Rainfall erosivity in New Zealand

Master Thesis

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Abstract

"The threat of nuclear weapons and man's ability to destroy the environment are really alarming. And yet there are other almost imperceptible changes - I am thinking of the exhaustion of our natural resources, and especially of soil erosion - and these are perhaps more dangerous still, because once we begin to feel their repercussions it will be too late."

(p.144 of The Dalai Lama's Little Book of Inner Peace: 2002, Element Books, London)

In a country, where rainfall can reach dimensions up to 10000 mm/year, water erosion is a very important task. Also climate change may lead to changes in rainfall characteristics and is therefore a major concern to soil conservation. This study aims to evaluate the spatial distribution of rainfall erosivity over the last decade(s) and to produce a map of average annual rainfall erosivity for New Zealand.

Rainfall erosivity is reviewed almost all over the world, but only a few scientists have used the (Revised) Universal Soil Loss equation (RUSLE) to evaluate the state of the art in New Zealand. It is very well known, that the R-factor is one of the major key elements within this equation. Among the major factors controlling soil erosion, rainfall erosivity has a major importance since its difficulty of prediction and control by humans. Accurate estimations of rainfall erosivity require continuous rainfall data, however, such data rarely demonstrates a good spatial and temporal distribution. Due to its multifaceted landscape and the influence of the Tasman Sea as well as the Pacific Ocean, it is not possible to identify one generally valid R-factor for the whole country or even for the North or South Island. Therefore, to evaluate R-factor values for New Zealand, gauging stations with a good spatial distribution all over the country were chosen. The main aspect of this thesis is to determine R-factor values for its different climatic regions within the country, in order to create a rainfall erosivity map. Therefore, the relationship, R = aPb between the annual precipitation (mm) and the annual rainfall erosivity rate (MJ.mm.ha-1.h-1) has been determined. With this relation, the empirical parameters a and b could be identified by transforming the linear equation into a power equation. With this attempt, the erosivity rate for gauging all over New Zealand could be roughly estimated. An important point in this study was, that the empirical parameters were edited for different climatic regions within the country and not for the whole country or one Major Island.

Even though the parameters were adapted, a 100% accurate reflectance is almost impossible with this amount of data. Next to the 29 analysed stations, the mean annual rainfall from 218 stations was calculated and the annual erosivity rate predicted. With the analysed data, an annual rainfall and an annual rainfall erosivity map was created in GIS, to compare the spatial distribution of the annual rainfall depth and the annual rainfall erosivity.

Zusammenfassung

In einem Land wo Niederschlag Dimensionen bis zu 10000 mm/Jahr erreichen kann, ist die Wassererosion ein sehr wichtiges Thema. Auch der Klimawandel kann zu einer Veränderung in der Niederschlagscharakteristik führen. Dies führt dazu, dass die Wassererosion einer der wichtigsten Themenpunkte im Bereich des Bodenschutzes ist. Das Ziel dieser Arbeit ist die räumliche Verteilung der Regenerosion zu evaluieren und eine Regenerosionskarte für Neuseeland zu erzeugen.

Regenersosion wurde bereits überall auf der Welt untersucht, jedoch haben bisher nur einige wenige Forscher die Revised Universal Soil Loss Equation (RUSLE) benutzt um den heutigen Stand der Dinge in Neuseeland zu untersuchen. Der sogenannte R-Faktor ist einer der Schlüsselelemente in der obig genannten Gleichung. Eine akkurate Vorhersage der Regenerosion benötigt sogennante "high resolution data" , wobei auch diese große Datenmenge nur einen geringen Überblick über die zeitliche und räumliche Verteilung des Niederschlages gibt. Wegen der sehr abwechslungsreichen Landschaft Neuseelands, sowie der Einflüsse der Tasmanischen See als auch des Pazifischen Ozeans ist es nicht möglich einen allgemein gültigen R-Faktor für das ganze Land anzugeben. Um eine genaue Spezifizierung des R-Faktors zu erreichen, wurden Messstationen im ganzen Land mit einer guten zeitlichen und räumlichen Verteilung untersucht. Der Fokus dieser Arbet ist es einen R-Faktor für die verschiedenen Klimazonen Neuseelands zu ermitteln und darauf gestützt eine GIS basierende Regenerosionsmappe zu erstellen. Um dieses Ziel zu erreichen, wird der Zusammenhang zwischen der jährlischen Niederschlagshöhe und der jährlichen Regenerosionsrate (MJ.mm.ha-1.h-1) untersucht. Mit diesem Verhältnis konnten die empirischen Parameter a und b identifiziert werden, indem diese lineare Gleichung in eine quadratische Gleichung umgewandelt wurde. Somit konnte die Erosionsrate für die Messtationen in Neuseeland die nicht über "high resolution" Daten verfügten ungefähr prognostiziert werden. Wichtig hierbei ist wieder, dass die empirischen Parameter für die einzelenen Klimaregionen bestimmt wurden und nicht für ganz Neuseeland.

Obwohl die Parameter genau adaptiert wurden, konnte keine 100 prozentige Reflexion bei der eher geringen Menge an Daten erreicht werden. Neben den 29 analysierten Messstationen wurde der mittlere jährliche Niederschlag von weiteren 218 Stationen berechnet um die jährliche Erosionsrate zu prognostizieren. Mit der analysierten Datenmenge, eine jährliche Niederschlagshöhenkarte sowie eine jährliche Regenerosionskarte wurden im GIS erstellt, um die räumliche Verteilung der jährlichen Niederschlagshöe sowie der jährlichen Regenerosion zu vergleichen.

Preface

The Master Thesis was conducted in the Department of Water, Atmosphere and Environment in the Institute of Hydraulics and Rural Management by the supervision of Andreas Klik of BOKU as well as Ian Fuller of the Physical Geography Department of Massey University in Palmerston North, New Zealand.

First and foremost, I would like to thank my supervisor Andreas Klik, for providing me the possibility to write my master thesis in New Zealand. His helpfulness and assistance in this thesis have been extremely supportive from the very beginning.

I also like to thank my supervisor at Massey University, Ian Fuller, who also supported my thesis right away, as well as NIWA (National Institute of Water and Atmospheric Research) for providing the necessary data for this thesis.

I would have not been able to write this thesis without the benefit from my wonderful family and all my amazing friends back home. They supported me in every way they could over the long distance, during my studies overseas. I also have to thank all the people I got to know during my time in New Zealand, for making my time here so wonderful!

Thanks to this opportunity and all the supportive background of my thesis, my postgraduate experience in New Zealand has turned out to be so successful - on a professional as well as on my personal level.

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Introduction and objectives

The rainfall – runoff erosivity factor (R) of the Revised Universal Loss Equation is one of the most well-known indicators of potential water erosion risk. A long term average of the annual sum of the kinetic energy (E) and the maximum 30 minutes intensity (I30) is calculated to determine the R-factor. For an accurate calculation, high resolution data (10 to 30 minutes) is required at least for the last 21 years. Even though New Zealand disposes over a well spatial distributed gauging network, such high resolution data is only available for the average of the last 10 years and only certain stations even consist of such data.

This study presents a rainfall erosivity map for the whole country. R-factor values will be calculated for in total 29 stations, with a good spatial distribution over the North and South Island and annual precipitation gradients, which range from 418.24 up to 4180.59 mm/ year. 328 years and 1167 storms are going to be analysed to determine the R-factor values for each station. In order to refine the mesh, the mean annual rainfall from 218 points will be taken to roughly estimate the mean annual erosion by using a simplified relationship between the annual precipitation (mm) and the annual erosion rate (MJ.mm.ha-1.h-1) according to Richardson et. al (1983). By making use of the power equation, the empirical parameters, a and b, in the equation are determined for New Zealand's climatic regions to predict the annual rainfall erosivity. These point estimations will be interpolated by using "universal kriging" to create an annual precipitation as well as an annual erosivity map in GIS.

So far, no records about spatial distributed R-factor calculations for New Zealand could be detected; therefore, this study presents the first attempt to create a rainfall – erosivity map for the country.

However, the results and the point estimations can be definitely improved in the future with additional data points and a longer time record of high resolution data, but nevertheless, the availability of a rainfall erosivity map is a key issue, not only for soil erosion and landslide risk assessment but also for agricultural management and soil conservation practices.

1. State of the art

1.1 Soil erosion

Soil erosion can be described as the loosening, detachment and transportation of soil particles from their original position. It is related to natural processes such as rainfall, runoff, wind, landslides, as well as to man's activities which modify the natural protective cover of the ground surface (Weggel et al., 1992). Simplified, it can be stated that soil erosion is a natural process enhanced by human activities. Natural (Geologic) erosion rates occur under natural (undisturbed) conditions and have operated for millions of years. Accelerated (Antrophic) Erosion occurs under disturbed environmental conditions (Toy, 2002). It can cause agronomic, economic, environmental and ecologic effects. Increased erosion and sedimentation can create hazardous conditions, destroy water quality and cause other environmental damage, requiring costly repairs. Therefore it is important to minimize the damage by planning soil conservation measures.

The main threats to the soil listed in the European Soil Protection Strategy (6th Environment Action Programmes (2002-2012) are:

1) Soil erosion by wind and water
2) Decline in organic matter
3) Soil contamination (local and diffuse)
4) Soil sealing
5) Soil compaction
6) Decline in soil biodiversity
7) Salinization
8) Floods and landslides

If the soil is once destroyed, it is not possible to restore the soil to its original natural performance. If the yearly soil loss exceeds the yearly soil formation it can be described as an irreversible process. (more than 1 t/ha/yr within a time span of 50-100 years). Impacts occur on-site as well as off-site. On-site in this term means the place where the soil is detached, whereas off-site means the place where the eroded soil ends up. On site effects occur mainly due to the loss of the nutrient - rich soil upper layer (reduction of topsoil thickness) and the reduced water holding capacity. It leads to a reduction of rooting depth, loss of nutrients and crop productivity, plus a decrease of filtering and buffering capacity as well as a decrease of soil water storage and soil aeration. The damaging on-site effects, in terms of decreased agricultural yields, are especially common in developing countries but there is also an increasing concern in the "developed" world (e.g. parts of the US, Eastern Europe as well as in New Zealand). The main off-site effect is the movement of sediments and agricultural pollutants into watercourses. It leads to silting-up of dams, disruption of the ecosystems of lakes and contamination of drinking water. Even increased downstream flooding can occur due to the reduced water absorption capacity. However, the dangerous part of it is, that once the effects have become obvious, it is usually too late to do something against it.

Drivers of soil erosion

Deforestation, overgrazing, intensive cultivation, soil mismanagement, cultivation of steep slopes and urbanization accelerate the soil erosion hazard and are the main causes for soil erosion. The three most important causes are: overgrazing with 35%, 30% deforestation and 28% to excessive cultivation. Soil erosion is also directly linked to the poverty level of a country. Farmers in developing countries depend on their food production every year and exclude conservation practices to reduce soil erosion risks (Blanco et al., 2008). Nowadays, also climate change can be listed to be one of the main drivers of soil erosion. Due to the global warming, the amount of erosive rainstorms increases. Soil erosion is also a key element in the sector of land use change. Studies have figured out, that soil erosion reduces the agricultural productivity approximately by around 10% for each 10 cm of soil loss. Depending on the soil texture, fertilizer etc. even higher soil losses are possible (Bakker et al., 2004).

Soil erosion in the future

As previously stated, soil erosion by wind and water is the most important soil degradation process worldwide. In Europe already 115 million ha (=12% of the total land area) are affected by accelerated water erosion and around 10 million hectares of cropland are lost annually (Mullan et al., 2012). Worldwide about 1.1 million hectares are affected, which is 56% of the total earth land area. Wind only affects 28% of total degraded land. (Blanco and Lal, 2009) In 2050, 80% of the EU agricultural area will be affected by water erosion as an effect of the climate change. In the last century, soil erosion has also led to a change in land use, due to the damaging effect of soil erosion on agricultural areas. Nowadays, areas with high slope gradients, high erosion rates and shallow soils tend to be excluded of cereal production. The obvious relationship between abandonment and soil depth indicates that erosion is likely to be responsible for abandonment (Bakker et al., 2005).

Due to the increasing world population and therefore consequently increasing food demand the annual loss of cropland and reduction in soil productivity starts to be a tremendous problem especially in Africa, Asia and South-America (Mullan et al.,2012). Also global warming will affect the extent, frequency and magnitude of erosion in several ways, directly and indirectly. Researchers in the UK found out, that erosion will particularly increase disproportionately in wetter years (Favis-Mortlock et al., 1995) The potential for increased soil erosion in the future depend on at least 2 main factors (Schmidt, 2000):

- changes in land use
- impact of climate change and CO_2 on plant growth

1.2 Water erosion

Water erosion is the most fatal type of soil erosion and appears in different forms such as, splash, inter-rill, rill, gully, stream bank, tunnel and coastal erosion (Schmidt, 2000). In one of the first definitions of water erosion (Ayres, 1936), the term is only divided into 1. sheet washing, 2. gullying and 3. stream erosion. Later, also the term rock erosion appears in the literature linked with water erosion (Zachar, 1982). Splash and sheet erosion are often known as inter-rill erosion, but they can be distinguished by their fluvial processes. (Blanco, 2002)

The main driver of water erosion is rainwater in form of runoff, but also snowmelt and irrigation are a part of water erosion. Water erosion consists of a whole process, including detachment, transport and deposition of soil particles. The driving force is the shear stress, generated by raindrop impact and surface run off relative to the resistance of the soil to detachment. If the sediment available for transport becomes greater than the transport capacity, deposition occurs, based on the basic understanding of every kind of sedimentation.

Four environmental factors have indeed a big influence on soil erosion: climate, soil, topography and interactively (Toy et. al., 2002). The eroded material can either form a new soil or fill lakes, stream banks, reservoirs etc. (Blanco et al.,2002)

Splash erosion

(or also called Raindrop Impact) represents the first stage in the erosion process. Rain drops act like small bombs and release their energy in form of the splash. Depending on the velocity, size and shape, the drops form craters in the soil. Processes of splash erosion involve raindrop impact, splash of soil particles and the formation of the crates (Ghadiri, 2004). The depth of the crater is equal to the raindrop energy penetration. Splash erosion is the main cause of soil detachment and soil degradation. (Blanco et al., 2009)

Inter-rill erosion

or sheet erosion, is the most common type of soil erosion and occurs due to the runoff. Rills get formed and the portion of runoff, which flows in-between, is called sheet or inter-rill erosion. The sediments get moved by the rain impact and the inter-rill areas to the rill areas (Toy, 2002). Shallow rain-impacted flows erode soil faster than non-impacted flows with the same depth and velocity (Kinnel, 1990). Together, splash and inter-rill erosion form about 70% of the total water erosion and occur simultaneously (Blanco et al., 2009).

Rill erosion

Rill erosion is the second largest water erosion form and occurs in small channels or rills. Due to the more concentrated impact in the small paths/ channels, the soil erodes faster in rills than in inter-rills. Between the rills, the removal of soil is done by sheet erosion (inter-rill erosion). Under intensive rain, rill erosion can lead to a tremendous soil loss, especially by using inappropriate tillage forms. In general the rill erosion is a function of the erodibility, runoff transport capacity and hydraulic shear flow (Blanco et al., 2009).

Gully erosion

Inappropriate cultivation and irrigation often lead to gully erosion. Not only marly badlands, mountainous and hilly regions are affected. Gullies also occur in soils subjected to soil crusting, like sand and loess, and dispersive soils due to tunnelling and piping (Valentin et. al, 2005). Gully erosion creates either U- or V-shaped channels. Hauge (1977) and Poeson et al. (1996) distinguish gullies from rills by a critical channel cross-sectional area of one square foot (929 cm^2). Valentin defines gullies with a width of 0.3m and a depth of 0.3m. As a matter of fact, the deeper and wider gully's get, the more sediment will be transported. Gully erosion distinguishes between ephemeral and permanent erosion. Ephemeral gullies are shallow channels and can still be corrected by tillage, whereas permanent gullies can only be recovered with expensive measures of control. Usually gullies simply get refilled with soil to avoid more erosion, to prevent an enlargement of the gullies. The two main factors for gully erosion are the shear stress of the flowing water and the critical shear stress of the soil. Simplified,

Shear stress of run-off < critical shear of soil = no gully formation

Shear stress of run-off > critical shear of soil = gully formation (Blanco and Lal, 2009)

Tunnel erosion

Is an underground soil erosion and common in semi – arid and arid zones and plays an important geomorphic and hydrologic role in many parts of the world, e.g. Europe, North-America, Australia and Africa. Soils, which consist of a stable A horizon and an instable B-horizon are mainly affected by tunnel erosion. The upper soil is stabilized by roots, e.g. grass, while the layer underneath is relatively loose e.g. due to natural cracks and animal burrows. It changes the geomorphic and hydrologic characteristics of the area (Blanco et al., 2009) and (Zhu, 2011).

Streambank erosion

It involves the detachment and transport as well as the deposition of particles. It starts with the raindrops detaching the soil and is followed by its transport. The amount of eroded material is related to the first two processes, dispersion and removal. The deposition can be either over a short distance or the eroded material can get carried over long distances. (Blanco et al., 2009) and (Wynn et.al., 2008). The process is mainly driven by two major components: the stream bank characteristics/ erodibility and the hydraulic forces. Riparian vegetation usually has a positive effect in order to prevent streambank erosion, but most of the times, the problem is more complex. To achieve a long term protection, only improving the bank stabilization is usually not sufficient.

Coastal erosion

Coastal erosion is an interplay between wind, water currents and waves. It occurs along beaches and shorelines. Shorelines erode in different ways, depending on, if they are sandy or rocky. Due to global warming, the sea level rises, which also leads to increased coastal erosion. In addition, global warming and increased ocean-water temperature lead to higher storm intensities. All these facts lead to the conclusion, that there will be enhanced coastal erosion in the twenty-first century, compared to the past records. (Komar, 2012)

1.3 Water erosion models

By modelling soil - erosion, it is important to understand the processes dominating soil erosion and to choose appropriate measures of erosion control and prediction (Blanco, 2002).
The crucial factor of erosion modelling were the sandstorms, also called “Dust – bowl”, in the U.S. In the 1920s, these sandstorms caused enormous agricultural damage and the erosion problem became progressively more important. Studies have increased in number and variety since then.
To get a data base to work on, researchers started with large number of soil erosion experiments (1928). Hence of this work, a lot of simplified empirical models for regional validity were developed.
Only 50 years later, Wischmeier and Smith developed the USLE equation, which was applicable for larger regions with similar conditions. Due to the fact that Europe didn’t have a kick-off event like the dust-bowl in the U.S., the soil erosion problem was finally recognised 50 years later, in the 1970s. Tillage and intensive agricultural in particular caused a need for soil protection and conservation. Starting with the USLE, research showed after some years that there are limitations in the applicability of the equation, e.g. large catchment areas, single events and rill erosion. To solve this determining problem, two strategies were used. Firstly: to improve the USLE by transforming the US conditions into European ones, e.g. ANSWERS (Beasley and Huggins, 1982) CREAMS (Knisel, 1980), EPIC (Williams et al. ,1984), WEPP (1985). Secondly: to develop models especially for the European conditions.
Unlike in the U.S., the European landscape and land use is structured in many different smaller areas. Determining the erosion rates for Europe is therefore much harder than for the large areas in the United States. Due to the different country specific laws and policies, it was not possible to develop joint research concerning the soil erosion problem in Europe, like the USDA for the U.S.. Nowadays, there are many different models, which are developed for a specific region and which are also only used in this area. The local constrictions and the multiplicity of models make it almost impossible to create a network for the data collection and standardisation for the results within Europe.

In principal, water erosion models can be represented at three levels, black-box, grey-box and white-box models.

In black-box models, a relationship between one or more input factors exists. These kinds of models are usually described by statistical relationships. Grey-box models (e.g. USLE) include some understanding of the relationship between Input and Output. Also these kinds of models are based on statistical relationships, but those are more complicated than the ones used in simple black-box models. White- box models are physically based and as many as possible erosion processes are described. Typical for white- box models are differential and difference equations. In reality, there is no truly white box model, but several process based and partially physically based models, including WEPP, EUROSEM and GUEST (Morgan et. al., 2011)

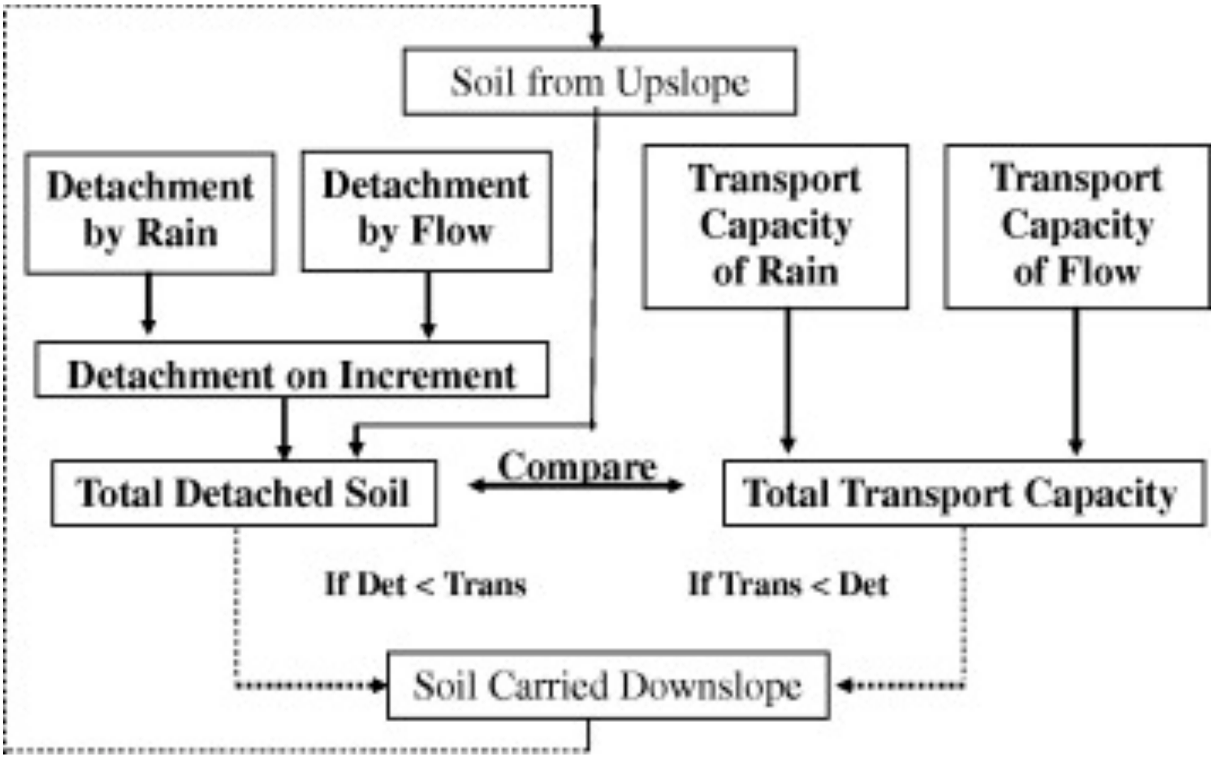


Fig.1: the Meyer-Wischmeier model, a conceptual framework for erosion modelling, 1969

To assess the soil erosion problematic, expert based methods as well as model based approaches can be used. For determining the soil erosion problematic, expert based methods are hardly available for any parts within New Zealand, concerning to rainfall erosivity. This leads to the use of model based approaches. The main focus in the thesis was more about to identify the long term annual soil loss rather than the single storm loss (event based). Problems can arise by pretty much all the models, due to the fact that all of them are point estimations. Therefore, results over a larger area have to be interpreted very carefully! It is also important to be aware of which processes are modelled. E.g. the USLE is designed to predict rill – and inter-rill erosion and is therefore rather unsuitable for e.g. gully erosion or any other kind of erosion. Another important point is the data availability. The data consideration is one of the main factors by choosing an appropriate model.

Classification of soil erosion models

Simplified, the soil erosion models can be divided into three classes: (Richter, 2004):

-physical: the model tries to display lifelike conditions. The physical conditions and dynamical laws of similarities are accurately readjusted in the laboratory (Dyck, 1980).

- analogue: these models are an intermediate level between physical and mathematical models. The operation mode is similar to the original model, but with simplified physical conditions (Dyck, 1980).

- mathematical: all processes and coherences are described with mathematical equations. These models can be further distinguished in stochastic and deterministic models (Dyck, 1980).

