**The evolution of risk from landslides:
concepts and applications for communities
in New Zealand**

by

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1. Introduction

Wright (2004), in the Massey Lectures, estimated that since the year 1900 the world's population has increased four times while economic activity has increased forty times. Our world is changing at a rapid pace; a dynamic, interactive construct emerges, driven by both geophysical and social forces (Etkin, 1999; Mileti, 2004). Against this background, risk, as the composite of processes in nature and society, cannot be assumed to be a static phenomenon (Kates, 1970; Ingold, 1992; Tierney, 1999; Oliver-Smith and Hoffmann, 2002; Oliver-Smith, 2004). Risk itself is a *process*, and this process is the focus of this thesis.

Generally speaking, the notion of 'risk' expresses the likelihood that something can be gained, while there is an accompanying likelihood that something is lost (chapter 3). Within the context of natural hazards and disasters, it is usually the loss coming to the fore, and 'risk' captures not only the likelihood of potentially harmful events occurring, but also the consequences when they occur (Crozier and Glade, 2005a). Referring to Kates et al. (1985: 21), Renn (1992: 56) defined risk as *'the possibility that an undesirable state of reality (adverse effects) may occur as a result of natural events or human activities'*, adding that *'undesirable effects can be avoided or mitigated if the causal events or actions are avoided or modified'*. Hence the notion of risk carries a strong possibilist connotation¹. Depending on the circumstances, however, this connotation cannot always be fully realised, as discussed in this thesis (chapters 2, 5).

The term 'natural risk' is used in this thesis to separate risk related to geophysical processes from technological or economic risks. It is recognised that this term, just as 'natural hazard' and 'natural disaster', is criticised due to an implication of nature intentionally harming humans as observed by Glade (2003a), and because the masking of social causations of risk and disasters. For pragmatic reasons, however, this terminology is used.

Varnes (1984: 10) defined 'total risk' according to the United Nations Disaster Relief Organisation (UNDRO, 1982) as the *'expected number of lives lost, persons injured, damage to property, or disruption of economic activity due to a particular natural phenomenon'* (see also UNDRO, 1991). This notion of risk is based on three components: 'elements at risk', 'hazard' and 'vulnerability'. The term 'elements at risk' describes objects which are potentially adversely affected, meaning people, properties, infrastructure and economic activities including public services. '(Natural) hazard' is a condition that expresses the probability of a damaging event occurring with a specified magnitude within a defined time period and area (Crozier, 1993; IUGS Working Group on Landslides – Committee on Risk Assessment, 1997). The term 'natural hazard' therefore addresses the 'how often' and 'how big' question in relation to processes such as earthquakes, storms, floods or landslides. 'Vulnerability' usually refers to the potential degree of damage that can be expected depending on the characteristics of an element at risk with respect to a certain hazard magnitude (chapter 5). As discussed in chapters 6 and 7, it is argued here that the concept of 'resilience', the ability to persist under pressure, should

¹ See also Renn (2008: 50).

accompany the widely accepted initial definition of risk as presented by UNDRO in 1982. Vulnerability and resilience are regarded in this research as separate though interlinked concepts which in combination influence overall levels of loss to natural hazards, in particular in the context of long-term loss assessment (chapter 7).

1.1 Trends in risk

Databases recording the occurrence and impact of disasters have registered several trends in the context of overall losses to natural hazards worldwide. Although these figures should be interpreted with caution², they indicate that changes occur rather rapidly. According to EM-DAT³ and Munich Re⁴, the number of recorded disasters has climbed progressively and substantially over the last 50 years. Likewise, between 1960 and 2005, economic losses have risen globally by a factor of 6.7 and insured losses by a factor of 13.5⁵. During the 1990s alone, disasters accounted for economic losses of about US\$ 54 bn per year (in 1999 prices) (Munich Re, 1999, in Benson, 2004). Hurricane Katrina, which struck the New Orleans region in the U.S. in August 2005, resulted in record losses of US\$ 125 bn. The 1995 earthquake in Kobe, Japan, is the second most costly disaster ever recorded (US\$ 100 bn) (EM-DAT³). Because of problems related to recording indirect costs, which usually arise in the long-term (UNDP, 2004a), these figures relate to direct costs only. While economic costs are on the rise, an encouraging trend is the decline of fatalities worldwide since 1900. However, the number of people affected by natural disasters has risen substantially over the same period of time⁶. The distribution of economic losses versus losses of lives is very heterogeneous worldwide, with Asia as a hot-spot of disasters recorded and lives lost⁷.

It is because of such alarming trends that the intergovernmental 'Hyogo Framework for Action 2005-2015' (United Nations, 2005: 12) identified the need for a deeper understanding '*of the ways in which hazards and vulnerabilities are changing in the short and long term, followed by action taken on the basis of that knowledge*'. This statement suggests that components of risk, such as hazard and vulnerability, ought to be analysed not only in terms of their spatial, but also their temporal variability. Worldwide, processes associated with increasing economic losses and greater numbers of people affected by natural hazards include: environmental degradation (UN/ISDR, 2004; Wisner et al., 2004), population growth and rapid urbanisation (Mileti, 1999; Kroeger, 2004; UNEP, 2005) particularly in the context of megacities and their frequent location in coastal areas (Kraas and Coy, 2003; Kraas, 2005; Klein et al., 2003), as well as marginalisation and poverty (Lavell, 2004; Anderson and Holcombe, 2006; Wisner et al., 2004).

² Aspects to consider when interpreting e.g. EM-DAT or Munich Re statistics are the improving recording technologies, more comprehensive and systematic recordings, and changes in recording methods. In addition, events not qualifying as 'disasters', but regardless inflicting great losses are not included.

³ <http://www.emdat.be/Database/Trends/trends.html>, accessed 19.5.2008

⁴ <http://www.munichre.com/>, accessed 20.9.2006

⁵ <http://www.munichre.com/>, accessed 20.9.2006

⁶ <http://www.emdat.be/Database/Trends/trends.html> accessed, 19.5.2008

⁷ <http://www.emdat.be/Database/Trends/trends.html> accessed, 19.5.2008

In the New Zealand context, fortunately loss of life due to natural hazards has been relatively low. Between 1987 and 1996, 19 people have been reported killed. Between 1997 and 2006 this number increased to 27, bringing the total number of fatalities during a period of just over 20 years to 46 (IFRC, 2007: 202). Looking at the number of people affected by natural hazards, the magnitude is much higher at 20,680 from 1987 to 2006 (IFRC, 2007: 202). With a population of just over four million, the overall number of people potentially killed and affected is comparatively low. This, however, should not distract from the enormous loss potential located in urban centres such as Wellington, in combination with a plethora of natural hazards such as earthquakes, volcanic eruptions, landslides, floods, tsunamis and storms threatening the country. The New Zealand Earthquake Commission has paid claims worth US\$ 14.8 m between 1976 and 1998 for immediate landslide damage, while indirect costs for soil conservation, erosion control and projects on sustainable land management paid by regional councils amount to US\$ 38.15 m for the period 1990 to 1995 (Glade, 1998). A more recent assessment of the costs relating to soil erosion in New Zealand, largely brought about by shallow landslides, estimated that the total annual cost of damage (such as loss of agricultural productivity, repairs) and prevention (such as soil conservation) amounts to over US\$ 81.5 m per year (Krausse et al., 2001).

1.2 Motivation: a dynamic perspective on risk

The difference between a static and a dynamic approach to risk is exemplified when considering how disasters are usually perceived: as single events at a specific point in time, suddenly and surprisingly occurring, triggered by the onset of a natural hazard manifesting. However, disasters are pre-configured by history, meaning by political, economic and social processes which may have been operating for decades or centuries (Oliver-Smith, 1994; Garcia-Acosta, 2002; Bankoff, 2004a). Likewise, the onset of geophysical processes is not time-independent but strongly influenced by the geosystem's history (Schumm and Lichty, 1965; Schumm, 1979; Brunsden and Thornes, 1979; Crozier and Preston, 1998; Preston, 1999). Regardless, research in temporal analysis of individual risk components, and risk as the composite, is rare as summarised by the following.

Hazard maps include a temporal component by expressing the frequency and magnitude of the process mapped (e.g. Petley, 1998; Guzetti et al., 1999; Bell and Glade, 2004; Jongens et al., 2007; Remondo et al., 2008 for landslide hazard mapping). However, they do not depict temporal variability of the hazard itself. It is only recently that changes in the frequency and magnitude of natural processes such as floods and storms are recognised, in particular in relation to the observations and projections of the latest IPCC report (IPCC, 2007a). Likewise, the 2004 and 2005 North Atlantic hurricane seasons were wake-up calls for the insurance industry (Munich Re, 2006).

Temporal changes of **elements at risk** are perhaps the best documented. This is because many disciplines address changes of populations, economies, the built environment and assets. In the context of natural hazards, Keiler (2004) for instance revealed a significant increase in population as well as the number and values of buildings and infrastructure between 1950 and 2000 for the town of Galtuer located in the Austrian Alps. She linked this development to an overall change from farming based activity towards a tourism-orientated economy accompanied by social changes within the community of Galtuer.

The element of time remains one of the most ignored issues of **vulnerability** (Bankoff, 2003; Cutter, 2003a; Wisner, 2003; Bankoff, 2004b). Alexander (2000) suggested a potential 'metastable' development of vulnerability, with a constant trend but interruptions, for example, when vulnerability decreases after new legislation is passed, only to be followed by activities which enhance vulnerability. Wisner et al. (2004) accentuated time as a factor especially related to a sequence of disasters. Generally, the more vulnerable social groups are, the longer their potential recovery phase is. The recovery phase can be interrupted by a subsequent event, which turns out to be disastrous – but only because it occurs before the recovery phase is completed.

Some empirical work has been undertaken to reveal temporal changes of vulnerability components. King (1999) detected noticeable changes of age distribution and other potentially relevant factors related to demographics for coastal Queensland, Australia, within only five years (1991 to 1996). Keiler et al. (2006) applied a vulnerability function to detect temporal changes of the vulnerability of buildings for the community of Galtuer. Cutter and Finch (2008) calculated an index of social vulnerability for the U.S. for several points in time. Still, studies identifying temporal changes in social vulnerability are rare, which may be related to methodological problems associated with measuring vulnerability in general (chapter 11).

Social **resilience** is a relatively new concept included in natural risk research. While methodological problems hamper vulnerability assessments, this is even more evident for the assessment of resilience (Buckle, 2006). A range of different approaches to assessing social resilience have been developed (Tobin, 1999; Buckle et al., 2000; Paton et al., 2001; Bruneau et al., 2003; Paton et al., 2008). However, neither these examples nor other studies address the temporal change of social resilience to natural hazards.

Shah (1995) reviewed the increasing **risk** of the world's largest urban centres with respect to earthquakes. Kakhndiki and Shah (1998) presented a conceptual framework for monitoring temporal change in risk from earthquakes for megacities. However, this conceptual work is not succeeded by the operationalisation of the methodology and production of results. Hollenstein et al. (2002) developed an approach towards incorporating the element of time into risk analysis, which includes changes in the likelihood of specific consequences, as well as positive and negative feedbacks. Fuchs et al. (2005) explored the temporal changes of damage

potential to avalanches for a community in Switzerland, including different scenarios of avalanche run-out length and the implementation of avalanche mitigation measures. The estimate of risk relates to the probable maximum loss of lives and value of assets (buildings). Social vulnerability and resilience are not considered.

As Alexander (2000) pointed out, the lack of dynamic approaches to natural risk is a serious lapse within risk analysis, especially in the context of our rapidly changing world. This view is shared by Cutter (2003a) who emphasised the need for dynamic models. She concluded that identifying temporal changes of natural risk, as well as the underlying processes, contributes to an improved understanding of today's risk levels. However, recent observations still detect a lack of dynamic approaches to risk (Bohle and Glade, 2008).

In summary, risk is usually treated as a static phenomenon. Conceptualising and measuring risk as a constant appears to be in line with usual practice in hazard and risk management. More than ten years ago, Mileti and Myers (1997) observed that a 'traditional planning model' dominated in the U.S., which is persistent in its routine and therefore static. While Tierney (1999) stated that due to a constant flux, decisions based on past observations are not feasible, it is argued here that identifying the process of risk is useful for the understanding of risk. Moreover, strategies for reducing risk, which need to be forward-looking, benefit from revealing the history of risk. For example, incorporating a dynamic concept of vulnerability would not only help to understand the processes and interactions that render people vulnerable, but also enables emergency managers to model scenarios, which improves planning and preparation for future crises (Glade, 2003a; Glavac et al., 2003).

1.3 Aim and objectives

The aim of this research is to identify temporal changes of risk from landsliding for several locations in New Zealand (the Western Hutt Hills, close to Wellington; Te Arai, close to Gisborne; Mt.Cook/Aoraki Village, South Island). While risk analysis usually targets a particular point in time, this research includes several five-year intervals (based on census years) starting in 1981 until 2006. The scale of this analysis is the community level.

Risk is not expressed as an absolute level of loss, for example a dollar value or the number of fatalities. Risk is rather considered as the probability and extent of adverse effects on a community inferred from landsliding. As such, risk is relative: the aim is to quantify risk for a community relative to another point in time, and relative to other communities. In addition, the degree to which risk levels vary between communities is quantified.

The objectives of the risk analysis are to:

1. establish landslide hazard, i.e. the frequency and magnitude of landsliding for each location,
2. develop an index of social vulnerability per census year and community,
3. develop an index of social resilience per census year and community,
4. combine 1.-3. and, together with exposure ('elements at risk'), determine risk from landsliding for each community through time.

1.4 Thesis structure

This risk analysis is structured according to the risk management path suggested by the Australian Geomechanics Society (2000) (figure 1.1). The first step, 'scope definition', clarifies the purpose of the analysis which is outlined in this introduction. Furthermore, this first step involves decisions regarding the methodology used, resource requirements and limitations, and the area studied. Secondly, hazard needs to be identified and described in terms of its characteristics (chapter 4), as well as the potential threat it poses (chapter 9).

These two preconditioning steps are accompanied in this thesis by a review of the history of natural hazard and risk research (chapter 2), and a reflection on the theoretical foundation for a, in particular dynamic, risk analysis (chapter 3). Furthermore, existing concepts of vulnerability and resilience are compared, analysed and synthesised, which results in the design of a model of vulnerability and resilience each (chapters 5, 6, 7). Chapter 8 summarises a range of variables (socio-economic, built environment, risk management) which are associated with vulnerability and resilience. The vulnerability and resilience models guide the methodology of the vulnerability and resilience analysis developed in this thesis (chapter 11).

As illustrated in figure 1.1, subsequently the module 'risk estimation' involves hazard analysis (chapter 10) as well as consequence analysis (chapter 12). In this thesis, not only vulnerability but also resilience is included as a component influencing overall risk of the communities included in this research.

Finally, the results are combined to quantify natural risk (chapter 13). Two options for calculating risk are presented and discussed. Both methods divert from the conventional methodology, which involves a combination of hazard, elements at risk and vulnerability while excluding resilience. This research does not proceed with risk evaluation and treatment (figure 1.1). Instead, risk analysis concentrates on the spatial and in particular the temporal variation of risk. It is demonstrated that risk is a process, and that in combination with process rates, risk assessment and treatment are based on a more informed basis compared to an approach which addresses risk as a static construct. Chapter 14 summarises the key steps and findings of this thesis.

Figure 1.1: The process of risk management based on the Australian Geomechanics Society (2000) and adapted by Crozier and Glade (2005: 10)

2. A history of natural hazard and risk research

This overview is essentially a history of how different the 'human-nature' relationship is perceived. At present, the field of natural hazard and risk research is diverse and fragmented. There is no consensus on how to reduce natural risk most effectively. It is not only the varying focus on hazard, vulnerability or resilience, but also the heterogeneous terminologies, methodologies and conceptual frameworks within these research fields that differ. However, synergies can be extracted as discussed at the end of this chapter. These synergies influence the conceptual work undertaken in this thesis (chapter 7).

The overview presented here cannot include all research currents and is therefore a selection only. However, some of the major developments in the field are presented.

2.1 Early days and the 'Age of Reason'

People's awareness of damage and loss due to natural hazards and disasters and their incentive to mitigate these losses date back to at least 4,000 years ago, when the first flood protection dams were constructed in the Middle East (Smith, 2004). Buildings designed to withstand major earthquakes were designed in Minoan Crete (2600-1450 BC), when for instance a ring beam was invented for holding walls together. Another, more recent example of human adjustment to natural hazard is the building style developed by the Incas of the 15th and 16th century. The Incas constructed massive stone structures with closely fitted walls, interlocked and leaning inwards. This gave them the strength to survive major earthquakes, and examples can still be seen at Sacsayhuaman, near Cusco, Peru (Alexander, 2000).

Just as today, past beliefs about the roots of natural risk influenced people's strategies of dealing with that risk and eventual disasters. The 1755 earthquake in Lisbon (the fourth largest European city at that time) destroyed nearly two-thirds of the town, and claimed up to 70,000 lives according to some sources (Dynes, 2000), while other contemporary sources estimate the death toll between 5,000 and 15,000 (Bradford and Carmichael, 2007). The seismic tremor triggered an equally destabilising theological and philosophical debate about the cause of this disaster. The Catholic Church regarded the disaster as God's condemnation for sins and vanity, only to be avoided in the future by praying for forgiveness and by abjuring immorality (Sanides-Kohlrausch, 2003). Generally, 'acts of God' were seen as a response to human failings (White et al., 2001). Still in modern times, explanations of disasters as God's punishment have been reported from people who experienced a massive storm that hit the southern UK in 1987, and survivors of the 1992 earthquake in Egypt near Dahshur (Homan, 2003). A cosmovision of at least one God responsible for disasters is reported from Latin America, for instance Mexico (Alcantara-Ayala, 2004; Alcantara-Ayala et al., 2004) and Ecuador (Morris, 2003). See also Venton and Hansford (2006) for a recent example of identifying God as the source of disasters. Perceiving natural processes as 'acts of God', as overwhelmingly powerful and without the chance to withstand, can portray disasters as unavoidable events of misfortune and destiny

(Weichselgaertner, 2001; Cardona, 2004). A sense of 'fatalism' can impede active prevention measures, as Crozier et al. (2006) illustrated for earthquakes.

While the Catholic Church claimed its position after 1755, it was strictly dismissed as cynical by philosophers Rousseau and Kant. Rousseau emphasised the human role in this disaster, since the city pattern with 20,000 seven storey houses in high density did favour their susceptibility to damage - one of the first notions of the modern concept of 'vulnerability' (Dynes, 2000). Immanuel Kant, who had studied many reports on earthquakes and drew on experience in Chile and Peru, clearly stated that building Lisbon in an earthquake-prone zone without drawing on construction-experiences elsewhere was the cause for the disaster (Sanides-Kohlrausch, 2003). Hence, as the 18th century progressed it was recognised that human action causes disasters, and that adjustment strategies, like avoiding hazardous areas or applying specific construction schemes, would have prevented the disaster or reduced its cost. Philosophers challenging the 'act of God' dogma shaped the growing confidence of 'human reason'.

The Lisbon earthquake disaster occurred during the emerging Enlightenment era in Europe. This period, the 'age of reason' conceptualised the natural environment mainly as a resource which humans have the right to exploit and control. Human intellect was channelled into the upcoming of science and technology (Hewitt, 1983; Oliver-Smith, 2004). The progression from pre-Enlightenment is therefore a rejection of fatalism and a motivation to not only utilise natural resources but to occupy new habitats. Resulting negative effects, such as natural hazards and disasters, are subsequently equally treated with 'human reason', this means with science and technology. Critical voices, such as Rousseau's, were pushed to the periphery. He stated that *'Men's ills come far more from error than ignorance and that what we do not know at all harms us far less than what we believe we know'* (cited in Dynes, 2000: 104 adapted from Masters and Kelly, 1992: 103).

In the Enlightenment, nature was 'disorder', and hazards and disasters especially were perceived as disturbing the order established by civilisation (Hewitt, 1983; Oliver-Smith, 2004). The western 'age of reason' relied on science to solve more and more 'secrets' of nature – which became 'disenchanted' and lost any meaning other than serving human needs. The Enlightenment paved the way for the industrial revolution in the western world, which focussed on nature as a source of raw materials to produce goods. It was a time when humans increasingly distanced themselves from the natural environment, and former largely rural societies changed into urban, industrial and 'modern' societies (Barry, 2007).

Extending the means of subsistence also entailed an increasing modification of nature, consequently producing not only goods but also conditions favouring the occurrence of natural hazards and disasters. For example, the first European settlers arriving in New Zealand in the early 1800s settled on the floodplains, drained swamps and increasingly progressed into the

interior of the hilly country to cut down forests for farming. Deforestation in the upper parts of the catchments, draining the swamps in the lower part and settling on the floodplains at the same time caused losses and damages within those early settler communities. To reduce these dangers, more and more levees were constructed, though with often limited success in reducing flooding (Poole, 1986).

2.2 The science and technology approach

In the early half of the 20th century, the Western world became more aware of the damage and resulting financial losses following the exploitation of their own environmental resources as accentuated by the philosophy of the Enlightenment. In the 1930s, mining, milling and cropping the slopes of the Appalachians in North America resulted in increased rates of slope denudation. In the 1930s, very destructive and extensive flooding occurred at the tributaries of the Mississippi and the Tennessee (Poole, 1983). In the later 19th century U.S. agriculturalists, supported by technological innovation as well as the railway and government policy, pushed the margin of production into a region of highly variable climate. As a result, severe droughts occurred in the subsequent decades, with the images of the 1930s dust bowls of the Great Plains in North America probably the ones most vividly remembered. During this time, the number of farms abandoned or sold spiralled and thousands of farmer families migrated towards the west coast (Warrick, 1983).

The *Zeitgeist* of the 1920s and 30s condensed the pursuit of progress, the celebration of speed and new architectural and technological advances, as well as the possibilities to master environmental processes. Attempts at controlling and predicting processes such as soil erosion and floods, usually with engineering measures, dominated within the scientific community. In 1936 the US Flood Control Act was passed, which triggered investment in this field. Simultaneously, the pressure to utilise natural resources increased, and so did the amount of money potentially assigned for public engineering works (Mitchell, 1990; Smith, 2004). After the extensive flooding of the Mississippi and Tennessee, the 'Tennessee Valley Authority' (TVA) was founded, which supervised a range of dam projects in order to control flooding. The TVA became an example for integrated flood control and land management (e.g. soil conservation programmes) scheme.

Earlier in New Zealand, efforts to sustain the colonies resulted into implementing River and Drainage Boards and River Trusts from the 1860s onwards, and the Land Drainage Act in 1893. A plethora of acts followed to utilise floodplains and swamps, which relied on capital investments, development of engineering constructions and equivalent heavy machinery. However the flood frequency was not lessened, while investment in crops and settlements continued regardless, which in turn raised the pressure on building more control schemes (Poole, 1986).

During the 20th century, major contributions of science and technology in the field of hazard and risk research are the increasing understanding of natural processes (such as plate tectonics) and the development of instruments for data acquisition and monitoring with satellite and aircraft remote sensing emerging in the 1980s. Computers became more powerful and enabled more complex data analysis and modelling. Storing, manipulating and mapping geographical data assisted the efforts to understand environmental processes (White, 1985).

At an international level, the trust in science was generally high. In 1972, the United Nations stated: *'It is believed that not only the causes of [...] disasters fall within the province of science and technology, but also, in some cases their prevention, as well as the organizational arrangements made for forecasting them and reducing their impact when they occur'* (United Nations Department of Economics and Social Affairs, 1972: 1). Consequently, the United Nations Advisory Committee on the Application of Science and Technology to Development promoted research in the fields of physical processes, forecasting, technological measures for protection and warning systems (Burton et al., 1978). This research stream continues until today, and against the background of recent disasters, has intensified on an international scale. However, damage was predominantly seen as proportional to the magnitude, frequency and type of the natural process only (Hewitt, 1983; UNDP, 2004a). What is more, in the 1970s and 80s 'risk' was used by natural scientists to express the likelihood of an event occurring (frequency and magnitude). The focus was very much on the natural process itself, without including damage or loss estimates (Timmerman, 1981; Cardona, 2004). The process-focused understanding of risk has now mostly shifted towards including the probability of damage and loss; this means the adverse consequences for humans and their environment. Also 'hazard' applied today usually implies that someone or something is threatened, while still in the 1980s, 'hazard' was frequently used to describe the natural process only (Hewitt, 1983). A shift in terminology reflects the development in the field of natural hazard and risk research, as will be seen in the following.

2.3 The human ecology approach

American geographer Harlan Barrows (1923) was amongst the first underlining the value of research into 'human-nature' interaction – a topic associated with human ecology and geography alike. However, his perspective did not influence the then dominant approach of loss reduction based on science and technology, and could not divert the substantial financial investments watering these fields. About twenty years passed before a human ecology approach gained attention within the natural hazards arena, when in 1945 Gilbert F. White published his dissertation 'Human adjustment to floods – a geographical approach to the floods problem in the United States' at the University of Chicago. In his introduction he stated: *'Floods are 'acts of God', but flood losses are largely acts of man'* (p. 2). Although God's role in flood events is contestable, White clearly places the responsibility for flood damage into the realm of human action. White, who had worked with Barrows, questioned the efficiency of the large

flood-control measure expenditures for dams, channel modification and levees (White et al., 1958, White, 1961). In retrospective, it is the discrepancy between 'good' intention and reality at the time which is striking.

Kates (1970) defined natural hazards as the *'interaction between humans and nature'* (p. 1), hence underlining the human role in causing hazard and risk. His definition is similar to definitions of human ecology provided by Eyre and Jones (1966) and Bohle et al. (1994) (chapter 3). As Hewitt and Burton (1971) advocated with respect to a human ecology perspective on hazards: *'An ecological approach to hazards recognizes the dual cause of hazards, both man and nature [...].'* They identified beneficial outcomes of this dualism (resources and goods) and negative outcomes, such as hazard and risk (see also Kates, 1970 and Burton et al., 1993).

Furthermore, human responsibility in generating loss from natural hazards is accentuated: *'Although the hazard results from the interaction of natural and social systems, the two cannot be equated as causes. Natural systems are neither benevolent nor maliciously motivated toward their members: they are neutral [...].'* (Burton et al., 1978: 32). White (1974: 3) had emphasised earlier that it is the settlement on floodplains which creates hazard, not the natural process: *'By definition, no hazard exists apart from human adjustment to it. It always involves human initiative and choice. Floods would not be hazards were not man tempted to occupy floodplains [...].'* White refers here to human responsibility in creating losses, and implies that humans can take action to reduce these losses.

Increasingly, the dominance of science and technology as providers of solutions to reduce losses was questioned. White (1974) referred to the focus on science to estimate the frequency and magnitude of natural processes to avoid hazards, and concluded that sound predictions are difficult to achieve: *'Were there perfectly accurate predictions of what would occur and when it would occur in the intricate web of atmospheric, hydrologic, and the biological systems, there would be no hazard. [...] Ordinarily, the extreme events can only be foreseen as probabilities whose time of occurrence is unknown.'* (White, 1974: 3). As White (1973) criticised, though the common aim was to optimise the cost-benefit ratio of mitigation measures (e.g. engineering flood protection works), the knowledge about physical processes and their behaviour is 'imperfect' and therefore mitigation measures are not as successful as envisaged, which reflects Rousseau's critique cited earlier. Today, the problem of uncertainty in prediction has still not been resolved for many hazards, especially for landslide hazard as Crozier and Glade (2005a) pointed out. As White continued, even if predictions were possible, the human role is not to be underestimated: *'However, there would remain the question of how, given the particular aims of a social group, to respond effectively to the completely predictable order of events'* (White, 1974: 3).

The waking-up call disseminated by the human ecologists was amplified when the human ecology school was increasingly institutionalised. In 1969 White was appointed at the University of Colorado in Boulder, which still hosts the 'Institute of Behavioral Science' (IBS) today since its initiation in 1957. The Institute developed an interdisciplinary character, with geographers, engineers, meteorologists and sociologists becoming heavily involved in natural hazard and risk research (Quarantelli and Dynes, 1977). From 1967 to 1973 the 'Program of Collaborative Research on Natural Hazards', shared by the University of Colorado, Clark University and the University of Toronto, was a forum for geographers working with psychologists in the field of human behaviour within a human ecologist framework (Mileti et al., 1975). In 1976, White established the 'Natural Hazards Research and Applications Information Centre', short 'Natural Hazards Centre' (NHC) at Boulder, which today is a centre of IBS within the Environment Program.

The evolution of the human ecological perspective on hazard and risk proceeded in a time when society's view on the environment changed towards an awareness of the negative consequences of exploiting natural resources. Parallel to the still dominant boost of science and technology, doubts about their reliability increased in the industrialised and non-industrialised world (Burton and Hewitt, 1974). Major disruptions like the drought in the north-eastern USA 1963 to 1965, the great Chicago snowstorm in 1967 and the Sahelian drought 1971 to 1976 trembled governments, scientists and managers alike (Hewitt and Burton, 1971; Copans, 1983). With the beginning of the 1970's, intensified media coverage of disasters raised the public awareness and concern, calling for preparedness and safety (Hewitt and Burton, 1971). Finally, the reflection on science and technology as the carriages of progress and dangers alike takes place and engulfs the wider public.

Against this background, the dominant 'solutions' proposed by science to technology to reduce losses are increasingly criticised. Reducing loss by technology-driven strategies proved to generate even more rather than less damage, just like already criticised by White in the 1940s and 1950s. Avoiding smaller losses in the short term turned out to increase losses in the long term (Burton et al., 1968; Kates, 1970, Burton and Hewitt, 1974; Burton et al., 1978). While for example the construction of dams reduces flood damages of a specific magnitude, 'protected' areas are still exposed to high magnitude events. During time, the aggradation rate of a river confined between levees can be enhanced, which potentially elevates the channel bed and amplifies the chance of overtopping. Additional costs after flood events are also incurred from damage to the flood protection works themselves (Hicks and Davies, 1997). Furthermore by constructing levees, human settlement is encouraged in a supposedly flood-protected area, which creates a false sense of security and increases the damage potential. Urban growth outside the range of levees raises damage potential further (Hewitt and Burton, 1971; White, 1973). A similar example is the increase of irrigation and technological innovations of agriculture after the period of the 1930s dust bowls in the United States. The investments into creating a

drought buffer fostered the establishment of communities which in turn were (and still are) heavily dependent on technologies. Hence, though the human-use system is adjusted to less severe, more frequent droughts, rare but severe droughts which exceed the capacities of technology can lead to even higher damage. This is because communities evolved to a larger extent than they would have without these technologies (Warrick, 1983). Much later, though not much wiser, Australia faces similar challenges today, with spiralling numbers of farming-based livelihoods endangered by droughts within large areas in the south-east of the country (Marks, 2007).

As Burton et al. (1968) demonstrated for the case of floods, relying on a technological fix can entail a relaxation of general preparedness measures. In general, focussing on predicting, modifying (for example hail or hurricane seeding) and controlling natural processes is seen as luring people to act carelessly, and to reduce their commitment to remove manageable risk (Hewitt, 1983). In addition, Burton and Hewitt (1974: 275) accredited engineers '*who occupy the driver's seat*' ignorance of the resulting social effects.

With all the criticism of the then dominating approach to reducing losses from natural hazards, which are the solutions the human ecologist school has to offer? Human adjustment to natural hazards is the central topic of the human ecologist school, which is also sometimes labelled the 'Chicago School' (Tobin and Montz, 1997) or the 'behavioural paradigm' (Pelling, 2003; Smith, 2004). As outlined previously, human responsibility in causing loss is accentuated. White (1974: 4) defined adjustment as '*a human activity intended to reduce the negative impact of the event*' (see also chapter 3). It is when the impact of a natural process exceeds the adjustments in place that damage and loss unfold, as the above examples illustrate. This entails '*a continuing effort to make the human use system less vulnerable to the vagaries of nature*' (Kates, 1970: 1). The Chicago School proposes a combination of adjustments such as 1. '*modify the cause*', i.e. keeping the hazard away from the population (for example by structural measures such as constructing levees, avalanche fences, or by operations such as snow melting, slope stabilisation), 2. '*modify the loss*' by keeping the population away from the hazard (for example warning systems, building design, land use planning), and 3. '*distribute and adjust to losses*' such as purchasing insurance (Burton et al., 1968, 1993; Kates, 1970; White, 1973; Mitchell, 1990). For a variety of adjustments in relation to different hazard types, see Burton and Hewitt (1974). A combination of structural and non-structural measures is seen as a toolkit for targeting both, humans and nature. Non-structural measures such as land use planning and insurance schemes are increasingly acknowledged since the mid of the 20th century (White, 1985). An example for reinforcement of a structural measure is the 2004 building code implemented by New Zealand policy. It defines how a building must perform during earthquakes of different magnitudes, and also includes snow, wind and fire impacts (Department of Building and Housing, 2006). Especially when '*modifying the cause*' is not possible, non-structural management options are rated as increasingly relevant. Therefore, common '*solutions*' of

science and technology are not dismissed as such, but rated to be insufficient by themselves and only effective if in combination with other strategies.

Repercussions of human adjustment to hazards are summarised by Hewitt and Burton (1971) and Burton and Hewitt (1974). A combination of the magnitude of a geophysical variable, like water discharge, and human adjustment delineates a zone where damage is not significant, i.e. does not cross a threshold above which the positive effects of resource utilisation flip into adverse effects creating 'negative resources' (hazards). These damage thresholds are closely interlinked with human adjustment strategies which can alternate the thresholds, hence widen or lessen the zone of insignificant damage. In addition, damage thresholds vary according to changes in the social realm, for example the implementation of new strategies or changes in land use. The zone of insignificant damage is adjusted to buffer 'normal' events of a certain frequency-magnitude relation. 'Extreme events' exceeding the damage threshold, however, are not covered and damage is incurred.

The zone of insignificant damage is what the climate change and global environmental change community calls 'coping range' (Smit et al., 2000; Ford and Smit, 2004), which can be extended by 'adaptive capacity' (Smit and Pilifosova, 2003; Adger, 2006; Smit and Wandel, 2006) (chapter 6, appendix A).

Ongoing human ecology research on responses to natural hazards feeds into a model of decision-making. The model is based on the work of Herbert Simon, who conducted research in the field of cognitive psychology and economic sociology, among others. He stated that *'Any particular concrete behavior is the resultant of a large number of premises, only some of which are prescribed by a role. In addition to role premises there will be premises about the state of the environment based directly on perception, premises representing beliefs and knowledge, and idiosyncratic premises that characterize personality'* (Simon, 1956; Simon, 1959: 274). Within the human ecological school, hazard perception is understood as *'the individual organization of stimuli relating to an extreme event or a human adjustment'* (White, 1974: 4). White (1961) incorporated Simon's ideas into a model of decision-making in resource management. He showed that in addition to perception, the value system of a manager or home owner is an aspect within the decision making-process. White further identified social, political and economic constraints which influence awareness of adjustment options and ultimately the adjustment chosen.

Perception of the environment is regarded as an important factor in resource management, because it potentially reduces the practical spectrum of managing strategies. Kates (1970) developed this approach further. His 'Natural hazards in human ecological perspective: hypothesis and models' is an outcome of the 'Program of Collaborative Research on Natural Hazards' (see earlier in this chapter). He analysed how people perceive hazard, how they perceive the range of possible adjustments and why there are differences in their perceptions.

Kates developed a model which is a good example of a classical dualist ontology in the context of hazard and risk (chapter 3). The link to a dualistic perspective, in particular in the context of systems theory, is also created by Chorley and Kennedy (1971: 308), who refer to Kates's model as a 'systems model of human adjustment to natural hazards', which in turn is an example for a 'control system' (i.e. a system influenced by humans, or a 'human-nature' system).

