78E-01	-0.086	1.40E-01	0.030	6.85E-01
Intensity 24 minute T-5 storm	0.022	6.22E-01	-0.006	9.12E-01	0.058	4.26E-01
Intensity 24 minute T-2 storm	0.020	6.63E-01	-0.023	6.90E-01	0.067	3.60E-01
Intensity 6 minute T-5 storm	-0.014	7.62E-01	-0.062	2.90E-01	0.031	6.72E-01
Intensity 12 minute T-5 storm	0.009	8.46E-01	-0.029	6.15E-01	0.045	5.41E-01
Intensity 12 minute T-2 storm	0.001	9.81E-01	-0.052	3.69E-01	0.049	4.99E-01
Fraction of catchment containing Geological Properties						
Surficial rocks	0.215	1.69E-06	0.246	1.86E-05	0.196	6.79E-03
Igneous	-0.174	1.18E-04	-0.302	1.07E-07	-0.016	8.29E-01
Weak sedimentary	0.165	2.64E-04	0.256	7.81E-06	-0.028	6.98E-01
Other (rocks)	0.159	4.40E-04	0.150	9.52E-03	0.198	6.26E-03
Metamorphic	0.097	3.34E-02	N/A	N/A	0.201	5.65E-03
Strong sedimentary	0.069	1.31E-01	0.252	1.12E-05	-0.262	2.74E-04
Fraction of catchment containing Vegetation Type						
Water LCDB	0.252	1.87E-08	0.230	6.12E-05	0.296	3.64E-05
Shrub+forest	-0.150	9.43E-04	-0.105	7.11E-02	-0.209	3.82E-03
Grass/crop	0.126	5.27E-03	0.121	3.72E-02	0.126	8.48E-02
Forest	-0.117	9.77E-03	-0.096	9.74E-02	-0.156	3.23E-02
Unvegetated	0.110	1.48E-02	0.084	1.48E-01	0.205	4.61E-03
Shrub	-0.101	2.61E-02	0.013	8.19E-01	-0.342	1.51E-06
Marsh	0.047	3.05E-01	0.057	3.25E-01	0.030	6.86E-01
Artificial LCDB	0.043	3.44E-01	0.006	9.17E-01	0.118	1.05E-01
Mean catchment soil properties						
Plant available water	-0.164	2.73E-04	-0.234	4.50E-05	-0.110	1.31E-01
Plant rooting depth	-0.075	1.00E-01	-0.131	2.41E-02	0.014	8.51E-01
Shallow macroporosity	-0.058	2.00E-01	-0.068	2.44E-01	-0.062	4.00E-01
Deep macroporosity	0.008	8.59E-01	0.016	7.86E-01	0.005	9.40E-01
Fraction of catchment containing soil texture category						
Skeletal	0.169	1.87E-04	0.186	1.28E-03	0.138	5.83E-02

Not soil	0.151	8.52E-04	0.135	2.03E-02	0.193	7.81E-03
Loamy	-0.082	6.98E-02	-0.180	1.88E-03	0.133	6.71E-02
Bedrock	0.073	1.09E-01	-0.001	9.85E-01	0.175	1.57E-02
Sandy	0.056	2.18E-01	0.013	8.19E-01	0.144	4.76E-02
Clayey	-0.043	3.43E-01	0.013	8.22E-01	-0.180	1.33E-02
Silty	0.034	4.50E-01	0.086	1.38E-01	-0.120	9.97E-02
Organic soil	0.026	5.72E-01	0.001	9.84E-01	0.066	3.67E-01
Fraction of catchment with Hydrogeological indices						
HydroIndex 4-5	0.155	5.85E-04	0.216	1.74E-04	0.042	5.62E-01
HydroIndex 0	0.126	5.30E-03	0.088	1.29E-01	0.205	4.57E-03
HydroIndex 1-3	-0.081	7.30E-02	0.011	8.47E-01	-0.299	2.87E-05
HydroIndex 6-8	0.022	6.35E-01	-0.149	1.03E-02	0.351	7.35E-07