Richter, 2004 further differentiates erosion models by the following features:

-legality of the model: in general, models are distinguished in stochastic and deterministic models. Stochastic models rely on statistical operations, whereas with a small data basis, synthetic statistical series can be generated. Therefore, a small amount of input data is sufficient to develop random variables as input parameters for the model. Deterministic models are based on mathematical equations and generate input data free from variation.

- approach of the model: the approach of soil erosion models is either empirical or physical based. Empirical based models, also called “black box” models, consist of equations without any physical background. They rely on experiments and monitoring and are applicable for stationary conditions. Physical based models try to recreate natural processes by using physical laws, but empirical based components are unavoidable (e.g. Darcy equation).

- decomposition over time: those can be subdivided into continuous and discrete models. Continuous model types deliver results over a longer time period; however discrete models are also applicable for a short time period (minutes to days).

- spatial: soil erosion models can be either linear (for one slope) or spatial (e.g. whole catchment area).

- structure: Soil erosion models can be split into lumped and distributed models. Lumped models calculate with a uniform parameter for the whole catchment/ slope whereas distributed models classify the investigation area e.g. in grids, triangles or contour lines.

A new approach in modelling soil erosion processes is to represent each individual process, including deposition as well as each erosion process. Also changes at the soil surface due to erosion and deposition processes have to be taken into account (Rose et al.,1990).

1.3.1 Empirical based water erosion models

1.3.1.1 USLE/RUSLE

The universal soil loss equation was developed by W.H Wischmeier and Smith, published in 1965 and has become the major conservation planning tool worldwide ever since. It is an empirically based mathematical model that describes the soil erosion process and to predict the annual erosion rate. Since then the equation has been gradually and systematically improved. Schwertmann, Vogl and Kainz, developed the ABAG (Allgemeine Bodenabtragsgleichung) model for the European standards based on the USLE equation in 1990, which uses SI units in comparison to the original equation. Due to additional research, experiments and tests, researchers transformed the Universal Soil Loss Equation into the Revised Universal Soil Loss Equation, shortly known as RUSLE, published in 1997. Even though the formula has stayed the same, there have been several improvements in determining factors, like new and revised isoerodent maps; a time-varying approach for soil erodibility factor; a subfactor approach for evaluating the cover-management factor; a new equation to reflect slope length and steepness; and new conservation-practice values (Renard et al., 1997). The USLE/RUSLE equation is used to assess the average soil loss in tons per hectare per year [t/ha*a] and to estimate the impact of inhibitive soil erosion measures. The MUSLE, which stands for Modified Universal Soil Loss Equation is also based on the USLE principles. Due to this modification, the use of MUSLE for predicting sediment loss on a storm event basis is possible.

$$A = R * K * L * S * C * P \qquad (1)$$

For this thesis, this model-based approach was used to assess the soil erosion risk. Even though there is a broad spectrum of soil erosion models, the RUSLE seemed to be adequate for the availability of input data. Other models simply require too much input-data. In addition, a comparison to other (somehow similar) countries/areas is possible due to the worldwide use of the RUSLE equation.

A = estimated average soil loss in tons per hectare per year [t/ha*a]

Next to the RUSLE equation, the t-value, which stands for tolerable soil loss, is often used. It describes the maximum amount of soil loss in tons per acre per year that can be tolerated.

1.3.1.2 R = rainfall-runoff erosivity factor [N/h]

The rainfall-runoff erosivity factor is used to estimate the area specific rainfall erosivity and combines the effects of duration, magnitude and intensity of each rainfall event.

The R factor contains the amount of rainfall as well as the peak intensity, the two most important parameters of storm erosivity. One of the main driving forces of rainfall erosivity is the kinetic energy with a maximum drop diameter of 6 mm, and a maximum fall velocities 9.3 m.s-1. (Klik, 2011) The kinetic rainfall energy represents the total energy available for detachment and transport, which can be explained as the direct impact of the falling raindrops on the soil. The term I_{30} can be described as the maximum 30 minutes Intensity of each rainfall, representing the erosional force of the surface runoff.

The R factor is usually ascertained by calculating the average annual sum of the product of a storm's kinetic energy E and its maximum 30-min intensity I30, known as the EI30 (= R-Factor) (Wischmeier and Smith, 1978).

$$EI = E * I30 \quad (2)$$

In accordance to Wischmeier and Smith (1978), the EI is almost congruent with the amount of soil loss from a field (Blanco, 2002). It has to be taken into account, that in the U.S. only storms exceeding an amount of 12.5 mm (equals 0.5 inches) or a 30-min intensity of 12.5 mm h-1 are considered as erosive, whereas in Europe storms exceeding 10mm which equals an I30 > 10 mm h-1 are used in the equation. All smaller values will not be considered as erosive. For this thesis, the European standards were taken.

Its calculation usually requires high resolution rainfall data – typically one data every 10 to 15 minutes or pluviograph records. In many parts of the world, such high resolution data is hardly available (e.g. in New Zealand only for the last decade). Therefore, another approach has been developed to estimate spatial distributed R-factor values. A number of studies have been devoted to estimating rainfall erosivity from coarser data such as highly available daily rainfall time series (Richardson et al., 1983; Bagarello and D'Asaro, 1994; Petkovsek and Mikos, 2004; Angulo-Martinez and Begueria, 2009; Meusburger et al., 2012).

After calculating the R-factor values with the described method, a relation between these values and longer available rain records (e.g. annual average) is established. The relation is then extrapolated, and the R-values for the other recording gauging stations, estimated. At the end, Isoclines can be drawn between the stations, and R-values for the area in between the stations can be interpolated by using an appropriate interpolation method in e.g GIS. This approach provides knowledge of the spatial R-factor distribution in countries, where high resolution data is not or only for a short time period available (Bonilla and Vidal, 2011).

In Europe, other relationships are already drawn. The main difference to the previously explained method is that in central Europe the most erosive rainstorms occur between May and October, whereas compared to New Zealand, it is almost equally distributed.

For example, for Bavaria (Germany), Rogler & Schwertmann (1981) established the following Regression equation:

$$R = 0{,}141 * N_S - 1{,}48 \qquad r = 0{,}961 \qquad (3)$$

R = mean annual erosivity (MJ.mm.ha-1h-1y-1)
Ns =average rainfall amount in summer (May-October) (mm)
(v.d.Knijf et. al, 2000)

In this thesis, a more simplified equation by Richardson was used to predict the rainfall – erosivity. Due to the fact, that it is the first attempt to determine the R-factor variability within the country, and no previous researches or attempts could have been found to base on the detected results.

$$R = aP^b \qquad (4)$$

<u>K = soil erodibility factor [t/ha]/[N/h]</u>

The K-factor values represent the susceptibility of soil to erosion and the amount and rate of Runoff, measured under the standard unit plot condition. The soil erodibility factor reflects all the effects, which influence the soil loss by rainfall and runoff, if the soil is not protected by e.g. crop residues, rock fragments or plants (Young et. al., 1990). The standard unit plot condition is an erosion plot, 22.1 meters long with a continuous steepness of 9% and tilled up and downhill to control weeds.
The K-value is calculated for several different soils. The soil erodibility factor ranges in value from 0.02 to 0.69 (Goldman et al. 1986; Mitchell and Bubenzer 1980). The factor reflects the fact that different soils erode at different rates, that soil texture, permeability as well as organic matter influence the K-value. It also tends to be higher in the spring, or in general when the soil is wetter, whereas autumn is known as a period with lower K-values.

<u>L = slope length factor [-]</u>

The slope length factor "L" describes the soil removal ratio of a slope to the standard unit plot condition under otherwise identical conditions. The following formula is used in the USLE as well as in the RUSLE.

$$L = (\lambda / 22{,}13)^m \qquad (5)$$

L = soil loss normalized to standard unit plot condition

m = slope length factor

There are several suggestions concerning the slope length factor. Zingg, 1940 proposed 0.6, Musgrave et al. 0.3. (Liu et al., 2001) 1956 Wischmeier declared 0.5 +/- 0.1 as a valid factor. Depending on the steepness of the slope 0.2-0.5 is applicable for a slope gradient up to 5%. The new approach basically says, that values greater than 5% don't change with the slope steepness.

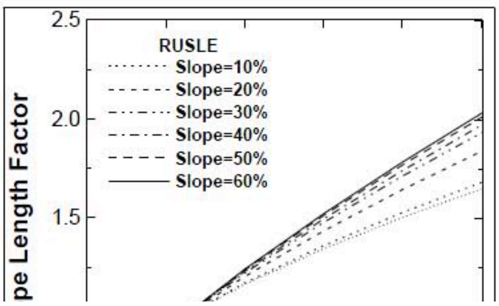


Fig. 2: RUSLE slope length exponent , m ,for different slopes(B.Y. Liu et al, slope length effects on soil loss for steep slopes, p.784-788, 2001)

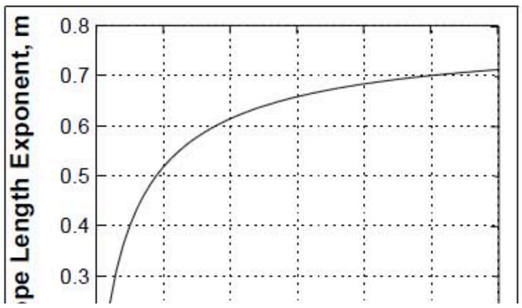


Fig. 3: USLE and RUSLE slope length factor **for** steep slopes (B.Y. Liu et al, slope length effects on soil loss for steep slopes, p.784-788, 2001)

S = slope steepness factor [-]

The slope steepness factor "S" describes the ratio of soil erosion from any field slope to the standard unit plot condition (9%) under otherwise identical conditions.

The RUSLE uses two functions, one for < 9% and the other one >9%. Recent analysis found out that for a slope greater than 22% a different linear function that the one used in RUSLE is necessary. Zingg, Smith and Witt, Musgrave, Wischmeier and Smith described how the effect of slope steepness on soil loss caused by rainfall and run-off are takes various forms. Recent relationships have described the effect as a linear function of the sine and slope angle (Nearing, 1997).

C = cover-management factor [-]

Describes the ratio between the soil loss of a slope with any cultivation to the standard unit plot condition. It is widely used to compare the impact of management options and conservation plans. Important parameters like soil cover, soil biomass and soil disturbing activities on soil erosion are considered. (Section I, RUSLE Erosion Prediction Ohio, FOTG) The cover management factor indicates how the annual soil loss gets influenced by conservation plans (Yoder et al., 2007).

For estimating the cover-management factor (C) in the universal soil loss equation nine sub factors should be considered: (1) amount of bare soil, (2) canopy, (3) soil reconsolidation, (4) high organic content, (5) fine roots, (6) residual binding effect, (7) on-site storage, (8) steps, and (9) contour tillage (Dissmeyer and Foster, 1981)

P = support practice factor [-]

The support practice factor reflects the effect of any support practices on the erosion rates to the corresponding soil loss after up and downhill cultivation and no support at all. This is mostly done either with field observations or air photographs. (Karydas, Sekuloska, Silleos, 2009)

Support practices, like contour farming, cross-slope farming, strip cropping and terraces; affect the erosion by reducing the transport capacity or redirecting the runoff.

1.3.1.3 Process based models

The fundamental principle for sediment transport prediction is the continuity equation of mass (Foster, 1982)

$$\frac{\delta qs}{\delta x} + \rho s \frac{\delta(cy)}{\delta t} = Dr + Di \qquad (6)$$

represents the change in sediment storage with respect to time

represents the change of sediment flow rate with respect to distance x

qs = sediment load

x = distance downslope

ρs = mass density of sediment particles

c = sediment concentration

y = flow depth

t = time

Dr = deposition rate

Di = sediment delivered to the rill from the interrill areas

(Blanco, 2002)

WEPP – the Water Erosion Prediction Project

The USDA – water erosion prediction project is a process- and computer based erosion model and was initiated in 1985. The computer model is based on fundamentals of infiltration, runoff, plant growth, hydraulics, tillage, soil consolidation and erosion mechanics (Nearing et al., 1989).

The model is widely used in the USA as well as in the UK. The skeleton of the model basically consists of four main groups: climate, slope, soil and management. The primary aim was to provide a landscape profile (hillslope) which considers in contrast to the USLE depositional areas, a smaller watershed version, which considers smaller waterways within the catchment area and a catchment and grid cell version which considers sediment transport (Foster et al., 1987). The main difference to other process based erosion models e.g. the one used in CREAMS is, that the rill and interrill erosion gets calculated differently. The WEPP model uses the concept that detachment and deposition rates in rills are a function of the portion of the transport capacity filled by sediment (Bazier et al., 2000). The main advantage compared to other erosion models is, that the WEPP model can estimate erosion for single hill slopes and whole watersheds (various hillslopes). For the WEPP model, the output in the Rainfall Intensity Summarization Tool is also available!

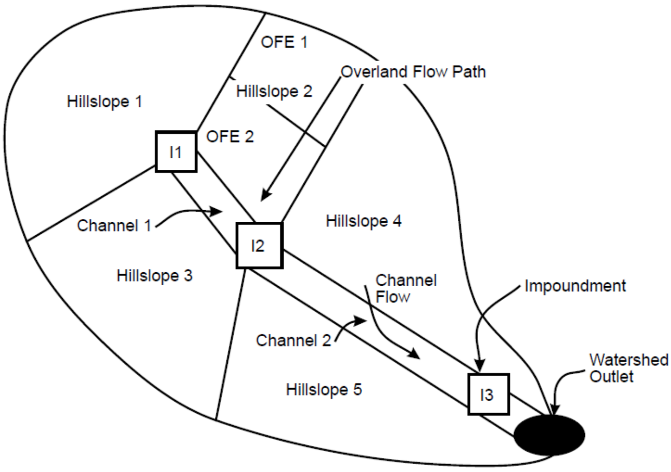


Fig. 4: small catchment area, WEPP (Flanagan, D. et al., 1997)

Other water erosion models

- Agricultural Non-Point Source pollution models (AGNPS)
- Annualized Agricultural Non-Point Source Pollutant Loading (AnnANPSPL) – output in RIST available
- Areal Nonpoint Source Watershed Environment Response Simulation (ANSWERS)
- European Soil Erosion Model (EUROSEM)
- Groundwater Loading Effects of Agricultural Management Systems (GLEAMS)
- etc …

Compared to the previous explained models, these ones have multi-purpose use and can also predict nutrient losses, next to runoff and soil loss.

1.3.2 Rainfall erosivity

Rainfall erosivity is determined by climate and provides estimations of the forces applied to the soil, which causes water erosion. Topography, vegetation and soil surface modify the forces applied to the soil as well as biological materials and soil management (Toy, 2002). No water - erosion would occur if all rains were non-erosive (= precipitation or EI30 smaller 10mm or 0.5 inches). The total erositiy of a rain depends on the amount, intensity, drop size, velocity and drop size distribution. The erosivity of a rainfall event also depends on the climatic region e.g. rainfalls in tropic areas are more erosive than those in temperate climate areas, because of the presence of strong winds and high temperature. In addition, rain events in tropical regions are biomodal, which means they are separated in two seasons and cause more erosion then unimodal rains (uniformly distributed within

the whole year). However, the most important factor is the rainfall Intensity. Simplified, a high amount of rain with a high intensity leads to high erosion. Usually, these storms are short but determine a large amount of erosion. The kinetic engergy of the individual raindrops form the total intensity of a storm. This means that the relation between rainfall and sediment yields is conditioned by the rainfall erosivity. Apart from its importance, rainfall erosivity is mostly implemented in model with a low spatial and temporal resolution (Meusburger et al., 2012).
Related to the frequent discussions about climate change, rain erosivity is definitely an important issue. Changes in more erosive precipitation due to warming up are expected worldwide (Verstraeten et al., 2006).

1.3.3 Relationship between rainfall intensity – kinetic energy

The relationship between rainfall intensity and kinetic energy is very important to predict accurate erosion hazards.
It is well-established that the amount of detached soil by a particular depth of rain is related to the rainfall intensity (van Dijk, 2002). Ellison, 1960 and various later studies stated, that the kinetic energy of a single raindrop is proportional to the product of its mass and the square of its velocity (see R-factor USLE), simply, the kinetic energy can be considered as an indicator for rainfall erosivity.

$$E = \frac{1}{2} * mV^2 \tag{7}$$

m= mass of falling raindrop (g)
V= fall velocity of the raindrop (cm s^{-1})

Rose (1960) declared that the rainfall momentum can be considered as a slightly better predictor than the kinetic energy, whereas Hudson (1971) concluded that kinetic energy and rainfall momentum are related with its intensity.
The main interest in soil and water conservation work is to determine the energy of the drops, that strike the soil (Ellison, 1960). One of the best ways, to describe a rainfall event is by using the drop size distribution (DSD).

DSD - Drop Size Distribution

Rain- drop- size- distribution (DSD) is a key attribute to connect rainfall rate with cloud processes and remote sensing observations (Marzuki, 2012) and it changes in space and time. The first report on drop size distribution was stated by Wiesner, 1895 by using a piece of absorbent paper dusted with a water-soluble dye. This “filter paper” became a common method to determine the drop size distribution by natural rainfall, as well as the “flour pellet” technique (Laws and Parsons, 1943; Hudson, 1964). Nowadays, electromechanical distrometers (Joss and Waldvogel, 1967), cameras (e.g. Kinnell, 1980; McIsaac, 1990) and also recently optical pluviospectrometers(e.g. Wang et al., 1979; Illingworth and Stevens, 1987; Lavergnat and Golé, 1998; Salles and Poesen, 1999) are used.

2. Materials and methods

The study area covers whole New Zealand (except Steward Island, Chatham Island etc.), which includes a huge variety of landscapes. The total land area is 270,535 km^2, which is about the size of Italy or the United Kingdom. The North and South Island are separated by the 32km Cook Strait. On the east coast lies the Pacific Ocean, and on the West coast the Tasman Sea. In general the climate can be described as temperate with sharp regional contrasts. The land use is divided into 30% forest, 50% meadows and pasture and 15% agriculture (permanent cultivation).

The geographic characteristics of the North Island (113,729 km^2) are Mt. Taranaki on the West Coast and the central plateau around Taupo with its volcanic activity. These are the only "real" elevations on the North Island, whereas the rest can be described as "rolling hill country", where most of it is farmed. Narrow ranges (Tararua, Ruahine and Kaimanawa) form a north east-belt of higher country (up to 1700m) from the North to the South on the North Island.

The South Island (150,437 km^2) is dominated by the Southern Alps (up to 3000m), which traverses most of its length. To the west of the Alps, rainforest defines the landscape, whereas to the east, the Canterburry region is well known for its farmlands formed by rivers originating from the mountains. Further distinctiveness's are the two main glaciers (Franz Josef and Fox Glacier), which almost reach the sea-level.

New Zealand now sits on the boundary of the Indo-Australian and Pacific tectonic plates. The volcanic activity and the earthquakes are a result due to its location on the Pacific 'Ring of Fire'. (http://www.teara.govt.nz/en/natural-environment/1)

2.1.1 (Water) erosion in New Zealand

Inordinately high rainfall and strong prevailing winds are New Zealand's dominant climatic features. New Zealand is geologically young and not comparable with any other country in the world. There is still volcanic activity on the North Island; on the South Island earthquakes are relatively common. The whole country is hilly with a small amount of floodplains. The high amount of rainfall, steep slopes, small catchments and earthquakes are the perfect basis for a high rate of natural and accelerated erosion (Jakobsson et al., 1991).

In particular, deforestation and unwise land use have led to increased soil erosion and also to an increased sedimentation in waterways.

In New Zealand erosion is dominated by mass-movement, like in any other mountainous countries. Also fluvial erosion, stream bank erosion and surface erosion are common. Processes include landslides, large gullies and earth flows. To determine the long-term erosion rate, the New Zealand empirical erosion model is used (Dymond et al., 2010).

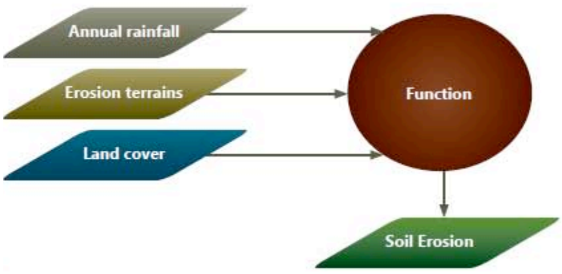


Fig. 5: Long term mean erosions rates for the North Island in 2002/2003 (http://www.landcareresearch.co.nz/publications/researchpubs/es_pamphlet_erosion.PDF)

$$e = a * C * R^2 \quad (8)$$

e= long term erosion rate in t/ km^2 /a

a = erosion coefficient depending on erosion terrain

C = factor depending on the vegetation type

R = mean annual rainfall in mm

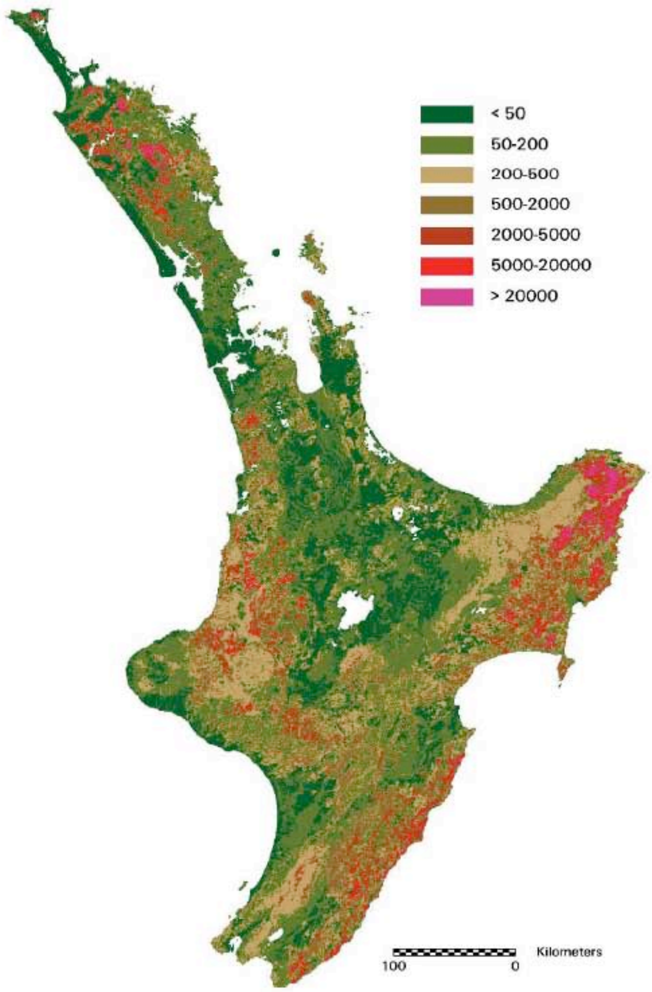


Fig. 6. Annual rainfall: national map of mean annual rainfall from LENZ at 100m pixels (Leathwick et al., 2003). Erosion terrains: national map of erosion terrains at 15m pixels (Dymond et al., 2010).

A large variability of mass movement models already exists, but they are all linked to certain geographic areas. A model, which makes use of land cover and land management factors in addition to geology and the mean annual rainfall, is definitely stronlgy recommended and needed for New Zealand. The erosion processes vary throughout the whole country. Therefore, the whole of New Zealand was divided into so called erosion terrains. These terrains contain landform and slopes as well as rock types and are differentiated with a 3 class hierarchical system. The top level refers to landform and slopes, the second level differences in rock types and the third level deals with erosion processes (Dymond et. al, 2009).