In the model human adjustment to natural hazards influences two systems: the 'human use system' and the 'natural event system'. The first system is characterised in terms of socio-economic and demographic factors, production activities, social activities and an inventory of damageable material wealth. The 'natural event system' is described by the magnitude, frequency, duration and temporal pattern of a natural process. Basically, the perception of adjustment options modifies the adjustment choice finally made. The choice of adjustment modifies the human use system, which modifies the natural events system, and which finally modifies the effect of a natural hazard. Evaluating adjustments against a set of criteria, such as economic benefit, technical and environmental feasibility, is seen as an individual and highly variable process. Perception depends on personal experience, the characteristics of the natural hazard, and individual personality, while socio-economic or demographic factors are regarded as less significant for the perception of hazards (Kates, 1962, 1970).

In industrialised countries, settlement on floodplains is attributed to a failure of assessment flood risk, by land managers and home owners alike. After a flood, people often re-establish the previous use of the land although they are aware of the recurrence possibility and potential disastrous consequences. An in principle similar pattern in less developed countries is seen as a contribution to cause disasters, for example when pastures loose their productivity through over-grazing.

From a human ecologist perspective, hazards are not perceived as exceptional and unrelated to normal conditions, but as imbedded in these. Within the decision-making model of the human ecological approach, choices of adjustment are seen as mirroring this limited human rationality, or 'bounded rationality' (Kates, 1970; White, 1973; Burton et al., 1978, 1993). Rational behaviour overruled by political or economic power is only marginally recognised within the human ecology perspective, which is identified as a major deficit by the emerging criticism (section 2.5.2).

Comparing developed and less developed countries resulted in a model of successive adjustments. At the time, it was assumed that less developed countries with a 'folk' society, will transform over 'mixed' and 'industrial' to finally a 'post-industrial' society. The different stages are associated with different adjustments and damage patterns, reaching the lowest loss of human life in the 'post-industrial' society (Kates, 1970; Burton et al., 1978, 1993).

The model relates to the dichotomy of wealth and stability between the then so-called 'First' and 'Third' World. An analysis of global data on disasters, gathered for a report by Sheehan and Hewitt (1969) over the period of 1947 to 1967, reflected very high losses of life, but relatively

low property damage in less developed countries, especially Africa and Asia. In contrast, for example in North America, loss of life was observed to be lower but property damage often to be very high (Hewitt and Burton, 1971).

This contrast between the more and the less developed countries continues until today, as data assembled by the Centre for Research on the Epidemiology of Disasters (CRED) between 1992 and 2001 show (Smith, 2004). Nowadays, the model's linear progression with a final stage of minimal loss of human life appears to be rather cynical and far from reality for many developing countries.

One component of a human ecologist approach to reduce losses is to include the socio-economic causes and effects of risk. The human ecology school defines 'vulnerability' as the '*capacity to be wounded*' (Kates, 1985: 9). The most vulnerable element, i.e. the one most susceptible to be wounded, is relative, this means it varies with hazard type and community type. Concentrating on these varying levels of vulnerability is seen as especially important. Applying the human ecological approach does not imply describing, for example, a flood by discharge, meaning the characteristics of the natural process, but by the damage done to people and their environment. This approach raised demand for data on damage, like the number of deaths and injuries, and financial loss, next to physical process data. The damage-focused perspective also channelled research into a direction of establishing an, until then, missing relationship between the magnitude of the physical process and socio-economic loss (Hewitt and Burton, 1971).

Despite this increase of human ecology perspectives on natural hazards, the findings were still at the periphery of international research agendas. For example, only two out of 30 recommendations of the 1972 UN Advisory Committee included behavioural aspects (Burton et al., 1978, 1993). Shortly after, White and Haas (1975) advocated a redirection of research funding in the U.S. to challenge the dominance of the technological approach and point to the lack of social, economic, and political aspects in order to gain a balanced view of loss reduction strategies. In addition, White and Haas (1975) observed a gap of social research within the field. To estimate the effect of various adjustments to natural hazards, they suggested that three interacting elements have to be analysed in order to estimate losses: the 'natural event generator' (for example frequency and magnitude of earthquakes and storms), the 'population-at-risk in each area' (density or distribution of people and buildings), and the 'vulnerability of population-at-risk to loss for a given severity of an event' (p. 123). This work paved the way for the concept of risk as it is often understood today and synthesised by the United Nations Disaster Relief Office (UNDRO, 1982) (chapter 5).

The *Zeitgeist* of the 1980s fuelled a human ecology perspective, not only within the field of natural hazard and risk. Entire modern societies begin to perceive themselves at risk, either by natural hazards or technological hazards such as Bhopal and Chernobyl (Burton, 1983; Mitchell,

1990; von Randow, 2006). This transformed society is what Ulrich Beck (1986) labelled 'risk society'. Of general concern within 'risk society' are health, socio-economic, cultural and environmental consequences of 'social progress' and particularly of scientific and technological inventions. These debates increased the loss of confidence in institutions of government and industry (Barry, 2007). A new 'environmental paradigm' developed which values nature and prefers low-risk technologies, and identifies the limitations of growth (Steiner, 1993). This movement and re-evaluation of the 'human-nature' relationship precipitated in social theory, though only at the periphery (chapter 3).

In summary, the emerging human ecology school shifted the focus from human control of nature to human adjustment to nature. By questioning the 'naturalness' of hazards, the effectiveness of purely scientific and engineering approaches to loss reduction, by promoting a set of adjustment strategies including non-structural measures of loss reduction, and by exploring people's perception and choice between different adjustment options, the human ecologist school widened the perspective on causes and reduction of losses. What is more, the human ecology school paved the way for a vulnerability concept which today is a key to understanding the magnitude of damage in the aftermath of natural hazards manifesting.

2.4 The sociological approach

Parallel to the geography-oriented human ecologist school, sociology's interest began with an often cited dissertation by Samuel Prince (1920). After a marine accident in the harbour of Halifax (Nova Scotia, Canada), he analysed long-term sociological consequences for organisations and communities, which can be negative, but also positive. In the long run, organisations or communities can, for example, benefit in terms of their power position or their status. These points are followed up considerably later by studies in the 1970s, such as Drabek et al. (1973) and Taylor (1977). However, in the early decades of the 20th century, sociological research stagnated. Efforts were strengthened by the National Opinion Research Centre (NORC) at the University of Chicago (1950-54), for example to analyse human reactions to disasters, with a first study published in 1954 by Fritz and Marks. NORC studies had a strong psychological context, like the general work at the University of Chicago at that time. Key findings on panic and convergence behaviour (many people and supplies arriving in the area) were of interest for policy and disaster preparedness (Quarantelli and Dynes, 1977; Drabek, 1986). The first sociological definition of disaster is given by Fritz (1961: 655), who stresses the social disruption and changes imposed upon society by a hazardous process. A disaster is *'an event, concentrated in time and space, in which a society, or a relatively self-sufficient subdivision of a society, undergoes severe danger and incurs such losses to its members and physical appurtenances that the social structure is disrupted and the fulfilment of all or some of the essential functions of the society is prevented'*. Fritz's essay has gained wide attention in the field, and is one of the cornerstones of disaster research. This was the first time that disasters are not seen in the pure physical context of a natural process - disasters were increasingly

perceived as a social phenomenon. With the increased sociological interpretation of disasters, the term 'natural hazard' is dismissed for stressing the physical rather than the social aspects (Quarantelli and Dynes, 1977). An institution contributing to the research output was the 'Disaster Research Group of the National Academy of Sciences-National Research Council' (1957-1963). The DRG (NAS-NRC) conducted field research and looked at human behaviour under crisis conditions. In 1962 Baker and Chapman edited 'Man and Society in Disaster', covering issues of human response to disasters, linking this with social theory and emphasising disasters as phases of extreme stress (Drabek, 1986). The Disaster Research Centre (DRC), founded at Ohio State University in 1963 also used NORC data, but focused on organisational response. It inherited DRG files and, where possible, the original data sources, which contained almost all the professional literature to that date. The DRC is engaged in individual, group, organisational and societal reactions to disasters. An example of a collaborative DRC field study is Drabek's (1968) 'Disaster in Aisle 13' on the Coliseum Explosion at the Indiana State Fairgrounds in 1963, which killed 53 people and left nearly 400 injured.

Major trends in sociological disaster research since the early 1960s are, for example, social organization (strongly supported by DRC), groups rather than individuals as the scale of analysis, the use of the 'system' concept, and a focus on the pre-disaster period as a factor for trans- or post-disaster responses (principle of continuity). The latter shows how trans- and post-disaster behaviour follows the same patterns already existent in the pre-disaster period. With little change of organisational or individual behaviour in general, disasters are not seen as necessarily triggering major organisational changes. In order to establish links between pre- and post-disaster conditions in society, the need for continuity in disaster research was underlined (Quarantelli and Dynes, 1977). At the times of the cold war, a motivation for hazard research in the US, though made less public, were interests in how populations would react after extensive destructions caused by, for example, nuclear bombs (Mueller-Mahn, 2005).

Barton (1969) essentially contributed to theory construction with his work on social process models, drawing on the extensive amount of field studies undertaken by NORC (Drabek, 1986). He identified problems of individual behaviour in disaster, such as the issue of role description, role competence and role conflict. In 1970 Dynes, who co- established the DRC, published 'Organized Behaviour in Disaster', which is a major analysis of the research output of the DRC. Each of these reports is classified according to disaster type. Dynes' publication highlighted that while usually disruption and disorganisation are associated with disaster, persons, groups of people and organisations do react in a structured way. The focus of this book is on community organisations rather than on individual response. How organisations within the community, such as fire and police departments, Civil Defence, the Red Cross and charities, interact during various stages of a disaster, is explored.

A community's complex organisation in modern society can be decoded best during a crisis: *'From a sociological viewpoint, perhaps the most useful crises to study are natural and man-made disasters, for they provide a natural laboratory for testing hypotheses about organizational and group behaviour under realistic conditions of severe strain and stress'* (Dynes, 1970: 4). Especially disasters are of interest, since they affect all parts of a community.

In addition, topics included are:

- community stress,
- mobilisation and recruitment of groups and their operational problems of how to function quickly, and
- how a community structure emerges by assigning subtasks.

Dynes explored the ability of a community to handle the situation dependent on the characteristics of the disaster agent, such as frequency, predictability, cause (man-made, natural), speed of onset, length of forewarning, duration, scope of impact (if affecting the whole community) and destructive potential. Dynes showed that relying on the geophysical process type (earthquake, flood, storm etc.) alone is not a sufficient method, if the aim is to understand human behaviour in crisis. In general, the individual or household level scale is not addressed as much in his work. Dynes regarded the community focus as the most beneficiary in terms of developing efficient disaster preparation.

During the 1970s and 80s, the DRC became the leading institution in the field, and moved to the University of Delaware in 1984. The DRC was able to send field teams into disaster areas of the US and for a certain time also internationally, and very rapidly. The DRC was strongly linked with a major sociology teaching department, and consequently many researchers with an interest in social and behavioural topics were affiliated with the DRC since its establishment and during the subsequent decades (Quarantelli and Dynes, 1977). Organisational behaviour not only of communities but also of individuals continued to be one of the most supported research fields in the following decades (Mitchell, 1990).

Compared with research activity in previous decades, it was mainly in the 1970s that sociological activity in the field of hazards and disasters grew very rapidly. In 1975, Mileti, Drabek and Haas publish *'Human Systems in Extreme Environments'*, which is another review of the social science disaster literature, which is extensively based on material provided by DRC. The aim was to gather and analyse material on human adaptation and response to natural hazards and disasters. The study was hosted by the 'Program on Technology, Environment and Man', and published by the 'Institute of Behavioral Science' at the University of Colorado (see above). The major difference to the previous efforts of Barton and Dynes is that only published material is used. The spectrum of topics was also broader, ranging from preparedness to warning, and long-term reconstruction. Also, as opposed to Dynes, this book

includes several system levels: individual, group, organisation, community, society (nation) and international.

In summary, sociology's interests in the field of natural hazards and disasters addresses firstly human reaction to disasters on different scales. Individual behaviour, such as panic and convergence, but also community and organisational reactions are investigated. Secondly disasters, as 'disrupting' a society and providing a 'natural laboratory', are the main focus of research. Just as the human ecology school questions the 'naturalness' of hazards and disasters, sociologists criticise the usage of the term 'natural disaster' because they increasingly characterise disasters as purely social processes. Thirdly, human behaviour according to the characteristics of a disaster rather than the type of disaster is studied. Additionally, topics of preparedness, adjustment, warning and relief are addressed.

It is not evident to what extent sociology as a discipline and the human ecology school collaborated. The study by Mileti, Drabek and Haas (1975) outlined above is one example for cooperation. Other joined projects would be likely since both disciplines addressed human behaviour, although from different directions, and an interface for collaboration is certainly present.

2.5 Halftime: vulnerability

In the late 1970s/early 1980s the concept of vulnerability emerges in several disciplines and becomes a milestone in the evolution of natural hazard and risk research. As defined by Kates (1985), generally speaking 'vulnerability' is the susceptibility to be harmed, therefore influences the overall degree of loss that can be incurred by a natural hazard. While today this understanding is widely shared, the focus on how to explain and remedy high levels of vulnerability differs greatly. This situation is partly a result of the development in the field outlined so far. In the 1980s, ongoing research based on this history developed into two different ways of interpreting and applying vulnerability: one as a continuous development of the human ecology school ('applied sciences'), the other the 'structuralist paradigm' triggered by criticism of the former and the general science-based approach.

2.5.1 Vulnerability and applied sciences

Applied sciences, such as engineering, economics, politics, geography and environmental studies, are increasingly inspired by the human ecologist school of natural hazards. Identification and mapping hazardous zones is developed as tool for land use planning and management, in combination with promoting sustainable ways of interactions between communities and the environment (Cardona, 2004; Smith, 2004).

The term 'risk' is now usually defined as not just the probability of an event occurring, but as the degree of potential damage related to a natural event (Cardona, 2004). In the emerging framework of risk assessment, for example in the context of hazardous substances, not only the threat imposed by chemical agents is considered, but also the 'ecological situation of the

communities' (Gabor and Griffith, 1980 in Cutter, 1996b). Additionally, topics range from assessing technological failure and risk analysis in terms of system reliability (Cardona, 2004).

At the end of the 1970s, the vulnerability concept is fostered and implemented in guidelines for future research in the fields of energy, risk management, and climate impact assessment. Models of social collapse and ecology are combined under the vulnerability umbrella (Timmerman, 1981). In the 'Proceedings of the World Climate Conference' in Geneva 1979, the World Meteorological Organisation subscribed to the identification of *'characteristics of human societies at different levels of development and in different natural environments which make them either specially vulnerable or specially resilient to climatic variability and change'* as one of their objectives (World Meteorological Organisation, 1980 in Timmerman, 1981, preface). It should be noted that here already the notion of resilience is introduced, although it will take some time for this concept to emerge more powerfully, as discussed later in this chapter.

Disciplines like geography extend their risk assessments methods by describing the vulnerability of people, infrastructure and buildings with respect to a specific hazard. What is more, not only human responses in form of adjustments in order to mitigate risk to one particular hazard type, but multi-hazard approaches emerge. The progress from single-hazard dominated research is particularly important considering the combined occurrence of many hazards, such as a hurricane followed by floods and landslides, or an earthquake triggering landslides. However, constructing a 'multi-hazard' assessment or even indicator of vulnerability still appears to be extremely challenging (UNDP, 2004a), because vulnerability is, to some extent, context specific (chapter 5).

Although the importance of social aspects is recognised, the concept of physical vulnerability, meaning the susceptibility of physical elements such as houses or infrastructures, still dominates the field (Mueller-Mahn, 2005). The applied sciences emphasise potential consequences of hazardous processes, and usually understand vulnerability as the degree of loss which can be expressed as a damage ratio. A numerical value is usually applied to represent the level of potential damage. This understanding is based on definitions suggested by the United Nations Disaster Relief Organisation (UNDRO, 1982). In terms of built structures, classifications of vulnerability (low, medium, high) are derived from, for example, building materials and structures (Glade, 2003a; Kiyono and Furukawa, 2004).

More recently, at least on the research level, socio-economic and demographic factors are increasingly included to analyse, either qualitatively or quantitatively, people's vulnerability as induced from the emerging 'social vulnerability' concept. The common catalogue of risk reduction measures is based on the adjustment strategies identified by the human ecology school. The applied sciences emphasise insurance as a means of adjustment to and for

distributing risk. However, problems with insurance emerge because risky behaviour can be encouraged, and because insurance is not necessarily affordable (Hewitt, 1997).

Vulnerability today is a key part of risk assessment and management in the context of natural hazards and disasters (chapter 5), although interpretations of vulnerability vary and in many cases neglect social implications. Generally, the applied sciences tend to either focus on technology-based solutions of vulnerability and risk reduction only, or apply these in combination with non-structural measures. The latter approach adds a human ecology perspective, which is pursued to varying degrees.

2.5.2 Vulnerability and the structuralist paradigm

In the 1970s, criticism of the increasingly dominant research approach to natural hazards and disasters, the combination of science, technology and human ecology, mounted. This criticism became to be known as the 'structuralist paradigm' (Smith, 2004), although it is questionable whether this emerging research stream developed into a paradigm in the sense of Kuhn. Researchers active within this field developed the notion of vulnerability into a more elaborate and multi-causal concept. The structuralist alternative to the then dominant understanding of vulnerability is a reflection of a change in perspective on human's role in natural hazard and disaster research. Increasingly, the focus is not so much on people's perception and their subsequent choice of adjustment, but on people's individual socio-economic and demographic characteristics within a specific social, cultural, economic, political and environmental fabric. It is not the choice as such, but the ability to choose between adjustment options that is the nucleus of this vulnerability research.

Just as Gilbert White was concerned by the ever increasing loss due to floods in the U.S. in the early 20th century, in the mid 1970s a worldwide rise in the number of disasters over the previous 50 years, with a tendency to occur in the less developed countries, is observed by O'Keefe et al. (1976). Their reflections matched the trend of high loss of life in the less developed, and high loss of property in the more developed world. This phenomenon had been noted earlier by Hewitt and Burton (1971).

Since the human ecologist school does not completely dismiss the scientific and technological approach, for example by combining structural measures with non-structural measures, and increasingly induced hazard management and policy making, the emerging criticism is not restricted to the classic science and technology approach. Hewitt (1983: 4) labelled the interface of science and human ecology as the 'dominant view' or 'dominant paradigm', which had resisted substantial critique so far. He continued: *'The most expensive actions and the more formidable scientific literature recommending action are concerned mainly with geophysical monitoring, forecasting and direct engineering or land-use planning in relation to natural agents'* (Hewitt, 1983: 5). It seems that history repeats itself, since just about ten years earlier, White

and Haas (1975), arguing from a human ecology perspective, had criticised exactly the same hegemony, but directed towards science and technology only (section 2.3).

It is criticised that within the dominant view, hazards are usually defined by the type of physical process: *'It may be accepted that "hazard", strictly speaking, refers to the potential for damage that exists only in the presence of a vulnerable human community. Actual usage almost invariably refers to an objective geophysical process, such as a hurricane or frost, as the "hazard". In turn, damage and human actions are defined by, or as responses to, the type, magnitude, frequency, and other dimensions of these processes'* (Hewitt, 1983: 5). And: *'The sense of causality or the direction of explanation still runs from the physical environment to its social impacts'*. The usefulness of better process understanding and improved forecasting is not doubted per se. The emerging paradigm questioned the prevailing conclusion that improved predictions will reduce damage and loss while ignoring social aspects, and that this is seen as the main strategy of avoiding disasters (Hewitt, 1983). The same criticism, however, was expressed by Gilbert White (1974: 3) earlier who questioned the reliability of predictions and missed an integration of alternative hazard reduction and management strategies.

Increasingly, again similar to White and colleagues, it is argued against labelling disasters as 'natural' (O' Keefe et al., 1976). Richards (1975) stressed the interaction of natural and social processes. He highlighted that *'such as economic development can affect natural systems causing famine and soil erosion for example. This should make us think again about the term "natural" disaster'* (cited in Timmerman, 1981: 11). The human role in causing disaster is certainly an aspect shared by the human ecology school, social sciences, applied sciences and the structuralist paradigm alike. However, suggested strategies of risk reduction differ and often compete.

Especially in less developed countries the unsuccessful strategies of loss reduction conceptualised by the 'dominant view' featured as an impetus for the structuralist paradigm (Smith, 2004). Increasingly, social scientists active mainly in the less developed countries of Latin America and Asia, could not sufficiently decipher the rising number of disasters by the characteristics of the natural process alone. Focussing on hazard as a specialised problem, which can only be cured by scientific expertise, is identified as part of the problem not the solution. The usual approach is seen as more of a technical monologue rather than a dialogue with 'grass root' knowledge (Copans, 1983; Hewitt, 1983). In this context, the success of knowledge and technology transfer for loss reduction from the developed to the less developed countries (as for example sketched out by the human ecology school) is criticised for exacerbating rather than abating crisis.

Application of Western science is perceived as a continuum of Western interference and imperialism in less developed countries. Disasters are regarded as an opportunity to strengthen institutional control over people by reinforcing dependency. International relief and aid agencies

of the developed nations are seen as not providing relief per se, but as using disasters to underline their existence (Waddell, 1983). In contrast, the strengthening of local knowledge about the environment and potential hazards, of local adjustment or adaptation strategies and coping capacities is emphasised within the structuralist paradigm (Smith, 2004). Furthermore, it is increasingly recognised that under the pressure of daily threat, local people have developed their own successful strategies to cope with hazards and disasters (Bankoff, 2004b; Heijmans, 2004).

The new and challenging interpretation of disasters leads to an ideological battle which rejects technology based approaches and the 'behavioural' paradigm of the human ecologist school radically. The 'dominant view' is flagged with 'naïve determinism' and 'technocratic optimism'. Political responsibility, capitalism and the resulting marginal situation of many are viewed within a Marxist context; 'Acts of God become Acts of Capital' (Waddell, 1983: 38). This is why some label the structuralist paradigm alternatively as Neo-Marxist (e.g. Pelling, 2003).

Hazards research within the social sciences is criticised, too. From the viewpoint of the structuralist paradigm, the social sciences work on hazard perception, response to forecasts, to *'hazard-zoning legislation and how people 'cope' when the volcano erupts or a crop is destroyed'* (Hewitt, 1983: 7), is welcomed. The majority of the work, however, is regarded as to be serving the dominant view: *'These interests [as listed above] seem entirely reasonable in themselves. They become less so as they are tributary to supposedly more sophisticated geophysical and engineering knowledge. [...] they easily miss the main sources of social influence over hazards'* (Hewitt, 1983: 7).

'Interpretations of calamity from the viewpoint of human ecology' (1983) edited by Ken Hewitt is certainly a milestone for the emerging questioning of the 'dominant view', for the development of alternative research agendas and a different understanding of vulnerability. In the first chapter of his book, Hewitt does not hesitate to illustrate his criticism by using examples of his own previous work, such as perceiving vulnerability as dependent on extreme processes in nature. The rising critique is therefore partly a development out of the existing human ecological body of research.

The understanding of vulnerability from a structuralist perspective incorporates a wider appreciation of the social, economical, cultural and political context people live in, as well as their day to day personal socio-economic situation (Blakie et al., 1994; Wisner et al. 2004) (chapter 5). Wisner et al. (2004: 11) identified a range of variables determining vulnerability as *'class (including differences in wealth), occupation, caste, ethnicity, gender, disability and health status, age and immigration status ('legal' or 'illegal') and the nature and extend of social networks'*. Chapter 8 discusses these variables in more depth. Sometimes poverty is identified as the main cause of vulnerability, since very often the poor are those who suffer the most (Cuny, 1983). A journalist named the earthquake disaster in Guatemala in 1976 a 'classquake' due to the apparent differences in suffering between the poor and the rich (Wisner et al., 2004).

Although it is acknowledged that the human ecologist school allows for the distinction of natural hazards and social agents, the interpretation of disaster as a result of the victim's 'imperfect knowledge' and 'bounded rationality' is denied. People are perceived as victims, without the ability to choose where they live or how they earn a livelihood, restricted by political and economical power structures. The 'bounded rationality' of the human ecologist school is replaced by a reality where potentially rational behaviour is suppressed by political, economic and cultural forces. It should be noted that White (1961), too, identified social, political and economic constraints influencing and potentially limiting people's perception and hence choice of adjustments as mentioned earlier. From White's perspective, however, the responsibility to undertake adjustments lies within the individual realm.

The process of pushing groups of people to the edge of subsistence in rural or urban space is the process of marginalisation. Wisner (1993) pointed out that not only remain marginal people marginal, but more people are rendered in marginal conditions. He rated the model of marginalisation as one of the most useful of disaster occurrence anchored in social theory. An example of marginalisation are livelihoods forced to be based on infertile land like desert margins in Kenya, or informal settlements in dangerous areas prone to landslides as recently underlined by Anderson and Holcombe (2006). Other examples are the steep hillside favelas in Rio or the urban squatters of Asia's floodplains (Susman et al., 1983; Waddell, 1983). Furthermore, global economic processes, resulting in phenomena such as cash cropping, are identified as amplifiers of unsustainable practices of resource use. These practices amplify environmental depletion (Waddell, 1983; Lavell, 2004). As an example, deforestation can favour processes such as flooding and landslides which, in turn, threaten people. A comprehensive model summarising this structuralist perspective on multi-causal vulnerability combining far reaching political, economic and cultural processes is the 'Pressure and Release' model (PAR). The complementary 'Access model' focuses on the household scale and identifies access to resources, such as capital, land, or relief, as the drivers of vulnerability (Blaikie et al., 1994; Wisner et al., 2004) (chapter 5).

The structuralist paradigm questions the view of society on one side and 'disaster' on the opposite side, hence creating a sense of 'normality' and stable conditions during the period between two disasters. This is seen as obscuring that disasters are part of every-day life, since it is the daily structures and conditions of society which cause disasters. Most disasters are seen as characteristic, not extreme accidental features of a place (Hewitt, 1983). Quarantelli and Dynes (1977) concurred and noted that concepts of disasters emerging in the 1970s perceive disasters as clearly identifiable events within temporal and spatial boundaries. However, slow and long lasting disasters like famine and epidemics do not fit into this category. Emphasising the 'event', especially in the context of less developed countries, is interpreted by some as a pro-western and technophile bias (Westgate and O'Keefe, 1976). Consequently, viewing disasters as interruptions of normality is increasingly dismissed. Instead, disasters are

seen as created by and as part of the way people try to make a living everyday (Wisner, 1993; Garcia-Acosta, 2002; Cardona, 2004; Wisner, 2004). Daily needs like acquiring food and day to day labour is seen as overriding the perceived risk imposed by natural hazards, as Anderson and Holcombe (2006) recently pointed out in the case of landslide hazard and disaster.

Pronounced economic, social, environmental and political marginalisation can generally render people vulnerable – no matter if they are threatened by a flood, a landslide or an earthquake. In this context, Briguglio (2003) and Cardona (2005: 12) used the term ‘inherent’ vulnerability. Allen (2003: 170) referred to this phenomenon as ‘underlying vulnerability’, which she interpreted as a *‘contextual weakness or susceptibility underpinning daily life’*. Wisner (2003) and Wisner et al. (2004) preferred the term ‘generalised’ vulnerability. In the context of community response to disasters, Quarantelli (1997) differentiated between ‘agent-specific’ (hazard-specific) and ‘generic’ factors.

A field of research influencing the structuralist perspective on social vulnerability during the 1980s and later is the British ‘Sustainable Livelihood’ approach (Carney, 1998). Also Sen’s (1981) ‘entitlement’ approach showed that major hunger crisis in India in the mid of the 20th century are rooted within the societal structures with different entitlements (access) for resources. A vulnerability model containing human ecological (for example effects of land use, desertification) and political-economic elements (household income, access to markets, price development) influenced by Sen was developed by Watts and Bohle (1993) and Bohle et al. (1994) (chapter 5). The economy based entitlement approach developed by Sen can be seen as a third field besides the human ecology school and the structuralist paradigm (Pelling, 2003).

In summary, the emerging paradigm pushes the social aspects of hazards and especially disasters into the centre of attention. Causations and solutions are mainly searched for in the social, economic and political sphere, meaning within the social system, while the physical process as such is placed in the background. A call for fundamental system changes, including the distribution of wealth and power, characterises the more radical current within the structuralist paradigm. Overall, the observation of immense differences between people’s loss and suffering have progressively deepened and diversified the concept of vulnerability.

2.6 IDNDR 1990-1999: a mirror of previous decades

The evolution of the natural hazard and risk field during the last 50 years or so is reflected as the ‘International Decade for Natural Disaster Reduction’ (1990-1999), declared by the United Nations General Assembly, progressed. The initial declaration of the IDNDR is generally strongly influenced by the pursuit of science and technology for disaster risk reduction (UN/ISDR, 2004). The IDNDR introduction identifies a seemingly contradiction: *‘the unacceptable and rising levels of losses which disasters continue to incur on the one hand, and the existence, on the other hand, of a wealth of scientific and engineering know-how which*

*could be effectively used to reduce losses resulting from disasters*¹. Belief in the possibilities of science and technology and fostering their application as a cure for the rising losses is a focus of the initial IDNDR agenda. Consequently, especially in the beginning of the IDNDR, human dimensions within policy and research strategies are only poorly addressed (Cardona, 2004). Though disasters are increasingly perceived within the scientific community as a composite of the interactions between people, environments and technologies, the initial concept of the IDNDR emphasises the physical vulnerability of structures without considering social vulnerability (Mitchell, 1990; Wisner, 1993).

However, in the following years the combination of disaster prediction, early warning and disaster awareness, coupled with strategies to lessen the burden of disasters on people and society, gains weight within the IDNDR (Cutter, 1996b). Half way through the IDNDR, in May 1994, the 'World Conference on Natural Disaster Reduction' is held in Japan. The 'Yokohama Message' is released as a reaction to the ongoing loss and disruption of development as a result of natural disasters². The declaration recognises insufficient risk reduction strategies focussing only on the traditional, science-based methodology. The Yokohama Message underlines the importance of reducing vulnerability in order to reduce disaster risk. Furthermore, it is stated that *'Community involvement and their active participation should be encouraged in order to gain greater insight into the individual and collective perception of development and risk, and to have a clear understanding of the cultural and organizational characteristics of each society as well as of its behaviour and interactions with the physical and natural environment'*³. This statement merges aspects of the social sciences, the human ecology school and the structuralist paradigm. In addition, the 'Yokohama Message' recognised that although risk reduction is most urgent within developing countries, work on an international level should not exclude developed countries.

Finally, on an international level disasters are not anymore solely seen as purely 'natural', but as phenomenon that are also socially constructed and dependent on people's perceptions, the cultural context and the relation of people with nature. What is more, in order to prevent disasters the protection of the environment as a basis for sustainable development is underlined (UN/ISDR, 2004). In retrospective, the IDNDR helped to widen the spectrum of explanations for disaster occurrence (UNDP, 2004a). The decade further achieved an enhanced acknowledgement of community participation as a necessary element of risk reduction (Wisner, 2003c).

2.7 The last decade: vulnerability meets resilience

The 'International Strategy of Disaster Reduction' (ISDR) succeeded the IDNDR in 2000. It reflects the worldwide recognition of an urgent need to continue efforts to reduce loss incurred by natural hazards on an international scale. Conceptually, the ISDR's perspective on risk reduction mirrors the appearance of a new stream within the natural hazard and risk field. *'The*

¹ <http://www.fire.uni-freiburg.de/programmes/un/idndr/idndr.html>, accessed on 20 September 2006

² http://www.reliefweb.int/ocha_ol/programs/idndr/yokohama/message.html, accessed 20 September 2006

³ http://www.reliefweb.int/ocha_ol/programs/idndr/yokohama/message.html, accessed 20 September 2006

*ISDR aims at building disaster resilient communities by promoting increased awareness of the importance of disaster reduction as an integral component of sustainable development [...].*⁴ Within the last decade or so, vulnerability research has been increasingly accompanied by the concept of 'resilience' (Omar and Alon, 1994; Paton, 2004, King, 2006). The term expresses the capacity not to break under pressure, meaning to maintain functioning or to 'bounce back' (chapter 6).

The usage of the resilience notion gained popularity from the late 1970s onwards, at first in environmental management research and only more recently within the field of natural hazards and disasters. C.S. Holling was amongst the most notable researchers aiming to decipher the resilience of ecological systems. In his 'Resilience and stability of ecological systems', published in 1973, he described the persistence of a system by changing system components or relations as a response to a disturbance (chapter 6).

In the context of natural hazard and risk the concept of resilience accounts for internal resources and competence to support strategies of dealing with adverse impacts of natural hazards (Buckle, 2006). As an example, it was thought that during a gas crisis in Australia, Melbourne's large proportion of women from the Horn of Africa was a special needs group. In fact, as a group benefiting from a social network, they were very resilient (Handmer, 2003). The notion of resilience is associated with focussing on people's strength, which is sometimes combined with a criticism of the concept of vulnerability for 'victimising' people.

The ISDR's recipe for risk reduction is to decrease people's vulnerability to natural hazards in the context of cultural, economic and political spheres, and to create resilient communities. The strategy also highlights the role of sustainable development and related environmental issues in order to reduce disaster loss (Geneva mandate 1999) (UN/ISDR, 2004). The intergovernmental 'Hyogo Framework for Action 2005-2015: building the resilience of nations and communities to disasters' (UN, 2005), a strategy stemming out of the ISDR-hosted World Conference on Disaster Reduction in Kobe in 2005, has fostered the implementation of resilience in disaster risk reduction programmes. Manyena (2006: 434) observed the '*birth of a new culture of disaster response*', and observed the increasingly frequent usage of terms such as 'sustainable and resilient communities', 'resilient livelihoods' and 'building community resilience' in the literature. The Hyogo Framework (UN, 2005: 12) stated: '*The starting point for reducing disaster risk and for promoting a culture of disaster resilience lies in the knowledge of the hazards and the physical, social, economic and environmental vulnerabilities to disasters that most societies face.*' This is an interesting statement since it combines the concept of vulnerability and resilience. Overwhelmingly, however, resilience is handled as an alternative to vulnerability. As argued in this thesis, effective risk reduction benefits from a combination of both concepts.

⁴ http://www.unisdr.org/eng/about_isdr/isdr-mission-objectives-eng.htm, accessed 27.06.2006

2.8 Summary and conclusion

From 'Acts of God' to the 'age of reason' and the dominance of science and technology, the human ecologist school around Gilbert White emerged in the 1950s. It was the first approach to address natural hazards and risk multi-dimensionally. Developing and emphasising the concept of adjustment (combining structural and non-structural measures), and recognising the role of hazard and risk perception and decision-making, this approach is an impetus for a more effective and sustainable strategy towards risk reduction. Valuable contributions on human response to and organisational aspects of disasters are developed by the social sciences.

The path of vulnerability as a key concept was paved by the human ecology school, and increasingly explored by several other disciplines. Its interpretation and application is advanced by the applied sciences and parts of the social sciences. Importantly, the vulnerability concept within applied natural hazard and risk research, for example to describe the susceptibility of built structures, is broadened to encompass the demographic and socio-economic characteristics of people and topics such as risk preparedness. From a structuralist perspective, globalisation and increasing socio-economic and ecologic marginalisation are identified as root causes for people's vulnerability, especially in the less developed countries. The structuralist paradigm opens the field of hazard and disaster research for socio-economic, cultural and political aspects within risk reduction strategies. Compared to the human ecology school, the recognition that some social groups are simply not able to adjust to hazards, or cannot choose between different adjustment options, is a major step forward.

Resilience is increasingly understood as an alternative to vulnerability. The conceptualisation and usage of the term resilience is not homogenous, like many other terms in hazard and disaster research, and fosters confusion and misunderstanding (chapter 6). As will be detailed in chapter 7, vulnerability and resilience are interpreted in this research as complementary rather than reciprocal concepts.

The human ecologist and the structuralist perspective anchor hazards and disasters in everyday life situations. Nevertheless, the human ecologist worldview is criticised by advocates of the structuralist paradigm for perceiving hazards and disasters as external, extreme 'unscheduled events', as 'archipelagos' in the landscape of human relations with their environment (Hewitt, 1983). However, in their 'The Environment as Hazard' (Chapter 8, 1978, and 1993) Burton, Kates and White emphasised the importance of recognising these daily interrelations in the context of hazard and risk. In addition, as emerged from this review, a strong dualist conceptualisation prevails within the human ecologist school, which counteracts the above criticism.

The notion of resilience, by focussing on people's strength when facing crisis, acknowledges people's abilities and resources to 'bounce back'. Such a perspective, however, would not apply

under the structuralist paradigm which mainly locates the responsibility for disasters not within the individual, but the socio-economic and political domain.

Social sciences and the structuralist paradigm favour disaster rather than hazard analysis. Historically, the first social science research centre worldwide was the 'Disaster Research Centre' (DRC) in Delaware, while the human ecology tradition lives on at the 'Natural Hazards Centre' (NHC) in Boulder. As opposed to hazards, disaster research is traditionally seen as part of sociology, with input from psychologists and anthropologists. Disasters are 'laboratories' of the social sciences, since they unveil social structures and critical conditions that otherwise remain unnoticed (Dynes, 1970; Bates and Pelanda, 1994; Garcia-Acosta, 2002). In anthropology, 'hazard' is defined as the pure physical process and 'disaster' refers to the situation when hazard and unfavourable conditions coincide (Mitchell, 1990). The focus on disasters is understandable, since they impose the most dramatic losses and pressing problems, especially upon the less developed world.

By focusing on disasters, loss and damage on a lower impact level or with lower death tolls are not treated equivalently (Hewitt and Burton, 1971). Smaller in magnitude of damage, but occurring more frequently, the cumulative damage of these events can be considerably large and as important as high magnitude events (AS/NZ, 2004; Cardona, 2005; Anderson and Holcombe, 2006).

During the review presented in this chapter, several aspects surfaced which indicate synergies between the two (openly) opposing 'paradigms'. These are summarised in the following.

2.8.1 Synergies

The structuralist paradigm acknowledges some key principles of the dominant view, especially with respect to the human ecologist school's focus on the human causation of loss, and its sceptic view of isolated technological strategies of loss reduction. Hewitt (1983) also acknowledged the value of scientific research and international action of emergency relief.

The 1972 United Nations statement cited earlier, promoting technology's role in damage reduction, was seen by Waddell (1983) as extremely influenced by authors White, Burton and Kates. However Burton, Kates and White themselves, in their 'The environment as hazard' (1978), critically concluded that this UN statement fosters a bias towards scientific research as the only 'cause' of disaster and a certain choice of mitigation measures, while aspects of human behaviour are neglected. Also, as indicated in this chapter several times, the positions of, for example White and Hewitt, on the limitations of physical process modelling and prediction, and a too narrow view on how to reduce losses, are quite similar. Another similarity is the noted discrepancy between the loss of lives and damage between the more and less developed countries, which is mutually linked to a narrow palette of mitigation measures. What is more, White (1961) and Burton et al. (1968) recognised that the choice of adjustment strategies depends on limitations arising not only from the natural environment, but also individual

character, society and culture. Hence they include societal structures as an explanation for unfavourable or possibly a lack of adjustment, though they argue from a viewpoint of individual responsibility and agency.

The key synergy between the applied sciences, social sciences and the (traditionally opposing) human ecology school and the structuralist paradigm is the underpinning that natural hazards and disaster are not just 'natural' but also social phenomena.

Interestingly, the similarities are acknowledged by Hewitt (1997). In his 'Regions of Risk' he does not necessarily place the human ecology school within the realm of the science and technology approach – this is what he called dominant 'hazard paradigm'. Rather, his explanation of risk is developed out of the human ecologist school and key elements of the structuralist/vulnerability approach. Hence here human agency (behaviour/adjustment) and societal structures potentially restricting human agency are combined. This synergetic perspective promises a comprehensive approach to reducing risk.

Studies under the structuralist paradigm fall usually within the context of development and hence focus on less developed countries. At the same time, the structuralist paradigm, although offering valuable contributions, does not attempt to develop a model for different social, economic and political contexts. Understandably, it aims to push for progress where it sees the largest deficits. However, research outcomes, such as the PAR-model, can also deliver insight and increase the understanding of how risk is created in the developed world, as demonstrated recently by the events during and following Hurricane Katrina.

Throughout the history of natural hazard and risk research the unifying aim was and still is the long-term reduction of natural risk. However, it emerges that specialisation in several fields, which each represent a component of risk, dominates this history. However, suggested strategies of risk reduction differ and often compete. Emphasising the concept of risk, as a consequence of the 'human-nature' relationship (chapter 3), refocusses the view of the 'big picture' and consequently supports synergies between different fields. Such a synergy is developed and presented in chapter 7.

3. Search for a theory of risk

As illustrated in chapter 2, research in the fields of natural hazard and risk has diversified substantially during the last 50 years. This diversification witnessed the dominance of the science and technology approach being challenged and complemented by a human ecology approach and sociological contributions, the emergence of the vulnerability concept, its further differentiation through a structuralist perspective, and recently a turn towards resilient societies. During this history the notion of risk changed from expressing the likelihood of geophysical processes occurring, such as earthquakes or landslides, to a concept which includes the possible overall adverse effects on people by drawing on multiple dimensions to understand the type and degree of damage inflicted on people, societies or economies.

With these considerations in mind, it is suggested here that the concept of risk includes two basic components:

1. The interrelation between social and geophysical processes, which ideally involves a conceptualisation or theory of 'human-nature' interactions.
2. The assessment of the outcomes of 'human-nature' interactions, which involves the perception and evaluation of risk in terms of its acceptability and tolerability. In this sense, risk is a socially defined construct.

A concept or construct can be defined as '*ideas that represent the phenomenon*' of interest, and 'conceptualisation' is the '*processes whereby these concepts are given theoretical meaning*' (Lewis-Beck et al., 2004: 161). Accordingly hazard, vulnerability, resilience and correspondingly risk can be labelled as concepts or constructs.

In contrast, the function of a theory is '*to identify underlying, generative structures*' to the extent that they are universal (Lewis-Beck, 2004: 1123). A high level of agreement on the meaning of a concept can be beneficial for theory building, because misunderstandings are minimised and gained knowledge is shared. Different and partly competing conceptualisations not only of hazard, vulnerability and resilience, but also of underlying (though usually not openly addressed) perspectives of 'human-nature' interactions within the field of natural risk research impede the shaping of a single discipline. In fact, we find monistic and dualistic perspectives on whether and how humans relate to nature. Consequently no theory is available to address 'human-nature' interactions in a way that is accessible and acceptable to the wide range of disciplines involved in natural risk research. Such a theory should acknowledge the independent existence of 'nature' and 'culture', with natural processes represented in a more meaningful way other than simply as external forces disturbing society. Simultaneously, society or 'culture' should be included in a more diverse fashion than just as the 'human factor' or 'human disturbance'. Developing such a theory of 'human-nature' or 'culture-nature' interaction is highly challenging since it involves interdisciplinary scholars carrying their own and partly contrasting

perspectives. The discussion group 'Interactive projects in geography' hosted by the Leibniz-Institut fuer Laenderkunde e.V. and the Institute of Geography at the University of Vienna¹, aims at carving out such a metatheory of 'human-nature' interaction. As subsumed during their 2007 meeting in Bonn, the process of theory development is ideally slow since it includes engagement with a range of different theories and concepts. As such, the process has to be mediated carefully. Several of the candidates for theorising human-nature interactions, as well as their linkages, are summarised and discussed here.

Both risk perception and evaluation are as important as 'human-nature' interactions when aiming to effectively reduce risk. Furthermore, they are not static (Kates, 1962, 1970; Bell et al., 1984; Tobin and Montz, 1997; Alexander, 2000; Anderson-Berry, 2003; Stefanovic, 2003). However, these fields cannot be explored further in this thesis.

The chapter firstly presents different ontologies paving the ground for the agenda outlined above by reflecting on views of 'nature' and 'culture' prevalent in different fields of academic research.

3.1 Ontologies of 'nature' & 'culture'

The history of natural hazard and risk research (chapter 2) clearly illustrates the variety of how risk reduction is approached by different disciplines. These are attached with different ontologies of 'nature' and 'culture'. From a geographical perspective Urban and Rhoads (2003: 211) argued that exploring different ontologies may seem to some as '*an esoteric exercise in navel-gazing*', but neutralises criticism of geography as a '*superficial and perhaps superfluous academic discipline*'. They added that this exercise is important because different ontologies shape the questions asked and therefore influence current and future research agendas. This aspect is not only relevant for geography, but natural hazards and risk research alike.

Along the spectrum of natural and social sciences a range of views prevail on what constitutes 'nature' and 'culture' or 'society'. Three views are illustrated in the context of this thesis: monistic naturalism, dualism and monistic constructionism (figure 3.1). 'Naturalism' aims to explain everything social, including mental functions and culture, with biology. Humans are seen as purely biological organisms, which are part of nature and therefore inseparable from nature. A nature-culture dualism is replaced by monism (Urban and Rhoads, 2003). This worldview favours biological 'blind' evolution rather than purposeful cultural evolution as an explanation of phenomena and processes. Naturalism reduces humanist perspectives. Therefore naturalism is close to environmental determinism, which in its most extreme form can support racism (Castree, 2005a).

¹ <http://homepage.univie.ac.at/peter.weichhart/TGPhHum/GespraechskreisHome.htm>, accessed 12.12.07

Figure 3.1: Views on 'nature' and 'culture'

Charles Darwin argued that evolution is 'blind'. This means it does not obey any will, least a theological imperative which was the common understanding of the world's genesis at Darwin's time (Barry, 2007; Desmond et al., 2007). This explains why his theory caused huge upheaval at that time. Darwin demonstrated that humans are not 'above' nature but related to it – direct descendents of primates. Darwin's theory of evolution implies that those species best adapted to their environment maximise their chances of survival, and produce well adapted offspring. Although Darwin himself placed more weight on environmental conditions as an explanation for social behaviour in the later stages of his career, generally his theory is not to be interpreted in a deterministic way (Castree, 2005a). Natural conditions dominating human development including social behaviour and mental capabilities is, as proposed by environmental determinism, not implied. Compared to a monistic, naturalist perspective a dualistic worldview prevails in Darwin's theory. Today, a dualistic worldview dominates public and science alike. The world is divided into two different 'halves' somehow interconnected: 'nature' and 'culture'.

A range of different sciences apply a dualistic ontology. For some, nature is seen as something that can be measured, empirically analysed, modelled, predicted and (potentially) controlled. This precipitated in the 'quantitative revolution' in geography of the 1950s/60s, which was greeted by many 'breathlessly' as 'real science' (Bayliss-Smith, 2003) – disputed by others as a 'mistake', greatly reducing the spectrum and type of questions asked (Hewitt and Hare, 1973). The aim was to explain nature with true facts about nature, in a neutral and value-free way. Nature 'speaks for itself' which has become known as the realism of the natural sciences. Human modifications of the biophysical world create 'un-natural' systems and processes, which can be observed from an external, objective position. This position rests in the tradition of the Enlightenment (Urban and Rhoads, 2003; Castree, 2005a; Hannah, 2005; Barry, 2007). Traditionally, natural hazards and disasters are placed into the sphere 'nature' only.

A dualist, but quite different ontology focuses on the social sphere and is proposed by humanities and social sciences. A common argument is that humans construct the non-human world through their perception and communication (constructionism). Therefore, what 'reality', or nature, is depends on sensory-cognitive processes which are culturally overlaid. In the German language 'Realitaet' (reality) is different from 'Wirklichkeit': while 'Realitaet' exists 'for real', 'Wirklichkeit' is what we perceive to be real, a 'phenomenon' (Huschke-Rhein, 1998). Generally, empirical results are greeted with scepticism because the approach to acquire and analyse facts is seen as influenced by the view of what nature is; hence facts are not considered as objective as they seem to be. Therefore, rationality is seen as socially and historically diverse

and hence relative (relativism). From this perspective a nature-society dualism emerges from the attempt of one side (the social) to explain the other (natural) (Castree, 2005a; Hannah, 2005; Barry, 2007). Consequently, not 'nature' but social structures are seen as the generator for environmental problems, such as 'natural' disasters (chapter 2). Hence the 'naturalness' of hazards and disasters is questioned, and both are 'de-naturalised'. The mainstream of social sciences sees society as a highly differentiated construct of different units which can be explained entirely by its own, internal structures. Nature is an external, often disturbing factor (Fischer-Kowalski and Erb, 2003). 'Human-nature' interactions within the context of 'Global Environmental Change', currently very prominent in the public and academic debate alike, are only marginally addressed by social science (Glaeser, 2004; Weichhart, 2005).

An extreme viewpoint of constructionism is when the existence of the biophysical world as such is denied, because everything exists through human perception and communication (Huschke-Rhein, 1998; Castree, 2005a). Nothing beyond the construction of nature is worth analysing. Hence only the social conditions which lead to certain perceptions of nature or economic costs and advantages are subject of such extreme constructivist research. This perspective does not provide solutions for the emerging problems of our time and is often criticised by natural scientist as arrogant and irresponsible (Fischer-Kowalski and Erb, 2006). As with naturalism, this worldview diverts from dualism into monism.

For an illustration of how these four ontologies apply in the context of climate and society consult Phillips and Mighall (2000) in Thornes and McGregor (2003). Geography is a discipline par excellence symbolising the struggle with these contrasting ontologies. The distance between the opposing positions might often not be great anyway, since many would not view the world as entirely independent of its physical-material elements and only existing through representation and language, or, in contrast, a view that sees every 'fact' as real and true and as not influenced by the way knowledge is produced (Whatmore, 2002). Bhaskar (1986), a philosopher of science, reached a compromise by concurring with relativism about scientific knowledge and theories, but regarding the success of natural science in gaining insights of how the world works as a proof for an independent existence of the 'real world'. His 'critical realism' has been taken up by human geographers during the 1980s and 1990s, and with some delay also infused physical geography (Castree, 2005b; Hannah, 2005).

As mentioned previously, risk research is characterised by a high level of diversification and segregation, which hampers the moulding of a single discipline and entails different emphasis of which aspects should be addressed, and which causation and solutions for reducing risk should be pursued. Different worldviews entail different perceptions and questions asked. In the following, candidates for theory-building of 'human-nature' interaction are summarised. Subsequently, these approaches are discussed and categorised according to the ontologies

outlined above. The chapter closes by extracting and discussing some shared ideas, which is followed by translating the concepts of 'human-nature' interaction into the field of natural risk.

3.2 Candidates for a theory of 'human-nature' interaction

3.2.1 Classical human ecology

The term 'ecology', derives from the Greek word 'oikos' for 'house' (The Concise Oxford Dictionary, 1995) and was introduced by Ernst Haeckel (1876: 354) as naming the science of *'the correlations between all organisms living together in one and the same locality and their adaptation to their surroundings'* (cited in Vidal de la Blache, 1926: 184). In the sense of Haeckel, organisms are seen as passive, as respondents to their physical and biological surroundings, while organisms can also be viewed as rather active modifiers of their environment to the extent of creating their own surroundings tailored to their needs (Steiner and Nauser, 1993). The adaptive element links ecology with Darwin's evolutionary biology.

The term 'human ecology' was introduced by J.P. Goode in 1907, a geographer at the University of Chicago (Castree, 2005a). Generally speaking, 'human ecology' addresses the reciprocal interaction between humans and the non-human world (Eyre and Jones, 1966; Bohle et al., 1994). Human ecology envisages unravelling the multiple paths of human-nature interaction. By doing so, it strongly resembles geography as a discipline, and both are generally characterised by a human-nature dualism (Weichhart, 2004). In the context of natural hazard and risk, the human ecology school exemplifies how a dualistic worldview shapes the questions asked and solutions sought (chapter 2). Figure 3.2 summarises the traditional human ecology ontology.

Figure 3.2: Human ecology conceptualisation of 'nature-culture' interaction

Lawrence (1993: 214) defined human ecology as *'an holistic, integrative interpretation of those processes, products, orders and mediating factors that regulate natural and human ecosystems at all scales of the earth's surface and atmosphere'*. He sees human ecology as a 'systematic framework' to analyse, from a temporal perspective, three 'logics': a 'bio-logic' (organisms), an 'eco-logic' (inorganic elements such as water, air) and a 'human-logic' (culture, society, individual). While the first two are part of the 'natural' sphere, the 'human-logic' is clearly

separated. Between these three logics, fluxes of energy, materials, human labour, knowledge and communication exist, which 'regulate' the world. All these logics are equally important. Lawrence (1993) concluded that people's values imprint on their perception of nature and on their motivation to change nature. Simultaneously, the environmental setting has some effect on how it is perceived and utilised by humans.

Traditionally, human ecology uses concepts of biology to analyse structures and processes in society, such as population growth, which are linked with the usage of nature as a resource (Bohle et al., 1994). Bruhn (1974) observed a continuous tendency of the social sciences applying terminology and analogies from the natural sciences, such as cities as 'metabolisms' (Lawrence, 1993) – a term originally coined by Karl Marx subsuming the way society utilises nature (Fischer-Kowalski and Weisz, 1999). The concept of 'metabolism' in sociology is currently further developed by the group 'social ecology' around Fischer-Kowalski (Institute for interdisciplinary research and education of the Universities Wien, Klagenfurt, Graz and Innsbruck, Austria), as will be discussed later in this chapter.

Butzer (1980) rejected the comparison of cultures with organic systems ('super-organisms') operating in cycles of youth, maturity and age only obeying the same laws as other organisms, which is pursued by the classical concepts of Spencer (1872; 1884/1982, in Barry, 2007). Butzer (1980, 1996) regarded civilizations as adaptive systems, with fluctuating states of stability and instability. This is based on the notion of systems which are characterised by an interaction between people, and by people with their biophysical environment. Hawley (1986) applied a system-theoretical approach to human ecology, in the sense that human collectives are systems which are able to adapt to their environment. He, like Karl Butzer, rejected a too strong orientation towards biological terminology and towards spatial patterns as pursued by authors of the 'Chicago School' such as Park, Burgess and McKenzie. Furthermore, Hawley underlined the importance of human behaviour within the cultural process of adaptation (Glaeser, 2004). His focus on adaptation was criticised by some as being environmentally deterministic, in the way that human action is, at the core, dependent on the settings of the non-human world (Steiner and Nauser, 1993). However, Friedrichs (2004) rated his work highly because it combines several concepts towards a theory of human ecology, which was not, and still is not today, well developed. He identified similarities between Hawley's system-theoretical approach and Luhmann's social systems theory as discussed later in this chapter. For example, a similarity is the conception that through the process of specialisation in an expanding system, different subsystems emerge fuelled by a growing availability of resources and information – a process which one single system, or one 'key function', could not undergo.

Influenced by the increasing scepticism towards the authority of science in the 'risk society', the human ecology concept experienced a reformation and modernisation (Blotevogel, 1997). A 'critical human ecology' emerged as a further development of the 'new environmental paradigm'

or 'new ecology paradigm (NEP)' appeared in the 1970s. The new critical thinking in human ecology is linked with researchers who question the still dominant dualistic view of the world as 'two halves' which are interrelated but separate (Massey, 1999). A critical human ecology perspective does not aim to externalise humans or to de-naturalise nature as it is often pursued in dualistic or monistic worldviews. Inspired by critical human ecology increasingly human geographers claim that we have always lived in a non-dualistic world (Castree, 2005a). This aspect is further discussed later in this chapter when introducing Bruno Latour's network theory and the concept of hybrids.

Today, there is not 'one' human ecology, and the term itself intersects considerably with other terms such as 'social ecology'. Hence a definition of human ecology is still vague, and can only be as precise as being a field which addresses the 'human-nature' interactions (Kaminski, 2004). There is also no consistency as to whether human ecology is a concept, a paradigm or a theory. As Friedrichs (2004) concluded, only Burgess' early model of city development can be seen as a theory in this area. Apart from this single theory human ecology draws analogies and develops propositions, and remains lacking one overarching theory. However, the dualistic worldview embedded within human ecology shapes questions directed at both, the natural and the social sciences within all fields dealing with 'human-nature' relations, such as risk. In particular, it appears that human ecology aims for a balanced perspective. Furthermore, a set of key principles promises to enrich the understanding of why risk is produced. In the following these key principles are extracted from the human ecology literature and, where necessary, transferred into the context of natural risk.

3.2.1.1. *Adaptation*

The process of adaptation plays a major role within the field of human ecology and has already briefly surfaced above. Complexity theorists such as Coveney and Highfield (1996) defined adaptation as '*any open-ended process by which a structure evolves through interaction with its environment to deliver a better performance*' (cited in Pelling, 2003: 11). This adds the dimension of a favourable outcome or gain, which is shared by the human ecologist Serbser (2004) referring to Baumgarten (1938). From the viewpoint of human ecology, adaptation can only occur in relation to another phenomenon, because from a human ecology perspective, all phenomena are interrelated. Therefore, adaptation is a 'collective' rather than an 'individual' process (Hawley, 1986: 3). This is coupled with the concept of a collective or community, which is another main aspect of human ecology as will be outlined soon.

Hewitt and Hare (1973) distinguished between two different options of adaptation: specialisation into an ecological niche, and generalisation which frees the organism from environmental limitations. Within this strict ecological context, highly specialised forms of adaptation can be frequently observed between species. During the evolutionary process, dependencies or 'obligations' between species develop through mutual adaptation. Commonly, these species are said to have an 'obligate' status. For instance the fruits of the Mauritian tree *Sideroxylon*

sessiliflorum need to be digested and the seeds distributed by a particular species of the pigeon family in order to germinate. These seeds usually have a hard surface which requires abrasion or chemical disintegration when passing through the digestive system of the obligate species. In the case of the Mauritian tree, this species was the dodo, which became extinct in 1681. By losing its obligate species, the survival of the tree is endangered (Richards, 2003). This example illustrates that a high level of specialised adaptation is coupled with a greater likelihood of extinction, because survival depends on only one other species. Due to a high degree of specialisation, the species left cannot easily change its survival strategy. If the obligate species diminishes slowly, the dependent species may be able to adapt and diversify its survival mechanism. However, fast changes are almost impossible to adapt to, because of flexibility required in the obligate species to meet these changes.

Translated into the field of natural risk, highly specialised adaptation to natural hazards can leave individuals, a community or a society more susceptible to natural hazards as compared with a strategy which rests on a combination of adaptive activities. A levee designed to withstand a certain flood magnitude loses its effectiveness when, due to changing climate or environmental conditions in the catchment area, flood magnitudes rise. Increasing risk of flooding is likely to intensify for certain regions due to global warming as for example Goudie (2006) discussed. While relying on the levee as the major protection measure, settlements will have increased to an extent where removing assets from the floodplain is not feasible (chapter 2). Financial resources, locked up in budgets for levee construction and maintenance, are not available for other mitigation options, such as afforestation in the upper catchment, subsidised insurance schemes, education or warning systems. This is an example of (over-)specialisation as described in the ecological context above. In such a situation, the only option is to continuously increase the height of the levee, which will continuously be overtopped at some stage, resulting in even higher losses. The Netherlands is an example of a country which relies heavily on levees as one main option to protect settlements and industrial assets. However, compared to a poor country like Bangladesh where even levee construction is hampered, they are in the fortunate position of channelling the overall greater financial resources into a variety of risk reduction strategies (Blasberg and Blasberg, 2007).

In contrast to specialisation, generalisation or increasing diversity is usually associated with a higher likelihood of successful adaptation (chapter 6). For instance, Adger and Brooks (2003) reported on recent positive results from adaptation strategies to environmental change in the Sahel, such as diversification of land use or diversification of income sources. Likewise, a broad variety of risk reduction measures does not only account for the multiple factors creating risk, but also allows for more flexibility when conditions change.

As touched on previously, adaptation is interpreted in this thesis as an active process that involves human purpose, agency and transformation of nature, aimed at a favourable outcome.

In summary, adaptation is

- a process of mutual modification between two or more elements, ideally aiming towards a favourable outcome for all,
- specialisation or generalisation,
- a collective rather than an individual process.

The suspicion of determinism adherent to the term 'adaptation' is rooted in the work of early advocates of a deterministic perspective, such as German geographer Friedrich Ratzel or the American Ellen Semple (1903, 1911). They regarded human culture as mainly related to the environmental conditions under which this culture evolved. With Semple's earlier studies on Appalachia (1901), for example, she underlined that the Anglo-Saxon race, which had developed well elsewhere, was 'retarded' due to the isolation of a mountainous and rugged environment (Hickey and Lawson, 2005). By assigning even mentalities to a specific climate, human culture was seen as directly dependant on the physical environment, and deterministic thinking was increasingly criticised for its racist and imperialistic elements (Castree, 2005a). Hewitt and Hare (1973), trying to understand the reluctant reaction of geography towards the wave of environmental awareness at the beginning of the 1970s, found an explanation in the stigmata of determinism which still adhered environmental topics in geography at the time.

The counterpart of a deterministic perspective was phrased by the French historian Lucien Febvre, a fierce critique of Ellen Semple (Agnew et al., 1996a). Febvre postulated that there are no necessities but possibilities everywhere - a position similar to geographer Paul de la Blache who encountered the strong determinism of the early 20th century by advocating a possibilist view on the interaction between humans and their environment (Ley, 1980). A more moderate position was taken by Carl Sauer (1925) who ascribed landscapes a habitat value, either present or potential, and stated that humans are part of and live with, are restricted by and modify the habitat at the same time. Jared Diamond's (2006) approach to explaining why some societies collapsed, while others did not, summarised these aspects: the environmental settings are important, but it is what people make (or not make) out of a situation, which decides their future. The modern approach of evolution theory, which is applied in human ecology, is not 'blind' but a product of coincidence and purpose and of a plethora of learning processes (Blotevogel, 1997).

Such a view concurs with Gilbert White and colleagues who rejected a deterministic view and placed problems of reducing losses due to natural hazards within the domain of public policy, underlining that people are not passive but active (Hewitt, 1997). A human ecology framework applied to natural hazards and disasters has to accept determinism to some extent, either born out of the natural environment or the political or cultural context. At the same time a human ecology framework bears a strong possibilist element by recognising that humans can create

possibilities of risk reduction by themselves. From the relational perspective of human ecology, humans are not external 'disturbing' factors, but parts of the problem and solution alike.

3.2.1.2 Time / evolution

Adaptation is a process and as such confined by time. Darwin, for example, applied the idea of 'deep time', of long time spans within which adaptation takes place slowly (Castree, 2005a). H.J. Fleure (1937) emphasised the evolutionary aspect of human ecology, or what he called human geography, referring to the temporal changes of landscapes without and, more importantly, with human imprints (Eyre and Jones, 1966). As Kates (1970: 25) emphasised, the interaction of humans and 'nature' is a 'continuous process'. This implied aspect of co-evolution is prominent in the definition suggested by Eyre and Jones (1966: 7): *'an organism and its environment affect each other and evolve together'*. Accordingly, Bates and Pelanda (1994: 147) underlined the temporal aspect implicit within the relationship of humans and their environment, since they *'impact on each other in a kind of evolutionary process'*. Also Lawrence (1993) rated the temporal perspective as an essential part of a human ecology framework, which has been eminent from the start, and has not lost its value today as Friedrichs (2004) concluded. The concept of co-evolution is further discussed by Ingold (1992), Oliver-Smith and Hoffman (2002) and Oliver-Smith (2004).

As mentioned previously, the term 'evolution' is strongly associated with Charles Darwin and his explanation of the creation of different life forms. However, the term 'evolution' has different associations: while some may use it with a sense of a gradual development through time, others imply not only a gradual but also inevitable and irreversible process. Change is often associated with irreversibility, simply because the probability of an object or a system regaining the exact original state after undergoing some change is minimal. In addition, new variables within a system can be created as a result of change, or existing ones lost (Hawley, 1986).

Within the field of natural hazard and risk research, human response can manifest as adaptation and/or as adjustment. *Adaptation* is regarded as a long-term response, which can take hundreds or thousands of years. It can occur in the form of biological adaptation, this means changes in the human body to better deal with, for example, changes in temperature. Adaptation can also be a cultural process and as such operate much faster than biological adaptation (Burton et al., 1993). Cultural adaptation encompasses changes of behavioural patterns which are aimed at reducing the level of adverse impact from natural hazards, for example when a society responds to flood hazards by building villages on levees, or develops a form of land use that is optimally adapted to the environmental conditions.

Adjustments are short-term actions, such as building a dam for irrigation or designing a house to resist earthquakes. Adjustments can be both purposeful and incidental, for example advances of communication also benefit hazard response. Additionally, a range of purposeful adjustments like insurance, building designs or warning systems can be combined to reduce risk from hazards significantly (chapter 2). The temporal distinction between adaptation and

adjustment is somewhat blurry, since adjustments can evolve into a society's long-term cultural adaptation to risk (Burton et al., 1968; Kates, 1970; Hewitt and Burton, 1971; White, 1974; Burton and Hewitt, 1974; Kates, 1985; Burton et al., 1993). It is important to note that within the field of 'socio-ecological' resilience primarily applied in the field of 'Climate Change and Global Environmental Change', usually only the term 'adaptation' is used and defined differently (chapter 5, 6, appendix A)

Time is a prominent topic in interdisciplinary environmental research. Historical human ecology, a field of its own, deduces its existence from an impetus to analyse the history of the human-environment relation. Similarly, other approaches, such as 'cultural evolution', have developed into distinct fields of research (Glaeser, 2004). This is where one of many similarities between human ecology and geography emerge. The historical development of 'human-environment interaction' has always been the key characteristic of geography as a discipline (Weichhart, 2003b, 2004, 2007). It is therefore surprising that transferred into the arena of risk research, static approaches dominate.

3.2.1.3 Community

Borrowed from the biological concept of 'biocenosis' is the idea of a collective which is formed through the linkages between individuals. Because of these relations, new phenomena emerge on the level of a collective, such as a community or a society (Hawley, 1986), which could otherwise not exist. The sum of individuals is not necessarily what best describes a community: the 'whole' is more than the sum of its parts as Aristotle concluded (Egner, 2006).

The concept of a collective, or community, coupled with its adaptation to its related surroundings, has long been, and still is, a central topic of human ecology (Friedrichs, 2004). In natural hazards and risk research buzzwords like 'community strength', 'social networks' and 'community resilience' have appeared more recently in the literature (chapters 2, 6, 8). They capture exactly what is described in human ecology as a collective.

Implicit in the concept of community is a specific level of spatial scale. When analysing vulnerability and resilience as components of risk, it quickly emerges that both are scale-dependent constructs (chapters 5, 6). The implications arising from the concept of community and its spatial context are discussed in chapter 11. In addition, specific reasons as to why the community scale is favourable in the context of natural risk in general and landslide risk in particular are given.

Classical human ecology, by focussing on the interrelations between the human and the non-human world, displays a dualistic worldview where both 'worlds' are perceived as clearly separated though related entities. A mutual element amongst new currents stemming from different disciplines is to challenge this dualism in order to find a concept which overcomes such a sharp divide. A chain of concepts and theories aiming to refresh the traditional view are discussed in the following section.

Within the field of risk, such a perspective aims to overcome classical dualistic boundaries and represents the 'human factor' in a more differentiated way. Social sciences are invited to inject social perspectives and ask different questions aiming at identifying causation of risk.

The continuing sequence of 'human-nature' interaction models introduced in this chapter aims to carve out the social sphere in such a more differentiated manner by drawing on Luhmann's theory of social systems. Therefore, before continuing with the stream of 'nature-culture' theories, a close-up on Luhmann's social systems theory is necessary. Additionally, systems theory has not been addressed so far, and because not all systems theory approaches can be included here its interpretation and application for the physical-material world (geomorphological systems) is discussed in chapter 4, while the focus in this chapter is on social systems.

3.2.3 Luhmann

Today's systems theory vocabulary is based on a transdisciplinary exploration of topics like information theory, cybernetics or game theory starting in the 1940s (Egner, 2006). These streams converged and in 1950 von Bertalanffy published his 'The theory of open systems in physics and biology' (chapter 4). He was the first to offer a 'general systems theory' as a metatheory for all disciplines (Egner, 2006). Modern social systems theory was pioneered by German sociologist Niklas Luhmann (1991). Luhmann's theory was a revolution in sociology: for the first time humans are not defined as part of the social system, but of its environment (Luhmann, 1991: 286, 288; Egner, 2008) as will be seen soon. In addition, Luhmann's theory diverts from the usually action-based social theories by focussing on communication (Luhmann, 1991: 154, 292; Staubmann, 1997; Egner, 2008). The following provides an outline of his theory.

Luhmann developed a theory of recursive communication which transfers a biological theory developed by the Chilean neurophysiologists Humberto Maturana and Francisco Varela for living systems into sociology. Driven by the questions of how life is organised and what constitutes perception ('The biology of cognition', Maturana and Varela, 1980), Maturana found a single answer for both questions. The biological theory he developed with Varela follows the concept that the operation of the living is based on cognitive processes. *'Living systems are cognitive systems, and living as a process is a process of cognition'* (Maturana and Varela, 1980: 13). Cognitive processes involve the differentiation between perceived phenomena, hence they delineate boundaries. This logic of difference is one point of entry into Luhmann's theory developed based on Maturana and Varela. Systems are defined by boundaries. A system must be different from its environment: only by being different can it actually be identified (by the observer, by itself) as a system (Luhmann, 1991: 35, 52). Consequently, different systems can be coupled ('structural coupling') but not combined into one system. The process through which the difference is recognised is called 'self-reference'. Only the system itself can evaluate and decide which elements are sufficiently similar, hence are part of the system, and which are different and therefore belong to the system's environment (Luhmann,

1991: 59, 67). The boundary between a system and its environment is consequently defined by the system. As a result, systems do not operate with their environment but only within themselves. In this sense, they are closed (Luhmann, 1991: 60). Conceptualising systems as closed, though not isolated (structural coupling) differs from the classical pair of 'open' and 'closed' systems as described for example by von Bertalanffy (Luhmann, 1991: 64). Luhmann allows for the exchange of material, energy and information between systems which will be addressed in the context of structural coupling below. This exchange, however, is not constitutive for the identity of a self-referencing system (see also Maturana and Varela, 1980: 89).

As will be detailed shortly, by defining social systems as self-referencing, as ultimately operating according to their own code, it is recognised that their external controllability is limited. Recognising the limited controllability of systems is greatly important in the context of risk.

Luhmann identified three main types of systems:

1. biologic or living systems ('Leben'),
2. psychic systems/consciousness ('Bewusstsein'),
3. communicative meaning social systems ('Kommunikation') (Luhmann, 1991: 296-297).

Figure 3.4: Systems and their environment, with arrows representing structural coupling

Each system's environment includes all other systems (figure 3.4). Each of these systems has its own way of operating which cannot be repeated by any of the other systems. For example, a biologic cell is only able to function as a cell, it does not have a consciousness nor can it communicate the way social systems do. A cell is a closed system that can only refer to itself. Similarly, communication can only produce communication, not living systems or consciousness (Luhmann, 1991: 61, 62). As Luhmann (1991: 67-68) explained: *'There are machines, chemical systems, living systems, psychic-conscious systems, sense-making communicative (social) systems; but there is not such a thing like a merging system unit'*. He concluded that humans can be regarded as a unit, but not a system. Human beings combine biological, cognitive, and communicative processes, and according to the logic of difference can therefore not constitute a system. In fact, humans are excluded from social systems, because their biological and

cognitive operations are located within the environment of the social system. According to Luhmann, social systems are systems of 'sense-making', of communication. As Staubmann (1997) summarised, Luhmann defines communication as a synthesis of information, transmission of this information, and understanding. Communication is therefore emergent: it only happens when these three elements are combined.