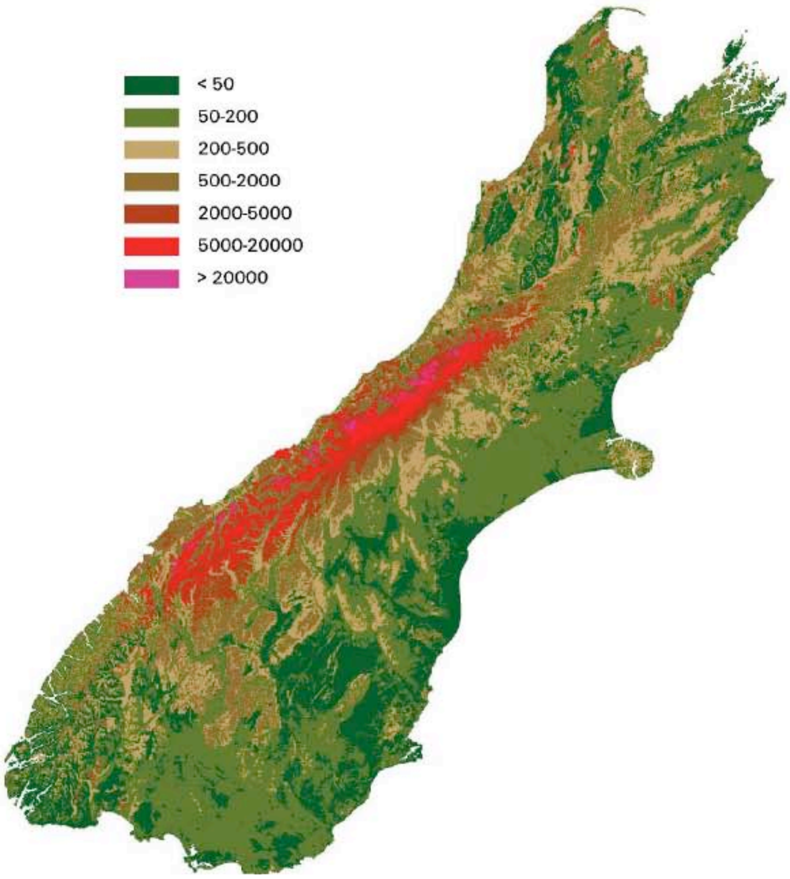


Fig. 7. Long term mean erosion rates for the South Island in 2002/2003 (http://www.landcareresearch.co.nze/publications/researchpubs/es_pamphlet_erosion.PDF (Dymond et al., 2010).

Erosion control techniques are very important to reduce the impacts of soil erosion on pastoral land, e.g. maintaining adequate vegetative cover, spaced or close tree planting, retiring land from pasture, fencing off and planting river banks as well as building debris dams to slow down the water flows in gullies. (Ministry of the environment, New Zealand)

In 1997 the Ministry of the Environment noted, that 50% of the country was already affected by slight erosion and 10% even by extreme erosion (eastern North Island and South Island - High country). Only 31% of pastoral farming showed no signs of any kind of erosion.

In addition, New Zealand is also strongly affected by coastal erosion.

2.2 New Zealand's Climate

The climate in New Zealand varies from warm subtropical in the north to cool temperatures in the far south.

The Mountain chain on the South Island builds a barrier for wind and rain coming from the Tasmanian Sea. Due to the mountains, the country is divided into several different climate regions. The mean temperature ranges from 10 degrees in the south up to 16 degrees on the northern island.

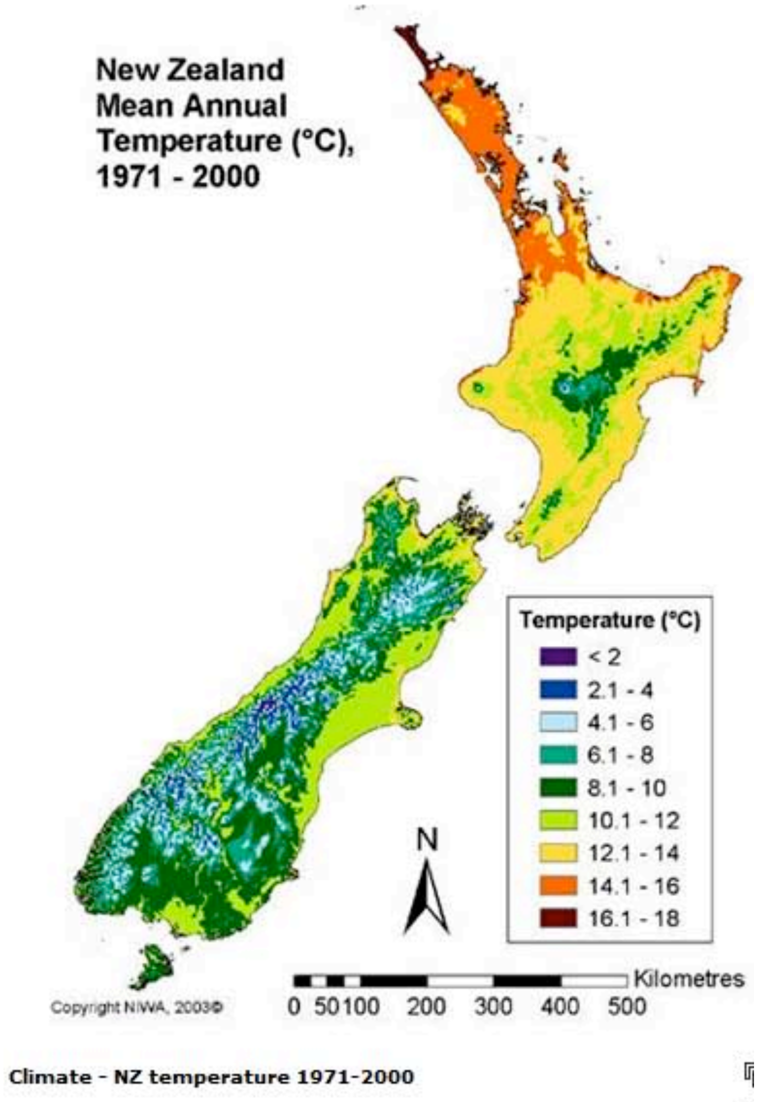


Fig 8: New Zealand mean annual temperature in degrees, 1971 2000 (http://www.niwa.co.nz/education-and-training/schools/resources/climate/overview

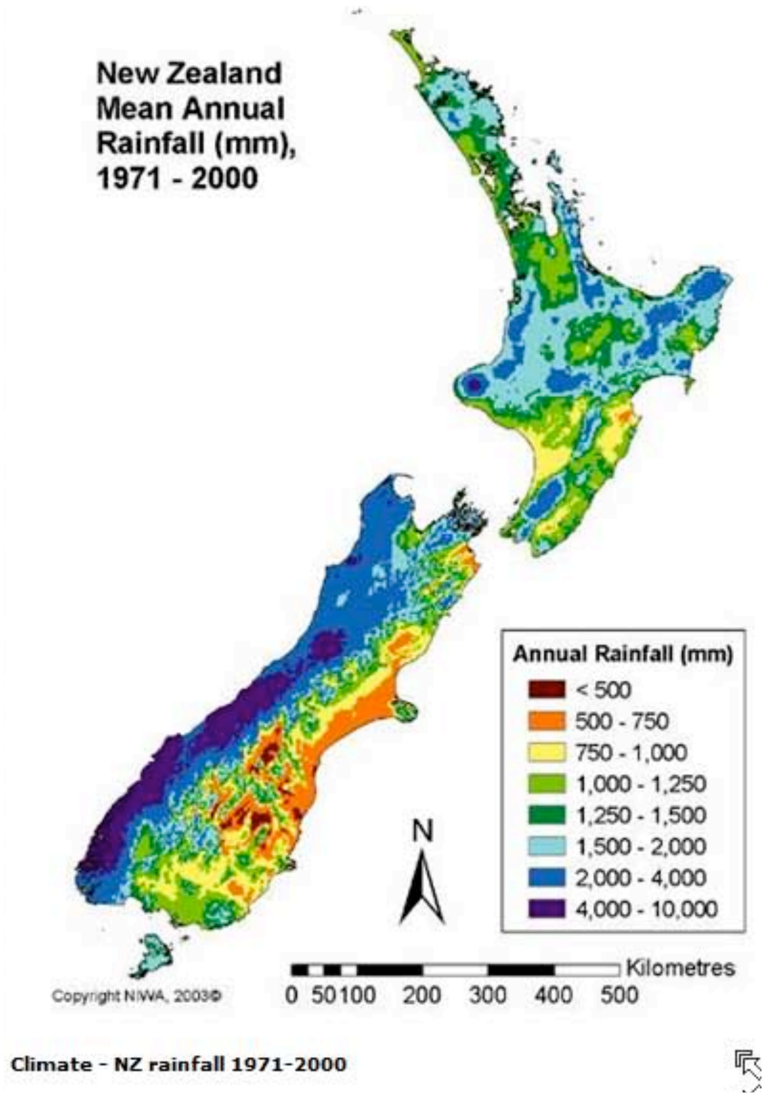


Fig 9: New Zealand mean annual rainfal,l 1971 - 2000 (http://www.niwa.co.nz/education-and-training/schools/resources/climate/overview

The temperature difference between summer and winter is generally small, nevertheless July is considered as the coldest month. and usually February is the warmest.

The west coast of the South Island is by far the wettest of the country. 100km east the driest region of the country is situated. The rainfall ranges between 400mm and 1600mm during the year. Dry periods in the summer are typical. On the North Island more rainfall falls in winter, whereas it is different on the South Island, with no real peak season.

2.3 New Zealand's Climatic Zones

According to NIWA, the following climate zones in New Zealand can be distinguished:

North Island

-Northern New Zealand: Kaitaia, Whangarei, Auckland, Tauranga

Warm humid summers and mild winters are typical for this sub-tropical climate zone. Tropical storms from the east or northeast are likely to occur in summer and autumn. The mean annual rainfall for this region is between 1100 – 1300 mm/year.

Fig.10: Central North Island: http://www.niwa.co.nz/education-and training/schools/resources/climate/overview/map_north

- Central North Island: Hamilton, Taupo, Rotorua

This region is sheltered by mountains to the south and east, which leads to less wind then in many other parts of New Zealand. The mean annual rainfall strongly depends on the altitude. Whereas 1000 – 1300 mm/year are common for Hamilton, Rotorua and Taupo, up to 3000 mm/year are likely at Mount Ruapehu/ Tongariro National Park. The volcanos are the first significant elevation, which almost leads to daily rainfall.

Fig.11: Central North Island: http://www.niwa.co.nz/education-and training/schools/resources/climate/overview/map_c_north

South West North Island: New Plymouth, Wanganui, Palmerston North, Wellington

This zone is very exposed to the weather fronts coming from the Tasman Sea and therefore it can get very windy. The mean annual rainfall in this region is around 1000-1200mm/ year, only in New Plymouth it can get up to 1500 mm/year. Around Mount Taranaki the rainfall increases dramatically with the altitude and mean annual rainfall up to 8000mm/ year are possible.

Fig.12: South West North Island: http://www.niwa.co.nz/education-and training/schools/resources/climate/overview/map_sw_north

Eastern North Island: Gisborne, Napier, Masterton

Sheltered to the west, this climate zone is dominated by winds from the north-east. Napier is one of the driest places on the North Island with an mean annual rainfall around 770 mm/year. Gisborne and Masterton reach an mean annual rainfall around 1000 mm/ year.

Fig.13..:Eastern North Island: http://www.niwa.co.nz/education-and-training/schools/resources/climate/overview/map_e_north

Northern South Island: Takaka, Nelson, Blenheim

Sheltered by high country to the south and west, this is the sunniest region of whole New Zealand. Mean annual precipitation ranges between 700 – 1000 mm/ year. Only at Golden Bay more rainfall can reach up to 2000 mm/year.

Fig.14.: Northern South Island: http://www.niwa.co.nz/education-and-training/schools/resources/climate/overview/map_n_south

Western South Island: Westport, Hokitika, Milford Sounds

Everything here depends on the exposure to the Tasman Sea and the lie to the Southern Alps. Annual rainfall can reach up to 10000 mm/ year in between the Southern Alps and can significantly change only within a few kilometres.

Fig.15.: Western South Island: http://www.niwa.co.nz/education-and-training/schools/resources/climate/overview/map_w_south

Eastern South Island: Kaikoura, Christchurch, Timaru

The East coast also depends on the lie of the Southern Alps to the West, but in general it the mean annual rainfall is low and ranges between 600 – 700 mm/ year. Long dry spells in summer are common.

Fig.16.: Eastern South Island: http://www.niwa.co.nz/education-and-training/schools/resources/climate/overview/map_e_south

Inland South Island: Lake Tekapo, Alexandra, Manapouri, Queenstown

The Inland of the South Island is very different. Whereas Queenstown and Manapouri are close to the South Alps, their mean annual rainfall is between 700 – 3000 mm/year depending on the lie to the Alps, Alexandra is the driest place in whole New Zealand with an average annual precipitation around 350 mm/year.

Fig.17: Inland South Island: http://www.niwa.co.nz/education-and-training/schools/resources/climate/overview/map_i_south

Southern New Zealand: Dunedin, Invercargill

This region is not really sheltered in any direction and therefore especially weather fronts from the south-east are likely to hit it. The mean annual precipitation between Dunedin and Invercargrill varies significantly. Whereas Invercargrill gets about 1200 mm/year of rainfall, Dunedin is way dryer with rainfall around 700 mm/year.

Fig.:18: Southern New Zealand: http://www.niwa.co.nz/education-and-training/schools/resources/climate/overview/map_south

2.3.1 Gauging Stations

North Island

Auckland

Region: Auckland region

Gauging station: Pukekohe Ews

Elevation: 88m

The region has a warm, temperate-climate and snowfall is very rare. High levels of rainfall are typical throughout the whole year, but vary within the region due to geographical differences. Winters are in general wet, summers are usually dry and mild.

Fig.19: Auckland – google maps

Gisborne

Region: Gisborne

Gauging station: Motu Ews

Elevation: 488m

Gisborne is New Zealands most eastern region with a Mediterranean climate and is one of the sunniest places in New Zealand. The high country to the west shelters this region which leads to warm summers and mild winters. The rainfall varies between the higher inland (up to 2500mm/yr) and near the coast (1000mm/yr).

Fig.20: Gisborne – google maps

Hamilton

Region: Waikato Region

Gauging station: Ruakura Ews

Elevation: 40m

Located next to the Waikato River, a damp and temperate climate is significant for this area.Due to the fact, that Hamilton is only 20 meters above the sea level and sheltered to the south and east, it is less windy than other parts in New Zealand. ccording to NIWA the mean annual rainfall over the last 30 years is 1108.4 mm/yr.

Fig.21: Hamilton – google maps

Kaitaia

Region: Northland

Gauging station: Kaitaia Ews

Elevation: 85m

Up in the far north, Kaitaia is the warmest place in New Zealand, situated in the oceanic, subtropical climate zone. Winter is the unsettled time of the year and brings more rain. In summer and autumn, tropical storms can pass by, bringing some heavy rainfall from the east.

Fig.22: Kaitaia – google maps

Martinborough

Region: Wellington

Gauging station: Martinborough Ews

Elevation: 20m

Due to the Wairarapa Valley and the Tararua Range to the west, the climate in the Wairarapa Region differs from regions in the west (e.g. Palmerston North). The climate is mild almost grading towards a Mediterranean climate.

Fig.23: Martinborough – google maps

Matamata

Region: Waikato

Gauging station: Hinuera Ews

Elevation: 106m

High annual rainfall, temperate climate and rich, free draining soils are typical for Matamata, therefore it is also called the Kentucky of New Zealand. This leads to excellent pasture growth all year round.

Fig.24: Matamata – google maps

Mt. Ruapehu

Region: Manawatu - Wanganui

Gauging station: Chateau Ews

Elevation: 1097m

The Tongariro National Park is situated in a temperate climate zone. The volcanoes are the first significant elevations and stop the winds from the west which leads almost to daily rainfall. The volcanos don't belong to a wider mountain range, but there are still noticeable differences in the annual rainfall between the East and West.

Fig.25: Mt. Ruapehu – google maps

Napier

Region: Hawke's Bay

Gauging station: Whakatu Ews

Elevation: 5m

Resulting from its location, the climate is warm and dry. Usually weather fronts cross the country from the west and shed their water at the mountain fronts before reaching the east coast. In summer remnants of tropical cyclones from the Pacific Ocean can pass by.

Fig.26: Napier – google maps

New Plymouth

Region: Taranaki

Gauging station: Stratford Ews

Elevation: 300m

The Taranaki region is affected by the weather from the Tasman Sea. Mount Taranaki causes a rain-shadow effect, which leads to a high rainfall probability throughout the year. The Rainfall ranges from 8000mm/yr at North Egmont to 1600 mm/yr in New Plymouth.

Fig.27: New Plymouth – google maps

Palmerston North

Region: Manawatu - Wanganui

Gauging station: Palmerston North Ews

Elevation: 21 m

The city is situated on the banks of the Manawatu River and at the foot of the Tararua Mountain Range. The mean annual rainfall is 960mm/year . Winters are generally cooler than in Wanganui and New Plymouth and it is also the most unsettled time of the year. Palmerston North is also more cloudy then the cities closer to the Tasman Sea.

Fig.28: Palmerston North – google maps

Taupo

Region: Waikato

Gauging station: Turangi Ews

Elevation: 375m

In the heart of the most active volcanic zone, Lake Taupo experiences a temperate climate with slightly cooler temperatures then the rest of the North Island. The region is sheltered by high country to the south and to the east.

Fig.29: Taupo – google maps

Wanganui

Region: Manawatu-Wanganui

Gauging station: Wanganui Spriggens Park Ews

Elevation: 15m

This region is very exposed to the weather fronts coming from the Tasman Sea. The precipitation is quite stable throughout the whole year, with peaks in the autumn and winter.

Fig.30: Wanganui – google maps

Whangarei

Region: Northland

Gauging station: Leigh 2

Elevation: 27m

Whangarei is located in the subtropical climate zone. Rainfall varies in-between coastal areas and inland areas. The mean annual rainfall reaches around 1600 mm/year.

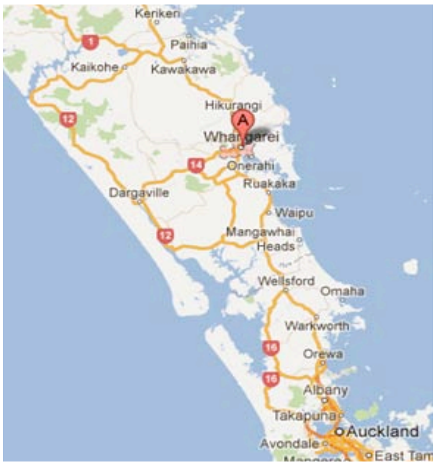


Fig.31: Whangarei – google maps

Wellington

Region: Wellington region

Gauging station: Wallaceville Ews

Elevation: 56m

Located on the south coast of the northern island, the city is windy all year round with high rainfall. The region enjoys a temperate climate, with an absence of temperature extremes. June and July are usually the wettest months. Snow is very rare but can occur, but frosts are quite common between May and September.

Fig.32: Wellington – google maps - http://maps.google.at/maps?hl=en&tab=wl

South Island

Alexandra

Region: Otago

Gauging station: Ranfurly Ews

Elevation: 450m

Due to the fact, that Alexandra is the district with the farthest from a coastline, it experiences a very dry oceanic climate and can be considered as semi-arid. Temperatures can drop below zero in winter and rise above thirty degrees in the summer. Otago is surrounded by mountains and high plateau country, which act as a barrier against coastal moisture-laden winds. These winds shed their water before reaching inland. Therefore central Otago is one of the driest regions in New Zealand.

Fig.33: Alexandra– google maps

Christchurch

Region: Canterbury

Gauging station: Lincoln Broadfield

Elevation: 18m

The city is situated in the east of the southern island. It has a dry, temperate climate, which is also described as an oceanic climate. Snow occurs once or twice a year. The climate is also strongly influenced by the Southern Alps to the west. The mean annual rainfall is in general low and dry spells in the summer are likely to occur.

Fig.34: Christchurch– google maps

Dunedin

Region: Otago

Gauging station: Musselburgh Ews

Elevation: 94m

Due its proximity to the Pacific Ocean, the weather conditions vary throughout the whole year. In general, the climate can be described as temperate. Infrequent snowfall can occur in winter. Dunedin is well known for light rain or drizzle, heavy rain is however relatively rare.

Fig.35: Dunedin– google maps

Franz Josef

Region: Westcoast

Gauging station: Franz Josef Ews

Elevation: 80m

Franz Joseph Glacier is located only two hundred meters above sea level, in a mountainous area and therefore subjected to great variations in its weather patterns. The glacier can experience all four seasons in one day. The West Coast is well known for its untamed rainy weather.

Fig.36: Franz Josef– google maps

Greymouth

Region: West Coast

Gauging station: Aero Ews

Elevation: 5m

In general, the climate on New Zealands West Coast is described as Maritime Temperate. The climate greatly depends on its exposure to weather systems from the Tasman Sea and the mean annual rainfall is very high.

Fig.37: Greymouth– google maps

Hanmer Forest

Region: Canterbury

Gauging station: Hamner Forest Ews

Elevation: 363m

The mountains to the west give Canterbury a climate of greater extremes than most other parts of New Zealand. Summers are mild and long dry spellings can occur. The mean annual rainfall is low compared to other parts of New Zealand.

Fig.38: Hanmer Forest– google maps

Invercargill

Region: Southland

Gauging station: Tiwai Point Ews

Elevation: 5m

Located in the far south, it is one of the southernmost cities in the world. Despite the fact, that Invercargill is situated in the cloudiest area in New Zealand it has a temperate oceanic climate and a relatively high rain frequency. Snowfall is occasionally seen during the w fig.37: Invercargill– google maps

Fig.39: Invercargill– google maps

Lake Moreaki

Region: West Coast

Gauging station: Lake Moreaki Ews

Elevation: 10m

Lake Moeraki has a humid climate. Typical for New Zealands West Coast, there is no dry season and warm summers with a high mean annual rainfall.

Fig.40: Lake Moreaki– google maps

Lake Tekapo

Region: Canterbury

Gauging station: Lake Tekapo Ews

Elevation: 762m

Lake Tekapo is sheltered by the Southern Alps to the west. The mean rainfall is low and long dry spellings can occur. The rainfall increases significantly towards the Alps.

Fig.41: Lake Tekapo– google maps

Manapouri

Region: Southland/Fjordland

Gauging station: West Army Jetty

Elevation: 178m

The mean annual rainfall increases dramatically towards the Alps and microclimates are very likely in this region (e.g. mean annual rainfall in Milford Sounds is around 6700mm/yr. whereas 1100mm/yr in Manapouri).

Fig.42: Manapouri– google maps

Mount Cook

Region: Canterbury

Gauging station: Mt. Cook Ews

Elevation: 765m

Heavy snowfalls, low temperatures and high winds are typical for this mountainous area. During the winter ice fields and snow start at 1000-1100 meters. In summer, anticyclones can bring settled weather.

Fig.43: Mt. Cook– google maps

Nelson

Region: Nelson

Gauging station: Appleby2 Ews

Elevation: 18m

The climate in Nelson is Mediterranean. The climate zone is sheltered by high country to the west and south and in some regions as well in the east.

Fig.44: Nelson– google maps

Takaka

Region: Tasman

Gauging station: Takaka Ews

Elevation: 20m

Takaka is located close to the Golden Bay in Tasman. The climate is moderate, but due to the hilly landscape different microclimates are very likely. The mean annual rainfall is around 2000mm/yr. which is significantly higher than in Nelson.

Fig.45: Takaka– google maps

Region: Canterbury

Gauging station: Winchmore Ews

Elevation: 160m

Timaru has a dry, temperate climate, which is very similar to Christchurch. Summers are warm and some snow can occur in winter. The mean annual rainfall is around 700mm/year, which is very similar to other cities on the East Coast (e.g. Dunedin and Christchurch).

fig.46: Timaru – google maps

Westport

Region: West coast

Gaugin station: Reefton Ews

Elevation: 198m

Situated on the west coast, the climate is mainly influenced by the precipitation of the Tasman Sea. Even though the mean annual rainfall is relatively high, dry spells in summer can occur.

Fig.47: Westport– google maps

2.3.2 Soil erosion and conservation policy in New Zealand

The soil conservation initiative in New Zealand started around 1930 linked to recent interest in soil conservation in the United States at this time. This also provoked the development of early soil conservation legislation, e.g. the Soil Conservation and Rivers Control Act 1941 and the Water and Soil Conservation Act 1967. In the last two decades, there was a growing interest in the occurrence of soil erosion in New Zealand. Even though it is declared as a natural hazard, the “visible” impacts usually affect open land rather than it is a thread for humans, such as landslides or floods. Soil erosion is much more considered as a whole process then one single event.

Especially on the South Island, most of the quantitative data on erosion rates refer to sediment yield from mountain or forest land rather than to soil erosion. Much of the recent studies deal with the increasing concern in downstream problems such as flood control, reservoir sedimentation and highway damage by mass movements, rather than with loss of soil as an agricultural resource.

This might be the one of the reasons, that the Act of 1941 is not repealed/ renewed (Mather, 1982), until 1991. The Resource Management Act 1991 (RMA) is the current overarching legislation for resource management and sustainability in New Zealand. Since 2001, the Ministry for the Environment also provides a Soil Conservation Handbook, which represents the best current practice in the field of soil conservation in New Zealand.