Recursivity is an important aspect in the context of self-reference and means that through a circular process eventually every element within a system affects itself. The outcome of this process is not predictable in the sense that a certain input prompts a certain output. This is because during this process elements can change. Recursivity therefore applies not only to stable but also to non-stable, non-predictable and non-linear processes, as Huschke-Rhein (1998) summarised. As discussed in chapter 4, these are important aspects to consider when deciphering geosystem behaviour. The outcome of this recursive communication process can be manifold: several options are possible. This is titled 'contingency'. After Aristotle, contingency subsumes something that is neither necessary nor impossible, something that is the way it is but could be different (Staubmann, 1997). Social systems are characterised by what Luhmann calls 'double contingency', this means at least two persons participating in the communication process, and both experiencing contingency. One sentence follows each other, a recursive dialogue enfolds during which each partner receives information, processes this information, and responds to it. The two communicative systems do not merge and each works on the received information according to its own internal structure or 'filter'. However, they mutually influence each other, observe each other, and learn from each other. This is what Luhmann calls a social system (Luhmann, 1991: 154-157).

Theorising social systems in this way has profound implications for risk communication, perception and evaluation, because limits and possibilities of risk reduction are identified as will re-surface shortly.

Another important aspect in Luhmann's theory of social systems is that of complexity. By simply using the logic of difference as the basis for the generation of systems, it would be difficult to decide whether the boundary itself is part of the system or of its environment. Boundaries, such as membranes, skins and walls, are a third item besides a system and its environment (Luhmann, 1991: 53-54). This is where the idea of complexity and a complexity gradient enters the theory. Self-referencing systems determine their boundary themselves because they have to reduce complexity. Systems and their environments are comprised of elements and relations. With an increasing number of elements eventually a threshold is reached where every element cannot be related to every other element. A system reaching this threshold is complex (Luhmann, 1991: 46). It then has to reduce its complexity by selecting which elements and relations belong to itself and which belong to its environment. Hence highly complex systems which have reached the threshold define themselves by a process of selection and, ironically, by a reduction of their complexity. The environment will therefore always be more complex than

the system (Luhmann, 1991: 47, 48). Systems have to reduce their complexity not only to identify their own structure and identity, but to maintain their operative functions. Staubmann (1997) used the example of a discussion group. Would all members talk at the same time, a discussion, and thus communication, would not be possible. The number of communicative relations must be reduced.

This understanding of complexity, which is based on the number of links between elements, differs from what complexity theory defines as complex as discussed in chapter 4. Here, the quality of relations, in particular with respect to non-linearity, not their quantity is crucial. Since the aim of this chapter is to shed light on different attempts to theorise 'human-nature' interaction which include Luhmann's theory to various degrees, it is necessary to carve out these differences. This is particularly important when evaluating possibilities for a theory of risk.

Back to the basic process of self-referencing: it differs from what is usually understood as 'self-organisation' which is why Maturana and Varela (1973) created the term 'autopoiesis'. They had to find a new term, a new language to describe their new theory. Autopoiesis translates into 'self-making', with 'auto' meaning 'self' and 'poiesis' meaning 'production' (Maturana and Varela, 1980: xvii; Huschke-Rhein, 1998: 195). By adopting the term 'autopoiesis' Luhmann (1991: 61, 64) stressed that self-referencing in systems entails an automatic *re*-production of the system itself. Through the process of recursive self-referencing of every element within the system, the system reproduces itself.

Autopoietic systems are autonomous, but not autarkic: they decide for themselves which operations are allowed and which elements are included, but they still need their environment to exist. A cell with its membrane acting as a boundary is an example of an autopoietic system: it is self-referencing, self-organised, reproductive but not autarkic (Maturana and Varela, 1980). Also social systems are autopoietic but need the consciousness of psychic systems in order to communicate (Luhmann, 1991: 40). Consequently, systems are not isolated from their environment (structural coupling), but the system's resonance to its environment is determined by its internal structures, not its external environment (Luhmann, 1986a: 14). As Egner (2008) referring to Luhmann (1989) underlined, autopoietic systems therefore cannot be controlled externally, which emphasises the significance of self-referencing for risk reduction mentioned previously.

Within the context of this thesis 'structural coupling' between systems and subsystems is addressed. Structural coupling of systems has surfaced several times in the above outline. Since systems are autonomous but not autarkic they need some way of interacting with their environment which can only be indirect because operationally they are closed. This is described as structural coupling and indicated in figure 3.4. Note that following Luhmann's logic structural coupling occurs between all different system types, while Luhmann himself exemplifies interpenetration structural coupling by using consciousness and communication only.

Structural coupling, as well as recursivity, implies the notion of time. In this context, 'interpenetration' is the relation between systems which mutually belong into each other's environment (Luhmann, 1991: 290). Hence interpenetration is a system-environment as well as a system-system relation. Interpenetration is when two systems mutually penetrate each other and evolve together. *'Only interpenetration enables evolution [...]. Evolution is, from a systems theory perspective, a circular process [...]'* (Luhmann, 1991: 294), and irreversible (Luhmann, 2003: 102). Note that 'circular' here denotes recursivity. Also Staubmann (1997) interpreted interpenetration as a form of co-evolution. As Luhmann (1991: 297) concluded: *'Interpenetration implies that systems of different operational type, such as 'life', 'consciousness' and 'communication' are able to connect'*. Luhmann (1991: 295) pointed out that his concept of interpenetration targets a 'deeper' level than fluxes of resources, energy and information although these are also possible. Luhmann's theory argues on the level of what essentially constitutes a system. He further explained that interpenetration enables the interfingering of autopoiesis and the system's structure: one continuously reproducing, the other discontinuously changing. Hence autopoietic systems can be structurally coupled (Luhmann, 1991: 298-300). This is based on Maturana and Varela who differentiated between the organisation and the system's structure. 'Organisation' encompasses the relation between system components, meaning their dynamics of interaction which is also described as *adaptation* (Maturana and Varela, 1980: xxi, 77). 'Structure' describes the properties of system components (Maturana and Varela, 1980: 77). While the system's identity is lost with varying organisation, changes of its structure, within limits determined by its organisation, do not alter its identity. Therefore, structural coupling, the interaction of independent systems, entails changes of both systems' structure without losing their identity – they evolve (Maturana and Varela, 1980: xx, 11). Consequently, structural coupling is the conservation of adaptation. Maturana and Varela (1980: 103, 105) described evolution as the 'history of change' when operations are not altered (the conservation of adaptation) hence the system's identity is maintained, while structural changes occur.

These structural changes sequentially lead to the reproduction of the system. Within this thesis, it is necessary to display these theoretical principles on how systems interact – in particular because risk is essentially a phenomenon that is based on system interaction. In addition, one recognises aspects which have already surfaced in the context of resilience and human ecology: changing without losing particular functions (or in this context, operations), adaptation and co-evolution (sections 3.2.1.1, 3.2.1.2, chapter 2). These similarities between rather different concepts and theories are significant when evaluating the possibilities of constructing a theory of risk.

A system can be characterised by several subsystems comprising elements which are more closely related to each other than to other elements. As touched on above, the development of subsystems is a form of specialisation, and as such a further reduction of the environment's complexity, because every subsystem resides within the environment of all other subsystems.

Subsystems can, just like any other array of systems, influence each other ('interpenetration'). According to Luhmann, societies are social systems which are comprised of several subsystems such as economy, politics, religion, science, education, and art (Staubmann, 1997). Every subsystem uses a different code which serves as a template for its separation from its environment (this means for being operationally closed) (Luhmann, 2003: 89). For example, walking into a bank ordering a loaf of bread would lead to confusion, as well as walking into a bakery wanting to open a bank account. Each subsystem is autopoietic and closed. Different subsystems use different 'filters' through which only particular information can pass, which in turn the system can respond to. It seems that interpenetration between subsystems with the same operational type (e.g. communication and communication) does not differ from interpenetration between systems of different operational type (e.g. communication and consciousness).

What would happen when different subsystems face the same problem – how do modern societies react to ecological crisis? And what are the implications for natural risk? As Luhmann (1986b) concluded, first of all modern society cannot react as one system. Only each subsystem can react in its specific way. As Egner (2008) pointed out due to different codes the same problem will be evaluated differently by each subsystem. The economic subsystem can only understand an environmental problem if expressed in the language of prices (benefit and loss) – it cannot respond to another code as recently demonstrated by the Stern Report on the economics of climate change (Stern, 2007). Is the problem expressed in a code the subsystem can understand, the subsystem must respond (Luhmann, 1986b) – the type of resonance, however, is determined by the system itself, not its environment. Synergistic effects between different subsystems influencing society can occur when the problem affects a range of subsystems, for example resource scarcity does not just influence the economy, but also influences politics (Luhmann, 1986b).

Transferring these ideas into the field of risk management, Egner (2008) underlined a lurking fallacy when confidence in controlling systems is high – an important aspect which already surfaced in the context of flood protection. In the sense of Luhmann, this fallacy exists because systems are autopoietic: they operate only according to their own selection or contingency. Following this logic, cracking the code, meaning communicating a problem into the code of the addressed system, would increase the chances of effective emergent communication which involves not only information and information transformation but also understanding. However according to Luhmann the way the system reacts to the information is only decided by the system itself and cannot be controlled by its environment.

Autopoiesis has therefore profound implications for 'managing' risk in social systems. The subsystem's response to the problem after risk is communicated can be positively influenced, in the sense that risk is reduced, but is ultimately out of 'control'. Ignoring the autopoiesis of these systems, coupled with the confidence of knowing precisely how they operate, can lead to

undesired outcomes, or even disaster and catastrophe. According to Luhmann (1989) a controlling action often alters less or more than is envisaged (in Egner, 2008). In particular non-linear system behaviour entails 'surprise'. This is an aspect shared with general systems theory and ecological resilience (chapters 4, 6).

As observed by Staubmann (1997), Luhmann's theory has been criticised as inhumane since it describes a social system where humans are excluded. Luhmann (1991: 289) anticipated such criticism and pointed out that his systems theory does not devalue humans, since the environment is equally important as the system itself.

Luhmann (1991: 34/35, 40) recognised the role environment plays for a system, firstly because of the logic of difference and secondly because systems are not autarkic. However, by focussing on the logic of difference the connections between systems are secondary – something that does not account for an increasingly interconnected world. In addition, the question of how humans directly interact with their environment, meaning living and geophysical-material systems, is not addressed. This is because humans are 'units' but not systems and hence are excluded from any structural coupling between systems. In addition, interpenetration and structural coupling as outlined above are difficult to comprehend, and Luhmann did not indicate how they could be operationalised. The latter has been observed by a number of authors, for instance Fischer-Kowalski and Erb (2003). The missing conceptualisation of how humans can directly alter other systems, which is what they do, is the key question which needs to be addressed against the background of 'human-nature' relations and risk.

This is in particular relevant in the context of risk. Arguing from his systems theory, Luhmann (1991: 47) identified risk as the outcome of the following link: complex systems need to reduce their complexity, which they acquire by selection. The need for selection bears contingency (things could be different), which implies risk: one can miss out on a favourable outcome. In his 'Sociology of risk' (Luhmann, 2003: 30) he defined risk as a social construct which matches this earlier thought on risk. In a situation of uncertainty about the degree of loss potentially experienced, there are two options. The first is that loss is the product of a decision made - a selection between relations that bear certain options. A decision must be made because not all relations and options can be realised. In this case one speaks of 'risk'. The second is that loss is accredited to something external, hence something in the social system's environment. In this case, one speaks of 'danger'. While risk therefore involves an active process where something can be gained, a situation of danger is imposed on a person and nothing can be gained (Luhmann, 2003: 31-32). Within such an understanding of risk, Luhmann does not need to operationalise human-nature interaction, because risk occurs only within the social realm. 'Danger' on the other hand, needs some ongoing explanation of how this is imposed on humans.

Within this thesis, risk is understood to be initially produced by the intersection of geophysical and social processes, while risk is evaluated socially as stated at the beginning of this chapter. Risk is therefore *not only* a social construct. This is why structural coupling, the relation between such different phenomena like 'natural' and 'social' systems is crucial. Defining risk as depending on a whether a decision is made for better or worse does not acknowledge that in many cases, people simply do not have a choice. Main outcomes of the structuralist vulnerability research would be dismissed, or classified under the label 'danger'. However then, again, Luhmann's focus of external causes of endangerment as the causation of danger does not concur with the structuralist perspective that internal structures or, using Luhmann's terminology, social systems themselves contribute to the situation of endangerment (chapters 2, 5). One could fall back into the obsolete position of explaining disasters as the result of 'natural', external processes. In addition, Luhmann's (2003) risk definition does not accommodate that people might be unaware of underlying processes, either geophysical or social, hence that decision-making is not based on the 'actual' risk but their perception of risk. This applies to 'experts' and 'lay' people alike. Some would argue that perceived risk is the 'real' risk, but from a risk analysis perspective, the 'real' or 'actual' risk differs and is ultimately based on geophysical and social processes producing risk. This is not to say that 'actual' risk is more relevant than perceived risk, or vice versa.

For Luhmann's risk understanding a specification of 'human-nature' or better 'human-environment' interactions is not essential, and when considering that he does not focus on 'danger' which would include such a relation, but on risk, this does not leave a theoretical gap within his theory. Naturally he approached his analysis of risk in society based on his social systems theory of recursive communication (Luhmann, 2003: 6, 13), in fact pleading for including risk into any theory of modern society.

However, such a gap opens up when conceptualising risk in a partly different way as argued above. Perhaps here the idea of humans, which are 'units' not systems according to Luhmann, acting as hinges between different systems or spheres, as has been described by Boyden, is helpful. This would prompt a re-definition of the terms 'interpenetration' and 'structural coupling' since according to Luhmann this occurs only between *systems* – a discussion started at the 2007 Bonn meeting of the group 'Interactive projects in geography'. Essentially, this would entail the identification of a more differentiated position for humans within Luhmann's systems theory. Also introducing human agency would allow for a more specific operationalisation of interpenetration, but then again this would be a complete contradiction to Luhmann's theory based on communication not agency.

Egner (2006, 2008) put forward a series of arguments for why Luhmann's system theory could serve as a metatheory for 'human-nature' or 'socioecological' research. It is argued here that a metatheory would involve a similar understanding of how social systems and non-social systems operate. This, again, would not only involve 'living' systems as included by Luhmann,

but physical-material systems as described for instance in geomorphology. A range of overlapping perspectives on how systems operate have been pointed out above, which also extends to how geosystems function. Within geomorphology, systems are traditionally differentiated as 'open' and 'closed' (von Bertalanffy, 1950a), as tending towards some form of equilibrium (Chorley and Kennedy, 1971). More recently the equilibrium concept is contested by nonlinear system behaviour attributed to thresholds or 'bifurcations', resulting into systems maintaining far from equilibrium or 'non-equilibrium' states (chapter 4). For a discussion on how geomorphological systems understanding can contribute towards a metatheory of linked natural and social systems, see Dikau (2005, 2006). Likewise, a contribution towards a metatheory with respect to complexity theory is provided by Ratter (2006). However, conclusive comments on whether enough similarities exists between a social systems theory, and general systems theory in the context of geosystems cannot be made within this thesis at this stage.

After this excursion into one particular social systems theory, the stream of 'human-nature' interaction models, sometimes also called 'socioecological' models, is picked up again in the following. As opposed to the human ecology concepts discussed previously, Luhmann's social system theory now features as one component within such models.

3.2.4 Sieferle

An expansion on Boyden's (1992) conceptualisation is Sieferle's (1997) socioecological model. Sieferle, a historian and sociologist, echoed the threefold construct by adapting the dimensions of 'nature' (N), humans or 'population' (P) and 'culture' (C) (figure 3.5). In addition, Sieferle aimed at creating accessibility to human ecology and Luhmann's theory of social systems, and regarded both as mutually important. By adapting Luhmann's system theory for the component of 'culture' he intended to represent the social sphere in a more differentiated way than the usual 'human factor' or 'human disturbance' approach. As concluded earlier, this has been subject to Boyden's model which, however, does not explicitly integrate social theory. At the same time, Sieferle recognised the function of a material-physical world providing resources necessary for societies to function. Referring to Luhmann's theory of social systems, he pointed out (Sieferle, 1997: 244): *'Human societies, however, cannot be reduced to cultural systems, that is, they cannot be reduced to systems of symbolic communication which are subsystems of a universe of information or meaning'* (cited in Weichhart, 2003b: 25). Note that as outlined above, Luhmann does not dismiss this materialist reality and flow of energy, material or information, but does not use this as a constitutive argument for what a system is.

In Sieferle's model, 'nature' comprises the components of a real existing, material world but excludes humans. Humans ('populations') are able to physically alter this physical-material world by using their physical bodies. Simultaneously, because of their mental abilities humans are the interface to 'culture' which is the symbolic world consisting of thoughts and language. Humans can translate symbolic meaning through language and their physical bodies into actions altering the physical-material world. Culture is defined according to Luhmann's theory as

an autopoietic system of recursive communication. While Sieferle (1997) described humans in their role as intersecting agents between 'nature' and 'culture' as 'amphibians', Fischer-Kowalski and Weisz (1999) and Fischer-Kowalski and Erb (2006) preferred the term 'hybrid' and expanded on this notion, as will be discussed later in this section.

Figure 3.5: Sieferle's conceptualisation of socioecological relations (after Sieferle, 1997).

The socioecological model includes a combination of 'nature' and 'population' as representing the 'human-ecology' system, while 'population' and 'culture' together form the 'social system' (figure 3.5). Sieferle added a component of time by referring to the process of 'cultural evolution'. Cultural evolution occurs via the exchange of information, and through this expansion and evolution of the symbolic sphere, especially through language, cultural evolution starts as an adaptive process but subsequently turns into an autarkic, autopoietic process (Sieferle, 1997). Again, the temporal aspect features as a strong component of such socioecological interactions which with respect to a risk theory underlines the dynamic element commonly neglected in risk research.

While Sieferle's model closes the chasm between 'nature' and 'culture' which Luhmann's theory of social systems leaves open (social systems cannot directly influence natural systems), and creates an access point to this Luhmann's theory, a contradiction arises in the grouping of the social and the human-ecological systems. A consequent application of Luhmann's logic of difference and the concepts of self-reference and autopoiesis would not allow to join such different phenomena like the material world and humans forming one system, joining humans with culture comprising another system, nor combining nature, humans and culture into one 'socioecological' system. Luhmann explicitly locates humans outside of social systems. Hence by using the term 'system' for these combinations, Luhmann's concept of 'system' is dismissed in Sieferle's model.

In addition, Luhmann's social systems theory appears to be only applicable for the 'culture' component – Sieferle remained silent on whether an adaptation for the other two systems ('nature' and 'population') is possible. Since Luhmann derived his theory from Maturana and Varela's work rooted in biology, a likely answer is 'yes' for 'nature' which includes Luhmann's living systems, but 'no' for 'population' which is, according to Luhmann, not a system. No indication is given on whether Luhmann's theory applies for the physical-material sphere which

is a part of 'nature' in Sieferle's model. Furthermore, Sieferle recognises adaptation in the context of cultural evolution which then develops into autarkic, autopoietic systems. In contrast, according to Luhmann autopoietic social systems are autonomous, but not autarkic.

These contradictions illustrate the problems encountered when aiming to combine different theoretical approaches into one model of 'human-nature' or 'socioecological' relation. If done hastily, access points for other disciplines, though envisaged, can become exit points. Against the background of a multi-disciplinary risk field, accessibility for different disciplines is crucial to enhance the progress of successful and sustainable risk reduction. In addition, the contradictions hinder the development of a metatheory of risk.

Sieferle's conceptualisations serve as a starting point for the ongoing theorising of socioecological systems which will be the final waypoint towards a potential theory of risk. However, again another approach which is taken on board of this ongoing socioecological work must be first introduced.

3.2.5 Latour

Bruno Latour's 'actor-network theory' (ANT) (Latour, 1993) is based on his observations of a world which is closely knit and inseparable. It is disputable whether ANT is a theory in the strict sense, but regardless his worldview is very interesting in the context of general 'human-nature' interaction theory and risk in particular. In his book 'We have never been modern' (Latour, 1993), he begins by citing articles published in his daily newspaper. These seemingly deal with different topics, such as the chemistry of the lower stratosphere (ozone hole), international politics on gas emissions and the 'Third World' expressing their right to develop. He concluded *'The horizons, the stakes, the time frames, the actors - none of these is commensurable, yet they are, caught up in the same story'* (p. 1). He does not see much benefit from either de-naturalising everything 'physical', or from excluding everything social from what is physical. Particularly the latter point is contrary to Luhmann whose theory is built on the logic of difference. Latour perceives the world as a tight network of relations between several elements. Not 'actors', but the French word 'actans' is used to express that elements within the network are not 'free', but that their actions serve a specific purpose (Forsyth, 2003). This network forms a platform on which the differentiation into 'natural' and 'social' as 'pure' forms has been artificially built by natural sciences and humanities alike. Within a network, the processes of relation-building between elements ('hybridization') are called 'translation'. Opposed to 'translation', 'purification' is the process which divides nature and culture and creates two different spheres (figure 3.6). He therefore differentiated between two 'levels': one that we see (nature-culture dichotomy), and one we cannot see, the underlying network. Hence modernity is characterised by a double dichotomy: between nature and culture on one level, and between two levels of reality. This separation is a product of modernity, but with respect to the underlying hybrid networks, we have never been truly modern, as the title of his book subsumes (Latour, 1993).

Latour concluded that attempts to explain those 'pure' forms and their interactions must fail, because they obscure the underlying tightly woven connections. He refers to environmental problems as the consequence of dualistic operating sciences unable to see the network beneath the artificially constructed dualism of nature and culture.

Figure 3.6: Why we have never been modern (Latour, 1993: 11)

Hybridization, the process of relation-building, creates new phenomena: hybrids. In a biological context, the term 'hybrid' means *'the offspring of two plants or animals of different species or varieties'* (The Concise Oxford Dictionary, 1995). In a wider sense, a hybrid is a *'thing composed of incongruous elements'* (The Concise Oxford Dictionary, 1995). As Latour (1993) pointed out, a hybrid is a combination of two forms, however these forms are not 'pure' because pure elements do not exist in networks. Examples of hybrids as a combination of 'nature' and technology are genetically modified crops such as soybeans (Whatmore, 2002), and cyborgs (Harraway, 1985). Beck (1986) and Beck et al. (2001) referred to the concept of hybrids in the sense of Latour, elaborating on how new risks such as genetic engineering or human induced climate change come to the surface. These are products of cultural and technological processes of the Western 'modern' society ('first modernity'). The 'World risk society' (Beck, 2007), replacing 'risk society' (Beck, 1986) increasingly witnesses the emergence of new or 'hybrid' risks.

As Whatmore (2002) commented, hybrids are part of everyday life because relations between elements exist and can change on a daily basis. This statement underlines that relations are essential, not secondary as in Luhmann's theory. Indeed, from the perspective of critical human ecology, which aims to overcome human ecology's classical dualism, hybrids exist through the relations between specific human action and the physical-material world (Weichhart, 2003a in Dikau, 2005). In critical human ecology, it is the dissolution between the often separated 'geo'- and 'social system' which is subsumed under the notion of 'hybrids' (Weichhart, 2004). Similarly

within ecology a new direction ('new ecology') aspires to overcome the 'nature-society' dualism. 'New ecology' regards the world as a hybrid, rather messy place (Castree, 2005a). In line with Lawrence (1993), Bates and Pelanda (1994: 147) called for a 'general ecology', where humans are *'fully recognized as a part of nature, rather than being cast as a kind of outside enemy of the environment'*.

Against the background of Latour's ANT and the history of natural hazards and risk research (chapter 2), it appears that strategies of risk reduction traditionally rely on the classic dualistic worldview – either tipped towards realism in natural sciences or constructionism in social sciences. Both are hardly compatible and polarise risk research, which is likely to be a contributing factor in the increasing number of disasters worldwide. Focussing on relations and recognising hybrid phenomena which cannot be classified as strictly 'natural' or 'cultural' can dissolve the classical boundaries erected between disciplines. Thus it becomes clear that solutions of risk reduction cannot be successful when developed and applied within one of the two realms of modernity.

The network concept, as such, is not new and has been used to define the term 'ecosystem' previously (Margalef, 1968; Hawley 1986). What is new is defining elements by their relations to each other, consequently rendering the boundaries between the 'natural' and the 'social' porous and redundant.

Nevertheless in order to express network-related ideas 'old' semantics such as 'human impact', 'non-human world', 'interaction' and 'interrelation' will still appear (Castree, 2005a). A human is still human and different from non-human phenomena, although humans could be labelled as 'hybrids'. Zierhofer (1999, 2004) did not regard this as a problem. He suggested that although nature and culture form a shared existence, for practical reasons this existence can be either seen as more natural or more human. In addition, depending on the quality of relations, some might be more prominent than others. However, this contradicts Latour's proposition of networks where no element is more prominent than others. Against a background of intensifying human-induced change of the physical-material world such a position is also questionable. By completely discarding a dualist language and ontology, a terminological gap is opened up which has not been filled as successfully compared to Maturana and Varela's 'autopoiesis'.

3.2.6 Fischer-Kowalski and colleagues

Fischer-Kowalski and Erb (2006) made a pragmatic compromise: they acknowledged that a strictly dualistic worldview is not necessary the reality. Moreover, they incorporated the notion of hybrids but designed a socioecological interaction model which still differentiates between different 'worlds' (figure 3.7). As Fischer-Kowalski and Weisz (1999: 244) stated: *'In our understanding, human societies are irreducible hybrids between a natural, material world and a cultural world of recursive communication.'* Fischer-Kowalski is associated with the group 'social ecology' located in Vienna, and the epistemological framework they developed, as discussed below, intends to bridge the 'nature-society gap' (Fischer-Kowalski and Weisz, 1999; Fischer-

Kowalski and Erb, 2003). They follow an interesting approach by combining such contrasting theories like Luhmann's social theory and Latour's actor network theory.

Figure 3.7: Interaction model society-nature, after Fischer-Kowalski and Erb (2006: 41)

The Vienna group based their 'interaction model society-nature' or otherwise labelled the 'mind-map social ecology' (Fischer-Kowalski, 2004: 315) on Sieferle's combined approach of human ecology and Luhmann's social system's theory. They conceptualised the linkage between geophysical/ecological and social processes based on the allegory of a 'metabolism' (Fischer-Kowalski and Weisz, 1999). Describing a society as a metabolism identifies processes of natural resource extraction (water, biomass, minerals etc.), transformation, and excretion. Fluxes of material and energy enable this metabolism, and resources are transformed into a wide range of products which, with different lag times, are excreted as waste and emissions. Depending on the society's mode of subsistence (e.g. agrarian vs. industrial), its metabolic profile will differ (Fischer-Kowalski and Weisz, 1999; Fischer-Kowalski and Erb, 2006). The existence of humans, or the 'population', depends on the exchange of material and energy. Humans can modify 'nature', especially through the process of colonization which will be addressed again below. Humans, or more precisely, society as a coupling of 'population' and 'culture' modifies natural resources, and such hybrids like domesticated animals, new plant species, land use systems and built structures emerge (Fischer-Kowalski, 2004). In addition, humans experience nature which is, in contrast to colonization, a passive process. Both processes combine elements of the material and cultural sphere, hence are hybrid processes. It should be noted that Weichhart (2003b, 2005), and Wardenga and Weichhart (2006) added 'hybrid systems' as a specification of 'population' as the intersection between 'nature' and 'culture' in the 'interaction model-society-nature'. However, this again is a contradiction of Luhmann's social systems theory as emerging in Sieferle's (1997) model and avoided by Fischer-Kowalski and colleagues.

Simultaneously, the population is dependent on reproducing knowledge and of 'making sense' (cultural or symbolic sphere). This direct exchange between humans and culture is based on communication as adapted from Luhmann. Communication unfolds in manifold ways, for

example in the economic process of selling and buying. Experiences with the material sphere are communicated, interpreted and coded against a cultural background, hence represented within the cultural sphere. At the same time, culture influences which and the type of activities undertaken by humans: a 'programme' feeds back from culture into nature via the population. Again, these processes of communication are hybrid, since the human body serves as a medium for carrying information and symbolism. The model is interspersed with hybrid phenomena which prompts the question whether a classical, dualistic concept with clearly defined boundaries can be maintained. This is where the pragmatism touched on above surfaces: although the world is perceived as full of hybrids, a total aversion from dualistic elements would hinder a 'soft coupling' between diverse disciplines aiming to bridge the 'human-nature' gap (Fischer-Kowalski and Erb, 2006). The interaction model society-nature therefore bears an opportunity for approaching risk with less friction between the different disciplines. Furthermore, the model fully acknowledges the two components of risk identified previously: 'human-nature' interaction and a differentiated representation of social processes.

As touched on above, the Vienna group does not follow the contradiction Sieferle's socioecological model displays. They advanced Sieferle's model and, as cited above, defined society clearly as a hybrid or unit combining elements of social (symbolic-communicative) systems and biophysical systems ('nature'), but not as a system itself (Fischer-Kowalski and Weisz, 1999: 244; Fischer-Kowalski and Erb, 2006: 40). Though the term 'system' is still sometimes used for society (e.g. Fischer-Kowalski and Erb, 2006: 45), this seems to be a sign of inconsistent terminology usage rather than a change of conceptual understanding.

However, an inconsistency emerges because hybrids are coupled with social systems via communication. This is a contradiction of Luhmann's theory of social systems since only social systems use communication, and hybrids (such as humans) cannot be regarded as social systems. The model combines two very different concepts, that of hybrids (everything is related, no difference between 'nature' and 'culture') and Luhmann's autopoietic systems (logic of difference). Therefore the question of how hybrids can be structurally coupled with systems emerges. Limitations of such an approach are met when the arising inconsistencies are not addressed or encountered by further theory development. This will be discussed in the second part of this chapter. The problem of how to define the coupling of hybrids and systems equally applies for the process of metabolism, which connects the material world (living and non-living systems) with hybrids.

Socioeconomic metabolism has proven useful for broadening the view of how society interacts with nature by focussing on processes of material and energy input and output. However, the Vienna group detected a limitation of the explanatory power of this approach regarding sustainability and new risk faced by modern societies. Consequently, the process of 'colonization' is introduced. From 'colonus' meaning 'peasant', the term describes *the intended and sustained transformation of natural processes, by means of organized social interventions,*

for the purpose of improving their utility for society' (Fischer-Kowalski and Weisz, 1999: 234). Colonization simultaneously affects both, the biophysical and the cultural world: in the form of changes in the physical-material world as well as in the form of perception, intention, communication, organisation and monitoring in the symbolic world of culture, respectively. Increased susceptibility of colonized systems towards collapse, such as decreased resistance to disease in monocultures of flora and fauna, or the occurrence of hazards and disasters are unwanted side-effects. Modern, industrialised societies tend to treat these adverse effects with newly invented science and technology 'solutions', which in turn generates new risks – a phenomenon described by Ulrich Beck (1986) as typical for 'risk society' as mentioned above. Fischer-Kowalski and Weisz (1999: 239) identified colonization as a process of risk 'generation' and developed the above described 'interaction model society-nature' as a theoretically base upon which studies of colonization or risk 'generation' can be placed. This concurs with the understanding of risk within this thesis. Besides, they identified, referring to Rosa (1998), such steps as risk identification, estimation, evaluation and management which are the main components of the well-established approach to risk management and assessment as summarised by the Australian Geomechanics Society (2000). Again this aligns with the two-step approach to risk as identified at the beginning of this chapter. While Ulrich Beck refers to 'new' risks strictly within the context of industrialised societies, Sieferle (1997) broadens the generation of risk and refers to the colonization process as the interaction between society and nature generally. Sieferle's view includes a range of society types as long as they are characterised by some form of colonization (Fischer-Kowalski and Weisz, 1999). According to Luhmann's (1997) understanding of risk as summarised above, Fischer-Kowalski and Weisz (1999: 239) interpreted the *'evolution of the society-nature relationship'* as *'a transformation process, in the course of which societies gradually transform dangers into risk'* through colonization or what Luhmann calls 'technique'. Hence not environmental, but social risks are generated. As they further concluded, not without referring to Beck (1995), dangers are translated into risk until the 'organising capacity' of society is reached and risks are reversed into dangers. What is described here as 'organisation capacity' is likely to echo the term 'adaptive capacity' as will be discussed in more depth in chapters 6 and 7. Note that adaptation as such plays only a marginal role in the model of Fischer-Kowalski and colleagues. With respect to cultural evolution Fischer-Kowalski and colleagues concur with Sieferle and only speak of adaptive operations during the first phase of a system's genesis which is gradually replaced by autarkic operations. Again this is a contradiction of Luhmann's theory.

In cases of increasing risk, Mueller-Herold and Sieferle (1998), who regarded this process as a consequence of colonization and the co-evolution between nature and society, use the term 'risk-spiral' (Fischer-Kowalski and Weisz, 1999). Colonization is, ultimately, seen as an irreversible process for both *'natural and social systems. Colonized systems never revert to their original state once particular forms of utilizing these systems are abandoned'* (Fischer-Kowalski and Weisz, 1999: 236). Furthermore, Fischer-Kowalski and Weisz (1999) adapted the notion of

time in the sense of co-evolution between social and natural systems, with respect to 'cultural evolution' as proposed by Sieferle (1997) as mentioned previously. Again, we recognise concepts that emerged previously, in this case irreversibility and evolution. The Vienna group empirically approaches this concept of colonisation by quantifying fluxes of material and energy for instance calculating the net primary production of a society (Fischer-Kowalski, 2004; Eisenmenger et al., 2007; Haberl et al., 2007).

The socioecological model should not be confused with what has become known as 'socio-ecological' systems under the auspice of the 'Resilience Alliance'². This body of research also aims at theorising 'human-nature' relations. The novelty of this approach, however, is limited since it remains unclear what 'socio-ecological' systems are if not 'human-nature' relations. In addition, the path of explanation runs from a sound ecological basis towards social system which runs the danger of applying ecological concepts for social processes which, if done hastily, locks rather than opens doors to other disciplines such as sociology and anthropology. Therefore the conceptualisation of 'socio-ecological' systems is not discussed here. However, many ideas subsumed under the concept of the panarchical 'adaptive cycle' are useful and have influenced resilience research which again infused the natural risk field. This model is discussed in appendix B.

3.3 Conclusion

As a first step in reflecting on the various models and theories discussed so far, they are grouped according to the ontology spectrum introduced at the beginning of this chapter.

3.3.1 Ontologies

As has been stated in the beginning of this chapter, dualistic ontologies dominate not only the (Western) public but also science in general. Human ecology and the models proposed by Boyden and Sieferle are essentially dualistic. While this distinction is quite clear in the case of human ecology, Boyden and Sieferle introduce a third element, 'population', sitting in between 'nature' and 'culture'. However this third element is seen as either part of nature ('human-ecological system'), or as part of human society ('social system'). Luhmann's social systems theory does not seem to follow this dualism since many different system types are possible. Humans, which mimic 'population' in Boyden and Sieferle's models, are something else, a 'unit' rather than a system and hence constitute a third element between systems and their environment as well. However they do not play a role in his theory as such and one does not learn more about their coupling with systems, or in fact, a coupling is excluded since structural coupling is only possible between systems (this means also between systems and their environment).

² An international conglomeration of resilience researchers, <http://www.resalliance.org/1.php>, accessed 9.12.2007

For simplicity reasons Luhmann's theory is grouped with the above into the category of 'critical realism' (figure 3.8). As discussed previously, this is a perspective suggested by Bhaskar which concurs with constructionism/relativism but acknowledges the existence of a 'real world'. Human ecology, Boyden, Sieferle and Luhmann acknowledge the 'real' world with its resources, although its role for the constitution of systems differs. Luhmann focuses on the logic of difference rather than the relation or exchange of energy or matter between systems.

Figure 3.8: Grouping of ontologies

Latour's actor network theory follows an ontology which is essentially a new form of monism. Neither 'natural' nor 'cultural' phenomena are disputed per se, but merged into a new phenomenon: hybrids. Hybridity overcomes dualism by focussing on tight interrelations between inseparable elements in a network, and therefore creates a new form of monism. There is a single element in 'reality': a hybrid network on which humans superimpose their common dualistic view.