2.3.3 Limitations of the Revised Universal Soil Loss Equation

The wide use and the minimal data input to operate this model has faced a lot of criticism. Researches state, that the RUSLE equation should not be used outside its original context, because it has not been tested and neither validated for New Zealand. Another major concern is that the equation only includes sheet and inter-rill erosion (Kinell, 2010) and is therefore not applicable for mass movements, gully erosion as well as channel erosion. Despite this criticism, the equation still can be used for highlighting spatial R-factor values within the country. Deriving results have to be interpreted carefully and the limitations of the model should always be considered in the background. (Shearer, 2011)

2.4 Database and Calculation of the Rainfall Erosivity

For this study, 29 gauging stations all over New Zealand were analysed, 14 on the North Island and 15 on the South Island. In total 328 years, 163 years on the North Island and 165 years on the South Island were considered. For every station, the following parameters were calculated:

- mean monthly, seasonal and annual rainfall
- average number of storms
- mean monthly, seasonal and annual EI30
- EI30 (%) within the seasons
- single storm energy
- mean monthly and annual max. 30 minutes Intensity

The measurement period of in average less than 15 years is not sufficient for determining a reliable long-term R factor analysis. For the USLE and RUSLE, a period of at least 22 years is recommended (Renard et. al, 1997). In accordance to Verstraeken, 2006, it is not possible to predict a long – term mean value of rainfall- erosivity (R-factor) with less than the recommended amount of years (e.g., 10 years).

Since the (R)USLE is not commonly used in New Zealand and there are not a lot of records about R-factor calculations, the available rain data for the last 10-15 years is analysed to create the first attempt of spatial distributed R-factor calculations. Missing months are replaced by the monthly average and highlighted in the calculation sheets. The rainfall runoff- erosivity factor for New-Zealand's climatic regions is calculated and temporal evolution in annual rainfall erosivity are analysed over the whole year. Differences in between the seasons are shown as well as differences between the different climatic regions. In addition, the single storm energy and the 30 minutes Intensity distribution in the country are analysed as well.

Due to the Islands rapidly changing landscape and influences from the Tasman Sea as well as the Pacific Ocean, it is not possible to determine one generally accepted R-factor for the whole country, not even for one Main Island. Therefore the country was divided in its climatic regions to get a relation between the mean annual precipitation and the mean annual erosion rate (climatic regions established by NIWA).

2.4.1 NIWA

The National Institute of Water and Atmospheric Research (NIWA) offers free access to climate data for gauging stations all over New Zealand, which are used for all the further calculations.
(http://cliflo.niwa.co.nz/ → a login is necessary! The download is restricted to 2.000.000 rows for one user.)
In order to achieve a good spatial distribution (to cover more or less the whole country = 268.680 $km^{2,}$ without the smaller Islands around the main land) as well as a long time period of data, the most representative gauging stations were chosen. NIWA provides special data sets and a ten minute rainfall data set is available for a lot of gauging stations all over the country. In average, gauging stations take 10 minute rain records since the last ten to fifteen years. This time period is too short to achieve a statistical trend analysis, but long enough to see changes concerning the yearly rainfall amount, the30 minutes Intensity as well as the investigated rainfall erosivity values. The results derived from the 10 minute data were compared with the mean monthly and annual rainfall over the last 20 years provided by NIWA.
(http://www.niwa.co.nz/education-and-training/schools/resources/climate/meanrain).
In order to make a statement about maxima's, the analysed annual rainfall was compared with the mean annual rainfall from the last 20 years. Extreme values, which exceeded the frequency of the last 20 years, were excluded from all further calculations, in order not to adulterate the demanded empirical parameters.
To analyse the rainfall data and to calculate the kinetic energy, the RIST (Rainfall Intensity Summarization Tool) program is used.

2.4.2 RIST

The Rainfall Intensity Summarization Tool is a Windows based program to analyze precipitation records. It was developed by the USDA – ARS National Sedimentation Laboratory, United States Department of Agriculture. The actual 3.5 Version is applicable for input to runoff, erosion and water quality models including the RUSLE (http://www.ars.usda.gov/Research/docs.htm?docid=3251).
The standard RUSLE outputs include a storm-by-storm summary, duration, intensity, kinetic energy as well as the EI30. Depending on the designated output, storms with less than 10 mm or 0.5 inches were excluded from the intensity calculations, even though other studies have shown that by changing the threshold to 0mm, the R-factor increases by no more than 3.5 – 5%. (McGregor et al., 1995; Lu and Yu, 2002) Furthermore, a storm period over 6h was used to divide a longer storm period into two storms.

As energy equation, Brown and Foster, 1987 was used:

$$e = 0{,}29\,(1-0{,}72e^{(-0{,}05i)}) \qquad (9)$$

e=energy

i= intensity

The output file was opened in Microsoft Excel, where all the further calculations took place.

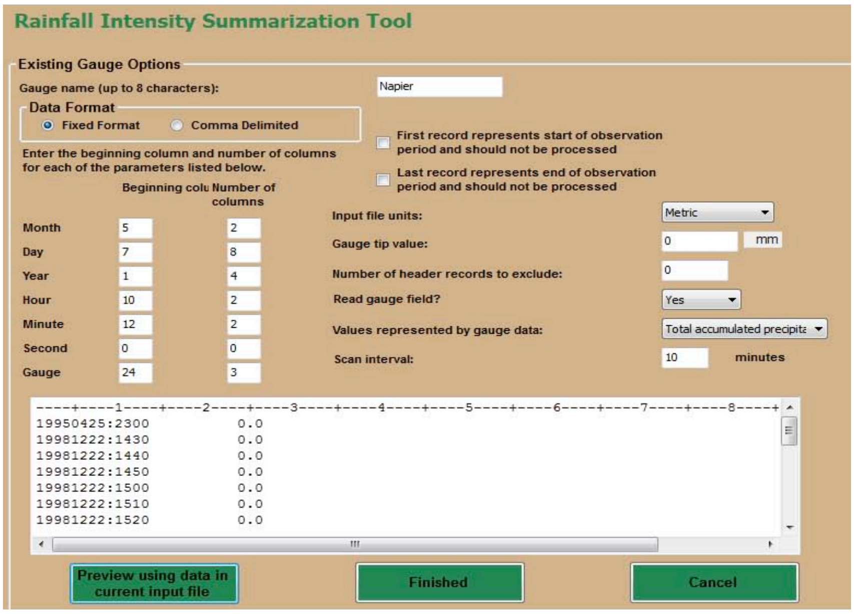


Fig.48: Screenshot Input – file, RIST

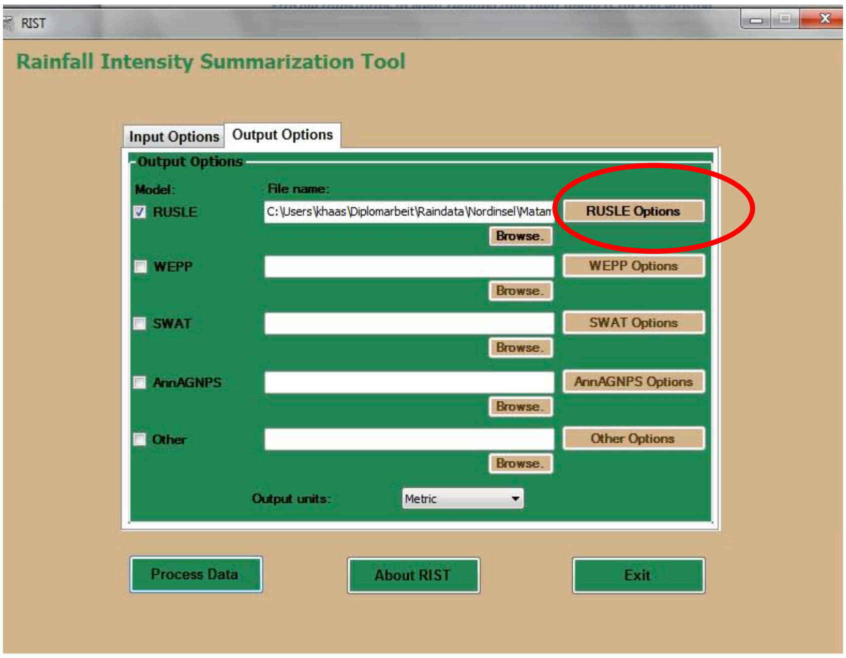


Fig.49: Screenshot Output-options, RIST

2.4.3 Excel

The factors E and I_{30} were determined by the RIST program, as well as the amount of precipitation, duration and the max.5-min, 15-min, 30-min and 60-min Intensity.

The total storm kinetic energy for a single rain event (E_i) is calculated as follows:

$$E_i = \sum_{r=1}^{o} e_r \, \Delta V_r \qquad (10)$$

e_r = rainfall kinetic energy per unit depth of rainfall per unit area (MJ ha1 mm1) = R-factor

DVr = depth of rainfall (mm) for the increment of the storm, which is divided into m parts, each one with basically constant rainfall. (Bonilla and Vidal, 2011)

The mean annual rainfall and runoff factor (MJ mm ha^{-1} h^{-1} yr^{-1}) is derived by summing up the product of the total kinetic energy and the maximum 30-min rainfall intensity for all rainstorms during n number of years. (Klik, 2011)

$$R_i = \frac{1}{n} \sum_{j=1}^{n} \left[\sum_{k=1}^{m_j} (E)_k \, (I_{30})_k \right]_j \qquad (11)$$

E = total storm kinetic energy (MJ ha1)

I30 = maximum 30-min rainfall intensity (mm h1)

j = index of the number of years used to calculate the average

k = index of the number of storms/year

n = number of years used to gain average R

m = number of storms/year

In the calculation file, the precipitation (mm) was summed up for every month, year and the four different seasons, to evaluate eventual existing trends and to compare the mean annual precipitation with the mean annual rainfall erosivity. Also the average number of storms exceeding 10mm/ year was computed.

For the R-factor calculations all storms exceeding 10 mm or an I_{30} > 10 mm h^{-1} (European Standards) were considered, as previously stated, other storms won't get considered as erosive in this thesis. The results were again summed up for each month, year and the different seasons, in order to get the average R-factor value for each year. Furthermore, the percentage of erosion in each season was determined and the maxima highlighted to analyse the season, where rainfall erosivity is most likely to occur with the overall highest percentage.

Based on the R-factor calculations, the average of the results was taken to derive the single event energy for all 29 sights.

For the I_{30} calculations, the average of the I_{30} > 10 mm h^{-1} was taken.

To make the visible comparison for all sights more easily, an overview for the North and South Island was created. The red highlighted results represent the seasonal maximums, which can be compared to the seasonal erosion percentage.

Table 1: screenshot outputfile excel

	annual precipitation (mm)																	
year	january	february	march	april	may	june	july	august	sept.	oct.	nov.	dec.	sum	dec*.-feb.	mar.-mai.	jun.-aug.	sept.-nov.	nr.of storms
1996																		
1997																		
1998																		
1999																		
2000																		
2001				9.00	61.40	42.40	57.80	82.40	9.80	56.40	94.20	116.80				182.60	160.40	14.0
2002	53.00	29.60	33.60	54.00	26.60	95.20	99.40	56.00	43.60	39.20	82.60	39.80	652.60	199.40	114.20	250.60	165.40	21.0
2003	43.00	13.20	10.60	31.40	17.40	82.30	34.60	42.80	114.60	97.80	57.00	15.00	559.70	96.00	59.40	159.70	269.40	19.0
2004	80.00	236.80	35.80	47.80	41.80	100.80	89.20	151.80	68.40	51.80	47.60	208.80	1160.60	331.80	125.40	341.80	167.80	35.0
2005	74.00	11.80	125.80	49.60	78.00	49.40	55.80	19.20	33.60	82.20	17.20	53.20	649.80	294.60	253.40	124.40	133.00	18.0
2006	38.20	40.20	54.00	61.60	83.40	109.20	215.00	111.20	17.60	121.60	73.20	65.00	990.20	131.60	199.00	435.40	212.40	26.0
2007	29.60	10.80	41.20	39.20	4.20	55.20	79.80	34.00	45.40	114.00	38.40	76.80	568.60	105.40	84.60	169.00	197.80	21.0
2008	17.80	19.00	41.80	90.60	84.50	88.20	145.40	103.00	26.20	64.80	13.40	77.20	771.90	113.60	216.90	336.60	104.40	29.0
2009	3.80	144.00	29.20	31.20	177.40	74.80	47.60	47.00	31.60	96.00	78.60	20.20	781.40	225.00	237.80	169.40	206.20	22.0
2010	73.80	10.80	37.00	11.20	117.40	95.20	82.60	136.80	81.20	35.40	30.60	26.20	738.20	104.80	165.60	314.60	147.20	22.0
2011	78.40	15.00	54.80	84.60	46.60	62.00	52.60	103.00	35.20	116.40	70.00	106.60	825.20	119.60	186.00	217.60	221.60	21.0
average	49.16	53.12	46.38	46.38	67.15	77.70	87.25	80.65	46.11	79.60	54.80	73.24	769.82	172.18	164.23	245.61	180.51	23
max	80.00	236.80	125.80	90.60	177.40	109.20	215.00	151.80	114.60	121.60	94.20	208.80	1160.60	331.80	253.40	435.40	269.40	
min	3.80	10.80	10.60	9.00	4.20	42.40	34.60	19.20	9.80	35.40	13.40	15.00	559.70	96.00	59.40	124.40	104.40	
Median	48.00	17.00	39.10	47.80	61.40	82.30	79.80	82.40	35.20	82.20	57.00	65.00	755.05	125.60	175.80	217.60	167.80	
standard dev	27.13	76.17	30.59	26.19	49.54	22.53	52.28	43.90	30.72	31.66	27.39	56.05	188.05	86.05	65.97	98.41	46.39	

Table 2: screenshot overview North Island

Gauging station	latitude	longitude	altitude (m)	data period	years	av. no. of storms	rainfall annual (mm)			rainfall - spring (mm)			rainfall - summer (mm)		
							average	max	min	average	max	min	average	max	min
Auckland -Pukekohe	-37.20637	174.86384	88.00	97-2011	14	32	1114.23	1624.10	278.20	293.71	532.50	177.60	215.89	375.60	121.60
Gisborne - Motu	-38.28566	177.52941	488.00	00-2011	11	46	2042.64	2434.80	1620.20	526,55	1055.80	352.00	425.19	685.60	303.40
Hamilton - Ruakura	-37.77879	175.31271	40.00	97-2011	14	37	1087.71	1384.60	734.60	252.94	353.20	152.00	244.83	429.20	87.60
Kaitaia - Kaitaia	-35.135	173.262	85.00	99-2011	12	32	1359.58	1643.20	1068.80	285.55	487.60	195.00	289.38	487.60	195.00
Martinborough - Martinborough	-41.25231	175.38985	20.00	2002-2011	9	23	769.82	1160.60	559.70	180.51	269.40	104.40	172.18	331.80	96.00
Matamata - Hinuera	37.87683	175.735	106.00	99-2011	12	33	1002.88	1409.80	706.00	238.54	330.00	104.20	239.85	455.80	87.20
Mt. Ruapehu - Chateau	-39.1977	175.54491	1097.00	2001-2011	10	59	2698.14	3463.90	2155.80	809.73	1113.20	590.60	640.36	1148.20	352.20
Napier - Whakatu	-39.61	176.912	5.00	1998-2011	13	14	719.48	882.80	428.60	137.84	246.20	49.80	146.00	369.20	35.40
New Plymouth - Stratford	-39.33726	174.30487	300.00	2003-2011	8	50	1862.76	2463.80	1183.00	436.44	704.60	14.00	435.18	867.60	230.60
Palmerston North - Palmerston North	-40.38195	175.60915	21.00	2002-2011	9	33	992.76	1354.80	649.20	288.91	366.20	165.00	234.40	439.20	131.80
Taupo - Turangi	-38.995	175.812	375.00	97-2011	14	43	1486.09	1974.80	1118.00	404.81	546.20	280.20	332.19	590.00	208.60

Gauging station	rainfall - autumn (mm)			rainfall - winter (mm)		
Auckland -Pukekohe						
Gisborne - Motu	average	max	min	average	max	min
Hamilton - Ruakura	277.69	532.60	174.40	368.36	648.80	146.60
Kaitaia - Kaitaia	449.82	822.40	272.00	662.22	945.20	443.60
Martinborough - Martinborough	244.56	395.00	145.00	338.35	546.00	187.80
Matamata - Hinuera	351.94	501.20	148.20	425.05	559.00	291.60
Mt. Ruapehu - Chateau	164.23	253.40	59.40	245.61	435.40	124.40
Napier - Whakatu	240.25	398.40	86.00	267.03	394.40	161.60
New Plymouth - Stratford	522.71	733.00	378.60	769.59	1150.40	497.60
Palmerston North - Palmerston North	191.96	341.20	50.40	237.93	322.00	163.60
Taupo - Turangi	416.27	673.00	96.80	596.84	870.20	427.60
	182.32	309.40	125.40	285.96	411.20	188.40
	310.16	558.60	189.00	451.44	728.00	268.40

2.4.4 Geographic Information Systems

Due to the additional rainfall analysis and the erosion prediction, enough point estimations were now available to create an annual precipitation and a R-factor map in GIS.

In order to compare the spatial distribution of the annual rainfall depth and the annual rainfall erosivity, two maps were created. One mean annual precipitation map and one mean annual rainfall erosivity map. For both of them the interpolation method "universal kriging" was used. Kriging can be explained as a group of geostatistical techniques to interpolate the value of a random point at an unobserved location from observations/ predictions/ calculations of values nearby. Next to Kriging, interpolation methods such as: inverse Distance Weighting, smoothed splines , Splines with tensions, simple kriging, ordinary kriging, ordinary kriging with anisotropy and many more are commonly used by mapping environmentally important parameters.

Erosion mapping is also an important point for large-scale soil erosion assessments, soil conservation management of natural resources, agronomy and agrochemical exposure risk assessments (Winchell et al., 2008).

With the advantage of GIS and the generalization of spatial interpolation techniques, maps of the main environmental parameters such as the R-factor, relevant for determining the soil erosion have become common. Many authors have used GIS applications to map the factors of the (R)USLE equation by using different interpolation methods (Shi, 2004; Lim, 2005; Mutua, 2006; Lopez-Vicente et al., 2008). Recent studies showed a keen interest in finding the method with the best adjustment to the observed/available data. There are already a few studies comparing between interpolation techniques for rainfall erosivity indices.

3. Results and Discussion

3.1 Rainfall

New Zealand is located in the Pacific Ocean, with the Tasman Sea on the West Coast and the Pacific Ocean on the East Coast. The topography as well as the exposure to the sea leads to tremendous rainfall, especially on the South Island's West Coast. Due to the Southern Alps, the rain arriving from the Tasman Sea breaks down before it reaches the inland, which results in a very high rainfall variability from the West to the East Coast.

As mentioned before, the high 10 minute resolution data is only available for the last 10-15 years, depending on the gauging station. As this is not a sufficient time period to make a statistical analysis, the results were compared with the mean annual rainfall over the last 20 years provided by NIWA. With this comparison, it is possible to discover, any annual maxima in the calculated time period, which exceeds the frequency of the last 20 years.

This case happened eleven times, at four sites on the North Island (Wellington (2004, 2006 and 2008), Kaitaia (1999), Martinborough (2004) and Palmerston North (2004) as well as at four sites on the South Island (Christchurch (2006), Dunedin (2000), Invercargill (2004) and Takaka (2004 and 2011). All the values were excluded from further calculations, as they could adulterate the parameters for the predicted erosion!

Unfortunately a comparison for Mt. Ruapehu and Taupo was not possible, because of a lack of similar gauging stations with the more or less the same altitude, nearby.

In general, the mean annual precipitation on the North Island ranges between 719.48 mm/year in Napier up to 2698.14 mm/year at Mount Ruapehu with the most precipitation in winter, except at Mount Ruapehu, where the most precipitation occurs in spring. The average annual precipitation for the North Island is 1331.9 mm/year.

On the South Island, the results are not as uniform as on the North Island. The mean annual precipitation is located between 418.24 mm/year in Alexandra and 4180.59 mm/year in Franz Josef with a mean annual precipitation of 1807mm/year. In comparison to the North Island, there is no peak season, where the majority of the annual precipitation is likely to occur. It seems like that on the West Coast, rainfall tends to be higher in summer than in winter, compared to the East Coast where no such trend could be identified. In general, the erosion is higher in summer than in winter, due to more heavy rainfall with higher energy and also because snow counts as precipitation, which has only a very low energy.

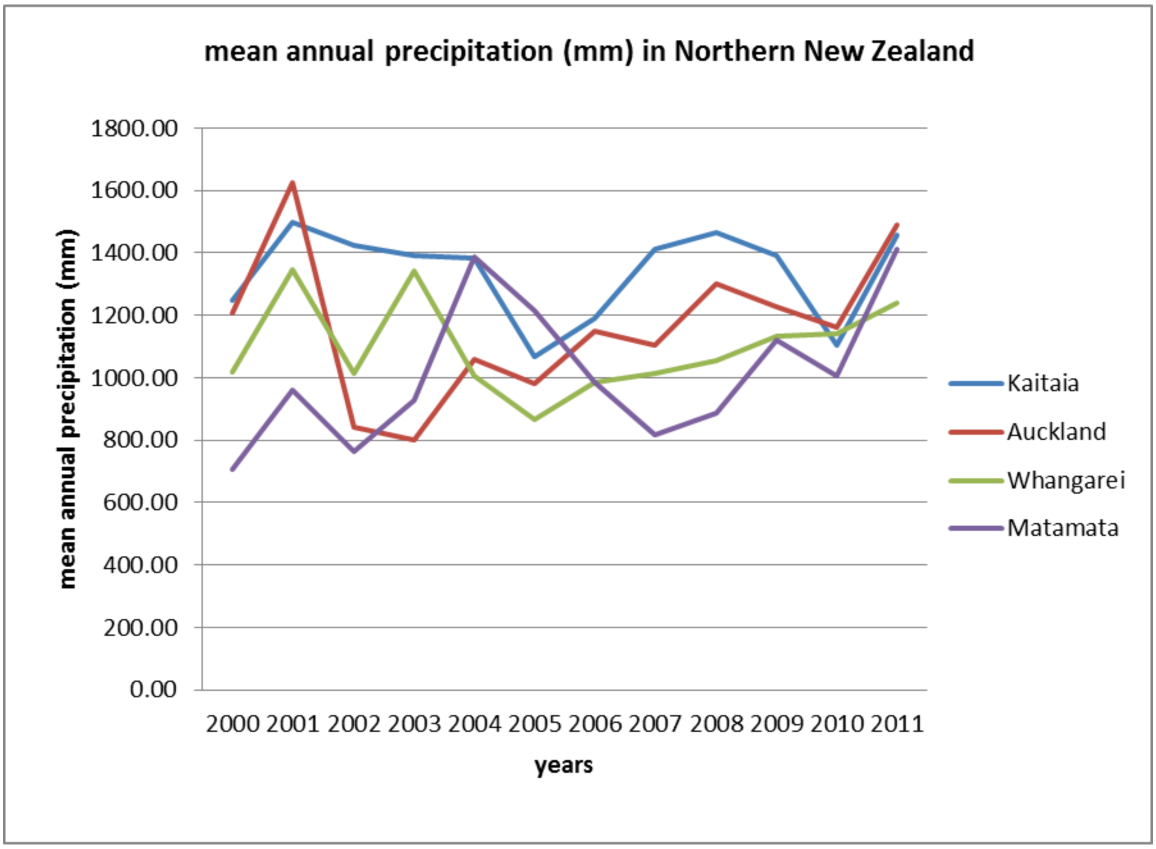


Fig.50: e.g. mean annual precipitation Northern New Zealand

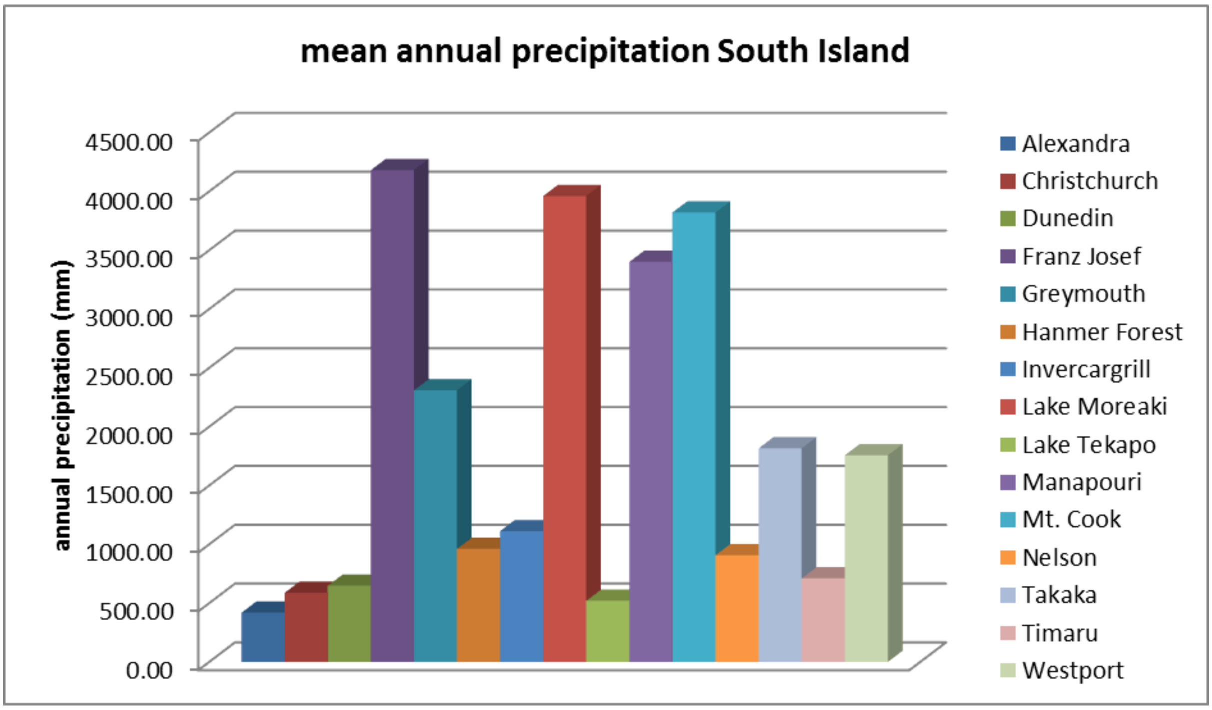


Fig.51: overview mean annual precipitation South Island

It is very well known, that the West Coast on the South Island gets the most rainfall in the whole country. Except Manapouri, all gauging stations with more than 2000mm/year belong to this area as well as Westport with an annual precipitation around 1500 mm/year. It has to be noticed, that the analysed gauging station in Westport has a much lower mean annual precipitation than the 20-years average, which is around 2150 mm/year.

Overall, the rainfall on the North Island has a lower variability than on the South Island, shown by the lower standard deviation (tab.3). It is also remarkable, that on the North Island the rainfall seems to increase with the altitude, correlation = 87% (fig.51), whereas no such correlation could be investigated for the South Island. The same phenomenon arises with the R-factor (fig. 52), but with less correlation for the North Island (54%). The gauging stations on the North Island are located between 5 and 1097m above sea level and on the South Island from 4 up to 765m above sea-level.

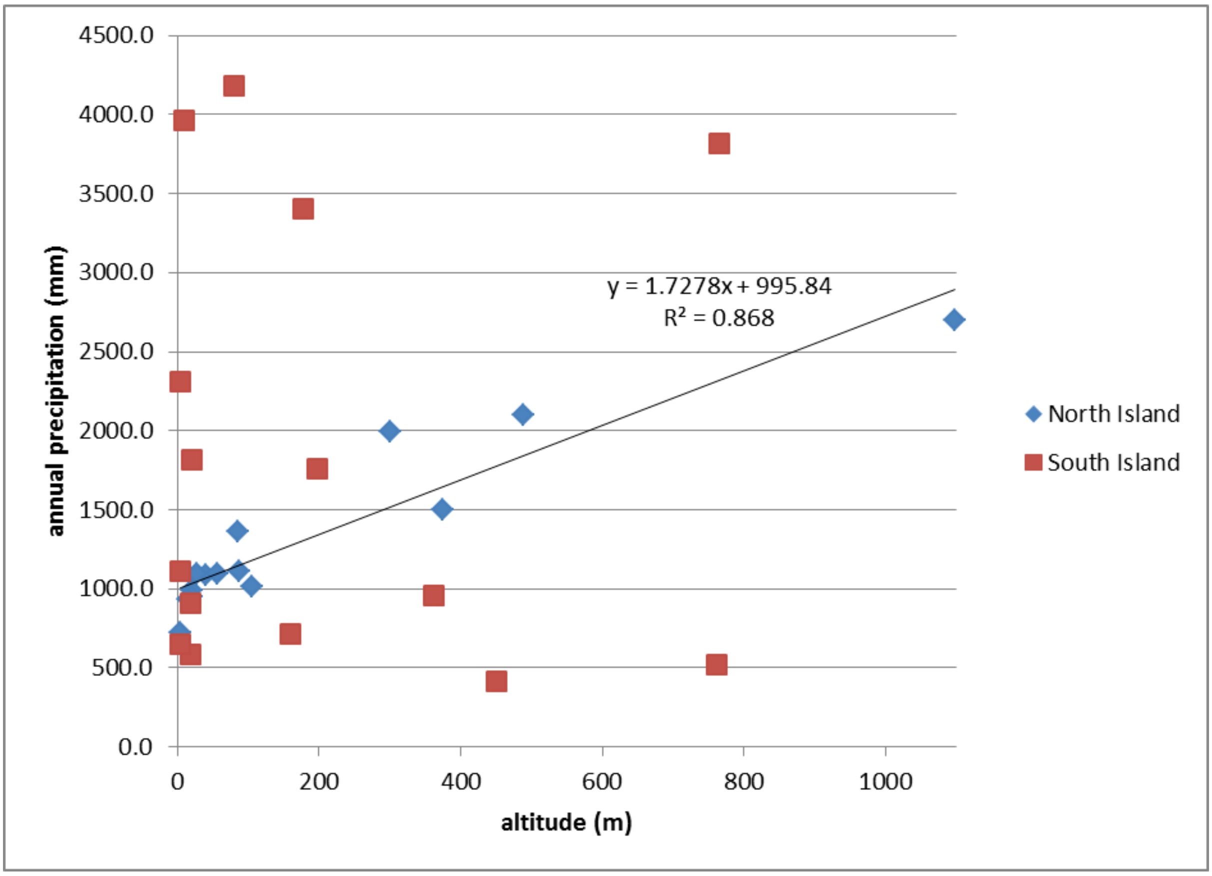


Fig.52: relationship between altitude (m) and the annual precipitation (mm)

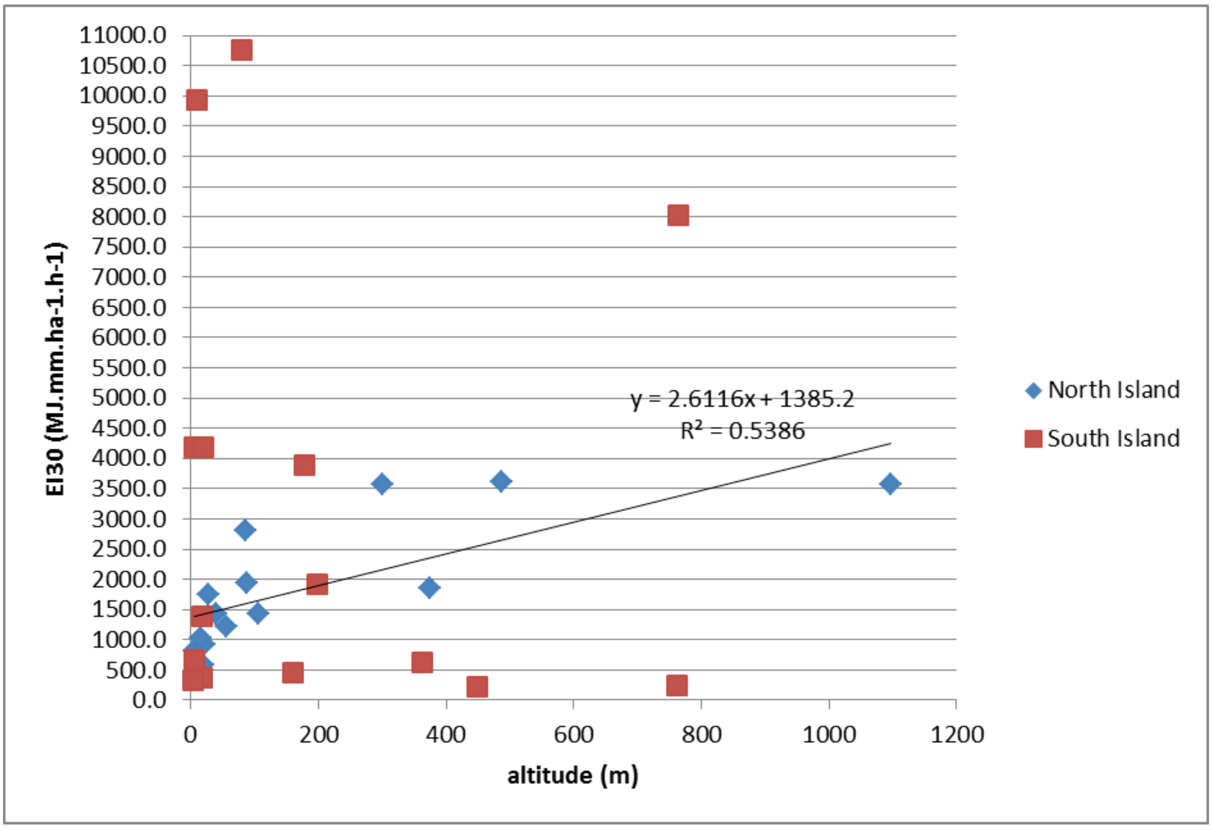


Fig.53: relationship between altitude (m) and the annual EI30 (MJ.mm.ha-1.h-1)

The mean rainfall results for the investigated stations are almost identic then the results for the last 30 years, measured by NIWA. On the North Island, a conspicuous difference in Gisborne, Taupo and New Plymouth was noticed. The reason for that, are the different locations from the gauging stations (Fig.53). On the South Island, the stations in Westport, Mt. Cook and especially Manapouri have shown high differences in the average annual precipitation. (Fig.54)

The green pins mark all NIWA stations and the purple ones all the investigated sites.

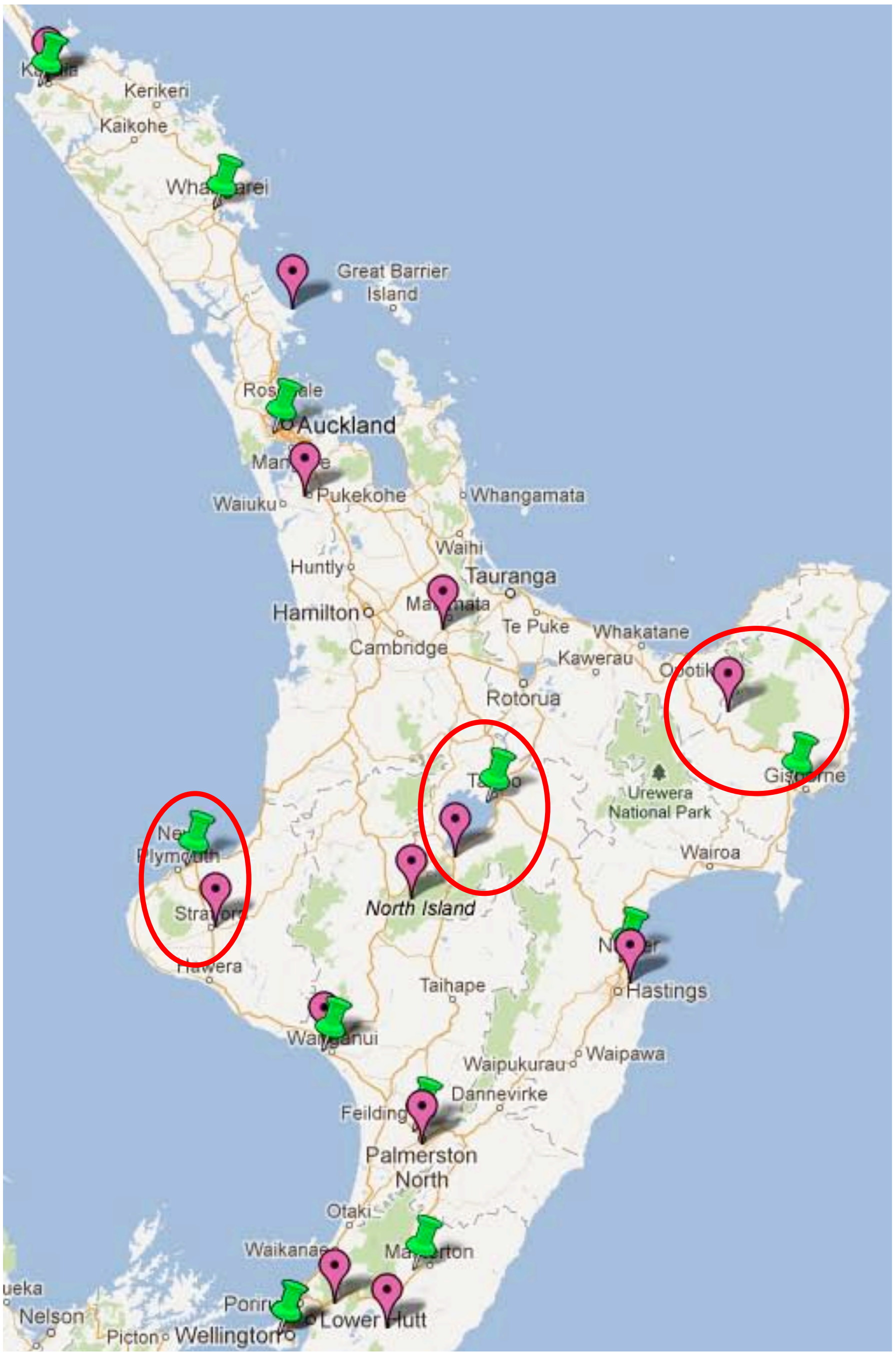


Fig.54: overview comparison gauging station NIWA and analysed 10min data – North Island, my places https://maps.google.co.nz/

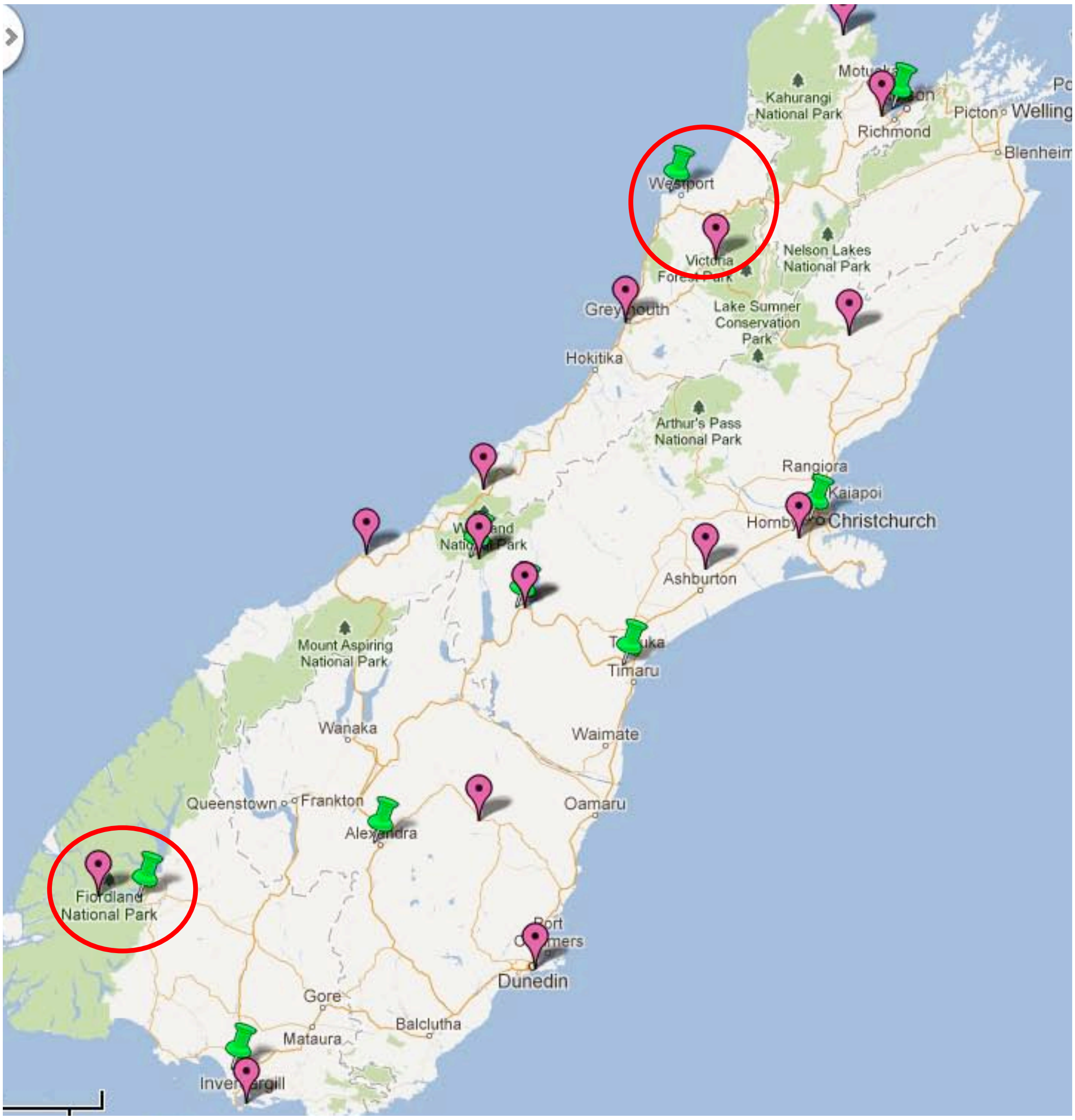


Fig.55: overview comparison gauging station NIWA and analysed 10min data – South Island my places https://maps.google.co.nz/

The differences in Manapouri are simple to explain, due to the fact that the rainfall dramatically increases towards the South Alps. The distance between the two stations is around 30 kilometres which explains a yearly precipitation distinction from around 2000mm/ year. The NIWA stations in Westport is much more exposed to weather fronts coming from the Tasman Sea, whereas the investigated station is more sheltered (forest park). Therefore the yearly difference from around 400mm/ year makes sense. All other annual rainfall distinctions and monthly differences are shown in table 4.

Table 3: Overview North Island

station	nr.of	P	R	Rss	I_{30}
	storms	(mm)	(MJ*mm/ha*h)		
North Island					
Auckland	37	1114.2	1940.4	52.4	10.7
Gisborne	47	2099.8	3607.5	76.8	10.6
Hamilton	37	1087.7	1429.1	38.6	10.3
Kaitaia	41	1359.6	2807.5	68.5	12.5
Martinborough	23	990.2	575.5	25.0	8.0
Matamata	33	1013.4	1435.9	43.5	10.3
Mt.Ruapehu	62	2698.1	3567.2	57.5	8.7
Napier	19	719.5	813.5	42.8	9.1
New Plymouth	50	1994.3	3565.7	71.3	10.5
Palmerston North	33	952.5	914.0	27.7	8.8
Taupo	42	1498.4	1857.7	44.2	9.0
Wanganui	32	931.3	1028.5	32.1	9.7
Wellington	38	1091.3	1223.2	32.2	8.7
Whangarei	33	1096.0	1738.0	52.7	11.1
average	38	1331.9	1893.1	47.5	9.9
standard deviaton	11	558			

Table 4: comparisons mean monthly rainfall – NIWA and 10min data

Mean monthly rainfall (mm)

Data are mean monthly values for the 1981-2010 period for locations having at least 5 complete years of data

Station details are available in separate table

	NIWA		NIWA		NIWA		NIWA		NIWA		NIWA		NIWA		NIWA		NIWA		NIWA		NIWA		NIWA				
LOCATION	JAN	JAN	FEB	FEB	MAR	MAR	APR	APR	MAY	MAY	JUN	JUN	JUL	JUL	AUG	AUG	SEP	SEP	OCT	OCT	NOV	NOV	DEC	DEC	YEAR	YEAR	Δ
Kaitaia	82.0	98.2	92.5	91.3	82.0	90.7	97.7	107.7	131.9	153.6	149.1	153.2	165.4	159.6	140.0	112.2	126.7	109.2	97.8	94.2	86.2	82.1	99.6	107.6	1349.2	1335.95	-13.21
Whangarei	81.2	87.3	95.2	79.6	118.1	78.2	98.9	69.5	111.2	128.7	131.5	104.1	168.6	128.0	128.4	97.2	112.2	79.8	85.3	80.3	77.1	63.7	96.4	95.7	1317.7	1096.04	-221.65
Auckland	73.3	73.9	66.1	59.3	87.3	67.8	99.4	83.3	112.6	126.5	126.4	122.0	145.1	133.2	118.4	113.1	105.1	94.4	100.2	102.5	85.8	91.4	92.8	101.3	1210.7	1114.23	-96.51
Hamilton	76.3	76.1	68.7	62.4	79.4	72.4	80.3	71.3	99.7	100.9	113.2	121.0	118.2	128.2	103.4	89.2	91.5	85.6	91.9	88.1	85.0	74.5	100.7	113.2	1108.4	1087.71	-20.70
Gisborne	56.2	146.4	71.3	96.8	91.4	110.0	98.2	129.7	101.3	218.5	104.6	249.5	127.7	220.2	76.2	192.5	73.5	182.3	72.5	204.8	67.1	151.0	56.2	182.0	978.7	2099.82	1121.16
Taupo	77.3	105.5	67.9	86.0	66.5	78.7	68.4	102.2	74.9	128.5	92.8	149.8	96.0	155.3	87.4	146.3	81.6	144.3	86.2	147.6	67.9	112.9	93.6	147.1	954.5	1498.44	543.95
New Plymouth	114.5	108.1	85.4	158.9	126.5	122.5	125.4	138.3	97.1	184.5	152.6	215.2	131.1	197.2	117.2	184.5	104.8	205.7	117.8	198.0	100.3	79.7	113.1	187.2	1398.0	1994.34	596.37
Napier	46.8	52.3	54.3	41.1	66.8	48.3	67.9	72.5	74.8	71.2	82.1	79.4	108.3	108.5	60.1	50.0	57.9	44.9	59.9	56.2	52.4	35.6	53.5	55.2	776.0	719.48	-56.51
Wanganui	59.2	63.1	75.5	66.4	62.9	49.4	69.2	73.6	79.5	77.1	88.8	89.2	85.3	89.5	74.4	82.9	73.7	76.0	88.0	96.0	75.4	73.3	86.4	103.1	916.7	931.25	14.57
Palmerston North	55.0	61.3	67.8	81.4	51.8	47.5	65.9	63.3	71.5	73.5	95.1	108.5	82.5	90.1	76.9	87.4	86.1	94.7	96.4	109.5	80.9	84.7	87.5	97.4	919.9	952.53	32.63
Masterton	44.4	80.0	68.9	236.8	84.5	125.8	54.0	90.6	93.6	177.4	105.3	109.2	90.9	215.0	86.7	151.8	73.7	114.6	77.2	121.6	77.5	94.2	70.9	208.8	922.9	990.20	67.29
Wellington	75.7	71.5	69.8	73.2	87.1	66.4	83.6	76.8	112.9	95.6	132.8	126.4	137.5	135.6	113.7	122.5	97.8	103.1	114.9	130.6	97.0	101.2	84.4	101.9	1215.4	1091.32	-124.03
Nelson	76.5	66.2	63.5	54.1	70.8	40.5	80.9	79.5	82.0	92.9	92.7	118.6	77.6	54.7	81.9	70.3	85.1	65.4	87.2	91.4	78.3	61.5	83.6	117.5	950.7	906.50	-44.17
Westport	178.2	123.7	128.9	99.1	158.9	100.1	156.7	132.6	174.2	157.5	212.5	211.8	167.6	137.5	185.0	148.9	187.4	172.4	200.3	197.0	169.0	139.8	203.0	163.9	2154.4	1756.80	-397.63
CHC	38.3	45.3	42.3	36.7	44.8	39.9	46.2	50.1	63.7	71.8	60.9	53.6	68.4	56.7	64.4	67.6	41.1	35.6	52.8	57.0	45.8	49.6	49.5	52.1	618.2	587.56	-30.67
Mt Cook	457.5	329.1	278.4	282.5	417.9	296.5	363.0	295.4	357.1	376.4	314.5	315.2	305.2	227.6	313.4	251.3	297.4	402.5	478.9	306.6	414.2	300.6	487.2	516.3	4491.2	3820.21	-670.95
Lake Tekapo	43.6	37.2	35.9	34.5	48.8	23.0	45.2	39.6	56.5	79.4	60.0	45.7	49.6	41.1	58.4	40.8	50.4	39.4	49.5	42.5	41.3	34.4	52.2	52.2	591.6	519.10	-72.51
Timaru	46.5	66.4	51.7	54.6	47.6	49.1	38.7	56.2	46.6	69.3	38.8	54.9	46.2	68.7	43.8	71.6	36.5	45.4	49.5	60.7	49.6	57.7	52.8	61.7	546.8	717.51	170.73
Alexandra	50.1	46.8	32.8	40.5	29.0	21.0	22.0	34.4	27.4	40.2	31.6	33.4	24.2	17.3	17.6	20.4	20.9	25.3	28.7	35.6	30.6	36.4	44.5	65.7	335.3	418.24	82.93
Manapouri	85.4	324.2	84.3	230.4	86.5	248.4	90.0	255.5	100.9	339.7	101.8	270.5	82.0	279.3	93.9	299.7	100.0	370.8	107.7	281.5	91.1	272.6	105.1	267.4	1092.2	3400.66	2308.51
Dunedin	72.9	64.9	67.8	64.3	64.0	52.0	50.9	46.3	64.7	68.2	57.9	47.7	57.1	48.2	55.7	51.7	48.3	44.0	61.7	54.5	56.4	54.0	80.2	71.3	726.2	647.58	-78.65
Invercargill	115.0	89.3	87.1	77.3	97.4	105.5	95.9	84.4	114.4	108.7	104.0	97.4	85.2	88.7	75.6	77.3	84.2	92.6	95.0	95.1	90.4	103.0	105.0	93.0	1146.6	1082.16	-64.48

3.1.1 number of storms

Concerning the amount of storms, exceeding 10 mm amount or with $I_{30} > 10$ mm.h^{-1} , in average 38 erosive events occur on the North Island and slightly more on the South Island (41). The number of storms on the North Island range from 19 in Napier to 62 at Mount Ruapehu, whereas in the South the minimum on erosive storms occurs in Alexandra (13) and the maximum at Lake Moreaki and Manapouri, each with 73 events a year. The variability of occurrence is therefore much higher on the South Island then on the North Island.