An interesting and rather bold step is undertaken by Fischer-Kowalski and colleagues (the Vienna group 'social ecology'). As demonstrated earlier, they adhere to critical realism motivated by pragmatism; however, they acknowledge the existence of hybrids. They 'drill' through Latour's second dichotomy (figure 3.6) and pull hybridity into the dualistic world. Therefore they combine a dualistic with a monistic ontology – a new ontology emerges which is called here (equally bold) 'triplism'. The threefold structure inherent in Boyden's and Sieferle's models is developed further and humans or 'population' become hybrids which are not grouped alternatively in the material world or in society, but reside only in the intersection between both. This step is prepared by Boyden and Sieferle but only with a direct link to Latour becomes a new ontology. As indicated before, ontologies shape the questions asked and with respect to risk research a different set of questions can be expected to be formulated when taking on any one of these ontologies discussed above.

3.3.2 Some guiding principles and ideas shared

In the following, a number of shared statements and concepts are summarised as key observations which lead to definitions guiding the research presented in this thesis.

- Luhmann's conceptualisation of risk is embedded within his social theory. Complex systems need to reduce their complexity which they acquire by self-determined selection of relations. The need for selection bears contingency (things could be different), which in turn implies risk. Risk is the positive or negative outcome of a decision (selective) process, while 'danger' is something that is imposed and impedes the system from the 'outside'. This understanding of risk is very valuable when addressing the social component of risk: risk perception, communication, evaluation and management.

- Generally, the thoughts on colonization as producing risk expressed by Fischer-Kowalski and colleagues matches with the conceptualisation of risk in this thesis where risk is seen as initially generated by the intersection of geophysical and social processes. The notion of colonization as defined by Fischer-Kowalski and Weisz (1999) is quite broad and can be interpreted as to include all forms of transforming nature, including (sub-)urbanisation, agriculture and forestry.

- One theme that all models and theories share is that of mutual influence between elements which leads to the process of (co-)evolution. This is associated with adaptation (Darwin, human ecology), colonization/metabolism (Boyden, Sieferle, Fischer-Kowalski and colleagues) or recursivity / structural coupling (Luhmann). Essentially all models and theories include the notion of irreversibility. Evolution is an irreversible process of mutual transformation (adaptation). Within this thesis the evolution of risk is defined this way. Risk is therefore a recursive, evolutionary process, not a static product. This interpretation concurs with Luhmann (2003) describing the evolution of risk as an irreversible process, although Luhmann's risk definition partly differs from the definition applied in this thesis.

- Human adaptation is an active process, a transformation of 'nature' guided by 'culture' aiming at a favourable outcome for humans, and therefore is not deterministic. Favourable outcomes can either be accompanied by unwanted 'side-effects' such as 'old' and 'new' (hybrid) manifestations of hazard. Favourable outcomes can also be entirely substituted by adverse effects: something has gone 'wrong' and the envisaged benefit turns into a cost. Adaptation is
 - a process of mutual modification between two or more elements, ideally aiming towards a favourable outcome for all,
 - specialisation or generalisation,
 - a collective rather than an individual process.

- Autopoiesis yields high explanatory power within the context of risk management which ultimately targets risk reduction. Controlling an autopoietic system is not possible. However, it can be influenced in a way that hopefully leads to the envisaged outcome. The nature of this outcome is determined by the system itself, not its environment (this means another system). Autopoiesis is very useful for improving risk communication, since specific codes can be used to favour a positive outcome (for instance the Stern-Report). It is also useful for realising the limits and dangers of seeking control: not only between systems of communication (social systems) but also between all other systems. Here, the linkage between social systems and 'other' living and non-living systems gains momentum and should be a focal point, as will be seen soon.

3.3.3 A risk theory?

When using a systems approach as a starting point for a metatheory of 'human-nature' interactions, which could then serve as a template for the production of risk, all systems need to be conceptualised in a similar way. It has to be agreed that social systems, living systems and non-living systems (geophysical) act according to the same principles. Luhmann's system's theory based on Maturana and Varela is one possibility. It is, however, not clear whether non-living systems (geophysical) are autopoietic – they cannot utilise cognition for differentiation and selection processes. Fischer-Kowalski and colleagues apply autopoiesis for all systems in the 'material world' (Fischer-Kowalski and Weisz 1999: 237). However, the lack of cognitive abilities needs to be replaced, conceptually, by something else. Perhaps cognition as such is not constitutive as long as the system's operations, on which the system's identity depends, are maintained by some form of internal self-organisation.

This question is less relevant if the structural coupling between systems, autopoietic or not, accommodates coupling between them. As Maturana and Varela (1980) pointed out structural coupling is not confined to living systems, but living systems are special because they are self-organised, autopoietic. More importantly, structural coupling could be expanded in a way that includes coupling between systems and non-systems (humans as 'units', 'hybrids'). Expanding on structural coupling allows an autopoietic system understanding and the existence of non-systems, of hybrids within this 'messy' world. Hybrids could then be included as an independent element within the environment of systems.

Combining two contrasting theories, Luhmann's social system theory and Latour's actor network theory, into one model as undertaken by Fischer-Kowalski and colleagues is a bold step towards a promising direction and, and the resulting model is not entirely coherent. Without addressing the question of autopoiesis for all systems, and even more importantly the question of structural coupling between systems and hybrids, such a fusion is incomplete.

In conclusion, a critical realist ontology which includes the notion of hybrids as 'hinges' between the 'natural' and 'cultural' sphere which each consist of autopoietic systems (and possible non-

autopoietic systems) is the best compromise available at present, realising some of the limitations due to the not yet answered questions.

The following model, modified after Fischer-Kowalski and Erb (2006), represents this conclusion (figure 3.9). The model recognises the predefined basic structure and paths of relations. It incorporates and expands on a conceptualisation of risk which was proposed by UNDRO (1982) (chapter 1) where risk is a function of hazard, elements at risk (people, their assets, society or the economy) and their vulnerability. Within this thesis, the resilience of elements at risk is included.

In contrast to Luhmann, who separates humans from society, society as a unit of people and culture is adapted here from Fischer-Kowalski and colleagues. Risk is the product of intersecting social and geophysical (non-living) processes. Humans and their artefacts are hybrids which function as 'hinges' between the two spheres, nature and culture. Simultaneously they constitute 'elements at risk'. They are coupled with 'culture' which encompasses autopoietic social systems. This is a weakness in the risk model since strictly speaking only systems, not non-systems (hybrids) and systems, can be coupled (as discussed previously). 'Communication' as a form of coupling can be questioned, but is included for now. Products of this, yet to be defined, interrelation are people's vulnerability and resilience. Vulnerability and resilience are socially defined constructs and produced through this exchange with culture. Social systems, such as politics and economy act as a 'filter' and shape the way vulnerability and resilience manifest for different groups of people (chapters 2, 5, 6, 7).

Figure 3.9: A model of natural risk

In the risk model, the experience of 'nature' is represented (interpreted, coded) and influences culture. Due to the autopoietic character of social systems they display an element of uncertainty (complexity, contingency, non-linearity, limited predictability). This is the field of risk perception and evaluation, risk communication and management. Risk management influences the material world through the 'program' and therefore risk at the intersection of the material and the cultural sphere.

Similar to the cultural sphere, autopoiesis in the 'material world' shapes system behaviour. As discussed in more depth (chapter 4), geosystem behaviour is often characterised by complexity, contingency, non-linearity and limited predictability. However, whether this results into an accepted similar understanding of how social and geosystems operate remains to be seen. Combined with human adaptation which includes transformation of geosystems, hazard is produced. Hazard, as the probability of occurrence of a geophysical process with a specific magnitude during a specific time span, is an expression of uncertainty. Should one know when exactly when and where such a process occurs, it would not be a 'hazard'. Human adaptation is shaped by culture (social systems) which defines the 'program' and is actioned by the interlinked population. The experience of 'nature', in which ever way (positive, negative) reflects back on people and their artefacts (assets). Like in the case of communication, the interaction between systems of the material world and hybrids is, for now, described as metabolism, but requires a sound theoretical basis.

Risk, as the probability of a certain degree of benefit or loss equally depends on hazard, vulnerability and resilience of the population and its artefacts (elements at risk). In the case of low hazard, low vulnerability and high resilience human transformation of natural systems are likely to result in gains, while high hazard and or high vulnerability and low resilience are likely to result in losses.

In this model risk evolution is located at the scale of people and their communities. This level is interlinked with higher level scales such as society and the surrounding environment. Risk evolution is inherent in this model. Risk manifests as a product of the co-evolution between systems and is therefore a process.

The risk model presented here does not claim to be theory as such, and some theoretical questions remain unsolved as discussed above. However, it can serve as a starting point for risk analysis, assessment and management since it offers access points for a range of disciplines across the natural and social sciences. Furthermore, despite the unresolved theoretical question of structural coupling within a systems theory approach, hazard, vulnerability and resilience represent the outcomes of this coupling. Within this thesis these three components (plus 'elements at risk') serve as tools for operationalising risk (chapters 4 to 8, 10 to 13).

4. Landslides: processes, hazard and hillslope systems

Landslides in New Zealand impose a common hazard to life and assets (chapter 1). Besides direct and indirect economic costs, rapid landslides in particular pose an immediate threat to people's lives and health. This chapter discusses landslides as geomorphological processes, as hazards, and as parts of geomorphological systems. Against the background of hazard and risk analysis, some key aspects emerge and are discussed at the end.

4.1 Landslides as geomorphological processes

A landslide is a '*downward or outward movement of a mass of slope-forming material under the influence of gravity, occurring on discrete boundaries and taking place initially without the aid of water as a transporting agent*' (Crozier, 1999a: 84). In the past various landslide classifications have been developed, and the most widely used is based on Varnes (1978) which was taken up by Cruden and Varnes (1996) and applies the terminology summarised by the International Geotechnical Societies' UNESCO Working Party on the World Landslide Inventory (WP/WLI, 1990, 1991, 1993). This classification of mass movements (table 4.1, figure 4.1) is based on:

- the type of movement (fall, topple, slide, spread, flow, complex),
- the type of material (bedrock, coarse soil, fine soil or 'earth').

Additional descriptions involve:

- the state of activity (active, reactivated, suspended, dormant, abandoned, relict),
- water content (dry, moist, wet, very wet),
- rate of movement (as outlined in table 4.1).

While Cruden and Varnes (1996) described rotational and translational slides as well as complex movements (combinations of different movement types) these are not included in their classifying table (1996: 38). Therefore Varnes' (1978) original classification is summarised in table 4.1.

With respect to slides, the main differentiation as indicated above is whether the type of sliding is rotational or translational. A rotational slide is a movement along a 'surface of rupture' or shearing zone which is often described as 'spoon-shaped'. Consequently, the head of the slide usually drops down vertically while the whole body is pushed down and simultaneously tilted backwards (figures 4.1, 4.2). In contrast, translational slides move along a planar surface of rupture such as the boundary between bedrock and regolith. Additionally, they are usually shallower than rotational slides and can develop into a flow (figure 4.3) (Cruden and Varnes, 1996).

Table 4.1: Slope movement classification based on Varnes (1978) and, abbreviated, Cruden and Varnes (1996). Block slides, as opposed to slides, involve one coherent mass of material moving while slides can be broken up into segments.

Type of movement		Type of material	
		Bedrock	Engineering soils
			coarse fine
Fall		Rock fall	Debris fall Earth fall
Topple		Rock topple	Debris topple Earth topple
Slide	Rotational	Rock slump	Debris slump Earth slump
	Translational	Rock block slide, rock slide	Debris block slide, debris slide Earth block slide, earth slide
Spread		Rock spread	Debris spread Earth spread
Flow		Rock flow (deep creep)	Debris flow (soil creep) Earth flow (soil creep)
Complex (combinations of two or more types)		e.g. rock fall-debris flow, rock topple-rock slide, earth slide-earth flow (Cruden and Varnes, 1996)

Figure 4.1: Types of movements according to Varnes (1978) and Cruden and Varnes (1996: 53). From left to right, pair wise: Fall, topple, slide, flow, spread.

Figure 4.2: Rock slump (rotational) (Cruden and Varnes, 1996: 57)

Figure 4.3: Debris slide (translational) (Cruden and Varnes, 1996: 57)

As opposed to slides which tend to preserve their surface of rupture, flows do not maintain their surface of rupture (figures 4.4, 4.5). Flows are continuous movements of a viscous liquid type where the material is deformed internally to a great extent. Complex movements as a combination of slide and flow are common and become more likely with increasing water content (Cruden and Varnes, 1996).

4.1.1 Rates of movement

The rate of movement is an important aspect of landsliding with respect to damage potential. Varnes (1978) classified the velocity of landslides as ranging from three metres per second to 60 millimetres per year. This scale has been modified to accommodate several velocity classes which bear much similarity with the Modified Mercalli scale of earthquake intensity (table 4.2).

Figure 4.4: Slow earth flow (Cruden and Varnes, 1996: 65)

Figure 4.5: Rapid debris avalanche (Cruden and Varnes, 1996: 65)

However, in the case of landslides the relationship between damage and the magnitude of the slide is less clear than compared to earthquakes. For instance, small but very rapid mass movements can cause loss of life and high levels of damage. In contrast, the damage incurred by large movements of moderate velocity can be much smaller, especially because people are warned and structures can be protected as much as possible. Consequently, landslide impact depends on the volume and the velocity of the movement, which together account for the degree of energy released. The vulnerability (potential degree of damage) of elements at risk is likely to rise with increasing velocity, because greater loss of life and damage can be expected in the case of rapid compared to slow landslides (Cruden and Varnes, 1996). The correlation between vulnerability and landslide velocity is based on various case studies and, generally, a certain degree of damage can be assigned for each velocity class as illustrated by Cruden and Varnes (1996) and replicated in table 4.2. They identified two important thresholds of velocity:

firstly between 'extremely rapid' and 'very rapid' at five metres per second since this is the approximate speed of a running person. Secondly, at 1.6 metres per year, the boundary between slow and very slow, where some structures located on the landslide remain unharmed.

Table 4.2: Velocity classes and potential damage degree, modified after Cruden and Varnes (1996: 50, 51)

Velocity class			Potential damage degree
1	Extremely slow	up to 16 mm/yr	Imperceptible without instruments, construction possible without precautions
2	Very slow	up to 1.6 m/yr	Some permanent structures undamaged by movement
3	Slow	up to 13 m/month	Remedial construction can be undertaken during movement; insensitive structures can be maintained with frequent maintenance work if total movement is not large during a particular acceleration phase
4	Moderate	up to 1.8 m/hr	Some temporary and insensitive structures can be temporarily maintained
5	Rapid	up to 3m/min	Escape evacuation possible; structures, possessions, and equipment destroyed
6	Very rapid	up to 5m/sec	Some lives lost; velocity too great to permit all persons to escape
7	Extremely rapid	more than 5m/sec	Catastrophe of major violence; buildings destroyed by impact of displaced material; many deaths; escape unlikely

Also Reichenbach et al. (2005) compiled a summary of landslide intensity and damages to the built environment based on a literature review. While these classifications are general indicators of how landslide velocity and the degree of damage are related, the actual damage for a particular situation will rely also on the type of landslide material for which Flageolett (1999) has developed a classification which is summarised by Glade and Crozier (2005). Note that total risk, this means the probability of a certain damage occurring, is not proportional to the characteristics of the landslide process but, as outlined above, depends on the vulnerability of elements at risk and a range of other factors such as space (location) and time (day/night). Based on Morgan et al. (1992), Fell and Hartford (1997) suggested the following framework to calculate risk, i.e. the probability of damage and loss due to landslides:

Landslide risk (individual):

$$R(DI) = P(H) \times P(S/H) \times P(T/S) \times V(L/T)$$

$R(DI)$ = risk = annual probability of loss of life to an individual

$P(H)$ = annual probability of a hazardous event (landslide)

$P(S/H)$ = probability of spatial impact (a house is hit where a person is located)

$P(T/S)$ = probability of temporal impact (the time people are in the building)

$V(L/T)$ = vulnerability of the individual

Landslide risk (buildings):

$R(PD) = P(H) \times P(S/H) \times V(P/S) \times E$

$R(PD)$ = annual loss of property value

$P(S/H)$ = probability of spatial impact

$V(P/S)$ = vulnerability of property (proportion of property value lost)

E = element at risk (value of property)

These approaches are widely applied in landslide risk assessments, and capture the scales and types of risks which are often considered: the individual person or building. Both can be analysed for different spatial scales, such as a local community, a whole city or region. Bell and Glade (2004), for example, analysed individual landslide risk to life for a community in Iceland, while Michael-Leiba et al. (2003) analysed individual risk to life and destruction of infrastructures with respect to landslides for the Cairns region in north-east Australia.

4.1.2 Causes of landsliding

There are a great number of explanations for why landslides occur, and often not only one but several causes combined are responsible, as discussed in depth by Crozier (1986). In addition, Varnes (1958) and Cruden and Varnes (1996) distinguished between a range of causes which can lead to

- increased shear stress, caused by e.g. the removal of the toe of a slope due to glacial or fluvial erosion, or human modification of a slope profile; added weight; uplift)
- reduced shear strength (discontinuities such as faults; layers of different permeability; highly weathered bedrock or clay when saturated).

The interplay of shear stress (T) and shear strength (S) governs the stability of a slope (figure 4.6). Both are expressed as a stress, meaning as an internal force acting per unit area (Kirkby, 2005). In soil mechanics shear stress (T) is a function of the weight (W), meaning the mass of the soil body, and the sine of the inclination angle (β) of the surface of rupture or shear plane (Sidle and Ochiai, 2006: 122):

$$T = W \sin \beta \quad (\text{equation 4.1})$$

With increasing inclination angle of the surface of rupture (β) sketched out in figure 4.6, shear stress increases as the sine of β tends towards 1.

More specifically, the weight (W) can be described as the non-saturated weight of the soil (γ_t) above the water table ($H - h$) and the saturated unit weight of the soil (γ_{sat}) (modified after Sidle and Ochiai, 2006: 122):

$$W = \gamma_t (H - h) + \gamma_{sat} h \quad (\text{equation 4.2})$$

The weight of a slope unit does not only contribute to shear stress (T), but also constitutes normal stress (σ , figure 4.6). Normal stress acts at a right angle or 'normal' to the surface of rupture or shear plane (Goudie et al., 1981; Crozier, 1986) and is therefore a stabilising stress. Normal stress is a function of the weight and the cosine of the angle of the surface of rupture (β) (after Huggett, 2007: 59):

$$\sigma = W \cos \beta \quad (\text{equation 4.3})$$

With increasing inclination angle of the surface of rupture (β) sketched out in figure 4.6, normal stress decreases as the cosine of β tends towards 0.

Shear strength (S , or τ_s) is not only a function of normal stress. The Mohr-Coulomb equation describes the factors which influence shear strength: soil cohesion (c), normal stress (σ) and the tangent of the internal friction angle (ϕ) (Huggett, 2007: 61):

$$\tau_s = c + \sigma \tan \phi \quad (\text{equation 4.4})$$

The angle of internal friction and cohesion are material properties and act together as the resisting forces against failure and are expressed as a stress (Kirkby, 2005). The angle of internal friction depends on the angle at which particles within the material are oriented as determined by their size and shape. Cohesion describes the degree to which particles tend to stick together, and may be influenced by capillary suction of water in soil pores, consolidation, chemical bonds, and carbonates or iron oxides which act as cements (Huggett, 2007). Generally, high degrees of clay minerals (e.g. in mudstone, till, shale) display lower angles of friction than other materials, and materials which are strongly consolidated (e.g. limestone, granite, sandstone) depict high degrees of cohesion compared to unconsolidated materials such as sand, gravels, clay or till (Kirkby, 2005).

Normal stress is modified by the pore water pressure of the soil body. The inclusion of pore water pressure in the stress equation accounts for situations when pore water pressure is high – such as during or following high amounts of rainfall. This has the effect of reducing normal stress (Huggett, 2007). Hence normal stress is replaced by 'effective stress' in the Mohr-Coulomb equation. Effective stress (σ') was defined by Terzaghi (1936) as

$$\sigma' = \sigma - u \quad (\text{equation 4.5})$$

With σ = total or normal stress and u = pore water pressure (Wu, 1996). Hence, the Mohr-Coloumb equation becomes

$$S = c + (\sigma - u) \tan \phi \quad (\text{equation 4.6})$$

and describes the shear strength (S) at point of failure (Goudie et al., 1981, Huggett, 2007: 61).

Only in undrained saturated conditions do normal stress and pore water pressure rise equally because further volume change of the material through swelling cannot be expected. Under these circumstances effective stress is unchanged. In contrast, under drained saturated conditions total stress and pore water pressure do not respond equally and effective stress rather than total stress needs to be considered. Under drained conditions pore water can move freely according to the gradient and excess pore water pressure does not build up, which is more common than undrained saturated conditions (Goudie et al., 1981).

Pore water pressure, for seepage parallel to the surface of rupture, is a function of the unit weight of water (γ_w), the vertical depth of the water table (h), and the cosine of the inclination angle of the surface of rupture (β) (Sidle and Ochiai, 2006: 122):

$$u = \gamma_w h \cos^2 \beta \quad (\text{equation 4.7})$$

Figure 4.6: Different stresses and parameters acting upon a slope (after Sidle and Ochiai, 2006: 122).

As mentioned above, the stability or instability of a slope is the result of the interplay between shear stress (T) and shear strength (S) and when expressed as a ratio is known as the factor of safety (F_s) within the 'limiting equilibrium' analysis (Crozier, 1986, Sidle and Ochiai, 2006: 123):

$$F_s = \frac{S}{T} \quad (\text{equation 4.8})$$

With increasing shear stress in relation to shear strength the factor of safety is below 1 and the slope is said to be 'unstable'. With increasing shear strength in relation to shear stress the factor of safety is larger than 1 and the slope is characterised as 'stable' (Sidle and Ochiai, 2006). While the principal conceptualisation of driving and resisting forces is very useful for an enhanced comprehension of landslide mechanics, the uncertainties in parameter acquisition and the dual concept of 'stable' and 'unstable' limit the application of the factor of safety, which will be re-addressed again later in this chapter.

Although landslides are multi-causal processes, there is usually only one 'trigger' initiating the movement, such as (Wieczorek, 1996):

- rainfall,
- rapid snowmelt,
- water-level change,
- volcanic eruption,
- earthquake shaking.

According to Wieczorek (1996: 76) a trigger is 'an external stimulus' of short duration, such as intense rainfall. However, sometimes 'internal' processes within the hillslope initiate slope movement after a threshold is crossed as discussed later in this chapter.

Against the background of landslide causes outlined above it appears that a rigid distinction between cause and trigger is difficult. For example, rainfall can be an underlying cause and trigger, while in other cases an earthquake might trigger the movement of a water-saturated, destabilised slope. Similarly, an earthquake might have fractured and weakened the slope, but intense rainfall triggered landsliding. Not only multi-causality but also interchangeable causes and triggers complicate the analysis of why landslides occur. A classification of causes and triggers based on the physical process is therefore problematic and appears to be represented more adequately in the context of slope stability based on Crozier (1986) (section 4.3.2). Nevertheless, the most relevant trigger in the context of this thesis is rainfall and therefore is discussed in the following.

Intense and short as well as moderate and longer lasting rainfall events have been observed to trigger landslides in many parts of the world. In particular shallow landslides on steep slopes are frequently triggered by such rainfall events. The triggering mechanism resulting in such landsliding is an increase of shear stress or a reduction of shear strength due to a temporary

rise of pore water pressure. Therefore, intense rainfall can trigger landslides with either dry or moist antecedent soil conditions (Wieczorek, 1996). It is not uncommon that spatially clustered, high density swarms of shallow landslides are triggered, as has been observed for example in California (Ellen et al., 1988) and New Zealand (Crozier, 2005) with 1988 cyclone Bola probably the best known example in New Zealand. Such simultaneous, spatially clustered occurrences can be described as 'multiple-occurrence regional landslide events' (MORLE) (Crozier, 2005). Minimum and maximum rainfall-thresholds for landslide probability in several parts of New Zealand, including the Wellington study area, have been established by Glade (2000) and Glade et al. (2000).

4.2 Landslides as hazards

Only when endangering people and/or their livelihoods, landslides become hazards. Establishing the frequency–magnitude relationship of landslides is a common tool for estimating the hazard imposed by these processes (Corominas et al., 2005). A frequency-magnitude relationship represents the temporal occurrence of a specific process magnitude, during a certain amount of time. Therefore with respect to hazards, the question which can be addressed by establishing the frequency-magnitude relationship is: How big and how often?

Wolman and Miller (1960) pioneered frequency-magnitude studies on river discharge and they discovered that generally, rare events are of a larger magnitude than very frequent events. Consequently, their probability of occurrence is low, but the magnitude and damage potential associated is high. While this bears profound implications in the field of natural risk, Wolman and Miller's (1960) aim was to find the 'dominate discharge' which is responsible for most of geomorphological work done during a specific amount of time. Since then, frequency-magnitude analysis in landslide research demonstrated that this typical relationship, which can be described by a power-law, is independent of the dataset size and the type of landslide trigger (Glade and Crozier, 2005).

Power law distributions have been described for various different phenomena, such as the frequency and magnitude of earthquakes, or frequency and size (magnitude) of world cities. In the earthquake example (figure 4.7), a power law describes that some quantity, such as the number of earthquakes (N), is expressed as some power of the quantity of energy (s) (after Bak, 1997: 27):

$$N(s) = s^e \quad \text{(equation 4.9)}$$

In the case of earthquakes, this relationship has become known as the Gutenberg-Richter law (Bak, 1997). When represented by a double logarithmic scale like in figure 4.7, the frequency-magnitude relationship is reflected by a straight line. The second example for world cities has become known as Zipf's law named after Professor Zipf who discovered such a power law distribution for world cities around 1920, hence human made systems (Zipf, 1949, in Bak, 1997).

Figure 4.7: Frequency-magnitude distribution of earthquakes in the New Madrid zone in the south-eastern United States, during 1974-1983, compiled by A. Johnston and S. Nava of Memphis State University (Bak, 1997: 13). This is a double-logarithmic plot since the x-axis represents the logarithm of energy released by the energy, not the energy itself.

In their study of landslide occurrence on the east coast of New Zealand, Reid and Page (2002) related the magnitude, in this case the number of landslides triggered in an event, with a certain amount of rainfall for a specified area and observation period. They then used the frequency-magnitude relationship of rainfall (established on historical rainfall records) for this area and they coupled a specific landslide magnitude with a specific rainfall magnitude. Based on the frequency-magnitude relationship of rainfall, a frequency-magnitude relationship of landsliding was established. As will be discussed later and in chapter 10, such an approach can be somewhat too simple when aiming at establishing a landslide hazard.

As outlined above, rainfall thresholds for the triggering of shallow landslides have been established for several regions in New Zealand (e.g. Crozier, 1986; Glade, 1998, 2000). Based on the rainfall threshold, in combination with historic rainfall records, the probability that landslides occur was calculated. As opposed to Reid and Page (2002), a specific magnitude of landsliding was not associated with a specific rainfall magnitude, but an increasing probability of landsliding with increasing rainfall. As will be demonstrated in chapter 10, based on the results of this work, this thesis develops an approach to establish the frequency-magnitude of landslides for the Wellington study area, which subsequently will be discussed critically.

Although frequency-magnitude analysis has been increasingly applied in the field of natural hazards, many questions remain unsolved. Compared to streamflow, landslides are less steady processes and consequently recording periods have to be longer in order to gain a reliable

database. Overall, the challenges are great, particularly as data recovery declines with time which results in the evidence of smaller landslides being possibly destroyed or not recognised (Crozier and Glade, 1999). As Glade and Crozier (2005) concluded, a reliable record of when landslides of a specific magnitude occurred is crucial for the application of frequency-magnitude relationships for landslide hazard analysis. Moreover, not only magnitude, but velocity is a factor influencing damage levels as demonstrated above.

Landslides are, as described so far, geomorphological processes which can impose a hazard. They can be described based on the type of material, the type of movement and the velocity of movement. Soil mechanics aid in understanding the forces acting upon a slope unit leading to different stability states.

At the same time, landslides are part of geomorphological systems, such as sea cliffs or hillslopes. The following section provides an overview of a systems approach which includes some of the most important concepts which support the understanding not only of geomorphological systems such as hillslopes, but also the processes acting within these systems, such as landslides and therefore landslide hazard.

4.3 Landslides as processes in geomorphological systems

As stated in chapter 3, general systems theory entered the field of geography and its sub-discipline geomorphology during the 1950s and 60s. In particular Strahler (1952) translated Ludwig von Bertalanffy's (1950a) ideas about open and closed systems into geomorphology (Huggett, 1988). Systems are defined as sets of interrelated elements which together form some sort of structure (Chorley and Kennedy, 1971). This structure can be described as a hierarchy of subsystems (or 'holons', Allan and Starr, 1982). According to Phillips (1992a: 195) in the case of geomorphological systems these elements are *'landforms, surface processes, and factors which control or influence forms and processes. The interconnections involve flows, cycles, transformations, and storage of energy and matter'*. Accordingly hillslopes potentially affected by landsliding can be regarded as geomorphological systems. For a model of hillslopes as systems with storage, inputs and outputs of material, see for instance Huggett (2007: 16). A systems perspective focuses on dynamic system behaviour, behaviour of individual elements and mutual adjustment which means that two elements affect each other (Phillips 1999). Adjustment is therefore an active rather than a passive process. Adjustment, or adaptation, plays a key role within this thesis as demonstrated in chapters 3 and 7.

General systems theory seeks to establish defining system properties, functions and processes which apply for all or at least most systems, therefore crosses disciplinary boundaries (von Bertalanffy, 1950b). As Graf (1988) concluded it is a tool for reducing complexity, a motivation already encountered in Luhmann's social system theory (chapter 3). Complexity is an inhomogeneous term that receives a specific meaning in complexity theory as will be discussed later in this chapter. Generally, however, a general systems theory approach enables the

observer (or the system itself) to identify the quantity ('quantitative revolution in geography', 'process geomorphology') and quality of the relationships between elements and the properties of these elements, to delineate boundaries and establish defined units – systems. The ontological problems encountered by drawing boundaries, by determining what belongs to a system ('internal', 'intrinsic') or its environment ('external, extrinsic') have surfaced in chapter 3 when discussing hybrid phenomena which cross boundaries of classical dualistic differentiations of systems. With respect to this fundamental difficulty general systems theory was early criticised for not delivering a solution and for remaining vague on what a system actually constitutes, see for instance Chisholm (1967). Chisholm (1967: 48) also made a point that *'growing points of knowledge tend to lie between the major disciplines, in the frontier areas'*, not within one discipline alone such as geology or geography.

Despite these difficulties, approaching the landslide hazard problem from a systems perspective entails two advantages: Firstly, an enhanced understanding of dynamics especially with respect to complex, nonlinear system behaviour which diverts from the classical general systems theory's focus on equilibrium as is developed in this chapter. Secondly, it offers a high degree of compatibility with the model of risk derived from the theoretical body of social and socioecological systems research introduced in chapter 3.

4.3.1 Equilibrium

Understandings of 'equilibrium' vary between different disciplines such as physics, mathematics or geomorphology (Thorn and Welford, 1994). However, from a general systems theory perspective, systems operate in a way which allows them to regain some form of equilibrium after they have been 'disturbed'. The equilibrium concept is deeply embedded for instance in classical human ecology. G.P. Marsh in his classic work 'Man and Nature' (1864: 29) stated *'Nature, left undisturbed, so fashions her [sic] territory as to give it almost unchanging permanence of form, outline, and proportion, except when shattered by geologic convulsions; and in these comparatively rare cases of derangement, she sets herself at once to repair the superficial damage, and to restore, as nearly as possible, the former aspect of her dominion.'* (cited in Forsyth, 2003: 64). Already, two basic aspects of equilibrium thinking are included here: time-independence and reversibility as discussed shortly. Furthermore, the term 'ecosystem' describes a mature system which, through the interactions of its different units, is in a state of equilibrium (Tansley, 1935). In ecology one finds examples of the equilibrium concept, such as the 'climax' vegetation after a period of succession which is inscribed in common practices of environmental management and conservation (Zimmerer, 1994, 2000) (chapter 6).

However, in early earth sciences, inspired by Charles Darwin, the paradigm of the 'cycle of erosion' by the American W.M. Davis (1899) was the dominating paradigm of the early to mid 20th century, especially in the United States, though challenged in Europe for example by Walter Penck (1924), who allowed for static relief or relief increase and decrease in time as the product of uplift and denudation (Phillips, 1999). In contrast Davis considered landscape evolution as an irreversible development from 'youth' to 'maturity' and 'old age', focussing on the passage of

time as the main agent of landform change. At the end of the cycle an ultimate state of equilibrium is reached which is, from a systems theory perspective, the state of maximum entropy within a closed system (Chorley, 1962) (figure 4.8 (f)). Davis included possible periods of tectonic uplift disturbing the rather rigid 'cycle of erosion'. However, lower-relief landforms always serve as starting points for new stages and dissection (Phillips, 1999).

A concept comparable to the 'cycle of erosion' emerged in human geography, based on the work of Spencer (1872) and Spengler and Atkinson (1926) who regarded societies as organisms completing a cycle of life (Butzer, 1980). Inspired by Darwin's evolutionary theory promoting the 'survival of the fittest' such biological views of society developed into 'Social Darwinism' (Barry, 2007). In earth science, Davis' cycle of erosion was increasingly criticised as being too general to be applicable. General systems theory successfully challenged his school of thought in the 1950s/1960s (Chorley, 1962) by embracing the theory of open systems (von Bertalanffy, 1950a), reinstating Gilbert's (1877) earlier ideas of 'grade' or 'dynamic equilibrium' or 'steady state'. In general, rather than emphasising time as the main process itself, time-independence was postulated.

General systems theory distinguishes between closed and open systems. The former are characterised by lacking a flux of material or energy across system boundaries, therefore progressing towards a state of entropy. In contrast, open systems are characterised by an input and output of energy and material (von Bertalanffy, 1950b, Chorley, 1962). They gain an equilibrium in which the input and output are balanced, which consequently preserves the system's state (for instance a landform). Negative feedback mechanisms operationalise the system's tendency of compensating changes, they reinstate a balance of fluxes (Mackin, 1948; Hack, 1960; Chorley et al., 1984). This tendency towards equilibrium was also described by Prigogine and Defay (1954) and is interpreted as a form of self-regulation and self-adjustment (von Bertalanffy, 1952). In geomorphology, such adjustment takes place between form and process (Chorley, 1962). Open systems cannot control the amount of energy or matter they receive, yet by adjusting the properties of their elements, such as slope angle or channel width, they determine in which way they respond to that change (Chorley, 1962 referring to Strahler, 1950; Wolman, 1955 and Hack, 1960). A similar form of self-organisation has been described by Luhmann (1991) in his theory of autopoietic social systems based on Maturana and Varela (1973, 1980): autopoietic systems undergo structural changes (the properties of their elements change, 'structural coupling') but remain their identity as long as the relations between the system's elements are maintained (chapter 3).

According to Chorley (1962) an actual reinstated equilibrium is rather rare, and he referred to von Bertalanffy (1950a, 1952), who stated that the tendency of a system towards equilibrium is the prerequisite for performing work at all. As will be seen shortly, this assumption has not remained uncontested. Also in Luhmann's theory one does not find evidence of equilibrium

conditions: systems are self-organised and autonomous but they are not driven by the tendency of gaining a 'steady state'

General systems theory differentiates between several kinds of equilibria (figure 4.8). These are for instance the steady state equilibrium (figure 4.8 (e)) which is 'dynamic' in Gilbert's terminology (see Chorley, 1962: B4) and means that the system fluctuates around a stable average value. Dynamic (gradually changing average value) or dynamic metastable systems (figure 4.8 (g, h)) display changing average values interrupted by discontinuous impacts or threshold crossings, which will be readdressed later in this chapter (Chorley and Kennedy, 1971; Chorley et al., 1984).

Figure 4.8: Different types of equilibrium (Huggett, 2007: 19, after Chorley and Kennedy, 1971: 202).