3.1.2 Intensity (I30)

Although the South Island gets in average more rainfall and has a higher number of storms, the intensity is somewhat lower then on the North Island (8.5 to 9.9 (mm.h-1)). This can be explained by the higher snowfall rate in the South Alps, whereas it rarely snows on the North Island (except in the mountains). However, the highest 30min Intensity appeared on the South Island, Lake Moreaki with 13.5 (mm.h-1) and the lowest with 6.2 (mm.h-1) in Hanmer Forest and Dunedin. In general, the areas Canterburry and Otago come up with a very low 30-min Intensity (all around 6.5 (mm.h-1)).

Usually higher rainfall intensity means an increase in rainfall erosivity. Soil erosion and rainfall intensity are related by a power function, which means rainfall intensity increases the erosion potential disproportionately. However, this function seems to fit for the South Island where R^2= 0.86 but on the North Island the data is only with almost 50% correlated to each other.

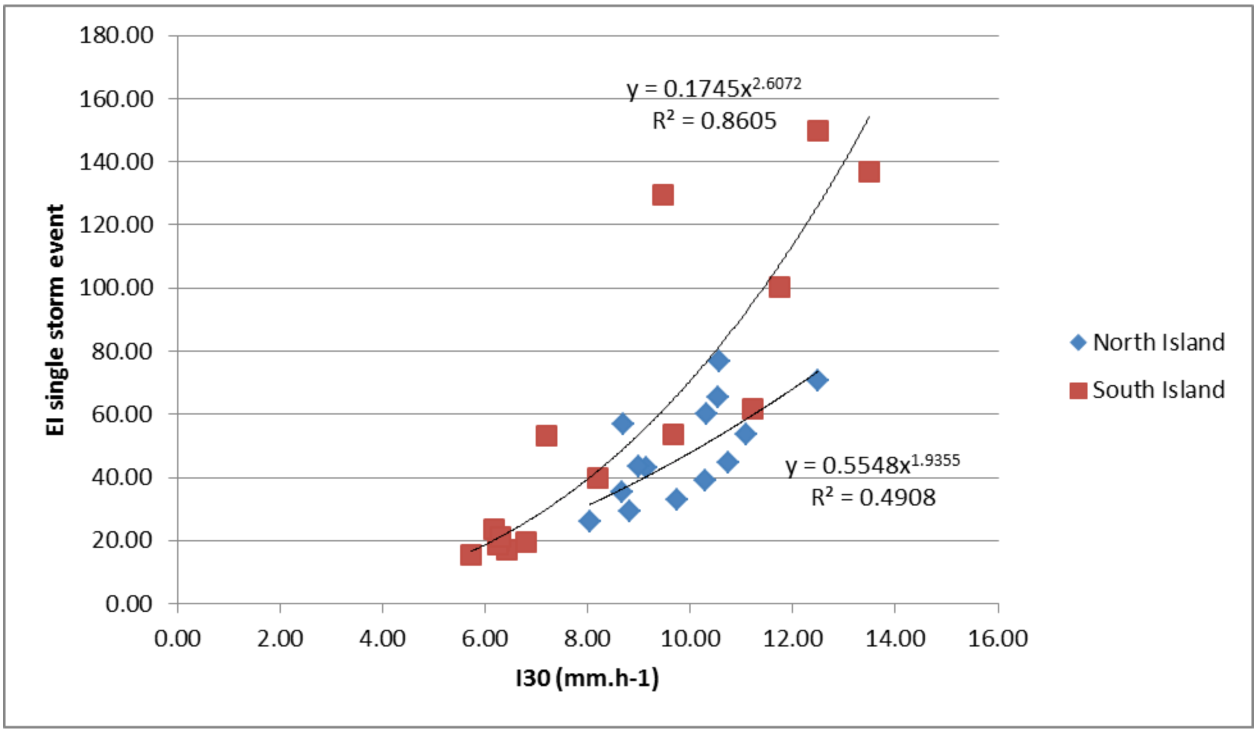


Fig.55: relation I30 – EI single event

On the North Island, the stations in Auckland, Hamilton and Wellington show the same average amount of storms in a year, but differ mainly in the maximum 30 minutes intensity, whereas the mean annual precipitation only varies in a very small amount (+/- 30mm/ year) the rainfall erosivity differs with more than 700 (MJ*mm/ha*h), which can be explained by the different geographic positions. This fact results, that Wellington also has a smaller max. 30 min. Intensity, which means, that the precipitation in Northern New Zealand consists of a higher energy. This might be able to be explained due to the tropical storms arriving from the South Pacific.

The same phenomenon arises by comparing the gauging stations in Matamata, Wanganui and Whangarei. Here, as well, Whanganui consists of the smallest R-factor and has the smallest Intensity. Another comparison can be drawn for e.g. Auckland and Taupo. Both of the stations have almost the same R-factor value, but in Taupo are more single storm events with less Intensity (42 to 37 – 9.0 to 10.7). An even bigger difference shows the comparison between Mt. Ruapehu and New Plymouth.

Table 6: comparison P, R, Rss and I30 – South Island

station	**nr.of**	**P**	**R**	**Rss**	**I_{30}**
	storms	**(mm)**	**(MJ*mm/ha*h)**		
South Island					
Alexandra	13	418.2	220.3	16.9	6.4
Christchurch	19	587.6	371.7	19.6	6.3
Dunedin	18	647.6	331.3	18.4	6.2
Franz Josef	72	4180.6	10756.0	149.4	12.5
Greymouth	65	2308.4	4186.7	64.4	11.2
Hanmer Forest	27	960.6	624.7	23.1	6.2
Invercargrill	35	1112.0	658.2	18.8	6.8
Lake Moreaki	73	3960.8	9942.7	136.2	13.5
Lake Tekapo	15	519.1	235.8	15.7	5.7
Manapouri	73	3400.7	3897.3	53.4	7.2
Mt. Cook	62	3820.2	8023.5	129.4	9.5
Nelson	26	906.5	1378.2	53.0	9.7
Takaka	48	1718.6	3793.5	79.0	11.7
Timaru	21	710.5	461.1	22.0	6.3
Westport	48	1756.8	1922.6	40.1	8.2
average	41	1800.5	3120.2	56.0	8.5
standard deviation	23	1382			

The R-factor for the two stations is almost identic (3567.2 – 3565.7) but at Mt. Ruapehu 62 storms occur within a year with an I30 of 8.7, whereas in New Plymouth only 50 storms a year but therefor with an I30 of 10.5 mm.h^{-1}. This can be explained by the low energy of snow, which is likely to fall at Mt. Ruapehu.

By drawing the comparison of the max. 30 minutes Intensity, the number of storms as well as the R-factor and the mean annual precipitation, the relation between the different climatic regions within the North Island and the South Island are again very obvious.

The most interesting comparison on the South Island is between Manapouri and Takaka. The R-factor values for both stations hardly vary, but the number of storms and the max. 30 minutes intensity show huge differences within their values. Storms in Takaka have a very high Intensity (48 storms – 11.7) whereas the amount of storms at the Lake Moreaki is very high but obviously with a very low Intensity (73 storms – 7.2).

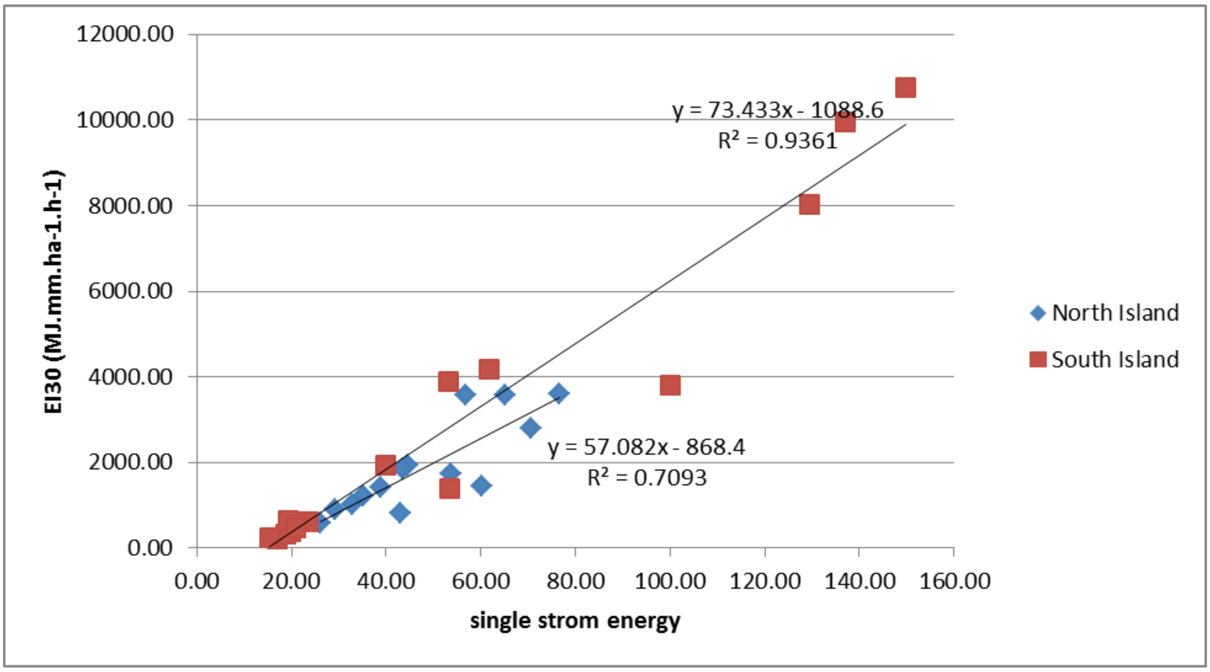


Fig.56. relation single storm energy – EI30

The same case happens between Hanmer Forest and Invercargrill. R-factor values and the max. 30min. intensity don't differ in a broad spectrum, but the amount of storms differ between 27 in Hanmer Forest and 35 in Invercargrill, which simply leads to a higher precipitation amount in Invercargrill.

Also a comparison between Takaka and Westport is quite interesting. Even though the two cities are very close to each other but separated by the Kahurangi National Park, they consist over the same average annual precipitation, but the R-factor for Takaka is way higher (3793.5 to 1922.6) and also the intensity shows quite a noticeable difference (11.7 to 8.2). As earlier explained, the analysed gauging station in Westport is somewhat sheltered and not really exposed to the weather fronts coming from the Tasman Sea, which could be one possible explanation for it.

Again, the South Island shows a better correlation of the results then the North Island (94% to 71%). The now already well-known station in Manapouri lies again outside the trend line, as well as this time the gauging station in Nelson on the South Island.

3.2 R-factor

The calculated R-factors for the North Island range between 532.5 and 3607.5 (MJ*mm/ha*h) with an average of 1893.1 (MJ*mm/ha*h). Compared to the South Island with a minimum of 220.3 up to a maximum of 10756.0 (MJ*mm/ha*h) and an average of 3147.1 (MJ*mm/ha*h). The allover maximum as well as the minimum occurred on the South Island. In 2009, the Mt. Cook gauging station reached a maximum of 14547.46 (MJ*mm/ha*h), the minimum of 65.78 (MJ*mm/ha*h), occurred also in 2009 in Alexandra (tab.5).

For both Islands a relationship between the annual precipitation and the R-factor was created. (Fig. 56 and 57)

North Island: $R = 1.73\ P - 415.79$ $R^2 = 0.8367$

South Island: $R = 2.51\ P - 1390$ $R^2 = 0.8986$

Furthermore, the same relationship was drawn for the different climate regions within New Zealand – therefore see table 5.

R-factor for the different climate zones:

Northern New Zealand: R = 1980.45(MJ*mm/ha*h)

Central North Island: R = 2284.66 (MJ*mm/ha*h)

South West North Island: R = 1682.85 (MJ*mm/ha*h)

Eastern North Island: R = 1665.52(MJ*mm/ha*h)

Northern South Island: R = 2787.19 (MJ*mm/ha*h)

Western South Island: R = 5350.65 (MJ*mm/ha*h)

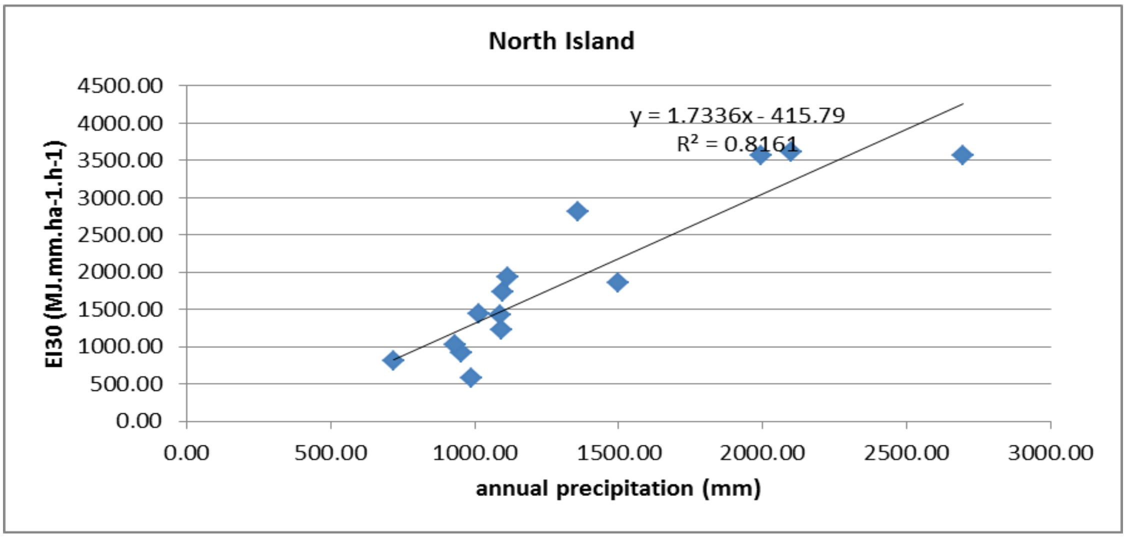
Eastern South Island: R = 485.83 (MJ*mm/ha*h)

Inland South Island: R = 1451.12(MJ*mm/ha*h)

Southern New Zealand: R = 494.75 (MJ*mm/ha*h)

The most rainfall- runoff erosion processes occur in summer, as well as on the North (29%) as on the South Island (34%). Even though the highest precipitation generally is in winter (see table 5), storms in this season are generally less strong (the I30 is way smaller than in summer) and another reason is, that also snow is taken into account, which consists of less energy than rainfall! The distribution is fairly constant among all the analysed gauging stations. Compared to other countries, the erosion rate is almost equally distributed within the season, whereas usually an outstanding maxima is reached in summer, e.g. according to Bonilla and Vidal, in central Chile with more than 60% between May and July and less than 10% from December to March and also in Europe, where usually soil erosion occurs from May to October. The monthly distribution in rainfall erosivity is important as the risk of erosion increases considerably when soil exposure occurs within periods of high erosivity. The calculated R-factors can be directly used for soil erosion estimations for the 29 gauging stations as well as their very close surroundings.

Fig.57 and 58: relationship between annual precipitation and EI30 for the North and South Island



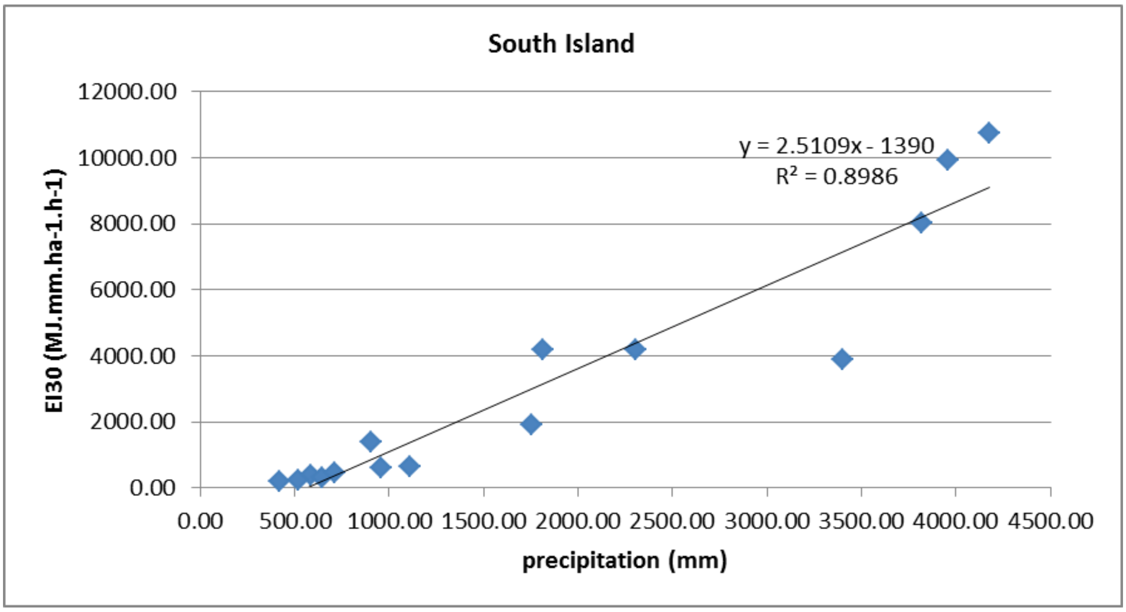


Table 5: Overview North and South Island incl. elevation, data-period, years, nr.of storms, P,R, R(%),Rss and I30

station	elevation (m)	data period	years	nr.of storms	P (mm)	R (MJ*mm/ha*h)	R (%) spring	summer	autumn	winter	Rss	I_{30}
North Island												
Auckland	88	97 - 2011	14	37	1114.2	1940.4	22.3	25.2	28.0	24.6	52.4	10.7
Gisborne	488	00 - 2011	11	47	2099.8	3607.5	23.8	24.8	23.0	28.3	76.8	10.6
Hamilton	40	97 - 2011	14	37	1087.7	1429.1	18.3	32.0	24.8	23.6	38.6	10.3
Kaitaia	85	99 - 2011	12	41	1359.6	2807.5	18.1	26.3	32.8	27.0	68.5	12.5
Martinborough	20	02 - 2011	9	23	990.2	575.5	21.9	38.6	25.7	26.5	25.0	8.0
Matamata	106	99 - 2011	12	33	1013.4	1435.9	17.6	32.6	29.8	20.0	43.5	10.3
Mt.Ruapehu	1097	01 - 2011	10	62	2698.1	3567.2	25.4	33.1	21.7	23.5	57.5	8.7
Napier	5	98 - 2011	13	19	719.5	813.5	16.4	23.7	32.1	27.1	42.8	9.1
New Plymouth	300	03 - 2011	8	50	1994.3	3565.7	20.4	27.6	28.3	21.1	71.3	10.5
Palmerston North	21	02 - 2011	9	33	952.5	914.0	35.1	31.1	20.2	23.5	27.7	8.8
Taupo	375	97 - 2011	14	42	1498.4	1857.7	22.3	29.6	25.7	23.1	44.2	9.0
Wanganui	15	97 - 2011	14	32	931.3	1028.5	20.8	37.4	20.9	19.8	32.1	9.7
Wellington	56	99 - 2011	12	38	1091.3	1223.2	26.2	33.7	22.1	28.1	32.2	8.7
Whangarei	27	00 - 2011	11	33	1096.0	1738.0	16.5	29.2	28.1	25.0	52.7	11.1
average	194.5		11.6	37.6	1331.9	1893.1	21.8	30.3	26.0	24.4	47.5	9.9
standard deviaton					557.6							
South Island												
Alexandra	450	01 - 2011	10	13	418.2	220.3	14.5	63.5	23.0	9.6	16.9	6.4
Christchurch	18	00 - 2011	11	19	587.6	371.7	20.6	34.2	31.6	21.2	19.6	6.3
Dunedin	4	98 - 2011	13	18	647.6	331.3	19.8	43.6	28.3	15.8	18.4	6.2
Franz Josef	80	04 - 2011	7	72	4180.6	10756.0	22.5	36.2	23.2	17.6	149.4	12.5
Greymouth	5	03-2011	8	65	2308.4	4186.7	17.2	25.9	32.2	24.6	64.4	11.2
Hanmer Forest	363	97 - 2011	14	27	960.6	624.7	23.0	24.1	25.1	25.9	23.1	6.2
Invercargrill	5	97 - 2011	14	35	1112.0	658.2	24.6	30.5	30.1	19.1	18.8	6.8
Lake Moreaki	10	05 - 2011	6	73	3960.8	9942.7	21.2	34.3	28.0	15.9	136.2	13.5
Lake Tekapo	762	04 - 2011	7	15	519.1	235.8	16.9	30.5	29.2	23.1	15.7	5.7
Manapouri	178	03-2011	8	73	3400.7	3897.3	25.3	31.0	24.3	21.8	53.4	7.2
Mt. Cook	765	01 - 2011	10	62	3820.2	8023.5	19.9	42.3	30.2	11.5	129.4	9.5
Nelson	18	02 - 2011	9	26	906.5	1378.2	15.2	30.8	27.4	28.6	53.0	9.7
Takaka	20	03 - 2011	8	48	1815.5	4196.2	21.4	21.5	28.4	28.3	87.4	11.7
Timaru	160	97 - 2011	14	21	710.5	461.1	16.5	39.1	23.9	19.2	22.0	6.3
Westport	198	99 - 2011	12	48	1756.8	1922.6	23.5	28.1	23.9	23.0	40.1	8.2
average	202.4		10.1	41.0	1807.0	3147.1	20.1	34.4	27.3	20.4	56.5	8.5

Table 6: complete overview including average R-factor climate zones North Island

station	elevation (m)	data period	years	nr.of	P	R	Rss	I_{30}
				storms	(mm)	(MJ*mm/ha*h)		
Northern New Zealand								
AKL	88.00	97 - 2011	14.00	37.00	1114.23	1690.93	45.70	10.96
Kaitaia	85.00	99 - 2011	12.00	41.00	1359.58	2917.68	71.16	13.42
Whangrei	27.00	00 - 2011	11.00	33.00	1096.04	1738.00	52.67	10.93
Matamata	106.00	99 - 2011	12.00	33.00	1013.41	1435.92	43.51	10.58
average	76.50		12.25	36.00	1145.81	1945.63	53.26	11.47

station	elevation (m)	data period	years	nr.of	P	R	Rss	I_{30}
				storms	(mm)	(MJ*mm/ha*h)		
Central North Island								
Hamilton	40.00	97 - 2011	14.00	37.00	1087.71	1429.08	38.62	10.27
Taupo	375.00	97 - 2011	14.00	42.00	1498.44	1857.74	44.23	9.28
Mt. Ruapehu	1097.00	01 - 2011	10.00	62.00	2698.14	3567.18	57.54	8.70
average	504.00		12.67	47.00	1761.43	2284.66	46.80	9.42

station	elevation (m)	data period	years	nr.of	P	R	Rss	I_{30}
				storms	(mm)	(MJ*mm/ha*h)		
South West North Island								
New Plymouth	300.00	03 - 2011	8.00	50.00	1994.34	3565.72	71.31	11.27
Wanganui	15.00	97 - 2011	14.00	32.00	931.25	1028.48	35.81	9.76
Palmerston	21.00	02 - 2011	9.00	33.00	992.76	976.76	29.60	8.84
Wellington	56.00	99 - 2011	12.00	38.00	1199.28	1360.79	35.81	8.75
average	98.00		10.75	38.25	1279.41	1732.94	43.13	9.65

station	elevation (m)	data period	years	nr.of	P	R	Rss	I_{30}
				storms	(mm)	(MJ*mm/ha*h)		
Eastern North Island								
Gisborne	488.00	00 - 2011	11.00	47.00	2099.82	3607.54	76.76	10.53
Napier	5.00	98 - 2011	13.00	19.00	719.48	813.54	42.82	9.00
Martinborough	20.00	02 - 2011	9.00	23.00	769.82	532.47	23.15	7.50
average	171.00		11.00	29.67	1196.37	1651.18	47.57	9.01

Table 7: complete overview including average R-factor climate zones South Island

station	elevation (m)	data period	years	nr.of	P	R	Rss	I_{30}
				storms	(mm)	(MJ*mm/ha*h)		
Northern South Island								
Takaka	20.00	03 - 2011	8.00	48	1815.54	4196.19	100.15	11.73
Nelson	18.00	02 - 2011	9.00	26	906.50	1378.18	53.55	9.68
average	19.00		8.50	37	1361.02	2787.19	76.85	10.71

station	elevation (m)	data period	years	nr.of	P	R	Rss	I_{30}
				storms	(mm)	(MJ*mm/ha*h)		
Western South Island								
Westport	198.00	99 - 2011	12.00	48	1756.80	1922.58	39.95	8.19
Greymouth	5.00	03-2011	8.00	65	2308.37	4186.73	61.65	11.21
Lake Moreaki	10.00	05 - 2011	6.00	73	3960.79	9942.65	137.02	13.49
Franz Josef	80.00	04 - 2011	7.00	72	4180.59	10756.01	149.73	12.50
average	71.00		8.67	62	2675.32	5350.65	79.54	10.96

station	elevation (m)	data period	years	nr.of	P	R	Rss	I_{30}
				storms	(mm)	(MJ*mm/ha*h)		
Eastern South Island								
Hanmer Forest	363.00	97 - 2011	14.00	27	960.63	624.67	23.50	6.18
Timaru	160.00	97 - 2011	14.00	19	710.49	461.12	21.02	6.30
Christchurch	18.00	00 - 2011	11.00	21	587.56	371.70	19.80	6.29
average	180.33		13.00	22	752.89	485.83	21.44	6.26

station	elevation (m)	data period	years	nr.of	P	R	Rss	I_{30}
				storms	(mm)	(MJ*mm/ha*h)		
Inland South Island								
Alexandra	450.00	01 - 2011	10.00	13	418.24	220.30	16.96	6.42
Lake Tekapo	762.00	04 - 2011	7.00	15	519.10	235.77	15.49	5.72
Manapouri	178.00	03-2011	8.00	73	3400.66	3897.28	53.23	7.21

average	463.33		8.33	34	1446.00	1451.12	28.56	6.45
Station	**elevation (m)**	**data period**	**years**	**nr. of**	**P**	**R**	**Rss**	**I_{30}**
				storms	**(mm)**	**(MJ*mm/ha*h)**		
Southern New Zealand								
Dunedin	4.00	98 - 2011	13.00	18	647.58	331.33	18.86	6.25
Invercargrill	5.00	97 - 2011	14.00	35	1112.00	658.16	19.32	6.80
average	4.50		13.50	26	879.79	494.75	19.09	6.52

In general, the climatic regions within the country reflect the area quite accurate, only in “Inland South Island” the gauging station Manapouri doesn’t really fit. The reason, why the annual precipitation as well as the R-factor is that high is, because the gauging station “West Army Jetty” is situated on the other side of the lake, and therefore closer to the Southern Alps (this has already been pointet out in chapter “rainfall”).

3.3 Relation between the R-factor and annual precipitation

In this study, the erosivity estimation for gauging station without high resolution data was derived by Richardson et. al (1983) exponential model.

$$R = aP^b \tag{12}$$

R = annual erosivity factor

a,b = empricial parameters derived from the power equation

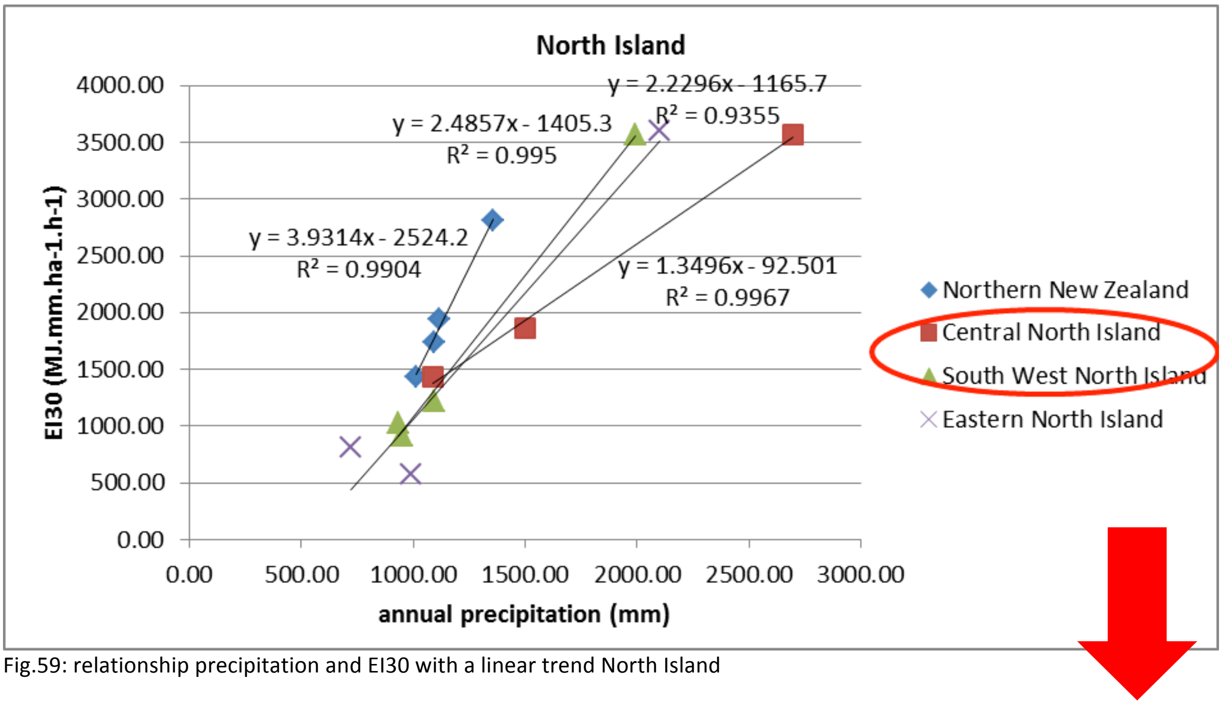


Fig.59: relationship precipitation and EI30 with a linear trend North Island

Due to its similar characteristics, the climate zones "South West North Island" and "Eastern North Island" were merged together for deriving the empirical parameters. The same was done on the South Island for the following climate areas: Eastern South Island, Inland South Island and Southern

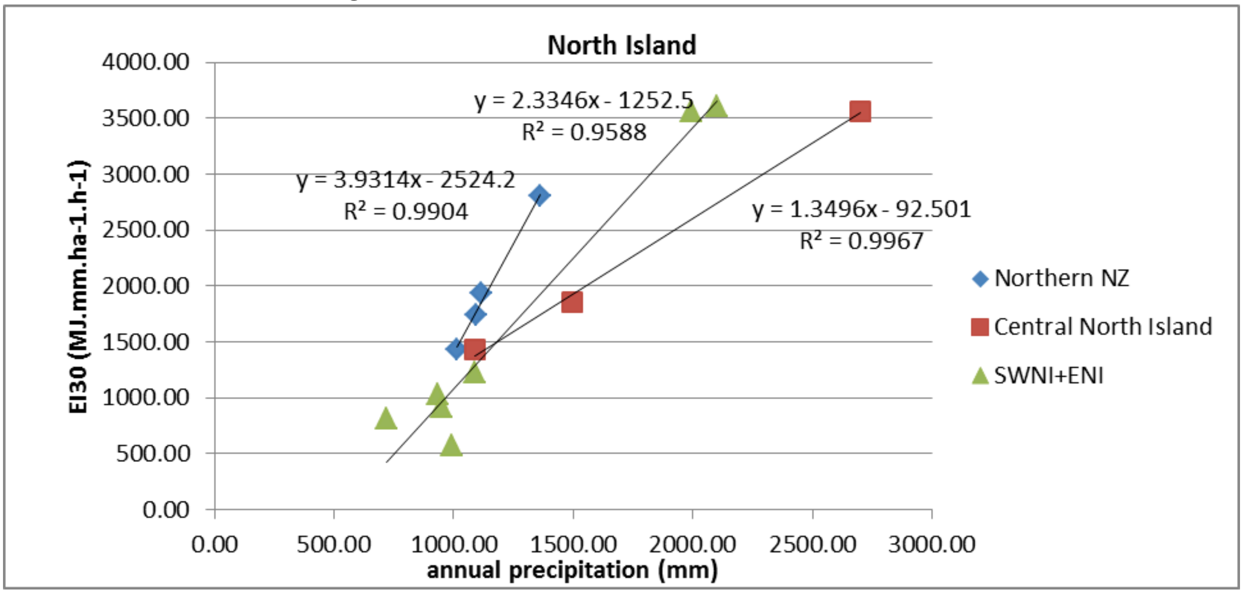


Fig.60: relationship precipitation and EI30 with a linear trend North Island – merged together

New Zealand.

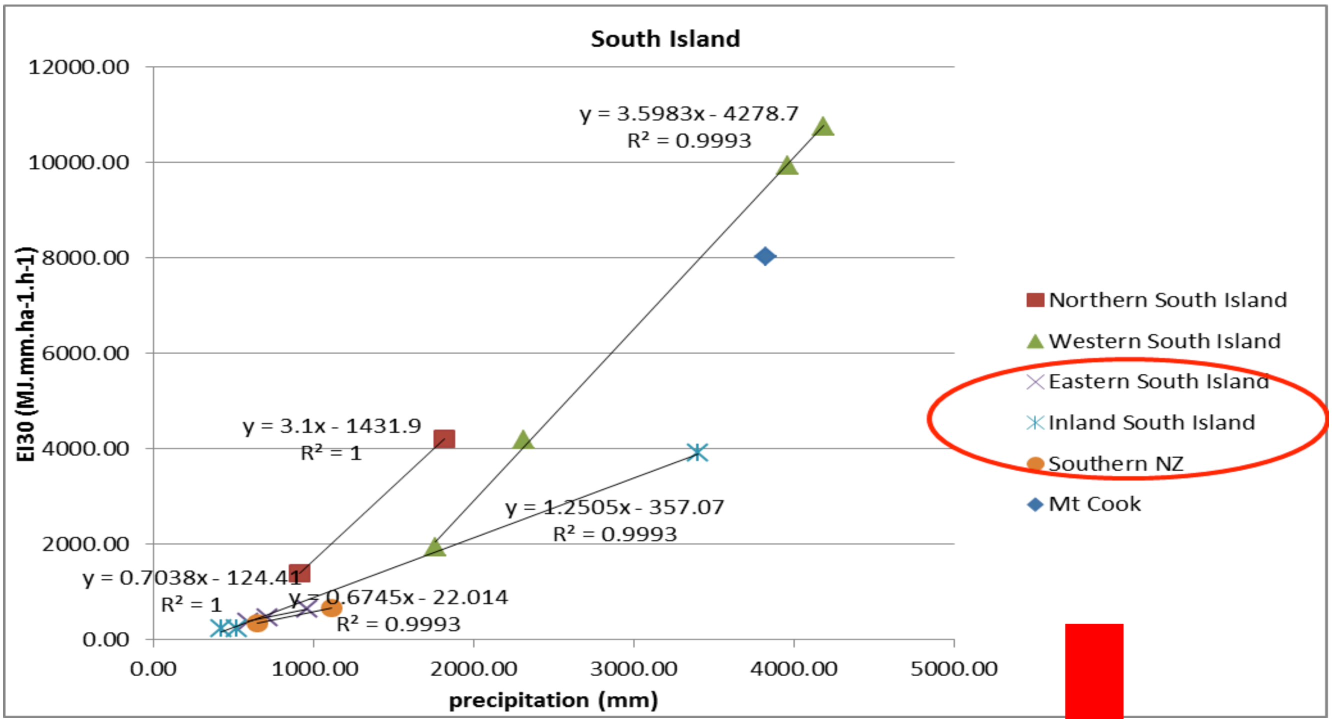


Fig.61: relationship precipitation and EI30 with a linear trend for the South Island

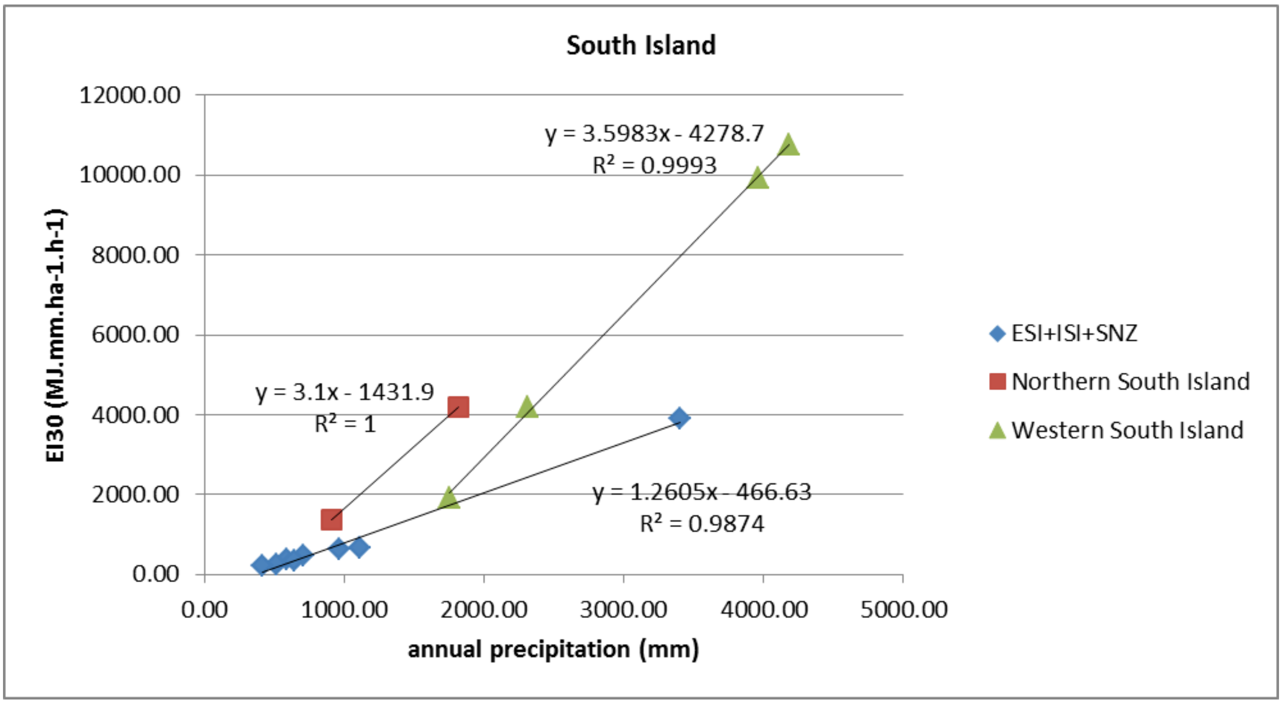


Fig.62: relationship precipitation and EI30with a linear trend for the South Island – merged together

By transforming a linear trend into a power trend line, the parameters a and b were defined for each of the six remaining climate areas (table 8). This model has been tested independently for the U.S. east of the Rocky Mountains (Haith and Merrill 1987), related models have also been designed for

Western Australia (McFarlane et al. 1986), Canada (Bullock et al. 1989), Western Arnazonia (Elsenbeer et al. 1993), Finland (Posch and Rekolainen 1993), Italy (Bagarello and D'Asaro 1994) and for south-eastern Australia (Yu and Rosewell 1996).Although the general relationship between daily rainfall amounts and EI30 is widely applicable, the parameter values seem to have considerable regional and seasonal variations. Also Zhang et al. (2005) used the same relationship for the Yellow River in China, Renard and Freimund (1994) for the continental USA and Bonilla et. al (2011) for Central Chile. The empirical parameters a and b change with respect to the rainfall – erosion relationship for each of the studies. As it is practically impossible to define an empirical parameter for whole New Zealand, both empirical parameters were derived for each climatic region in the country (see table 8), which is still not 100% accurate, due to its changing topography and influence from the Tasman Sea as well as from the Pacific Ocean.

Nevertheless, the theoretical relationships for the two Islands would be:

North Island: $R = 0.0844P^{1.3484}$

South Island: $R = 0.0071P^{1.6989}$

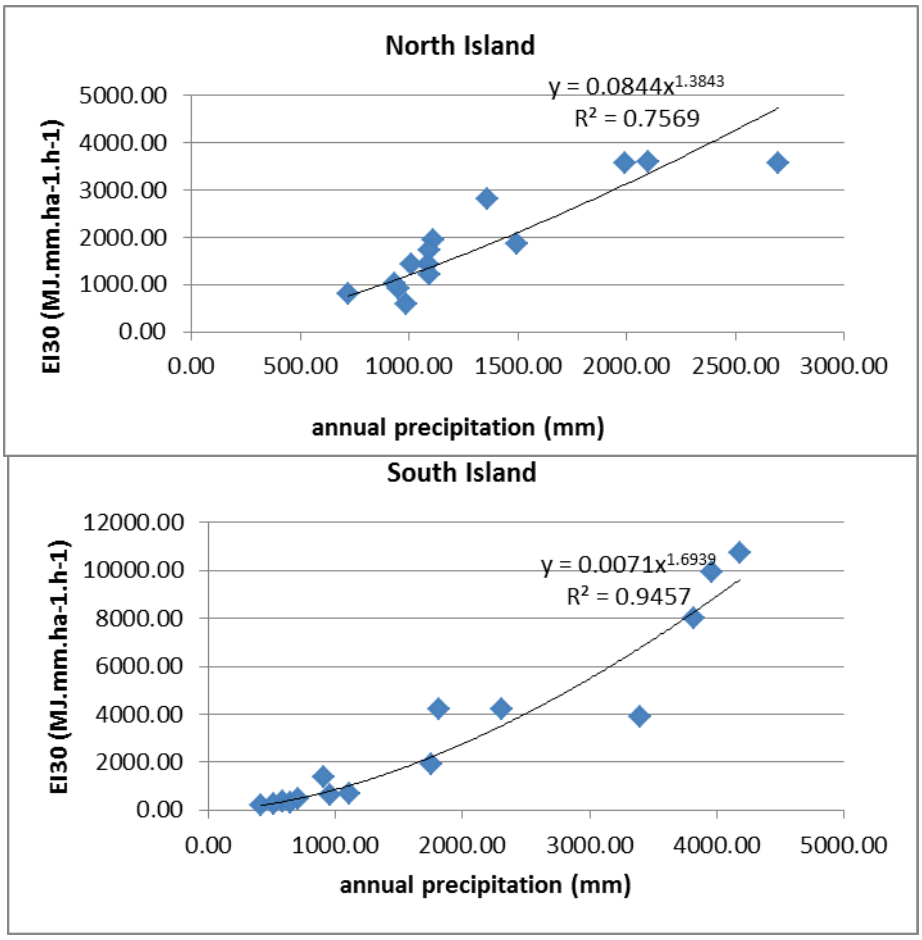


Fig.63. relation – annual precipitation and EI30 with power regression

Table 8: calculated R-factor (MJ.mm.ha-1.h-1) based on longterm rainfall 1981-2010

station	a	b	P	calculated R-factor
North Island			(mm)	(MJ.mm.ha-1.h-1)
Kaitaia	0.0003	2.2323	1349.16	2913.16
Whangarei	0.0003	2.2323	1317.69	2763.64
Auckland	0.0003	2.2323	1210.74	2287.81
Tauranga	0.0003	2.2323	1176.47	2145.74
Hamilton	1.1174	1.0196	1108.41	1420.97
Rotorua	1.1174	1.0196	1358.90	1749.07
Gisborne	0.0118	1.6465	978.66	990.73
Taupo	1.1174	1.0196	954.49	1220.06
New Plymouth	0.0118	1.6465	1397.97	1782.16
Napier	0.0118	1.6465	775.99	676.13
Wanganui	0.0118	1.6465	916.68	889.55
Palmerston North	0.0118	1.6465	919.90	894.71
Masterton	0.0118	1.6465	922.91	899.53
Wellington	0.0118	1.6465	1215.35	1415.29
South Island				
Nelson	0.025	1.6031	950.67	1486.01
Blenheim	0.025	1.6031	720.05	951.88
Westport	0.0014	1.9083	2154.43	3214.59
Kaikoura	0.0468	1.385	695.86	404.70
Hokitika	0.0014	1.9083	2901.38	5673.06
Christchurch	0.0468	1.385	618.24	343.55
Lake Tekapo	0.0468	1.385	591.61	323.23
Timaru	0.0468	1.385	546.78	289.81
Milford Sound	0.0014	1.9083	6715.44	28140.68
Queenstown	0.0468	1.385	741.35	441.80
Alexandra	0.0468	1.385	335.31	147.23
Manapouri	0.0468	1.385	1092.15	755.56
Dunedin	0.0468	1.385	726.24	429.38
Invercargill	0.0468	1.385	1146.64	808.26

As Renard and Freimund (1994) recommend not to use power functions for mean annual precipitation > 850mm/ year as it tends to underestimate the R-factor values, and a quadratic polynomial function for those areas is suggested. However, there is not a single region in the country where all the annual precipitation values are lower than 850 mm/ yr. Bonilla and Vidal (2011) performed several tests to analyse the parameter improvements by comparing those two functions for Central Chile. As they haven't found any significant improvements for their values, due to simplicity all tests for New Zealand were performed with the previously described power function. Moreover, researchers in India stated, that the power function gives the highest coefficient overall. (Elangovan and Seetharaman, 2011)

3.4 Isoerodent map

In addition to the 29 gauging stations and the provided NIWA data, annual average rainfall from 218 points all over the two Islands were analysed to predict the annual rainfall erosivity rate. Figure 63 and 64 show both, annual mean rainfall and an R-factor map. The mean annual precipitation was based on the rain records from 218 stations all over the country. Due to the two established maps a comparison between the spatial distribution of the annual rainfall depth and the annual rainfall erosivity is possible. The mean annual rainfall ranged between 418.24 mm/year in and 4180.59 mm/year. By making use of the power equation, R-factor values from of 220.3 up to a maximum of 10756.0 (MJ*mm/ha*h) for the analysed gauging stations were calculated, whereas the predicted rain erosion goes up to 28140.68 (MJ*mm/ha*h) in the Milford Sounds.