An important aspect within systems theory is the factor of time: systems are not regarded as static but dynamic. In fact only by changing, by adjusting, they maintain their overall state through time – ironically, they become time-independent.

A conceptual model of system development in time based on the assumption that systems tend towards a form of equilibrium, but highlighting the 'transient' phases between such equilibrium states was postulated by Brunsden and Thornes (1979). Here, the time span required for a system to recover and gain a new, steady state after a disturbance occurred is divided into 'reaction time' and 'relaxation time'. While 'reaction time' is the length of time between a disturbance and related response of the system, 'relaxation time' comprises the time between system reaction and achievement of a new equilibrium (figure 4.9). In some cases the length of time until a reaction occurs is such that the actual cause is blurred (Glade, 2001). Additionally,

due to an increasingly global interaction of processes, the actual cause for change and its effect, for example environmental degradation, can be thousands of kilometres apart, which limits the local ability to monitor and adapt to change (Oliver-Smith, 2004). Transient system states persist if the relaxation time is longer than the recurrence interval of disturbance (transient-form ratio) (Brunsden and Thornes, 1979; Phillips, 1995). Non-equilibrium states can therefore prevail depending on the system-inherent ability to gain a new equilibrium and the frequency of 'external' disturbing events.

Figure 4.9: Reaction and relaxation time from an equilibrium perspective (Hufschmidt et al., 2005: 377, after Graf (1988) and Brunsden and Thornes, 1979).

A conflict between time-independent equilibrium thinking and evolution as an inevitable irreversible succession dependent on the passage of time is apparent. The first does not fully acknowledge progressive system change (e.g. progressive relief reduction), while the latter is not flexible enough to describe the coupling between elements of a system and between systems which can lead to negative feedbacks and hence the preservation of systems. As will be seen shortly, the concept of different time spans governing a system's state offers a solution to this conflict. While a steady state (dynamic equilibrium) is likely to be established at shorter time scales its utility is limited in the case of long-term analysis (Chorley, 1973). For longer time spans, different equilibrium models are more appropriate since they accommodate system changes and incorporate time as a factor, which resulted into Schumm and Lichty's (1965) categorisation of 'steady', 'graded' and 'cyclic' time scales ranging from short to long periods, respectively. Therefore advocates of the equilibrium concept do not devalue historical perspectives as such, but pleaded for a less strict view on the development of process-form relations as summarised by Chorley (1962).

From a system's theory perspective, an important aspect which applies for any temporal analysis is that the chosen time span determines the system state perceived by the observer. As mentioned above, Schumm and Lichty (1965) and Schumm (1977, 2003) distinguished between 'cyclic' (e.g. 10 million years), 'graded' (1 million years) and 'steady' (1000-100 years)

time (figure 4.10). Note that the specific lengths of these time spans are irrelevant and can be substituted with any other length as long as they are arranged sequentially. Unfortunately, the terminology does not quite concur with terminology based on Gilbert (1877) where 'dynamic' equilibrium is equalled with 'graded' and 'steady state' (see also Thorn and Welford, 1994). However, Schumm and Lichty (1965) demonstrated with this categorisation that steady states are associated with short periods rather than long periods of time. The observer's perception is restricted to the time window used. As exemplified by figure 4.10 the channel gradient decreases through cyclic time with oscillations around a mean value. Looking at graded time, one might only see one of the oscillations; therefore it is not clear if the gradient follows a pattern or trend. Finally, a much shorter time frame creates the perception of a static gradient, with no change recognisable (Schumm and Lichty, 1965; Chorley and Kennedy, 1971). Dependent on the chosen time span, the observer recognises different system states, which leads to different interpretations of system behaviour. One has to be aware that findings within the time span chosen might not be transferable to other time spans.

Figure 4.10: The period of observation determines the perceived system state (Chorley and Kennedy, 1971: 254, after Schumm and Lichty, 1965).

So far, much emphasis has been placed on time. However, time cannot be separated from space. From a system's perspective a landscape is conceptualised as a set of hierarchically structured systems, a nested structure comprising landforms of different sizes. Depending on the landform size, its response and reinstating of equilibrium differs. Generally small systems are believed to react and reinstate their equilibrium faster than medium or large scale landforms (Brunsden and Thornes, 1979). This is associated with Trudgill's (1976) observations of karst landscapes in Iran where karst features are relicts of a previous wetter climate but

subsequently, due to a change in climate, small karst features are eroded by frost activity. The current climate is only reflected in the micro forms, not in the meso or macro forms (figure 4.11). As a consequence of the time-space interplay landscapes are polygenetic: they are comprised of interrelated systems operating at different spatial scales responding on different temporal scales. Spatial and temporal scale, however, are not the only factors influencing a system's behaviour as captured by the concept of 'sensitivity' discussed in the following.

Figure 4.11: Different landform responses to climate change (line 1) depending on landform size: micro (line 2), meso (line 3) and macro (line 4) (Schumm, 1991: 52 after Trudgill, 1976)

4.3.2 Sensitivity

Schumm's (1979) and Brunsden and Thornes' (1979) papers on geomorphological thresholds and landscape sensitivity are among the first to deliver an in depth discussion of the sensitivity concept and its application value in geomorphology. Sensitivity is defined as '*the propensity of a system to respond to a minor external change*' (Schumm, 1991: 78).

In a highly sensitive system small external seismic or climatic triggers can foster a reaction, such as a landslide. In contrast, an insensitive system possesses a buffer capacity, and no or little reaction will result even with an external trigger of significant magnitude, hence a very high threshold level as illustrated below (Schumm, 1977, Brunsden and Thornes, 1979; Schumm, 1979; Thomas, 2001). Therefore, whether the system responds to an external trigger such as rainfall is equally dependent on the internal state of sensitivity as well as the magnitude of that external trigger in relation to the internal sensitivity (Brunsden, 2001). Figure 4.12 is an excellent empirical example of such a combination of intrinsic and external thresholds which together determine system behaviour. During time, the slope angle of an alluvial fan apex increases due to depositional processes. Simultaneously, the instability of the apex rises. When the critical slope angle (line 2) is reached, the fanhead collapses at point B. This is an example for a change not initiated by an external trigger but as a result of system internal processes. The key argument is that a system's state of sensitivity is variable in time. Both, internal or external

factors follow thresholds which have to be crossed before a system reaction can follow (Schumm, 1979). These thresholds change in time.

The vertical lines in figure 4.12 represent runoff events of various magnitudes. While these do not trigger any system reaction at a small slope angle, even low magnitude events will trigger a response as the fan apex approaches its critical slope angle, as indicated by point A. According to the time-dependent state of internally determined, or self-organised sensitivity the same magnitude of an external 'disturbance' may or may not trigger a response.

Figure 4.12: Thresholds in geomorphologic systems (Schumm, 1991: 82)

In the case of landslides, assessing the sensitivity of a slope is crucial before any decision about development, for example of new subdivisions, can be made. Often, slopes are classified as either 'stable' or 'unstable' as calculated by the 'factor of safety', which is a simplification requiring considerable qualification before it is applicable. It is more realistic to assess slopes on a spectrum ranging from 'stable' to 'unstable' where unstable ranges from 'marginally stable' to 'actively unstable' (figure 4.13) (Crozier, 1986; Glade and Crozier, 2005). If the margin of stability (i.e. excess of shear strength over shear stress) is high enough, all destabilising forces are neutralised and the slope is 'stable'. 'Unstable' or 'marginally stable' slopes are subject to failure at some point in time when transient forces are sufficiently active. Actively unstable slopes are characterised by movement due to the action of transient forces. The major point is that a temporal shift along the spectrum of the three states can be related to changes in both internal susceptibility and the energy levels of external destabilising factors. 'Predisposing' or 'preconditioning' factors are internal factors which are static, but can accentuate other destabilising factors, like for example when the structuring of bedrock increases the effects of undercutting by a river or a road. 'Preparatory' factors are not static, can be internal or external, and can push a stable slope into a marginally stable state by enhancing its susceptibility to failure over time, but without causing movement directly. For example, as weathering progressively acts on a slope's regolith, the stability of the slope potentially decreases (Alexander, 2005). Another example is a catchment that has been deforested for pasture farming and suddenly, stripped of its protective vegetation cover, displays an enhanced

susceptibility to landsliding. 'Triggering' factors, such as rainfall or seismic waves, initiate movement and shift a slope to an actively unstable state. They are usually external factors, though rarely cases of internal triggering are identified, as for example the rock avalanche at New Zealand's highest mountain, Mt. Cook, in 1991. Finally, 'controlling' or 'sustaining' factors such as rainfall or the topography of the terrain, govern the form, rate and duration of movement (Crozier, 1986; Crozier, 1999a; Glade and Crozier, 2005).

Figure 4.13: Stable, marginally stable and actively unstable states of hillslopes (Glade and Crozier, 2005: 45 after Crozier, 1986)

Thresholds are embedded within a number of points in the above model of slope sensitivity, for example when rainfall exceeds a threshold and triggers mass movement through which the whole hillslope systems changes in terms of form, process regime and stability state. Hillslopes characterised by landsliding are superb examples for, often rapid, changes in system sensitivity. An example of a threshold change is the situation of 'sediment exhaustion', when the landslide itself stabilises the terrain by excavating loose material leaving less susceptible bedrock behind, as demonstrated in examples from New Zealand by Crozier and Preston (1998) and Preston (1999). With only bedrock exposed, a high magnitude rainfall will not produce landslides. This coupling of system sensitivity and threshold level is a source of non-linearity and adds to the complex temporal behaviour of systems. It also complicates the often applied methodology of correlating a thick layer of sediments with a high-magnitude trigger, such as a rainstorm, since the amount of sediment deposited does not necessarily correlate with the magnitude of the associated rainfall as demonstrated by the example of fan apex sensitivity above.

Not only 'internal' system configurations, but also processes which are often regarded as 'external' triggers are changing over time as well. Climate related processes such as wind and rainfall have amplified over time in some parts of the world due to human-induced globally increasing temperatures (Hilhorst, 2004; IPCC, 2007a).

4.3.3 Complexity

In the context of systems sensitivity two key words, complexity and non-linearity, have surfaced above. They carry profound implications for hazard and risk studies since they are associated with 'surprise' and uncertainty in geosystems as discussed in the following.

General systems theory's focus on equilibrium has not remained unchallenged - not only in geography, or more specifically geomorphology, but also for instance in ecology. In the light of rapid environmental change a 'new ecology' (Castree, 2005a) accentuates disequilibrium and chaotic behaviour as opposed to equilibrium states within the natural and modified environment (Zimmerer, 2000). General systems theory's concept of open systems, which are able to gain a steady state by self-regulation through negative feedbacks have been frequently applied for ecosystems, just as traditionally in geomorphology (Stoddart, 1965, Hawley, 1986). However, Hewitt and Hare (1973) already questioned the notion of stable equilibrium in ecosystems. As an example they referred to cleared areas in tropical rainforest which do not re-establish rainforest since the soil has been changed irreversibly during the non-forest state. More recently, a number of disciplines have described non-equilibriums where equilibrium was expected but was not observed, for example combinations of chemicals not gaining a 'steady state' of one colour but fluctuating between different colours (Richards, 2002). 'New ecology' focuses on disturbances in the short-term and system changes during longer time periods. Within such a 'disturbance-ecology', single extreme events are understood as expressions of a 'disturbance regime', which itself is imbedded within a long-term process such as climate change (Mueller-Mahn, 2005). Once perceived as mere shocks to a system in equilibrium, disturbances such as fire, drought or landslides, are now seen as able to irreversibly alter a system. Also, they are regarded to occur more often and more widespread than usually thought (Zimmerer, 1994): they are the norm rather than the exception. Within geomorphology, the emergence of the equilibrium concept contested the then dominant, time-dependent Davis school of thought as outlined above and for example summarised by Sack (1992). The focus on equilibrium states in geomorphology itself was subsequently challenged and more recently shifted towards sensitivity, thresholds (see above, also labelled 'bifurcations' Phillips, 1992b: 223) and non-linearity in complex systems (Phillips, 1992a, 1992b; Renwick, 1992; Phillips, 1999, 2003).

The relatively new field of complexity theory subsumed these concepts and is increasingly applied in physical geography (Richards, 2002; Harrison, 2005). Approaching complexity theory is somewhat difficult since the term 'complexity' is understood in different ways, for example Schumm's (1991, 2003) 'complex system behaviour' differs from complexity theory. Per Bak (1997: 5) equated complexity with a high degree of variability. Variability describes a set of different phenomena. For instance, according to Bak, crystals are not complex due to their very regular structure, but landscapes with their plethora of different forms and processes are. Yet again, in complexity theory 'complex' is not to be confused with 'complicated': Not the sheer number of related elements but the quality of their relationship is what defines the complexity of

systems. Hence 'simple' systems comprising only a relatively small number of elements and interrelations can be complex. Especially non-linear, 'surprising' and sudden system changes are of interest (Ratter, 2006). The element of time is a fundamental ingredient of complexity theory. As Manson (2001: 406) stated: '*Complexity research is concerned with how systems change and evolve over time due to interaction of their constituent parts*' (cited in Ratter, 2006: 111). Complexity theory diverts from the notion of equilibrium, which assumes that equilibrium states are the defining states of systems, while all other states are 'just' transition phases (Ratter, 2006). What is commonly discarded as 'noise' or measurement errors is interpreted as the result of complex system behaviour which produces new, unanticipated patterns and structures through the action of non-linear processes or as a result of process coupling within a system also known as 'order from noise' as coined by von Foerster (Huschke-Rhein, 1998). Recursivity can amplify the smallest effect resulting into new, emergent hence surprising structures ('butterfly-effect', Lorenz, 1963). Such (deterministic) chaos is the result of high internal sensitivity to small perturbations which entail effects that tend to persist and increase in time (Phillips, 2003). Self-organisation is associated with such emergent behaviour which is only determined by the system itself, not its environment (Huggett, 1988). Nobel laureate Prigogine (1980) described spontaneous emergent structures of matter as 'dissipative structures'. Dissipative structures are those where order is maintained away from equilibrium through the dissipation of energy (Prigogine, 1980; Phillips, 1992b). Open systems and the irreversibility of processes are pre-requisites for geomorphological dissipative structures which are met by most geomorphological systems (Phillips, 1992b). Understanding geomorphological systems as dissipative systems implies that '*although geomorphological processes are universal, a given system will not always follow the same sequence of change under the same process regime*' (Huggett, 1988: 47). Geomorphological examples of dissipative structures are coastal systems where wind and wave energy is dissipated within the coastal area (beach cusps), as well as sand dune formation due to self-organised, nonlinear dynamics between a number of factors such as local sand transport rates, migration rates of sand heaps and avalanching (Baas, 2002). Spontaneous, emergent behaviour does not always produce clear patterns, which is associated with 'chaotic behaviour' (Thorn and Welford, 1994 referring to Prigogine and Stengers, 1984) as mentioned above.

The crossing of thresholds, or 'bifurcations' as they are labelled in the context of nonlinear behaviour, are crucial for the understanding of dissipative structures which links Schumm's work on internal and external thresholds with ideas of dissipative structures or systems in geomorphology. After such a crossing, the system's elements are reorganised, a new form might be adapted but the elements as such maintain their existence – a process iterated with every fluctuation or bifurcation yielding different system configurations (Huggett, 1988).

The self-organisation of complex systems is also the key aspect in the theory of 'self-organised criticality' (SOC) developed by physicist Per Bak and colleagues. Note that Bak uses a specific

definition of complexity as outlined above. The 'sand pile model' exemplifies the theory of self-organised criticality: Dropping grains of sand on the same spot on a beach will result into a pile of sand. During this build-up the pile becomes steeper and little 'sand slides' occur as a form of adjustment to the increasing slope angle. During time, with a continuous trickle of sand suddenly large sand slides occur which entail a rearrangement of the whole pile. The statistics of the sand slides follow a power law (see above). A critical state (critical slope angle) had been reached and even just one additional grain of sand triggers a reaction of the whole system. The processes of the sand pile building up and forming its shape could not be predicted by the individual sand grains themselves, hence the sand pile is another example for an emergent phenomenon. In a SOC-world, a massive effect does not require a massive external event (Bak, 1997). This state of 'criticality' is the equivalent of a highly sensitive state as described by Schumm, however the focus is here on the self-organised nature of the system. Bak applies SOC as an explanation of emergence and contingency (slight changes entail vastly different outcomes) which can be associated with non-linearity as outlined above. He underlined that we must accept surprise and non-predictability and the importance of long-time studies to study SOC relations as expressed by the power law. Furthermore, he pinpointed that large events occur due to the same mechanisms which produce small, everyday events. This concurs with Hewitt (1983, 1997) who, with respect to the generation of natural disasters, emphasised the day to day processes which can lead to catastrophe, not necessarily a 'freak' event (chapter 2). Disasters are *'examples of a general problem, easily observed because of their magnitude'* (Bates and Pelanda, 1994: 158).

As in the case of the classical equilibrium of open systems approach which includes parallels to autopoiesis, the concepts of recursivity, self-organisation, non-linearity and emergence reappear which again hint at a potential compatibility with the theory of autopoietic systems as developed by Maturana and Varela for biology and adapted by Luhmann for sociology.

4.4 Conclusion

How can systems theory and the more recent turn towards complexity theory guide the understanding of landsliding? And which consequences arise in the context of landslide hazard? First of all, a landslide can be understood as the symptom of a sensitive, actively unstable system. Once an area is affected by landsliding, it might become a permanent source of hazard (Reimer, 1995; Crozier and Glade, 1999). It is common practice to interpret the presence of landslides within a system as representing an on-going, characteristic and immutable level of hazard. In unstable systems, however, this would require a state of equilibrium which is likely to persist for only relatively short periods of time. Rather, slope instability is, in the long term, a self-annihilating process: the process (by reducing slope height or slope angle, or by exhausting susceptible material) repeatedly destroys the conditions for its occurrence (Crozier and Glade, 1999).

While the concept of open systems is useful for understanding geomorphologic process-form relations, in the context of hillslopes characterised by landsliding the often associated equilibrium principle meets its limitations. As concluded above, steady state conditions are usually associated with relatively short time spans, while successive systems changes are associated with longer time spans (e.g. relief reduction). Brunsden and Jones (1980), in their study of sea cliff retreat through landsliding, concluded that over a long observation period the whole system is in equilibrium since through the continuous operation of landsliding the whole system is conserved. However, this equilibrium requires a constant erosive agent, in this case wave energy, and unlimited sediment supply which is met by the cliff retreating. Under these conditions, one could detect some form of equilibrium which, however, is likely to diminish as soon as either the constant erosive agent or the sediment supply change. In addition, because landslides are self annihilating processes it is difficult to detect and define a 'characteristic' hillslope form which could be interpreted as the defining equilibrium.

From an equilibrium perspective, system changes are reflected by different forms of equilibria as summarised by Chorley and Kennedy (1971) and Schumm (1977, 2003). However, such equilibrium thinking assumes that systems always tend towards some form of equilibrium, which distracts from complex system behaviour including chaos and non-equilibrium. Perhaps not discarding the equilibrium concept and associated ideas of order and stability entirely but shifting the focus towards non-equilibrium states is the most promising position from which to approach geomorphologic systems, including those characterised by landsliding. Especially in the context of hazards, transient or non-equilibrium conditions come to the fore and reflect reality more appropriately than equilibrium states, or even the tendency towards equilibrium. The questions asked need to address temporally and spatially changing sensitivity and thresholds, resulting in non-linearity, and also non-linearity as the result of complexity, together producing 'surprise' and uncertainty rather than considering if or when some form of equilibrium state is gained.

Additionally, in retrospective one defining characteristic from a systems theory perspective is that of self-organisation. Classical equilibrium theory identifies negative feedback loops as indicators of self-organising systems. Similarly, complexity theory demonstrates that criticality, non-linearity and emergence are expressions of self-organisation which is consistent with Maturana and Varela's biological theory and Luhmann's theory of social systems where recursivity, hence time, is a strong element. In the context of complexity, self-organisation ultimately implies that the understanding of how exactly systems operate can never be complete, and attempts to fully 'control' such systems are fallacies. For the observer, surprise and uncertainty are intrinsic system properties which is also emphasised by resilience research in the context of ecosystem management focussing on non-equilibrium system states, as will be discussed in chapter 6.

Both equilibrium and non-equilibrium thinking recognise self-organisation of systems. Nevertheless, equilibrium-thinking especially in the context of steady state (which is associated with the notion of reversibility) regards time as a secondary factor for explaining system operations. Ongoing concepts developed under the umbrella of systems theory uncover the explanatory power of the time factor, which is associated with complexity, recursivity and irreversibility. This should not be interpreted as a renaissance of the Davisian school, but as a synthesis of a systems theory approach to geomorphological form-process relations, such as hillslopes characterised by landsliding.

Frequency-magnitude relationships based on historical records are commonly used for deriving probabilities of earthquake, flood or landslide occurrence. In the case of landslides, thresholds for landslide-triggering rainfall are sometimes coupled with frequency-magnitude relations of rainfall in order to establish the probability of landsliding – sometimes including a specific magnitude. However, such an approach assumes linear system behaviour: A certain amount of rainfall will, in the future, trigger a certain magnitude of landsliding. Two assumptions feed such an approach: First, the conditions which lead to landsliding are fully understood, and second these conditions do not change in time. As has been discussed in this chapter, both assumptions are contestable. Phases of changing internal sensitivity as well as internal sensitivity in relation to changes of external, potentially landslide triggering processes of a certain magnitude and frequency are not considered.

It is argued here that in order to estimate hazard, the time-dependent sensitivity states of geomorphologic systems such as landslide-affected hillslopes, as well as changing frequency-magnitude relationships of external triggers such as rainfall must be considered. Both imply non-linearity and complexity. In addition, the self-organisation of systems, hence the limits to external control, needs to be recognised. The crucial questions to answer are: How far away is the system from an internal, self-organised and self-determined actively unstable state? Which magnitude and frequency of external triggers in relation to which internal sensitivity state is likely to produce landslides of which magnitude?

The landslide hazard analysis undertaken in this thesis addresses these questions and includes the issue of time-dependent system perception. Conclusions are drawn with respect to the usability of frequency-magnitude relationships in hazard analysis against the background of non-linearity as introduced here (chapter 10).

5. Vulnerability

'One man's hazard is another man's disaster' – this title introduced an article addressing people's vulnerability just after the 2004 Asian tsunami disaster (Large, 2005¹). The headline pinpoints the core of the vulnerability concept as it is widely understood today: the same physical process - a tsunami, a landslide - has different consequences for different people. From Latin 'vulnerare' = to wound (The Concise Oxford Dictionary, 1995), the vulnerability concept aims to explain why some people suffer more from peril than others.

It is increasingly acknowledged that explanations of natural hazards peaking into disasters are not only rooted within the realm of natural processes, but equally (some say only) within the human sphere (chapters 2, 3). The causes for casualties and economic damage lie within 'nature' as much as in 'culture': on the one hand, the degree of harm depends on the type and magnitude of the natural process (chapter 4). On the other hand, the degree of harm depends on people's socio-economic situation and on the conditions of their built (infrastructure, buildings) as well as their cultural and ecological environment.

This chapter firstly compares several definitions of vulnerability before suggesting one definition used here. Subsequently, some key characteristics and related terminology are summarised. In addition, this chapter reviews and compares a selection of vulnerability models stemming from different disciplines. The review helps to not only better understand different perspectives on vulnerability, but also consolidates a synthesising perspective adapted in this thesis.

5.1 Approaching vulnerability: terminology and key characteristics

As the vulnerability concept has developed in natural hazards and risk research over the past 30 years, its meaning has become increasingly diverse. One explanation for this diversity are the multiplying and intensifying relations between humans and nature, amplified by dynamic, multi-dimensional and multi-scalar issues such as globalisation and global environmental change. In response, a wide range of disciplines enter the field which define the vulnerability notion from different backgrounds (Mitchell, 1990; Cutter, 1996b; White et al., 2001). The result is a mix of methodologies and conceptualisation of vulnerability. This 'mix' causes 'methodological immaturity', a need for 'intellectual rigour' and 'conceptual clarity' (Buckle, 2006: 88-89). Already in the early 1980s, Timmerman (1981) expressed his concern about the versatile application of the term 'vulnerability' which he concluded reduces its usefulness. 'Vulnerability' is of course not exclusively used in the field of natural hazard and risk, but is also commonly applied in fields such as psychology or public health. Even within one discipline, like geography, research topics range from the 'Geographic Vulnerability and the Positional Good' (IGU, 2006) to 'The groundwater's vulnerability from the Dacic Basin, Romania' (IGU, 2004).

¹www.alertnet.org/thefacts/ref/reliefresources/110571576782.htm, accessed 07.3.2005

A second explanation for alternating interpretations of vulnerability is that different views of 'nature-society' interactions are carried into the field of vulnerability studies by different disciplines. White et al. (2001) differentiated between three main interpretations of vulnerability which can be found in the literature today:

- *'The degree to which a system is susceptible to injury, damage or harm (one part – detrimental – of sensitivity)'* (referring to Smit et al., 2000: 238), widely used and applied in the first edition of the authors' book 'The environment as hazard',
- a combination of exposure, the sensitivity to a danger and adaptive capacity (*'the potential or capability of a system to adapt'*, synonym to 'adaptability' (Smit et al., 2000: 238), with resilience as the reciprocal,
- emphasising the social and structural causations of vulnerability and disasters (referring to Blaikie et al., 1994, see also Wisner et al., 2004).

As White et al. (2001) concluded, a shift of views on what triggers loss and harm characterises this list: from a view that underlines nature as a cause towards a view that sees humans as the cause. Inherent in all views is the idea that humans and nature are interrelated. However, this interrelation fades when focussing on either nature or society as the main cause for disasters; a situation comparable with the ontologies of 'human-nature' interaction discussed in chapter 3.

Vulnerability is *'context specific rather than being a universal concept'* (Green, 2004: 324) – a proposition underpinned by several authors such as Anderson (2000), Cannon (2000), and Brooks (2003). Context specificity is another source for the diversity that prevents a homogeneous conceptualisation of vulnerability. It implies that vulnerability studies should be guided by the coordinates of the place studied: hazard type, the political, economic and cultural structures, and the spatial scale (chapters 2, 7). For example, while some people or infrastructure are vulnerable to hurricanes, they are not as vulnerable to floods or earthquakes (Cardona, 2004). Furthermore, variation is added by the regions chosen, for example if one compares less developed and developed nations (Cutter, 1996b).

Although vulnerability explanations need to be hazard-specific, political, ecological and economic marginality can create 'inherent' (Cardona, 2005), or 'generalized' (Wisner, 2003a) vulnerability which exists independently of hazard type (chapter 2). Moreover, Allen (2003) contrasted livelihood-models (see below) addressing the daily underpinnings with 'event-centred' approaches of vulnerability, which are hazard-specific but are at risk of over-focusing on the hazard-related factors of vulnerability. In these cases, Allen identified a potential neglect of underlying vulnerability. Therefore, conceptualisations of vulnerability should be balanced enough to comprehend both the hazard-specific and underlying or 'inherent' vulnerability.

As a result of different disciplines entering the vulnerability discussion, carrying their own worldviews, and added diversity due to the context-specific nature of vulnerability, current research struggles to shape one universal theory that fits all places and, as Oliver-Smith (2004)

underlined, all disciplines. Even agreeing on a definition of vulnerability is problematic, as illustrated in the following.

Cutter (1996b) listed eighteen different definitions of vulnerability that have appeared since 1980. From these, conjoint with other sources and more recent literature, the following keywords are extracted here:

- *'degree'/'measure of loss'* (Timmerman, 1981, UNDRO, 1982; Downing, 1991; IPCC, 1992; Bohle et al., 1994; IPCC, 2001; Alcantara-Ayala, 2002; Wisner, 2003; Wisner et al., 2004, IPCC 2007b),
- *'adverse consequences'* (Pijawka and Radwan, 1985; Downing, 1991; Cutter, 1993),
- *'(re)act adversely'* (Timmerman, 1981; Kates, 1985; Yamada et al., 1995), and
- *'coping capacity'* (Watts and Bohle, 1993; UNDP, 2004a; Wisner et al., 2004).

The first keyword demonstrates that many authors express vulnerability as a degree, indicating that vulnerability can be measured in a qualitative, semi-quantitative or quantitative way. The remaining keywords express the sometimes criticised 'negative' connotation of vulnerability, meaning the adverse consequences that arise from being susceptible to harm and unable to 'cope' with crisis.

One early definition that has been widely applied is based on the work of the Office of the United Nations Disaster Relief Co-ordinator (UNDRO). From 1972 onwards, UNDRO promoted the vulnerability concept and released several publications on the topic (e.g. UNDRO 1977; UNDRO 1978). In 1979, UNDRO organised an expert group meeting which addressed the conflicting usage of terminology and consequently defined such terms as hazard, vulnerability and risk. Vulnerability is defined as *'meaning the degree of loss to a given element at risk or a set of such elements resulting from the occurrence of a natural phenomenon of a given magnitude'* (UNDRO, 1982: 5).

Much later and based on a different school of thought, Wisner et al. (2004: 11) offered the following definition of vulnerability: *'By vulnerability we mean the characteristics of a person or group and their situation that influence their capacity to anticipate, cope with, resist and recover from the impact of a natural hazard [...]. It involves a combination of factors that determine the degree to which someone's life, livelihood, property and other assets are put at risk by a discrete and identifiable event (or series or 'cascade' of such events) in nature or in society.'* This interpretation encompasses many aspects and taps into what is also associated with resilience (capacity to cope with, resist or recover) (chapter 6).

Against the background of a diverse vulnerability comprehension and definition as sketched so far, UNDRO's definition offers several advantages, the first being its conciseness. Moreover, it offers a large common ground for different disciplines to work with - it captures the core aspect: the degree of potential loss. In addition, it refers to the magnitude of the hazard, which is an important aspect often accounted for by including 'exposure' into the concept of vulnerability,

which is not necessarily beneficial as will be discussed below. Finally, the definition excludes aspects often related to the notion of resilience, therefore assures a clearer distinction from resilience than for example Wisner et al. (2004) proposed.

While providing an intersection for different disciplines and a clear distinction from resilience, UNDRO's definition lacks any kind of explanation. It does not explicitly include that vulnerability is the result of a range of causative factors. When searching for an explanation of causality, other authors such as Wisner et al. (2004) deliver more insight.

A compromise between the two approaches, while capturing the keywords of the wide range of other suggestions (see above), is to define people's vulnerability, or 'social vulnerability' as *the potential degree of loss manifesting as adverse effects to people's physical and mental health as well as their livelihood (income opportunities, assets, savings), caused by their susceptibility to be harmed by a natural hazard. This susceptibility is related to cultural, economic, institutional, political and environmental dimensions, and the built environment.*

While this interpretation of social vulnerability provides terminological clarity and a basic level of explanation, it points towards a range of dimensions which influence social vulnerability. Indeed, vulnerability research has diversified from solely assessing the susceptibility of built structures towards including economic, environmental and institutional aspects (Birkmann and Wisner, 2006). Social vulnerability as defined above, the focus of the research presented here, can only be understood in the context of these different dimensions. The built environment and economic, political, institutional and cultural aspects are detailed in chapter 8, and some dimensions reappear as 'resources' in chapter 7. The following provides an introductory overview.

In terms of the **built environment** which includes critical infrastructure or 'lifelines', vulnerability factors are usually the type of material, its age and design as well as construction quality. As Handmer underlined during the second meeting of the 'Expert Working Group on Measuring Vulnerability' (EWG) in Bonn (2005), **social** and **economic** aspects of vulnerability are interrelated, hindering a clear categorisation, and might only be accessible by long-term participant observation 'from within' (Birkmann and Wisner, 2006). Especially informal economic activity is not visible in official statistics, hence is hard to obtain, and is unlikely to be openly addressed in focus groups (Birkmann and Wisner, 2006). Furthermore, **institutional** aspects address for example how vulnerable governments, health systems and economic structures such as markets are with respect to hazards. Included are governmental or non-governmental risk reduction strategies and related implemented structures of for example education, emergency relief and structural and/or non-structural adjustments. As illustrated during and after hurricane Katrina devastated New Orleans in 2005, institutional failure from local to federal level worsened the situation for many people. Depending on the **cultural context**, institutions, including the military, enjoy different levels of trust in the public. From a structuralist paradigm

perspective, institutions can create and amplify vulnerability (chapter 2). The cultural context of institutional vulnerability is an important aspect, since different countries prefer different organisational structures and philosophies, which influence the inter- and intra-flow of information. Generally, there is much potential for improving institutional vulnerability on several levels. As presented at the second meeting of the EWG (Expert Working Group on Measuring Vulnerability), the number of people affected by floods in Asia has doubled during the last ten years, despite the number of institutions dealing with and managing risk and disaster being generally high (Birkmann and Wisner, 2006). It should be noted that no statement is made on whether the frequency of flooding has increased, which would be an interesting aspect in this context.

Finally, **environmental** or **ecological** (Bohle, 2005) aspects of vulnerability especially arise in the context of climate change and global environmental change. Natural hazards, such as droughts or landslides, are interlinked with desertification and soil erosion. In general, environmental changes can lead to severe degradation of the non-human sphere, impacting on for example people's nutritional state and therefore human vulnerability. For instance Adger and Brooks (2003) reflected on the sequence of droughts before the 1972/3 Sahelian famine, illustrating the link between environment and livelihood. Another example of interlinked environmental and social vulnerability is when mangroves, which can protect coastal zones from the impact of hurricanes and tsunamis, are lost. Environmental aspects of vulnerability are especially relevant in the context of development and its linkage with sustainability research (see the model of Turner et al. (2003), section 5.2.6). However, the linkages between human and non-human spheres are generally not yet well addressed. During the second EWG meeting, the question arose as to how to conceptually view environmental vulnerability: is it on the one hand regarded as ecological fragility separate from human activities (naturalistic position)? Or, on the other hand, since ecological and human well-being are inseparable (like clean water, fertile soils), is impact on humans the defining element (anthropocentric position)? The Millennium Ecosystem Assessment (2006)² for example applies the latter perspective on environmental vulnerability, which also precipitates increasingly in research on sustainable human development connected to environmental sustainability (Birkmann and Wisner, 2006).

Anderson (2000: 20-21) synthesised that vulnerability:

1. is complex, in the sense of being diverse,
2. is dynamic,
3. is sometimes irreversible, e.g. when a resource is depleted,
4. is compounding and cumulative, e.g. vulnerability after a disaster can be higher than before a disaster, and often several factors of vulnerability are interlinked,
5. has no borders and cannot be contained, because hazardous processes can spread widely or globally (such as volcanic ash fall), hence the origin of hazard and vulnerability are spatially separated.

² <http://www.millenniumassessment.org/en/Synthesis.aspx>, accessed 7.3.2007

The second, third and fourth aspects carry a temporal component, while the last is a spatial aspect. Complexity, the first characteristic, is not only a result of interconnectivity amongst diverse agents and factors producing vulnerability, but simultaneously the result of temporal and spatial variability. No matter how diverse the understanding and application of vulnerability may be, its core still is to explain variability - as Anderson and Woodrow (1998: 11) stated: '*Because people have different degrees of vulnerability, they suffer differently*'.

5.1.1 Some notes on related terminology

As in this research, often the prefix 'social' (Cutter, 1996b; Uitto, 1998; Ragozin and Tikhvinsky, 2000; Liu and Lei, 2003; Sidle et al, 2004) or 'human' (Dibben and Chester, 1999) is used to clarify the vulnerability of people as opposed to the vulnerability of the built environment. 'Physical' or 'biophysical' vulnerability can mean several things, and is often related to an understanding of hazard which does not include the magnitude of, but only the likelihood and type of the process. In the context of climate change, 'physical' or 'biophysical' vulnerability is seen as the combination of the physical process (without the magnitude), exposure and sensitivity (Brooks, 2003). The syllable 'bio' accounts for the biological or social element. As will be seen later, in this context exposure expresses the magnitude of the natural process in the sense that distance to the source of the physical process reflects its magnitude. As Brooks clarified this understanding of biophysical vulnerability includes not only likelihood, exposure (magnitude of impact) and sensitivity, but also the consequences of harmful events. This understanding of biophysical vulnerability reflects what is captured by the term 'risk' in this thesis. 'Biophysical' is also used in the sense of hazard only, describing the frequency but not necessarily the magnitude of a natural process and implying environmental fragility or sensitivity towards change, as applied for example by Cutter (1996b), Cutter et al., (2000) and Cutter (2003a), as well as Brooks (2003). While the prefix 'social' or 'human' can add clarity with respect to the vulnerability of people rather than the built environment, 'biophysical vulnerability' postulates an understanding of vulnerability, hazard and risk different from wide usage in the natural hazards and risk field.

'Exposure', i.e. the proximity to a hazard, is sometimes included as a component of vulnerability, assuming that with increasing proximity to the hazard source vulnerability increases (Cutter, 1996b after Alexander, 1993). For example, the Australian Greenhouse Office adapted an approach from Schroeter (2004) which defines vulnerability as a function of a potential impact and a system's adaptive capacity. Potential impact here is a function of exposure (to climate factors) and the system's sensitivity to change (Australian Greenhouse Office, 2005). Exposure as an element of vulnerability can be found in some of the conceptual models of vulnerability discussed in the section below. Also Cardona (2005), in the study 'Indicators of Disaster Risk and Risk Management' included exposure as one element for measuring vulnerability. Generally literature in the climate change field includes exposure within the notion of vulnerability (e.g. McCarthy et al. (2001), Brooks (2003), Turner et al. (2003),

Adger (2006), Smit and Wandel (2006), IPCC (2007b, c). However, for the following reasons exposure is not regarded as an element of vulnerability in this thesis.

Exposure is often seen as representing different levels of proximity to a hazard, hence implying different hazard magnitudes. However the term 'hazard', as widely used, already refers to a specific magnitude and frequency, within a specific period of time. This means for example that while people upstream in a catchment experience a 50 year flood event, people downstream are confronted with a 100 year event, according to different water levels for different parts of the catchment. A hurricane passing a region will diminish as it progresses over land and is consequently reclassified as a type 2 or 1 storm. Wave heights during a tsunami will subside as the water progresses inland, hence the magnitude and hazard changes spatially, and should be expressed by the definition of hazard for a certain place. What is more, the aspect of process magnitude is already implicit within vulnerability, since vulnerability should be analysed within the context of a certain hazard. This context related approach cumulates in the notion of 'risk' as a function of hazard, vulnerability and resilience, which are the cornerstones of this thesis. Therefore, including exposure as a measure of process magnitude, combined with hazard, would double-up the role of process magnitude within the overall risk function. However, models aiming to decipher vulnerability, while not or only peripherally referring to a risk-context, and research focussing on mitigation and adaptation tend to see exposure as an element of vulnerability.

Also when focussing on vulnerability 'only', exposure should be treated externally to vulnerability, since people's socio-economic and demographic characteristics are not changed when their proximity to a hazard changes. For example, in the case of evacuations, people's exposure is reduced completely, but their vulnerability is not changed at all. When levees are built, people's exposure is reduced to some extent, but not their vulnerability. Therefore, while risk can be altered, vulnerability as such cannot be modified by reducing exposure.

Conceptualising exposure as an element of vulnerability can foster approaches which cure the consequences rather than tackle the causes of hazards and disasters. This is because the spatial location of the element at risk is addressed rather than its vulnerability. Furthermore, this understanding of exposure is likely when within the notion of risk the focus is placed on vulnerability, while hazard is something that vulnerability needs to be related to. As Alexander (2000) observed, vulnerability studies tend to be increasingly decoupled from the emerging field of risk research, which he explained by an academic preference for specialisation.

An example of a separate conceptualisation of exposure and vulnerability can be found in the United Nations Development Programme's (UNDP) report on reducing disaster risk. A 'disaster risk index' (DRI) is presented in order to compare the vulnerability and exposure of countries to natural hazards and disasters on a global scale. Risk here is a function of 'physical exposure'

and vulnerability. 'Physical exposure' reflects the number of people in a hazardous area multiplied by the frequency of a hazardous event to incorporate an element of time. In terms of magnitude, high-level events are implied since the aim is to compile a disaster risk index. Hence here physical exposure is understood to be the product of hazard and the population at risk (UNDP, 2004a: 100), which includes a space-time dimension of those elements at risk. According to UNDP, exposure is *'not an indicator of vulnerability, but a condition sine qua non for disaster risk to exist'* (UNDP, 2004a: 31). Other authors such as Mitchell (1990), Davidson (1997), Uitto (1998), Comfort (1999), Mileti (1999), Granger (2003a) Hollenstein (2005), Gallopin (2006) and Thywissen (2006) differentiated between exposure and vulnerability and all but Hollenstein apply 'exposure' in the sense of 'element at risk', i.e. the number of people or structures exposed to a natural hazard. Turner et al. (2003) defined exposure as an element of vulnerability but used the term in the sense of 'elements at risk' as well. Other sources, such as Sidle et al (2004), use 'exposure' inconsistently which dilutes its comprehension and clarity of usage.

Obviously though there is an interconnection between exposure and vulnerability: high levels of vulnerability can increase exposure, for example when people of low socio-economic status are forced to settle in unsafe locations (Smith, 2004). Exposure can be included as an attribute directly related to elements at risk. For example, being inside or outside a building during a storm or a landslide event is a factor which influences the likelihood of adverse consequences, therefore risk. In addition to the spatial dimension, temporal exposure influences risk. Spending all day within a building lessens the exposure to high wind speeds or moving debris, compared to a person commuting to work or being bound outside for other reasons. In contrast, an earthquake striking a residential area at night will entail people having a higher exposure to collapsing building material than during daytime, hence increases the likelihood of adverse consequences to people. As Alexander (2000) illustrated, the high death toll of the 7.4 earthquake striking Izmit (Turkey) in 1999 can be partly related to the time of its occurrence: 3:02 at night. Also, Hollenstein (2005) used 'exposure' as an indicator of the spatio-temporal distribution of an element at risk, rather than 'just' an account of what is potentially harmed by natural hazards and disasters. This comprehension of exposure does not imply an influence on vulnerability as such, but represents an additional component of risk.

Exposure in this thesis is understood as a pre-condition for a hazardous situation, this means that without exposure of 'elements at risk', there is no hazard.

5.2 Models of vulnerability

As Tobin (1999) pointed out, the need to develop theoretical frameworks arises if the aim is to apply concepts in different settings and, as Tobin might imply, to different scales. Such frameworks or models further provide guidance when designing methodologies of vulnerability measurement, especially with respect to scenario development as Downing (2004) concluded.

However, as mentioned in the previous section, there is no universal theory or model of vulnerability. Because it is questionable whether such a theory and model can exist, one way of gaining a deeper understanding of vulnerability is to compare a range of models and extracting some key characteristics. Within the following section several models of social vulnerability are presented and discussed. Most of these models reside within wider frameworks of risk, and most illustrations include a hazard component. The detail of vulnerability explanation varies between the models presented here. The aim of the model selection is to use models as representations of their research field. In combination a range of different approaches is covered. The aim is not to rate the models since most differ in their perspectives and aims, which cannot be assessed as such. However, where appropriate, differences in terminology usage are pointed out, indicating the degree of model applicability within this thesis. In addition, the key characteristics are extracted and summarised in the final part of this chapter.

5.2.1 'Pressure and Release' (PAR)

As addressed in chapter 2, Wisner et al. (2004) introduced the 'Pressure and Release' model (PAR) to explain vulnerability. Turner et al. (2003) generally use the term 'PAR' for models addressing political and economic structures which limit people's ability to adapt to hazards, for instance whether they can choose safe housing. Within the PAR model as presented by Wisner et al. (2004), the pathway of vulnerability runs from 'root causes' (such as the political and economic system), to 'dynamic pressures' (like rapid urbanisation, deforestation, lack of local markets, lack of press freedom), to 'unsafe conditions' (such as unprotected buildings and dangerous locations, lack of preparedness and local institutions) (figure 5.1). Only when a hazard, such as a flood, earthquake or landslide, impacts on a vulnerable population, does disaster occur (Blaikie et al., 1994; Wisner et al., 2004). The PAR model reflects a structuralist perspective on vulnerability (chapter 2).

Figure 5.1: The 'Pressure and Release' model (PAR), Wisner et al. (2004: 51)

This model recognises the spatially and temporally remoteness of factors which make people vulnerable at the local scale, at one point in time, as for example observed by Mitchell (1990). The PAR model implies that 'release' can only be achieved by tackling dynamic pressures and root causes, not just natural processes as the usually defined 'triggers'. Oliver-Smith for example explored the causation of vulnerability, and hence the differences in loss of life and assets, during and after hurricane Katrina (US Gulf Coast, 2005) under the framework of the PAR model. Amongst other factors, he showed the linkage between unsafe conditions and marginal socio-economic situations that people lived in before the hurricane struck (Birkmann and Wisner, 2006). The PAR-model as presented by Wisner et al. explicitly connects processes on the national and regional scale with processes at the 'pressure point', which are addressed by the 'Access' or 'Livelihood' model in more detail (section 5.2.2).

The PAR model includes the notion that as vulnerability progresses exposure can increase: This means that root causes channelled by dynamic processes can entail settlements in dangerous locations – hence places which are very exposed to natural hazards. Furthermore, the role of infrastructure, which is vital for 'social vulnerability', is included within the PAR model, since 'unsafe conditions' can also be a result of unsafe or unprotected buildings and infrastructure.

Related to the PAR group of models is the 'entitlement approach' by A. Sen (1981) who explored the factors governing access to food ('food entitlement') and hence making people more or less vulnerable towards famine (chapter 2). Another concept strongly related to the PAR approach is marginality (chapter 2).

Hazards are increasingly recognised as parts of a complex interaction between people and nature (Mitchell, 1990; Garcia-Acosta, 2002). Although the holistic concept of marginalisation is embodied within the structuralist paradigm, environmental vulnerability does only play a small role in the explanatory chain of the PAR model.

Although the PAR-model does feature processes, rather than just factors, it is static in the sense that adjustment or adaptation after damage and disaster are not included. Another point is that the forces of root causes, channelled by dynamic pressures into unsafe conditions, are very remote from the day-to-day reality. They can also be remote in a temporal perspective, for example when an unsafe condition materialises a certain time after root causes worked the switches. Hence the chain of causation can be diffuse and difficult to capture and prove, as Wisner et al. (2004) admit. Furthermore, identifying root causes implies that changes of political and economic structures are necessary to decrease vulnerability. However justified, this surely is the most difficult part, with governments and regimes not voluntarily willing to change their way of ruling. Amongst those being affected, a sense of fatalism can prevail since a radical system change is difficult to achieve, although this can and has happened in the past when

conditions after a disaster are so severe and amplified by the government that a regime is challenged, as happened in Nicaragua in 1979 (Albala-Betrand, 1993).

Shifting explanations solely outside the individual sphere might discourage the search for practical solutions of reducing risk and might overlook local capabilities which, as Wisner and colleagues point out, can be enormous. With respect to effective disaster management, the linked 'Access' or 'Livelihood' model discussed below provides a higher degree of operationalisation, while the PAR model is useful to comprehend the causation of vulnerability – the 'big picture'.

5.2.2 'Access' or 'livelihood' model

This second model developed by Wisner et al. (2004) focuses on the processes at the 'pressure point' of disasters within the PAR model (under the magnifying glass, figure 5.1). It focuses on combining social and economic aspects of household vulnerability ('micro-scale'), while imbedded within the PAR model's regional, national and global processes (dynamic pressures, root causes). It also includes how people cope and interact with institutions, which is seen as part of their vulnerability. It is, in contrast to PAR, not static but dynamic by including iterations and defining disasters as processes, not just events. Within the model, hazard and household livelihoods collide when by a geophysical process the 'normal' ('daily') life situation is turned upside down. This impacts on normal life and entails different levels of coping and subsequently adapting within the means of the household. Depending on available risk mitigation measures, the previous 'unsafe' condition is preserved, lessened or worsened. In addition, if risk mitigation measures are introduced, they will, depending on their nature, influence the hazard in its temporal and spatial occurrence. At the household level, individual decisions are made to earn a livelihood, which are infused by the structure of the household (social relations) and its economical and political context (structures of dominance). Vulnerability also stems from the individual profile regarding the socio-demographic characteristics of a person (age, gender, etc.) within a household. Though the model would alter according to a specific hazard type (hazard context), it aims to carve out some ubiquitous factors that generate vulnerability. In general terms, it illustrates how in 'daily' or 'normal' situations of earning a livelihood, people have different access to resources such as materials, social relations and political power. It is very similar to the concept of 'sustainable livelihood (SL)' presented by Chambers and Conway (1992) in a development context, but which does not explicitly refer to natural hazards and disasters. Like the Access model, SL encompasses five groups of 'capital' which a person utilises to earn a livelihood: human capital (such as skills, knowledge), social capital (networks, institutions), physical capital (technology, infrastructure), financial capital (savings, credit) and natural capital (natural resources) (Wisner et al., 2004: 96). Depending on the degree to which an individual or household can access these five resource groups, vulnerability alters between high and low levels.

The Access model provides an in-depth discussion of a range of factors that play a role in defining people's vulnerability within a household, such as ethnicity, occupation, gender or

socio-economic class to name only a few (chapter 8). The role of infrastructure is acknowledged within the Access model, since infrastructure are a means of access to safety and resources, and are combined with the quality of buildings, a factor which can make a location 'unsafe'.

Generally, the model is well equipped for comprehending vulnerability and identifying vulnerable populations and estimating risk in combination with hazard. As Wisner et al. (2004) pointed out, applying the model entails a reduction in those factors which are most important to the user, which in turn is influenced by the user's theoretical perspectives. The model is 'externalist' (p. 122), this means it acknowledges that different users will define and interpret vulnerability, hazard and risk differently, according to a different perception of the researcher. Furthermore, not all factors are of equal prominence in different situations or locations, this means they depend on the context of the vulnerability study. The model is therefore regarded as a flexible framework, in which also methodologies and scales can differ - for example the household can be substituted by the individual if more appropriate to address the specific aim of a study. However, this framework is restricted to the micro-scale and only in combination with PAR allows for a holistic explanation of vulnerability.

5.2.3 'Applied sciences' (AS)

A bundle of approaches towards vulnerability commonly adapted within the applied sciences is based on UNDRO's (1982) terminology and conceptualisation, where risk is a function of exposed elements at risk (e.g. people, built structures, economy), hazard and vulnerability. Here, exposure is independent of vulnerability and generally interpreted in the sense that only when 'elements at risk' are in fact exposed, a risk situation manifests. Hazard is defined in terms of frequency and magnitude of a natural process (Glade, 2003; Bromhead, 2005; Crozier and Glade, 2005). This understanding of risk has shaped risk management as for example applied by the Australian Geomechanics Society (2000). However, explanations of vulnerability, which is generally understood as the susceptibility or sensitivity of being harmed, are rather restricted. In contrast Alexander (2000) and Wisner et al. (2004), who adopted the UNDRO conceptualisation of risk, provided a separate model of vulnerability each (sections 5.2.4, 5.2.1). For a very comprehensive compilation and evaluation of AS approaches to vulnerability, covering a range of natural hazards types, see Hollenstein et al. (2002). Within these, Hollenstein (2005) detected a dominance of earthquake and wind related vulnerability models.

An example for a typical applied sciences model is the following approach of analysing vulnerability in the context of landslide risk studies. Scales covered in such landslide vulnerability and risk studies are the very detailed, local scale, the regional scale, or the more abstract scale of society when calculating 'societal' vulnerability and risk. Generally, when analysing the vulnerability to landslides, the following factors are taken into account:

1. the location of the element at risk in respect to the landslide (uphill, on the landslide, or downhill),

2. the impact of the landslide, assuming that the level of vulnerability changes with the level of impact, which depends on:
 - a. The velocity of the landslide
 - b. The depth of the landslide
3. the characteristics of the element at risk; for structures this is well documented, e.g. in order to design structures which can resist the impact (IUGS Working Group on Landslides - Committee on Risk Assessment, 1997). See Corominas et al. (2005) for an example of such a conceptualisation. Leone et al. (1996) developed a damage matrix to classify the potential damage according to the building structure. Another approach is to assemble historical data on damages, as done by Remondo et al. (2005) for the built environment within a catchment in northern Spain. However, the problem with historical data is their availability, and even if data on historical damage are available, the level of detail is often not sufficient to capture landslide type and magnitude (Glade, 2003).

People's vulnerability is usually regarded as dependent on the structure and hence the vulnerability of the building the person occupies at the time of impact, see for instance Ragozin and Tikhvinsky (2000). It is therefore defined through exposure rather than people's individual characteristics or societal structures. Comparatively, an approach to incorporate the characteristics of people themselves which may or may not make them more vulnerable is much less developed. As shown above, the focus is usually on the characteristics of the hazard, of the building structure and on the probability of a person being hit, which mainly depends on where and when the landslide occurs and where the objects is located at that moment. People's socio-economic and demographic factors are traditionally not considered. This is rooted in a dominant natural science approach with an emphasis on technological aspects with an engineering background, as reviewed by Glade (2003). Glade also observed a lack of standard method for analysing the vulnerability of people to specific landslide hazards, which he interprets as a fundamental drawback for any landslide risk analysis.

Liu et al. (2002; 2003) presented an approach which assesses vulnerability to landslide risk in a broader fashion. They quantitatively assessed debris flow risk in Southwest China on a regional scale. Overall vulnerability is segregated into four categories: 'physical' (infrastructure and buildings in terms of monetary loss, not as influencing social vulnerability, this means people's well-being), 'economic' (GDP as an index of economic development, social wellbeing and capacity to recover), 'environmental' (loss of land, monetary value), and 'social' (loss of life). Social vulnerability depends on population density and 'quality'. 'Quality' is the sum of the percentage of elderly people and the young, the percentage of uneducated people, and the percentage of rural population as they are regarded as less wealthy compared to urban population. All four aspects are summed to produce overall vulnerability on a scale of 0 to 1, which is then multiplied with hazard (on a scale of 0 to 1), to calculate risk. While Liu et al. merge all four categories into one to calculate overall landslide risk, Ragozin and Tikhvinsky

(2000) in a similar approach keep them separate to specifically calculate economical, social (loss of life) and environmental risk (loss of resources). Although the work of Liu et al. incorporates some socio-economic and demographic aspects, their deduction seems somewhat crude, and some variables are neglected, such as gender ratio. Also, the focus of the vulnerability concept is again on the potential loss of life of an individual, on a regional scale. The vulnerability indicators applied do not provide much insight in understanding the causes of vulnerability. The role of infrastructure for social vulnerability is not explicitly addressed in the examples above, and often vulnerability of people and vulnerability of infrastructure are treated separately.

Since the prediction and control of landslides, especially for first time failures, is limited, the assessment of vulnerability and consequently the identification of loss reduction strategies are especially important. As Liu et al. (2002; 2003) demonstrated this is highly relevant for debris flows, in which case the modification of the human system (removing people and assets from hazardous areas) is the most feasible strategy to reduce landslide loss. Dai et al. (2002) proposed adjustments in landslide risk management which resemble the set of measures developed by the human ecologist school (chapter 2). This implies a combination of restricted land use, of construction codes, physical protection measures and warning systems. Alexander (2005) underlined that vulnerability can determine the extent of losses to a greater extent than the landslide process itself. Overall, the importance of the vulnerability concept in landslide risk studies has been and is increasingly acknowledged. However, vulnerability to landslides is usually considered for individuals in relation to buildings, for buildings themselves and roads in the potential path of the landslide. Explanations of social vulnerability are only included marginally.

5.2.4 David Alexander

David Alexander's research on hazard, risk and vulnerability can generally be associated with the applied sciences (e.g. Alexander, 2005). In his vulnerability model he derives the causation of vulnerability from a perspective which includes social, technological, cultural, political and economical dimensions, illustrating the broadening of the applied sciences towards multi-causal perspectives on vulnerability. He draws a generalised 'vicious circle' of increasing vulnerability, see figure 5.2 (Alexander, 2000: 13). The starting point of this circle is a development activity which is supported by politicians, planners and developers which channels into an electorate and facilitates democratic processes. Simultaneously, a lack of environmental regulations, a laissez-faire attitude, environmental costs and populism can outweigh the positive effects of the development activity, hence create vulnerability.

Figure 5.2: The 'vicious circle' of vulnerability (Alexander, 2000: 13)

His argument implies that the negative implications are almost inevitable and create, on the long-term, unsustainable development – unless the built-in opportunities to mitigate risk are utilised (abating factors). He acknowledges the role of hazard and risk perception, which influences decision-making, which in turn can exaggerate or lessen vulnerability. Expressed as a formula, vulnerability (V) is the result of a group of factors amplifying bad practice (Ra), a group of factors implying good practice (Rm) (meaning mitigation), and the perception of risk (Rp):

$$V = Ra - Rm \pm Rp$$

In Alexander's model, perception influences vulnerability in a negative or positive way. Risk perception influences people's willingness to adapt to hazards, hence would be tightly related to Ra and Rm. A perception of risk leading to precautionary activities can only exert a positive influence on vulnerability in relation with 'good practice', while it would amplify 'bad practice' and increase overall vulnerability.

However, one could argue that for two reasons in this formula, risk perception is superfluous: Firstly, bad practices combined with a 'laissez faire' attitude will continue though risk perception is high. Secondly, good practices, i.e. risk mitigation, presuppose that the endangerment of risk is actually perceived. Without perception of risk, mitigation activities are unlikely to occur. Therefore it seems that the relation of Rp to Ra and Rm is more complicated than presented in this short formula.

Alexander's 'vicious circle' is a dynamic model in which positive feedback mechanisms influence subsequent model stages, although this is not explored further. This model targets not necessarily the individual or household scale, but implies a broader scale which potentially includes groups of people or society as a whole. The focus is on political and economic processes, which are categorised broadly, but do not account for situations unrelated to

development activities. This means that this model implies a push for 'progress' to explain vulnerability, which is likely to be the dominant driver of processes in diverse cultures, though not in all and not necessarily always. Often, people struggle to maintain a status quo or are becoming vulnerable for other reasons which are not directly related to developing activities. Interestingly, although Alexander subsequently discussed risk and its contributing factors, this is a 'stand-alone' vulnerability model not embedded within the context of hazard, exposure and overall risk. From the models discussed in this chapter, only Bohle, Dowing and Watts (1994) pursue a similar approach.

5.2.5 'Hazards-of-a-place' model

Based on the human ecologist approach of Hewitt and Burton (1971), who presented a case study which includes 'all hazards at a place', Susan Cutter developed the 'hazards-of-a-place-model of vulnerability' (Cutter 1996b, Cutter et al., 2000, Cutter et al., 2003). The model differentiates between two dimensions of vulnerability: 'social vulnerability' and 'biophysical vulnerability' (figure 5.3).

Figure 5.3: 'Hazards-of-a-place-model' of vulnerability (Cutter et al., 2003: 244)

Both produce the vulnerability of a place. 'Social vulnerability' encompasses factors which govern people's susceptibility to harm and their ability to cope, including the type of environment (such as the degree of urbanisation), the type of built structures or the economic vitality (note that this categorisation changes somewhat within the sources cited above, at least graphically). Social vulnerability is influenced by the 'social fabric' which encompasses the experience and perception of hazards and risk, socio-economic factors and the capacity to cope. 'Biophysical vulnerability' accounts for the susceptibility of the biophysical environment towards disturbance, labelled 'environmental' or 'ecological' vulnerability by other authors (see above and below). In a case study, hazard characteristics such as the type, frequency and 'zonation', are chosen as variables to describe biophysical vulnerability (Cutter et al., 2003). In Cutter's model,

environmental fragility (susceptibility) and hazard are moulded into one notion of biophysical vulnerability. The geographic context ('geographic filter') of a location influences biophysical vulnerability, amplifying or lessening the probability of a natural process occurring, and is connected to the social fabric. It includes exposure ('proximity'). Geographic context and social fabric are governed by the 'hazard potential', and hazard potential is a function of risk and mitigation. Cutter emphasised 'place' as the key aspect of this model, hence the context-specific nature of vulnerability, and adds a time dimension by building in a feedback from place vulnerability to either directly risk or to risk via mitigation measures. In addition, she underlined the importance of generally changing rather than static model parameters, and follows a multi-hazard rather than a single-hazard perspective.

The terminology used in this model differs considerably from the terminology applied in most models presented here, and from the terminology applied within this thesis. Cutter (1996a: 525) sought to clarify the plethora of definitions and settled risk as *'the likelihood or probability of an event occurring'*. She continued: *'Hazards include risk (e.g. probability), impact (or magnitude) and contextual (socio-political) elements'*. In other papers, risk is defined as the 'likelihood of a hazard' occurring, plus the source of the risk and its consequences (Cutter, 1996b, Cutter et al., 2000). Then again, risk is simply 'exposure' (Cutter, 2003a: 6). Hence the definition of risk is unclear.

In this thesis, risk is a function of hazard and consequences. Hazard implies the likelihood of an event of a specific magnitude, with likelihood based on event frequency. Hazard as such is not defined clearly in the description of Cutter's model but is amalgamated with environmental fragility, and seen as part of risk, filling in for the likelihood aspect. Hazard potential is seen as a result of risk and mitigation measures, whereas in this thesis, hazard is, combined with vulnerability, understood as influencing risk. Risk, according to the interpretation in this thesis, is the end product of processes and does not influence something like 'hazard potential'. In Cutter's model, hazard is not to be interpreted as necessarily including the magnitude of the processes – it is rather understood as the type of process (a flood, an earthquake), and its spatial extent. From this perspective, Cutter's (1996a) definition of hazard as cited above can, but must not imply the process magnitude. This is confusing and masks at which point the magnitude of the process enters the vulnerability model. Also, in Cutter's model risk (the likelihood of a hazard) influences hazard potential, whereas one could ask whether *hazard* potential would not rather influence the likelihood of a hazard occurring.

Overall, the usage of risk in this model concurs with an early perspective held by natural scientists and engineers, which is nowadays mostly replaced by a view that includes the consequences of both hazard and vulnerability and potentially resilience. Although Cutter aims to explain vulnerability within the wider context of risk and hazard, due to the very different use of terminology the benefits for this thesis are limited. What is more, due to the different usage of

the terms 'risk' and 'hazard' within her own work, the model as mapped out above is not easy to follow.

Additionally, 'biophysical vulnerability' is not used consistently when describing the model. Furthermore, the model sees 'resilience' (capacity to 'spring' or 'bounce' back), with an explicit reference in Cutter and Emrich (2006), as part of vulnerability, while in this thesis, vulnerability and resilience are regarded as two different though not mutually exclusive concepts. Also, 'place vulnerability' does not necessarily address the degree of loss, but rather overall susceptibility, since place vulnerability is a product of biophysical and social vulnerability. Social vulnerability, the focus of this thesis, occupies a comparatively small room within the model. Finally, the role of infrastructure ('lifelines') is only described in Cutter et al. (2000: 717), but not included in the model. Cutter's work generally focuses on socio-economic factors as indicators of social vulnerability, while a path of explanation, as for example provided by the PAR model of Wisner et al. (2004), is not offered. Hence it is not multi-scalar but focuses on explanations within one 'place'.

5.2.6 'Airlie House' model, Turner and colleagues

The vulnerability concept enjoys increasing popularity within the environmental sciences as reflected, for example, in the IPCC report of 2001 and 2007, and is according to Bohle (2005) orientated towards ecosystems. When related to humans, 'environmental criticality' (an anthropocentric perspective of 'environmental vulnerability') is defined as *'situations in which the extent and/or rate of environmental degradation preclude the continuation of current human-use systems or levels of human well-being, given feasible adaptations and societal capabilities to respond'* (Kasperson et al., 1995: 25; Kasperson, Kasperson and Turner., 2005).

Against a background of environmental science with a focus on sustainability of 'coupled human-environment systems', Turner and colleagues developed the 'Airlie House vulnerability framework' (figure 5.4). Their research is tied into the 'Research and Assessment System for Sustainability Program' (2001), and they present their model, for example, in Turner et al. (2003), Turner et al. (2003a) and Kasperson, et al. (2005).

They evaluate existing frameworks such as 'RH' (Risk-Hazard) models where hazard is the starting point on the path towards risk. Vulnerability is a function of exposure and sensitivity, which together entail a certain degree of 'impact' or consequences. Turner and colleagues consider 'RH' models as masking the *'complexity of the components, states, and interactions that enter into a more robust construction of vulnerability, and thus they frequently provide simplistic indices and measures that may be misleading or even incorrect'* (Research and Assessment System for Sustainability Program, 2001: 2). They see a further drawback in the omission of an explanation of how vulnerability might be amplified or hazards are created internally. This means that interconnections are ignored and, importantly in the context of this thesis, dynamics between the different players within a vulnerability framework are dismissed.

Another criticism is that models do not usually account for 'coupled human-environment' systems.

Figure 5.4: 'Airlie House vulnerability framework' Turner et al. (2003) in Kok et al., 2006: 133)

The model Turner et al. proposed underpins the connection between humans and nature ('human conditions' and 'environmental conditions') and aims to comprehend vulnerability of the system as a whole - this probably means both the human and non-human spheres. The model consists of three main elements: firstly, connections between the human and non-human world. Secondly, hazards as 'perturbations' and 'stress' resulting from the human and environmental conditions and connections between them. Finally, the 'coupled human-environment system' itself which displays a certain level of vulnerability including coping capacity, impacts, adjustments and adaptations (Turner et al., 2003). Their model is designed to include multiple 'stresses' which arise internally and externally, and are interlinked through feedback mechanisms. Stresses are allowed to build up in environmental and human systems, and when they collide the system(s) experience negative consequences. Stresses can be remedied by human adjustment, for example by constructing flood mitigation measures or other non-structural adjustments, reflecting back on the environmental and human system respectively. High levels of stress, this means disaster, can overtop the ability to cope which feeds back onto the subsequent availability of resources. Adaptations are defined as '*significant system-wide changes in human-environment conditions*' (Turner et al., 2003: 8077), and while adjustments are not defined as such, it can be assumed these are rather insignificant, localised changes in the human-environment conditions. In contrast to adjustments, adaptations are applied when the impact is so large that adjusting would not lead to stress relief. An example is when land use strategies are altered in order to adapt to changing environments. Another way of adaptation is to direct stresses towards the 'macro-forces' (on a larger scale: environment, economy, policy).

For example, CO₂-induced climate change may motivate policy-makers to create incentives for reducing CO₂ emissions. The model therefore includes linkages between different spatial scales through these macro-forces impacting on local systems, and vice versa. A place or 'location', the target level of the model, is therefore embedded within different scales, which includes the global level. The model aims to enhance an understanding of a particular situation inherent in a location. Hence the model is 'place-based' while, in contrast to Cutter and colleagues, at the same time aiming towards identifying general mechanisms which surface at other places. The linkages between human and the non-human world are seen as non-linear, multi-scalar and highly dynamic, which is regarded as a challenge towards developing a framework for vulnerability and resilience alike. Vulnerability and resilience are rated as key concepts within integrated sustainability research. Turner and colleagues acknowledge the complexity of their model, and see it as framework or 'template' which enables comparison with other models, and is a starting point for subsequent refinement and application in various contexts (other 'places'). From their point of view, applying a model reflecting the complete diversity of a placed-based vulnerability is very unlikely, since data limitations place constraints on such a model. Therefore, their model will need to be 'reduced' or simplified and adjusted to the location under study, while at the same time preserving the awareness of interrelations, feedbacks and scale-dependencies (Research and Assessment System for Sustainability Program, 2001; Turner et al., 2003). This further implies that variables and methods for vulnerability assessment will depend on the place (Turner et al., 2003a).

A strength of this vulnerability model is its dynamic nature since it allows feedback mechanisms to operate, which can increase or decrease the overall state of sensitivity. As indicated already, vulnerability, as much as hazard and risk, is not static but changes in time and space - a proposition which, nevertheless, is only sparsely recognised by risk researchers and risk managers. Another advantage of this model is the prominence of an inseparable connection between humans and nature, which is a novelty compared to most other models discussed here. It therefore represents a bridge between the more science and technology oriented AS-approaches and the structuralist schools of thought (PAR). Another strength the model displays is the acknowledgement of different contexts, underpinning variable validity of a vulnerability model depending on a particular location: hence hazard (environment), society (culture, policy and economy) and scale. The issue of scale is emphasised, meaning that not all factors or processes exist on every scale, and that linkages between scales can also be interrupted or 'skip' one scale. A novelty is also the internal creation of vulnerability, meaning the system-inherent susceptibility to change which is not induced by external forces. This is also coupled with the aspects of non-equilibrium and non-linearity, which are important concepts from a system's perspective on hazard and risk (chapters 3, 4, 6).

Though including processes of 'coping' and 'adapting', the Airlie house model focuses on the 'big picture' and certainly adds elements towards a comprehension of vulnerability, mainly the

strong link between humans and their environment. However a close-up revealing what happens at the individual or household scale of social vulnerability is not included. To be fair, this is hardly possible since the model as such is already quite comprehensive. This illustrates the advantage of a combined approach like PAR & Access which delivers as much explanation as possible or needed according to the scales covered.

In this model, resilience is regarded as an element of vulnerability. Infrastructure and the role of the built environment in general are not included.

5.2.7 The 'BBC-framework'

Social, economic and environmental vulnerability are identified as three cornerstones within the realm of sustainable development. The BBC-framework, named after work undertaken by researchers Bogardi and Birkmann (2004) and Cardona (1999; 2001) (Birkmann and Wisner, 2006; Birkmann, 2006b), combines these three types of vulnerability, which accordingly result in three types of risk (figure 5.5).

Figure 5.5: The BBC-framework (Birkmann and Wisner, 2006: 22)

This approach stems from three incentives:

- to couple sustainable development with vulnerability and human security (human security as a concept addressing the *'threats that endanger the lives and livelihoods of individuals and communities'* (Bogardi and Birkmann, 2004: 76),

- the need for a holistic perspective on disaster risk assessment, and
- with respect to sustainable development, the necessity to advance frameworks for appraising environmental degradation (Birkmann, 2006b).

Feedback loops link various components within the model and enable risk reduction mechanisms to operate. Has risk precipitated in the form of a disaster, a process of vulnerability reduction ($t=1$) can be triggered which will influence the environmental, social and economic spheres - the three 'sustainability dimensions' (Birkmann, 2006b: 35). Changes in these three dimensions can inject changes in the hazard domain, and the full circle of risk reduction is completed. Note the dotted line of the feedback loop pointing toward hazard, probably indicating that risk reduction should be foremost achieved by reducing vulnerability and, optionally, hazard.

The feedback loop can already start before an event occurred ($t=0$), therefore the model differentiates between pre- and post-disaster periods. By doing so, the need for proactive vulnerability and risk reduction rather than just reactive operations is underlined (Birkmann, 2006b). By including feedback loops, the dynamic nature of vulnerability, hazard and hence risk is captured. The model provides a comprehensive framework for the overall process of risk (and disaster) generation, where vulnerability plays a central role. The three risk and vulnerability types are interrelated – these links would probably also apply between the three 'spheres' at the left side of the diagram, although this is not indicated. The model is therefore multi-dimensional and mirrors the holistic and sustainable perspective envisaged.

Generally, the model seems to target the 'big picture' rather than an in-depth model of vulnerability, which is probably reflected by the authors' choice of labelling their approach a 'framework' rather than a model, which ultimately is a risk model. While Turner and colleagues target the 'big picture' as well, comparatively they provide more insight into vulnerability at the micro-level. The BBC-model of vulnerability only goes as far as adapting a similar conceptualisation as Turner and colleagues by including exposure, the capacity to cope and what is interpreted here as sensitivity ('vulnerable elements').