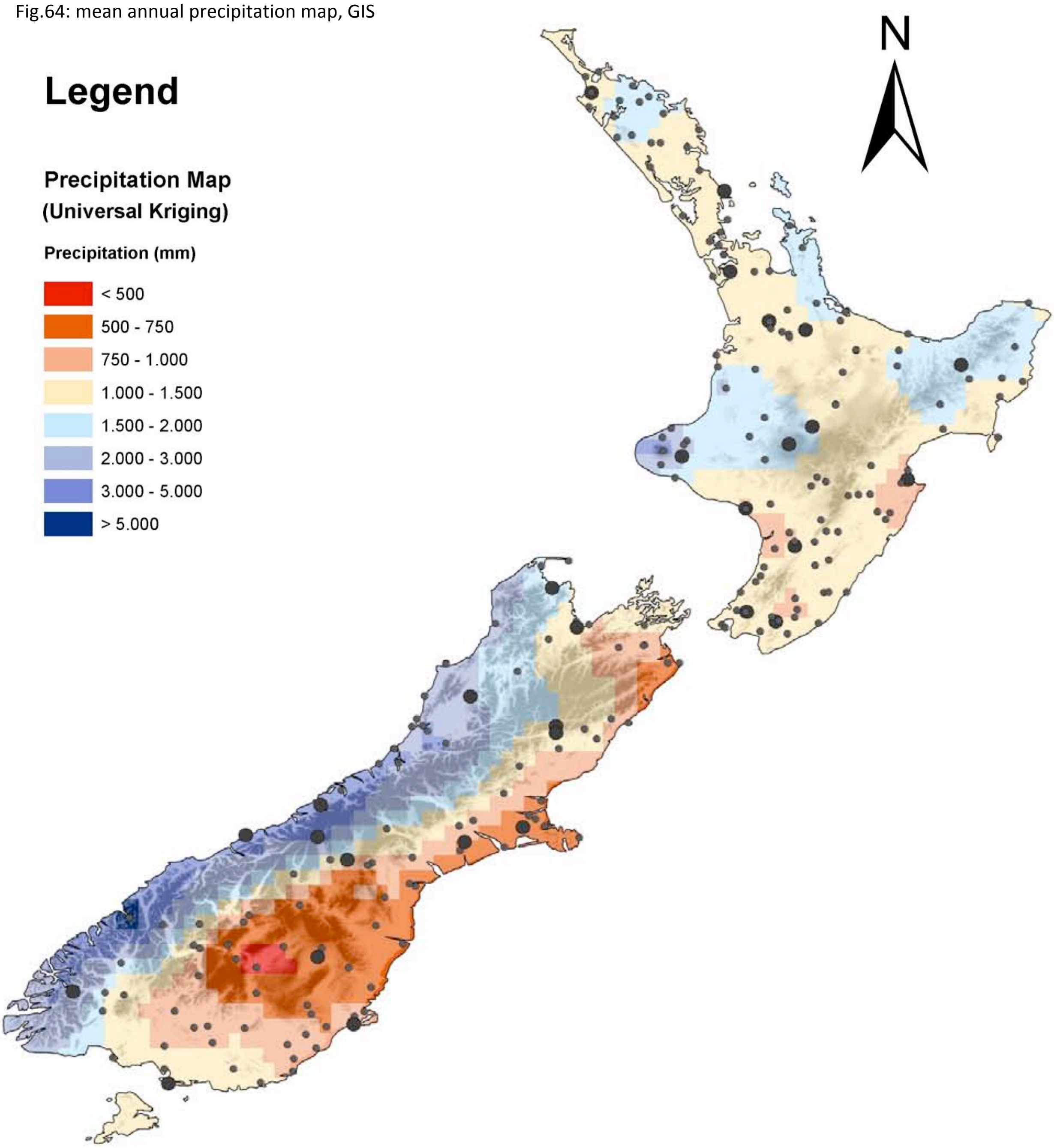
As an interpolation method, “universal kriging” was used to create both maps. As Angulo-Martínez and Beguería (2009) compared several techniques for mapping the rainfall erosivity in a large and climatologically complex area (Ebro basin in North- Eastern Spain), they detected that all methods were able to capture the R-factor regional distribution when used with a spatially dense precipitation data base with a high temporal resolution. Differences between interpolation methods were only evident for theEI30 index (mean erosivity of all rainfall events), but not for the R-factor values (Bonilla and Vidal, 2011).

The mean annual precipitation map reflects the previously discussed results quite accurate. Maximas in the Mount Taranaki region and the Alps are very reasonable, as well as the minimas around Otago and Canterburry. For Steward Island, no rain records were analysed and the resulting values are due to interpolation (universal kriging).

On the North Island, the mean annual precipitation and the rainfall erosivity goes pretty much hand in hand. However, the higher erosion potential in Northern New Zealand might be explained by heavy tropical rainstorms in summer, arriving from the South Pacific Ocean, which tend to have a way higher 30min. Intensity then “normal rainfall”. Also Coromandel and the most eastern part from the North Island are affected by this phenomenon. Apart from that, the North Island doesn’t show any noticeable indications. High erosion potential around the Mt. Taranaki region comes with the high mean annual precipitation.

The South Island shows an enormous West Coast – East Coast rainfall gradient. All the rainfall shuts down before passing the Southern Alps, which leads to very dry regions afterwards. Especially the areas around Alexandra is for New Zealand standards very dry (<500mm/year), which is comparable to areas around Tunis (Tunisia), or parts of Spains Inland. Sometimes even deserts get designated as areas with a mean annual precipitation less than 500mm/year, but this area doesn't show any other significance for a desert. Therefore, considering this as "New Zealands desert" is not really appropriate.

Fig.64: mean annual precipitation map, GIS



Also the R-factor map reflects this matter of fact, with the difference that it now affects an enlarged area, starting in Kaikoura with an increasing belt down to Dunedin. Only a very small band from the North to the South between the Southern Alps and this area draws an R-factor area around 2000 – 2500 MJ*mm/ha*h. Towards the Alps, the R-factor reaches extremely high dimensions, up to more than 25000 MJ*mm/ha*h in Southland/ Fjordland.

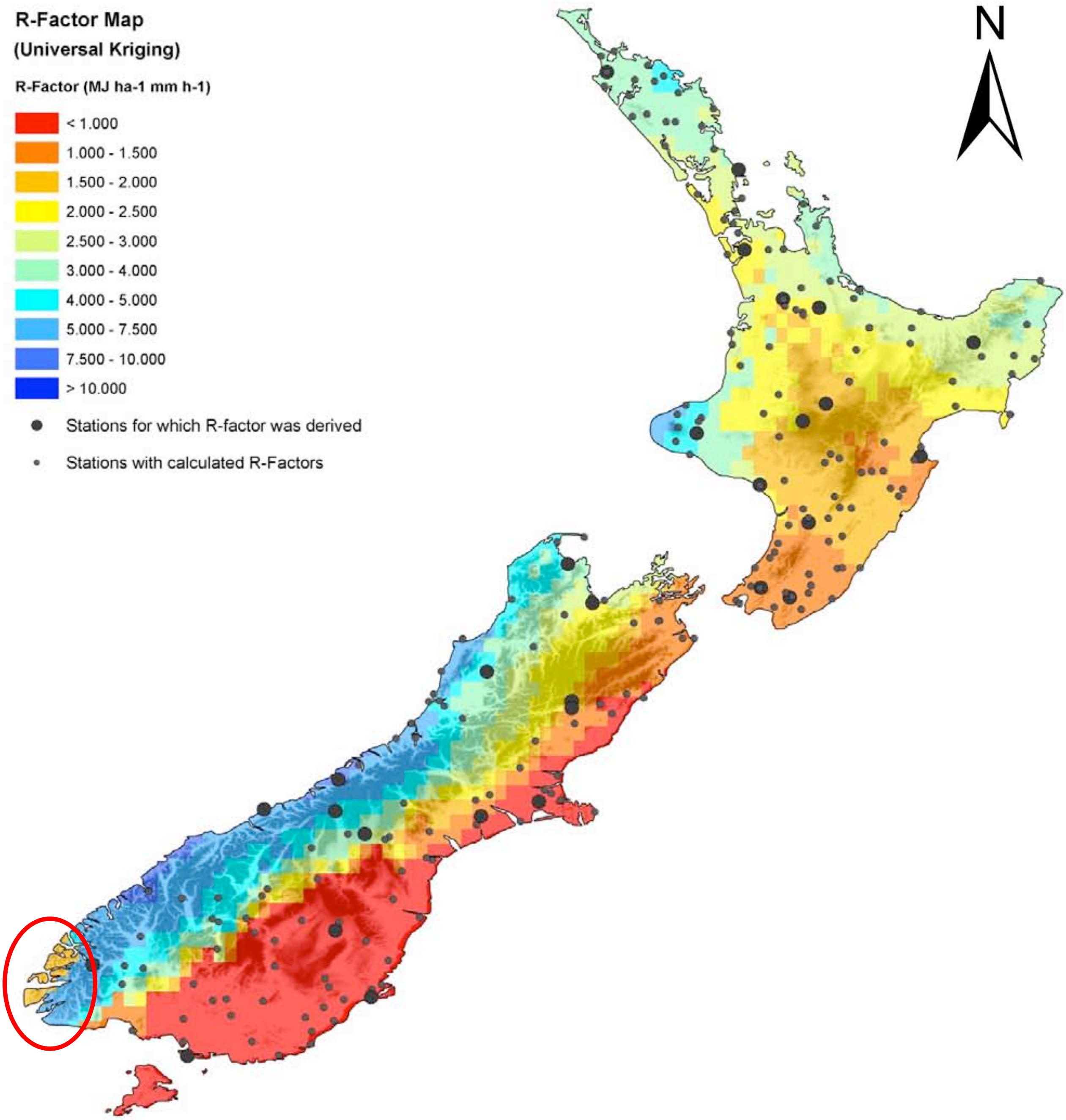
Due to insufficient data, the south-west of Southland/Fjordland is illustrated in "orange", which means a R-factor value around 1500 (MJ*mm/ha*h), whereas "blue" would be definitely more appropriate (5000 – 10000 MJ*mm/ha*h) – the area is marked with a red circle in fig. 65..

However, the spatial distribution of the mean annual rainfall and the R-factor is definitely based on the weather fronts coming from the Tasman Sea as well as the influence of the Pacific Ocean. The effect of elevation is more related and relevant for the North Island than for the South and has not that much influence on the spatial distribution as it has in other countries. Due to its large range in rainfall as well as in rainfall – erosion, it is hard to compare the results respectively to other countries/ published results by other authors. The rainfall erosivity map is the first attempt for New Zealand and can be definitely improved by analysing more high resolution data all over the country, in order to refine the mesh with more calculated values. Also the empirical parameters for the climatic regions will change by increasing the amount of analysed gauging stations, which is followed by a more accurate erosion prediction.

The established R-factor map not only provides a good tool for activities linked to land-use planning and should be also useful for the agricultural perspective.

Another difficulty by the process of creating these maps, was that the areas, where the most precipitation and linked to it also the highest rainfall – erosivity is likely to occur, are mostly unsettled. Hence, there is no high resolution data available for these areas and the results are only based on the interpolation in GIS.

Fig.65: R-factor map, GIS



In general, the results for New Zealand are hard to compare to any other country due to several reasons. The first and largest one is the fact, that New Zealand is an Island mainly influenced by weather fronts coming from the Tasman Sea, whereas e.g. Austria lies in a temperate climate zone influenced by the Atlantic climate. The highest calculated R-factor value for e.g. Upper Austria is under 1000 (MJ*mm/ha*h), which would be comparable to the South Islands East Coast. In general, R-factor values in Europe hardly go higher than 1000 (MJ*mm/ha*h) (European Soil Bureau, 1995). Only places in Spain, which are exposed to weather fronts coming from the Atlantic Ocean can consist of higher rainfall erosivity. A recent study about the spatial and temporal variability of the rainfall erosivity factor for Switzerland (Meusburger et al., 2012) shows results for alpine regions comparable to those on the South Island. Maximum R-factor values almost up to 5000 (MJ*mm/ha*h) in the Swiss Alps were identified. These results are comparable with the results from the New Zealand Alps, even though they only scratch the lower limit. Furthermore, they considered the high amount of snowfall in the European Alps with an improved relationship between the annual precipitation and the rainfall erosivity, which hasn't been done in this study.

Also a comparison with Australia shows that even though the two countries are "relatively" close to each other, the R-factor values for Australia are more comparable to Europe then to New Zealand. The spatial R-factor values calculated for the Victorian region reach a maximum of 1500 (MJ*mm/ha*h) (Sheridan and Rosewell, 2003). In comparison to New Zealand, already a lot of research in this topic has been done for all the different parts of Australia. Moreover, Australia's landscape is more likely for the use of the RUSLE equation then the landscape in New Zealand. Large areas with similar landscapes and same weather conditions are preferable for the use of the Revised Universal Soil Loss Equation, due to the fact that it's been originally developed for large areas in the United States and no adequate adaption of the parameters has been performed by now for New Zealand.

R-factor values up to 20000 (MJ*mm/ha*h) as on the South Islands West Coast also exist for example in the west of Brazil (Amazon region), where R-factor values also go up to 20,035 (MJ*mm/ha*h) (Da Silva, 2004). Despite the high R-factor values, the two regions have nothing in common after all and are therefore not suitable for an appropriate comparison.

4. Summary and conclusions

This study presents a mean annual precipitation as well as a rainfall erosivity map for whole New Zealand.

With the previous described method, mean annual precipitation rates and rainfall erosivity values were calculated and a relation between them and the more readily available annual precipitation data was established. In total, 29 gauging stations were analyzed and in addition, the mean annual rainfall from 218 stations was determined.

The results show that the empirical parameters fit more or less well for both Islands (efficiency North Island = 75%, efficiency South Island = 95%). However, it is not possible to transfer the specific R-values calculated for New Zealand to other countries with similar characteristics or even to define one valid rainfall erosivity equation for the whole country with this amount of data. In order to achieve this goal, linear relationships between long term annual R-factors and long term annual precipitation in New Zealand need to be established to simply estimate the R-factor for stations in the country, with similar rainfall characteristics.

Mean annual precipitation and rainfall erosivity in New Zealand go hand in hand in most parts of the country. On the North Island, Northern New Zealand shows a higher potential erosion risk in some areas, which might can be explained, by tropical storms with a very high rainfall intensity arriving from the South Pacific Ocean. On the South Island, the Southern Alps are the major key element concerning the annual precipitation and rainfall erosivity. A tremendous west – east gradient in both terms is noticeable. The rain shuts down before it reaches the Inland of the Island, which can lead to an annual precipitation up to 10000 mm/year in parts of the West Coast. Another phenomenon is that the amount of rainfall is only marginally linked to its elevation and only has a small impact on the spatial rainfall and R-factor distribution, whereas in other parts of the world, elevation strongly influences the amount of rainfall and can play a major role in the spatial precipitation distribution. Such trend could only be identified for the North Island but no such relation exists for the South Island. Due to the extremely wide range in R-factor values, starting from 147.23 up to 28140.68 MJ.mm.ha-1.h-1 (predicted rainfall erosivity); the country is very unique concerning this topic.

The results reflect the high rain and erosion variability within the whole country. As an interpolation method, "universal kriging" was used and performed in GIS, in order to create both presented maps.

All the results reflect the extremely high variable character in rainfall as well as in rainfall erosivity of the country. The obvious west-east gradient on the South Island with differences almost up to 28000 MJ*mm/ha*h between areas only separated by around 370 kilometres makes this country, regarding this topic, very unique.
The accuracy of this study can be improved by analysing more gauging stations and especially due to a longer time record of high resolution data. Also a statistical analysis (e.g. seasonal Mann-Kenndall Test) is highly recommended by working with longer time-series, in order to identify monotonic trends of a time-series.

Nevertheless, the rainfall erosivity map should be useful tool for land – use planners all over New Zealand and as guidance for soil protection and conservation practices by making use of Revised Universal Soil Loss Equation.

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5. References

ANGULO-MARTINEZ, M. and BEGUERIA, S.; Estimating rainfall erosivity from daily precipitation records: A comparison among methods using data from the Ebro Basin (NE Spain), Journal of Hydrology 379 p.111–121,2009

ANGULO-MARTINEZ, M. et al.; Mapping rainfall erosivity at a regional scale: a comparison of interpolation methods in the Ebro Basin (NE Spain), Hydrology and Earth System Sciences Discussions, 2009

BAKKER, M. et al.; Soil erosion as a driver of land-use change, Agriculture, Ecosystems & Environment, Vol. 105, Issue 3, p. 467-481,2005

BAZIER, R.E.et al.; equifinality and uncertainty in physical based soil erosion models; application of the glue methodology to WEPP- the water erosion prediction project-for sites in the UK and USA, Earth surface processes and landforms 25, p.825-845, 2000

BLANCO, H. and LAL R., Principles of Soil Conservation and Management,2002 and 2009

BONILLA, C.A. et al., Rainfallerosivity in Central Chile, Journal of Hydrology, Volume 410, Issues 1–2, Pages 126–133, 15 November 2011

DA SILVA, A.M., Rainfall erosivity map for Brazil, CATENA Volume 57, Issue 3, Pages 251–259, 2004

DISSMEYER, G. E. and FOSTER, G.R.; Estimating the cover-management factor (C) in the universal soil loss equation for forest conditions, journal of soil and water conservation, 1981

DYCK, S.; Angewandte Hydrologie, Teil2. Der Wasserhaushalt der Flussgebiete; 2. Aufl., Berlin,1980

DYMON, J. et al.; An erosion model for evaluating regional land-use scenarios, Landcare Research, New Zealand, 2009

ELANGOVAN A.B. and SEETHARAMAN R., Estimating Rainfall Erosivity of the Revised Universal Soil Loss Equation from daily rainfall depth in Krishanagiri Watershed region of Tamil Nadu, India, 2011 International Conference on Environmental and Computer Science IPCBEE vol.19,Singapore2011

FAVIS-MORTLOCK, D. et al.; Nonlinear responses of soil erosion to climate change: a modelling study on the UK South Downs, Catena 25, p. 365-387,1995

FLANAGAN, D. et al.; '1.1 Chapter 1. Overview of the WEPP', Journal of Soil and Water Conservation March/April 1997 vol. 52 no. 2 96-102, 1997

FOSTER, G.R.et al.; user requirements – USDA,NSERL report No.I, 1987

GHADIRI, H.; Crater formations in soils by raindrop impact, Wiley InterScience, Earth Surf. Process. Landforms 29,p. 77–89, 2004

HUDSON, N.W.; Soil Conservation, Batsford Ltd, London pp.388, 1971

JAKOBSSON, K. M. et al.; Water and Soil Management in New Zealand, Journal of Environmental Management 33, 1-16, 1991

KARYDAS, C. G. et al.; Quantification and site-specification of the support practice factor when mapping soil erosion risk associated with olive plantations in the Mediterranean island of Crete, Environmental Monitoring and Assessment 149:19-28, 2009

KINNEL, C.; modelling erosion by rain-impacted flow, Catena Supplement 17, p.55-66, 1990

KLIK, A. et al., rainfall erosivity in North-Eastern Austria, International Symposium on Erosion and Landscape Evolution (ISELE) Anchorage, Alaska, September 18-21, 2011

KLIK, A., DOSTAL T.; soil erosion and sediment transport measurement and assessment, CTU Prague, p.1., 2010

KOMAR, P.D.; Coastal Erosion Processes and Impacts: The Consequences of Earth's Changing Climate and Human Modifications of the Environment, Treatise on Estuarine and Coastal Science, Volume 3, Pages 285–308,2012

LEE, J.H. et al.; Evaluation of estimation methods for rainfall erosivity based on annual precipitation in Korea, Journal of Hydrology, Vol. 409, Issues 1–2, 28, Pages 30–48, 2011

LIU, B.Y. et al.; slope length effects on soil loss for steep slopes, 10th international Soil Conservation Organization Meeting, p.784-788, May 2001

Lu, H., Yu, B., 2002. Spatial and seasonal distribution of rainfall erosivity in Australia. Aust. J. Soil Res. 40, 887–991.

MATHER A.S., The changing perception of soil erosion in New Zealand, The Geographical Journal, Vol. 148, No. 2,. pp. 207-218, July 1982

MAZUKI et. al.: Estimation of raindrop size distribution parameters by maximum likelihood and L-moment methods: Effect of discretization, Atmospheric Research, Vol. 112, Pages 1–11, August 2012

McGregor, K.C., Bingner, R.L., Bowie, A.J., Foster, G.R., 1995. Erosivity index values for northern Mississippi. Trans. ASAE 38 (4), 1039–1047

MEUSBURGER, K. et al.; Spatial and temporal variability of rainfall erosivity factor for Switzerland, Hydrol. Earth Syst. Sci., 16, pp. 167–177, 2012

MINISTRY OF THE ENVIRONMENT, soil conservation technical handbook, June 2001

MORGAN, R.P.C. et al.; Handbook of erosion modelling, Blackwell Publishing Ltd, 2011

MULLAN, D. et al.; Addressing key limitations associated with modelling soil erosion under the impacts of future climate change, Agricultural and Forest Meteorology, Vol. 156, , p. 18–30, 2012

NEARING, M.A.et al.; a process based soil erosion model for USDA-water erosion prediction project technology, Transactions of the ASAE, Vol. 32, No.5, pp.1587-1593, 1989

NEARING, M.A.; a single continuous function for slope steepness influence on soil loss, published in soil Sci. Sco. Am. J.61 917-919, 1997

RENARD, K.G. and FREIMUND, J.R., Using monthly precipitation data to estimate the R-factor in the revised USLE. J. Hydrol. 157, 287–306, 1994

RICHTER, M.; 'Ermittlung des Erosionspotentials für das tschechisch/deutsche Einzugsgebiet des Flusses Mandau unter besonderer Berücksichtigung des sich hieraus ergebenden Handlungsbedarfs', Diplomarbeit, Hochschule Zittau/Gürlitz, 2004

ROSE, C.W.; Soil detachment caused by rainfall, Soil Science 1989, p.28-35, 1960

ROSE, C.W. et al.; interpreting the role of soil strength in erosion processes, Catena Supplement 17, p.153-165, 1990

SCHMIDT, J.; Soil Erosion: Application of Physically Based Models, Section I, RUSLE Erosion Prediction Ohio , FOTG, 2000

SHEARER, M.; Soil erosion and intertidal sedimentation in Lyttelton Harbour, Harbour/Whakaraupō: The ongoing legacy of land use change assessed using the Revised Universal Soil Loss Equation (RUSLE), Honours Dissertation, 2011

SHERIDAN, G.J. and ROSEWELL C.J., an improved Victorian erosivity map, Australian Journal of Soil Research, 41, p.141-149, 2003

STRAUSS, P. et al:, Rainfall erosivity – a comparison Austria – Bavaria, Z.f. Kulturtechnik und Landesentwicklung 36,p,304-308, 1995

TOY, T.J et al.; Soil Erosion: Processes, Predicition, Measurement, and Control, 2002

VAN DER KNIJF J.M. et al:, Soil erosion risk assessment in Europe, European Soil Bureau, 2000

VAN DIJK, A.I.J.M., Rainfall intensity – kinetic energy relationships: a critical literature appraisal, Journal of Hydrology, Vol. 261, 2002

VALENTIN, C. et al.; Gully erosion; Impacts, factors and control, CATENA Volume 63, Issues 2–3, 31, Pages 132–153, October 2005

VERSTRAETEN, G. et al.; Long-term (105 years) variability in rain erosivity as derived from 10-min rainfall depth data for Ukkel (Brussels, Belgium): Implications for assessing soil erosion rates, JOURNAL OF GEOPHYSICAL RESEARCH, VOL. 111, D22109, doi:10.1029/2006JD007169, 2006

WEGGEL, R. et al.; Soil Erosion by Rainfall and Runoff-State of the Art, Department of Civil & Architectural Engineering, Drexel University, Philadelphia, Pennsylvania 19104, USA, 1992

WYNN, T.M. et al.; Changes in streambank erodibility and critical shear stress due to subaerial processes along a headwater stream, southwestern Virginia, USA; Geomorphology Volume 97, Issues 3–4, 15, Pages 260–273, May 2008

YODER, D.C.; chapter 5 cover management factor, p.146, 2007

YOUNG, M. et al.: temporal variations in soil erodibility, Catena Supplement, p. 41-53, 1990

YU, B. and ROSEWELL, C.J.; Rainfall erosivity estimation using daily rainfall amounts for South Australia. Aust. J. Soil Res. 34, 721–733, 1996

ZACHAR D.; Soil Erosion, Volume 10,p.48, 1982

ZHU, T.X.; Gully and tunnel erosion in the hilly Loess Plateau region, China; Geomorphology Volumes 153–154, Pages 144–155, 1 June 2012

Internet references

NIWA, the National Institute of Water and Atmospheric Research

http://www.niwa.co.nz/education-and-training/schools/resources/climate/overview

USDA US Department of Agriculture http://www.ars.usda.gov/Research/docs.htm?docid=3251

Te ara – the encyclopaedia of New Zealand http://www.teara.govt.nz/en/natural-environment/1

Figures

Tables