The way coping capacity is exactly defined remains unclear in the description of the model (Birkmann, 2006b, Birkmann and Wisner, 2006) which is also reflected by the visual overlap between exposure and 'vulnerable elements' with coping capacity. Referring to Bogardi and Birkmann (2004: 76) it seems to be generally used as 'response (coping) capacity' with respect to the ISDR (2002) definition of 'capacity'. However this is just an assumption, and the authors might equal 'response (coping) capacity' with adaptive capacity/resilience as for example Turner et al. (2003).

Although the model is designed to show the close link between the 'anthroposphere' (social and economic) and the 'natural' sphere (environment) (Birkmann, 2006b), 'natural' hazard resides outside the environmental sphere. Though conceptually hazard is not excluded from the

environmental sphere (Birkmann, 2006b: 37), this divide is introduced visually, which pushes hazard to the margin of the risk framework which overall focuses on vulnerability. This focus, as Birkmann (2006b) stated, is intentional. The dotted line linking hazard with the feedback loop of risk reduction further indicates that vulnerability reduction is obligatory while hazard reduction is optional. However, it can be argued that both are equally important to reduce risk most effectively. Furthermore, only in cases where sustainable hazard reduction is impossible or not feasible should vulnerability reduction be the focus (and resilience for that matter). Infrastructure, which play a vital role for people's well-being and therefore vulnerability, are neither addressed within the wider BBC-framework or the vulnerability module.

5.2.8 'Bohle, Downing, Watts (BDW)'

In their paper 'Climate change and social vulnerability', Bohle, Downing and Watts (1994) argued that in order to estimate future impacts of climate change, for example in the context of food insecurity and famine, one has to understand the complexity and causal structures of vulnerability. To them, based on Chambers (1989), vulnerability includes three aspects: exposure, the capacity to cope and the capacity to recover. These demarcate the three corners of a triangle which maps the social space of vulnerability (figure 5.6). The capacity to recover is also called 'potentiality' and used synonymously with resilience (Bohle et al., 1994: 38, 41). The aim of their model is to explain the *'historically and socially specific realms of choice and constraint - the degrees of freedom as it were - which determine risk exposure, coping capacity and recovery potential'* (p. 39). The authors present a framework of social vulnerability which draws on three key elements to shape the spatial and temporal context of vulnerability: 'human ecology', 'expanded entitlements' and 'political economy'.

Figure 5.6: BDW-framework of vulnerability (Bohle, Downing and Watts, 1994: 39)

In brief, human ecology encompasses issues of human utilisation of and impact on ecosystems, hence also the susceptibility of nature being degraded and becoming sensitive to natural

hazards and disasters. This concurs with 'environmental' or 'ecological' vulnerability as discussed previously, while underpinning an anthropocentric perspective. Expanded entitlements are based on Sen's concept of entitlements (*'commodities over which [a person] can establish ownership and command'* in Sen, 1999: 162), which supports the explanation of famine when food availability as such is not limited (see also Sen, 1980). Political economy is regarded as the wider context of economical processes and class relations, which are linked to individual's rights and entitlements.

These three spheres overlap or 'touch' along tangents, in order to explain the causal structure of vulnerability. Within this social space of vulnerability, endowments (*'ownership over productive resources as well as wealth [...]'* in Sen, 1999: 162) determine entitlements but also the ecological situation (for example, quality of land and water) and hence relate to risk exposure. Political ecology represents the way in which production is governed and resources are managed, therefore represents the tangent of human ecology and political economy. Class relations and empowerments are placed where entitlements and political economy meet, and are seen as the basis for the capacity 'corner'.

Placed along the axes of their model, Bohle et al. (1994) identified groups with a specific vulnerability characteristic, such as 'rural smallholder agriculturalists' or the 'urban poor', in combination with factors such as gender, age or disability. As with an understanding of vulnerability based on marginalisation, this model is grounded within a social theory which aims to combine and equally address structures and individual agency (Wisner, 1993).

The authors stressed that vulnerability is context specific: firstly in terms of time, which means that vulnerability is seen as dynamic; secondly with respect to space, which means vulnerability varies between countries and social groups. For example, in an earlier presentation of their model, Watts and Bohle (1993) trace changing levels of vulnerability for different actors, such as small farmers ('long-term baseline vulnerability' increased) or agricultural labourers (relatively safe), in southern India commencing before the onset of the 'Green Revolution' in the 1970s until a drought crisis in 1987/88. While providing a broader framework of vulnerability, and building on a variety of concepts as building material for the model, BDW embraces specific 'micro-scale' situations of vulnerability like the 'individual command over basic necessities' (Watts and Bohle, 1993: 46), which also depend on socio-demographic factors. The model therefore incorporates different spatial scales and provides insight into the 'big picture' as well into what happens at the household scale.

Subsequent development of the BDW model has added a second triangle, as mirrored below the original one, underlining that exposure is the 'external' side of vulnerability, while coping is the 'internal' side (Bohle, 2001). This differentiation is based on Chambers (1989) and Chambers and Conway (1992), where exposure is not only related to presence at a locality or distance to the source of a natural hazard, but also accounts for structural dimensions which

increase or decrease people's exposure. Coping, however, is regarded as completely intrinsic, operating within a household or group of people.

Within the BDW model, vulnerability of the built environment is not addressed. Furthermore, it is not evident how adaptation or adjustments are incorporated, or how structural measures can play a role. The model is designed for and is most applicable within the context of food security and famine, hence within a development context. The relations of the vulnerability model to overall risk are not explored, and hazard as such is not addressed but might be implied within the ecology part of the human ecology sphere.

5.3 Conclusion

The vulnerability models described and discussed above have been developed from different academic disciplines. However, a set of characteristics has crystallised which helps to compare and summarise these models (table 5.1).

Firstly, none of the models is hazard specific, nor placed within a certain societal context, although some models display a certain degree of bias (see A and B in table 5.1).

Table 5.1: Comparison of a selection of vulnerability models

		PAR	Access	AS	Alex- ander	Haz. of place	Turner et al.	BBC ¹	BDW ²
context- specific	hazard	-	-	-	-	-	-	-	-
	society ³	A	-	-	B	-	-	-	A
	scale ⁴	✓	✓	✓	-	✓	✓	✓	✓
infrastructure ⁵		✓	✓	✓	-	unclear	-	-	-
dynamic		-	✓	-	✓	✓	✓	✓	✓
adaptation		-	✓	-	✓	✓	✓	✓	-
multi-dimen. ⁶		✓	✓	-	C	C	✓	✓	✓
multi-scalar ⁷		✓	-	-	-	-	✓	-	-
exposure/coping capacity/resilience part of vulnerab.		-	-	-	-	-	✓	✓	✓

¹ = Bogardi, Birkmann, Cardona

² = Bohle, Downing, Watts

³ = i.e. whether a bias towards specific types of societies/countries is translucent

⁴ = most models implicitly target the vulnerability of elements at risk (people, households, groups of people, built structures) in varying degree of detail

⁵ = the role of infrastructure for social vulnerability

⁶ = including at least three of the social, economical, environmental, political and institutional spheres of vulnerability

⁷ = this means a model structure which accommodates different spatial scales, which can be combined with a focus on a specific scale

A = by the choice of factors, pointing towards a development context, and therefore less developed countries

B = by the choice of factors, pointing towards a non-development context, and therefore more developed countries

C = bi-dimensional

In terms of scale, all models imply the individual, household or group level - mostly without making this explicitly clear. Only the ACCESS model devotes itself to a great extent towards exploring what happens at this 'micro'-scale.

Secondly, the models differ as to whether they incorporate the role of the built environment for people's vulnerability. People-centred vulnerability models, which draw on political, economical, institutional and/or social dimensions, are increasingly developed and applied within research on international platforms of hazard and disaster reduction. However, the role of infrastructure, traditionally within the realm of engineering, is either neglected (Alexander, Turner et al., BBC, BDW) or unclear (Hazards-of-a-place), although they play an important role for maintaining people's access to clean water, electricity and relief and hence influence social vulnerability (chapter 8). Infrastructure and buildings are included in PAR and Access and generally focussed on in AS.

A third characteristic is the element of time: Access, Alexander, Hazards-of-a-place, Turner et al. and BBC clearly incorporate changes of vulnerability components. The BDW model acknowledges temporal changes in their model description, and the decadal changes in vulnerability are addressed in Watts and Bohle (1993). The PAR model also acknowledges the factor of time, but the model itself is not designed to represent temporal changes of vulnerability components. AS-models are generally static. Those clearly dynamic models accommodate time by allowing for adjustment measures to mitigate hazard and risk. This is the preferred route chosen for a dynamic concept, implying that adjustments can be undertaken after an event, which potentially changes the conditions of a place and hence the prepositions for future hazards and disasters. Over the longer run, adjustments can evolve into adaptations. However, changing dimensions of vulnerability as such, i.e. independent of adjustment/adaptation, are only addressed by Turner and colleagues, and partly in Access where several stages within the model are subject to change, due to for example altering decision-making processes or a changing demographic profile of households is built in.

Fourthly all models other than AS (one-dimensional) and Alexander's and Cutter's models (bi-dimensional), include multiple dimensions of vulnerability. This means they include at least three of the social, economical, environmental, political and institutional spheres of vulnerability, which are commonly identified throughout the body of literature. Cutter (to some degree), Turner and colleagues, BDW and the BBC-framework address the human ecology of the connections between human conditions and the state of the non-human world which delivers resources and serves as a habitat. Especially Turner and colleagues underpin the role the environmental resources play for people's vulnerability. Hazard is generally interpreted as the result of 'environmental', 'ecological' or 'biophysical' vulnerability. This encompasses the sensitivity of the physical-materialistic world to change, which can favour the manifestation of this fragility as hazards and disasters. However, hazard and 'environmental vulnerability' are not to be used interchangeably as Cutter does, since hazard is a specific term and concept of its own. The BBC framework and also Turner et al. provide a good example of this interconnection while maintaining a distinction.

Fifthly, the models differ in the way they deal with the issue of scale. Combining several scales of explanation is highly beneficial for the understanding of what makes people vulnerable, though difficult due to the need for a compromise on the level of detail given for each scale. As Allen (2003) stated, addressing and incorporating the linkages between different scales is a problem in vulnerability research. The challenge is to include several scales while focussing on one scale for which vulnerability manifests, i.e. being scale-specific without ignoring the interrelation of different scales on the path to explaining vulnerability. Wisner et al. include several scales in their PAR model, while the Access model, although coupled with PAR, is essentially not multi-scalar. Turner and colleagues deliver an elegant structure with their nested spatial arrangement of global, regional and local levels, which includes a certain level of detail on the micro-level. Also BDW aims towards such a scale-split. However Cutter focuses on one scale - the 'place' - while excluding higher level scales where explanations are hidden. A single-scale approach is also offered by the BBC-model and AS models.

Finally, some models are similar in placing resilience coupled with exposure into the notion of vulnerability (Turner et al., BBC (possibly in case of resilience), BDW). AS-models, Cutter's and Alexander's model supposedly distinguish between resilience (by not mentioning it) and vulnerability. Furthermore they do not regard exposure as a component of vulnerability. This is an interesting observation and reflects a general difference in conceptualising vulnerability. As mentioned earlier, White et al. (2001) distinguished between three different camps, which broadly concurs with Adger's (2006) recent review of vulnerability research. These groupings are generally supported here but modified according to the observations made during this review and fleshed out in the following (see also appendix A).

Turner and colleagues are related to what is here called the '*Climate Change and Global Environmental Change*' stream. Vulnerability is defined as a function of exposure, sensitivity and adaptive capacity/resilience (Kasperson et al., 1995a; McCarthy et al., 2001; Folke et al., 2002; Brooks, 2003; Adger, 2006; Smit and Wandel, 2006; IPCC, 2007b, c). It should be noted that in the climate change related literature, exposure is defined as including the magnitude of a physical process. Within this stream, adaptive capacity is an element of resilience and tends to be used interchangeably (Carpenter et al., 2001; Berkes and Jolly, 2001; Pelling, 2003; Adger, 2006; Folke, 2006; Smit and Wandel, 2006; see also Mueller-Mahn, 2005: 75). Furthermore, adaptive capacity is used interchangeably with coping capacity (Smit et al., 2000; IPCC, 2001; Brooks, 2003; Ford and Smit, 2004; Adger, 2006; Gallopin, 2006; Smit and Wandel, 2006). As discussed in chapter 2, the concept of 'adaptive' or 'coping' capacity has been developed by the human ecology school of natural hazards research, where a zone of 'insignificant damage' is delineated by a combination of a geophysical event and human adjustment (Hewitt and Burton 1971; Burton and Hewitt, 1974).

A second stream of vulnerability research, labelled here as *'Development and Livelihood'*, defines vulnerability as a function of exposure (external) and coping capacity (internal) (Chambers and Conway, 1992). Watts and Bohle (1993), Bohle et al. (1994) and Bohle (2001) based their vulnerability research on this approach. Sen (1984, 1987), Chambers and Conway (1992) and Anderson and Woodrow (1989, 1998) further relate their work on the concept of 'capability', meaning the ability to cope with stress and shocks as well as utilising livelihood opportunities. Capabilities can be either reactive (coping) or proactive (dynamically adaptable) (Chambers and Conway, 1992: 14). The term 'capability' is also sometimes used interchangeably with 'capacity' (ISDR³). The BDW-model identifies capacity as one cornerstone of vulnerability, besides exposure and potentiality (resilience in the sense of recovery potential).

Therefore, both streams place exposure and resilience within the domain of vulnerability - the difference being in the understanding of resilience: While the first stream equals resilience with adaptive capacity which in turn includes coping capacity, the *'Development and Livelihood'* stream separates resilience (potentiality) from capacity, which subsumes coping as well as adapting. The similarity between the two streams and models can be explained by a shared interest in climate change and climate triggered hazards, such as droughts. Such a conceptualisation of vulnerability explains why both streams regard vulnerability as the 'flipside' of resilience: An increase of resilience directly decreases vulnerability, while a decrease of resilience would directly increase vulnerability. This conceptualisation works like a formula where changing one side of the equation influences the other (chapter 7).

PAR and Access are placed here within the *'Development and Livelihood'* stream since they draw on the concept of entitlement which ultimately implies access to resources in order to explain vulnerability. Their understanding of capacity, however, includes the notion of resilience since vulnerability per definition (Wisner et al., 2004) includes not only the capacity to cope, but also to resist and recover. This is not spelled out explicitly, but can be interpreted this way. Such an understanding of vulnerability concurs with the *'Climate Change and Global Environmental Change'* stream. However, exposure is not part of vulnerability, though a link between vulnerability and exposure is acknowledged (PAR: dangerous location). Explanations of vulnerability include the built environment, as well as social, economic, political, environmental and cultural structures in combination with people's socio-economic characteristics explain vulnerability (structuralist paradigm).

The BBC-framework, aiming at a combination of sustainable development, vulnerability and issues of environmental degradation, resides in between these two streams, which is probably the reason why coping capacity, 'vulnerable elements' and resilience remain fuzzy.

A third stream of vulnerability research is identified here, labelled *'Human Ecology'*, where vulnerability is generally defined as the degree to which a person, household or society is

³ <http://www.unisdr.org/eng/library/lib-terminology-eng.htm>, accessed 18.8.2008

susceptible to injury and damage (Burton et al., 1978, 1993; White et al., 2001). Exposure and resilience are not components of vulnerability, and risk is regarded as a function of exposure, hazard, vulnerability and, potentially, resilience. This conceptualisation is ultimately based on UNDRO's (1982) terminology (chapter 2), and as mentioned above applied in 'AS' and Alexander's model. Note that PAR and Access apply this conceptualisation of risk but include resilience (here the capacity to resist and recover) according to Wisner et al.'s (2004) definition into the realm of vulnerability. From a perspective of human ecology, resilience seems to be what is called 'absorptive capacity' (Burton et al., 1993: 54). This interpretation takes into account that absorbing is generally associated with resilience (e.g. Holling, 1973). 'Absorptive capacity' within this stream is not to be confused with adaptation and adaptive capacity as used in the first stream. Adaptation and adjustment are rather seen as processes which influence resilience/absorptive capacity: *'they create the level or capacity of individuals, managerial units, and social systems to absorb the effects of extreme environmental fluctuations'* (Burton et al., 1993: 54). While the 'Climate Change and Global Environmental Change' stream bases its synonymous usage of adaptation/adaptive capacity and resilience on this causative link, the 'Human Ecology' stream appears to treat them separately.

Within this stream, the degree of vulnerability causality expands along the following sequence:

- a mono-causal perspective focussing on hazard, where vulnerability of the built environment influences people's potential to be harmed (AS)
- a multi-causal perspective, with the built environment and people's perception influencing adjustment and adaptation, hence their vulnerability (Kates, 1970; Kates, 1985; Burton et al. 1978, 1993) and additional people's socio-economic characteristics (White et al., 2001). Alexander's model fits into this category since it displays a multi-causal perspective, and Alexander's work is generally affiliated with the 'applied sciences' approach.

Cutter's conceptualisation and terminology ('biophysical vulnerability', and in relation hazard and risk) though based on Hewitt and Burton's (1971) Human Ecology approach, is not compatible with any of the three streams.

The development of these three streams has not occurred in isolation of each other, as indicated by the similarities pointed out as well as the models which combine elements of several streams (PAR, Access, BBC). The 'Climate Change and Global Environmental Change' stream displays the highest degree of cross-fertilisation with (ecological or 'socio-ecological') resilience research.

A synthesis of the comparison and discussion provided here, in combination with a discussion of the resilience concept, yields a social vulnerability model developed for this thesis which is presented in chapter 7. This model draws mainly on the 'Human Ecology' and 'Development and Livelihood' streams, which add a multi-causal perspective to 'AS' approaches.

6. Resilience

'Building disaster resilient communities' could become the catchphrase of the early 21st century. From the Latin 'resilio', resilience translates as 'springing back' (The Concise Oxford Dictionary, 1995). Within the field of natural hazards and risk, resilience generally implies the ability to recover from damage inflicted by natural hazards.

Compared to the concept of vulnerability, resilience has overall received less attention throughout the history of hazard and disaster research (Buckle, 2006). This, however, is changing rapidly, with resilience enjoying growing prominence within the last decade or so (chapter 2). The delayed appearance of the resilience concept on the stage of natural risk research comes somewhat as a surprise, since its recognition within several disciplines can be traced back to the mid-last century at least. While vulnerability research has evolved into different facets and models (chapter 5), comparatively few resilience models are available for comparison within the field of natural hazards and risk research.

This chapter commences by expanding on the notion of resilience as introduced in chapter 2, followed by a more detailed review of how the resilience concept is interpreted from an ecological perspective and more recently transferred to so called 'socio-ecological systems'. Subsequently, several resilience models are introduced, discussed and compared. The comparison and conclusions drawn feed into a synthesis of both, resilience and vulnerability (chapter 7).

6.1 Approaching resilience: terminology and key characteristics

More than 25 years ago, Timmerman (1981) noted that the resilience term is used in a much more restricted way than vulnerability, suggesting that the term may therefore be more useful. Not surprisingly, this perspective has changed to a great extent. During its relatively short history, the notion of resilience has already gained much diversity: interpretations of what resilience means to whom differ (Carpenter et al., 2001). Additionally, resilience in relation to vulnerability is interpreted in various ways.

Comparable to the landscape of vulnerability research, Klein et al. (2003) observed an increasing number of disciplines that have been and still are getting involved with the resilience concept within the field of natural risk, interpreting and developing resilience according to their specific ontology. This poses similar challenges towards settling on a definition and explanation of resilience as faced in the case of vulnerability. In fact, the understanding of resilience with respect to vulnerability may be the greatest source of disharmony.

While some trace 'resilience' back to mechanical engineering, ecology and physics, Manyena (2006) observed that most literature refers to psychology and psychiatry of the 1940s as the cradle of the resilience concept: at the time these disciplines focussed on the negative effects that stressors such as war or divorce can inflict on children.

Manyena (2006) listed a number of definitions of resilience, from which the following keywords are extracted:

- *'capacity to absorb and recover'* (Timmerman, 1981; Cardona, 2003),
- *'capacity to cope'* (Wildavsky, 1991; Pelling, 2003),
- *'ability to adapt'* (Comfort, 1999; Pelling, 2003, ISDR, 2005),
- *'ability to withstand (without devastating losses, or a large amount of assistance from outside the community)* (Miletti, 1999),
- *'ability to respond'* (Kendra and Wachtendorf, 2003), and
- *'learning'/'anticipate and plan'* (Wildavsky, 1991; Paton et al., 2000; ISDR, 2005).

Interestingly, compared to the concept of vulnerability an implication of some form of measurement ('degree') is not included.

Within the field of mechanical engineering, Gordon (1978) described resilience as the ability to deflect under pressure without breaking. Within ecology, Holling (1973: 14) had previously defined resilience as a *'measure of the persistence of systems and of their ability to absorb change and disturbance and still maintain the same relationships between populations or state variables'*. From Holling's perspective, resilience can be assessed by the magnitude of disturbance a system can absorb until its fundamental structure is altered. Holling's influential definition introduced the aspect of measurement. 'Absorbing' here explicitly implies the process of changing variables within the system in order to maintain key functions of the system.

Holling's (1973) understanding of resilience was captured and developed further by the 'Resilience Network', an international conglomeration of resilience researchers today called the 'Resilience Alliance'. As expressed by Carpenter et al. (2001: 766), the Resilience Alliance suggests the following definition of resilience: *'(a) the amount of change the system can undergo (and implicitly, therefore, the amount of extrinsic force the system can sustain) and still remain within the same domain of attraction (that is, retain the same controls on structure and function); (b) the degree to which the system is capable of self-organization (versus lack of organization, or organization forced by external factors); and (c) the degree to which the system can build the capacity to learn and adapt'*. Compared to Holling's original comprehension of resilience, the ability of self-organisation, learning and adaptation are added and the definition of ecological systems is expanded to 'socio-ecological systems' (SES). Generally, 'SES' are systems of human-environment interaction and as such have since long been on the research agenda of such fields as human ecology and geography.

In the context of natural risk the International Strategy for Disaster Reduction (ISDR) adopted the resilience definition carved out by Holling and colleagues, describing resilience as *'The capacity of a system, community or society potentially exposed to hazards to adapt, by resisting or changing in order to reach and maintain an acceptable level of functioning and structure. This is determined by the degree to which the social system is capable of organising itself to*

*increase its capacity for learning from past disasters for better future protection and to improve risk reduction measures.'*¹

Wisner et al. (2004: 359), though not defining resilience explicitly, concentrated on the household scale and summarised the ability of a household to re-establish '*its livelihood, physical assets and patterns of access*' under this notion. Adger (2000: 361) focussed on the community scale and defined 'social resilience' as '*the ability of communities to withstand external shocks to their social infrastructure*'. Buckle et al. (2000: 13) (and Buckle, 2006) included the ability to prevent and mitigate losses as the first step towards resilience, followed by the capacity to '*maintain normal living conditions as far as possible, and thirdly to manage recovery from the impact*'. Tobin (1999) linked sustainable and resilient communities and sees them as '*structurally organized to minimize the effects of disasters, and, at the same time, have the ability to recover quickly by restoring the socio-economic vitality of the community*' (Tobin, 1999: 13). Similarly, King (2006) differentiated between mitigation (minimising effects) and recovery, but added the dimension of immediate response during and shortly after a damaging event, which can also be found in Paton's (2006) conceptualisation of resilience. King (2006: 300) concurs with Tobin (1999) when including the aspect of a fast recovery within the notion of resilience: '*the speed and extent to which a community bounces back from disaster is a measure of resilience*'. A quick recovery is also what Ronan and Johnston (2005) included into their conceptualisation of resilience. They underlined the role of prevention: low preparation levels potentially entail slow recovery. Ronan and Johnston (2005) further emphasised the need for a sustainable approach to fostering and building on the strengths within a community.

Three important aspects of resilience surface in the definitions and keywords so far:

1. The change of components ('absorbing') within a system, e.g. a community, in order to preserve its overall structure and quality (Holling, 1973, Timmerman, 1981, Holling et al. 1995, Carpenter et al., 2001, ISDR; 2005, Cardona, 2003).
2. The ability of self-organisation (Carpenter et al., 2001, ISDR, 2005), the inherent strength of a community or system, in the sense that no or only little support from outside is necessary to remain functioning (Miletti 1999, Ronan and Johnston, 2005).
3. Recovery (Timmerman, 1981, Buckle et al., 2000, Cardona, 2003, Buckle, 2006), also Watts and Bohle (1993) and Bohle et al. 1994 (chapter 5); fast recovery (Tobin, 1999: Ronan and Johnston, 2005; King, 2006), which is also indicated by the word resilience itself, translating into 'springing' back.

It should be noted that especially within the stream of 'Climate Change and Global Environmental Change', the term 'coping' or coping capacity is used in the sense of 'adapting' or adaptive capacity which tends to be used interchangeably with resilience. In contrast within the 'Development and Livelihood' stream, 'coping' refers to the internal side of vulnerability and

¹ <http://www.unisdr.org/eng/library/lib-terminology-eng%20home.htm>, accessed 23.6.2006

is associated with 'capability' or 'capacity' (chapter 5, section 5.3). 'Responding' is a term that is generally used to bracket all responses to natural hazards, i.e. adjustment and adaptation (chapter 2). Therefore both, coping and responding do not add clarity with respect to a clear definition of resilience and differentiation from vulnerability.

Considering this multi-disciplinary background of how resilience is interpreted, aspects such as 'resisting' or 'withstanding' are in conflict with an ecology-based notion of 'absorbing' impacts *through* changing, hence implying flexibility rather than rigidity. Especially with respect to the non-linearity, hence uncertainty, of system responses, this flexibility appears to be more important than resisting or withstanding. Even more so, with respect to the notion of vulnerability the ability to remain functioning although being wounded is clearly a characteristic of resilience. In addition, within the realm of hazards and disasters a fast recovery should be an element of resilience. Generally it is preferable when households and communities re-establish their well-being and livelihoods quickly. This is where the application of resilience as seen from an ecological viewpoint is difficult, since a short recovery time is dismissed as 'engineering resilience' and not regarded as applicable to ecological, or socio-ecological systems. A quick recovery should not imply an obligatory return to a previous status quo, but can include new activities which promote resilience in the long-term.

A synopsis of these aspects is to define social resilience as the *ability to maintain social functions and to recover from adverse effects of natural hazards on physical and mental health as well as (re-)building livelihoods (income opportunities, assets, savings) quickly. This ability to maintain and recover is related to the degree of utilising resources within the social, economic, institutional, political and environmental dimensions.*

As with the concept of vulnerability, the concept of social resilience appears to be multi-dimensional, including the built environment, economic, institutional, political and environmental dimensions (chapter 7). While some argue the built environment per se cannot be resilient because it is not able to adapt or learn (D. Paton, email-correspondence with Manyena, 2006: 443), others prefer a broader view on systems. From this perspective, humans as closely tied to their natural and built environment producing one system, which then can be characterised by low or high resilience (D. Mileti, email-correspondence with Manyena, 2006: 444). Both views are certainly justified, however they are not conflicting; for example, while a road is not resilient as such, but characterised by a certain degree of vulnerability, the importance of the built environment and especially infrastructure serving mitigation, communication, and recovery is profound. Hence the functioning of the built environment plays a role on the scale of community resilience, as underlined by McEntire (email-correspondence with Manyena, 2006: 444). In addition, with respect to the ability to 'bounce back', some infrastructure, for example those designed to include automatic backup systems, may be labelled as 'resilient'.

With respect to the definitions and keywords listed above and Tobin's, King's, Ronan and Johnston's and Paton's perspectives on resilience, three phases of resilience are differentiated:

- pre-impact (learn, anticipate and plan)
- during impact (absorb, cope, maintain, react)
- post-impact (recover, learn, anticipate, plan).

As touched on above, these three phases are interlinked. For example, the ability to react during an impact depends on the level of preparedness which is in turn influenced by the ability to learn, anticipate and plan. Likewise, preparedness influences the ability to recover (or bounce back, react). Along a timeline, the ability to recover will influence future ability to plan and cope (see also Paton's resilience model, section 6.3.2). The linkages between mitigation and recovery are underlined for example by King (2006) and Manyena (2006), when recovery activities as a form of adaptation lead to the implementation of mitigation and preparedness measures based on previous experience. Such adaptive recovery is more sustainable than re-establishing the exact status quo – 'getting back to normal', a point also emphasised by Ronan and Johnston (2005). Note that within the field of 'Climate Change and Global Environmental Change', adaptation and coping are used interchangeably (chapter 5). Furthermore, adaptation is usually contrasted with mitigation (Smit et al, 2000; McCarthy, 2001; IPCC, 2001; IPCC, 2007b, c). Mitigation, when based on the legacy of human ecology, can be seen as a form of adjustment or adaptation (chapter 2).

Like vulnerability, resilience is to some extent 'generalised', meaning that a range of factors apply regardless of hazard type. For example, strong social networks will ease the adverse effects of floods as well as landslides. However, as Paton (2006) pointed out, some resilience aspects will vary with hazard type, influenced for example by the speed of onset, the duration of hazard and its degree of irreversibility. As Paton et al. (2006) exemplified, sudden and fast moving physical processes such as wildfires bear different implications for building adaptive capacity as compared to insidious and potentially irreversible environmental degradation such as salinity. Resilience is therefore also context-specific, this means that it differs according to hazard type, the fabric of a community, and the point in time of interest (King, 2006).

Although social resilience research can target individuals or households, the key characteristics necessary for not 'breaking' under pressure seem to stem from variables which also manifest on a higher scale, for instance the community. As mirrored by the definitions summarised above, the community as the object of resilience features frequently. Paton et al. (2006) referred to the concept of 'competent communities' drawing on resources in order to bounce back when adversely affected, but underlined that the individual's capabilities should not be ignored. It is rather the combination of individual and community characteristics which together shape resilience: both, of the individual as a member of the community and the community as a whole. This combined perspective is what the notion of 'social system' can express. As King

(2006:293) concluded: Resilience is a *'characteristic that grows out of the people and their communities.'*

A point to add here is that although the inner strength of communities, their self-reliance and self-organisation, is often underlined within the context of resilience, communities should not be left to defend themselves (Paton, 2006), but benefit from support which can be offered from state institutions or other organisations, such as NGOs.

While some see resilience as the new paradigm, others regard it more as an accomplishment to vulnerability and risk, mirroring tendencies in the hazard and disaster discourse which have been there before (Manyena, 2006). The term 'vulnerability' is frequently critiqued for implying, intentionally or not, a sense of people or society as passive and weak. Within a development context, people suffering from hazards and disasters are often labelled as 'victims', a term that carries associations of helplessness and dependence on external powers (Cuny, 1983). The cause for their condition is regarded as related to the social context rather than individual behaviour (Hewitt, 1997). Their capabilities, when existent, are often seen as overruled by top-down relief organisations based in western countries. This view dominates in the structuralist paradigm (chapters 2, 5). In contrast, the resilience concept is associated with emphasising people's strengths, for instance local knowledge, as a valuable contribution towards coping capacity (Bankoff, 2004a). People are not so much seen as victims, but as pro-active agents within a community who have the power to help themselves in a situation of crisis (Fordham, 2004). It is for the more positive connotation that some researchers call for focussing on resilience rather than vulnerability (Handmer, 2003). However, Buckle's (2006) view that both concepts are crucial for understanding hazardous situations and disasters is shared here.

The notion of vulnerability and resilience as two ends of the same spectrum (reciprocals), as observed by Timmerman in the early 1980s, is present in current research, for example in Bohle (2005), King (2001, 2006) and Handmer (2003), and at the international organisational level. However, this view is contestable (chapter 7).

Although resilience is far from being interpreted and applied homogeneously, its introduction into the hazard and disaster discourse has not entailed the same level of conflict between competing worldviews compared to the entrance of the (social) vulnerability concept into the science and technology dominated scene of the 1970s (chapter 2). Resilience is often associated with sustainability, and applied within the context of social justice and political ecology. Therefore, resilience shares a similar worldview with the livelihood/structuralist vulnerability paradigm, and together they have profoundly altered the view on hazards and disasters.

6.2 Resilience from an ecological perspective

This section is devoted to outlining the resilience research that has its origin in ecology. Because the resilience comprehension as expressed by the ISDR is strongly influenced by the

Resilience Alliance's definition, hence has entered the field of natural hazards and disasters, its origin, implications for ecosystem management and its further development is summarised and discussed in the following. Based on ecological research, the resilience notion later expanded to include resilience of coupled ecological and social systems, so-called 'socio-ecological systems' (SES), and it is this 'socio-ecological resilience' which is reflected by the ISDR. The role of SES with respect to finding a theoretical base for risk studies is discussed in appendix B.

Holling's (1973) original conceptualisation of resilience is founded on his own ecological research and a range of case studies he draws upon to build his argument. Memorising his definition cited above, the degree of a system's resilience depends on the magnitude of disturbance it can absorb and still persist. One of the case studies Holling referred to is the sudden collapse of the trout population in Lake Michigan that had been harvested at a high yield for more than forty years. The appearance of the sea lamprey, though small in numbers, was identified as the trigger of that collapse. This disturbance within a situation of maximum harvesting pressure and possibly predatory stress imposed by other species caused the trout population to switch from one 'domain of attraction' to another: from a large population towards near extinction. The 'domain of attraction' is characterised by stability (also called 'stable equilibrium') and in subsequent works is referred to as 'stability domain'. In this example, the trout population was not resilient: a small impact magnitude could not be absorbed. It had lingered for a long time at the boundary of its domain of attraction, from where it suddenly flipped into another domain. This must have caused much surprise within the fishing industry, since the industry did not see the disaster coming.

Another example Holling (1973) referred to are arid cattle grazing lands in the western States of the U.S., which became slowly invaded and finally dominated by shrubs and trees. This change of grassland to shrubs and trees, hence the shift from one domain of attraction to another, was triggered by the combined effect of grazing pressure and fire prevention which favoured shrubs and trees compared to grassland. It appeared that once the trees had established themselves, a grazing stop would not necessarily entail the recovering of a grassland system. The conversion from grassland to a shrub and tree dominated ecosystem therefore occurred slowly and, without major shrub and tree reduction, irreversibly.

While so far Holling's comprehension of resilience is quite clear and accessible, some inconsistencies appear when following his continuing argumentation. On the one hand non-resilient systems, located close to the boundary of their stability domain, cannot absorb even small disturbances, and consequently would switch to another stability domain. They do not have the ability to absorb disturbances by internally changing their system configuration. Resilient systems would persist by absorbing disturbance through altering their configurations. On the other hand, following Holling's (1973) ongoing argument, this change of configuration can include a switch not only between different stability states within one domain of attraction, but *between* different domains: systems can '*move from one domain into another and so persist*

in a changed configuration' (1973: 10). Holling underlines this point when referring to the existence of several domains of attraction and alterations between them (1973: 15): *'instability, in the sense of large fluctuations, may introduce a resilience and a capacity to persist'*. This notion of resilience therefore would include that systems can also alter between different stability domains and still be resilient – it in fact implies that only through even larger changes the system persists and is resilient. This, again, concurs with the first argument: Persisting through change. Therefore systems could be considered resilient when they persist over longer time periods while undergoing larger changes, although they have lost the ability to absorb even small disturbances. Hence systems would be resilient and non-resilient at the same time.

Additionally, the trout population example is not very suitable to illustrate a lack of resilience. According to Holling's ongoing comprehension of resilience, this example would actually represent resilience. The trout population plummeted from a high number of trout to a very small amount close to extinction. What Holling identified as a new domain of attraction was a population close to extinction, but not extinct, which means that the trout population as such persisted, only on a different level, and therefore would be regarded as resilient. It changed between several stability states within the same domain of attraction.

The question of ecological resilience seems to be tightly associated with time. A system might, on a very long time scale, return to its defining configuration, for example grassland converting to shrubs and trees, and back to grassland. Hence in the long-term, it can be described as resilient. Moreover, Walker and Abel (2002) illustrated that for a defined period of time, a system can maintain its biophysical and socio-economic functions, while the system progressed through several different configurations or 'stability states'. As Walker and Abel (2002) concluded, the judgement regarding whether a system persists or ceases to maintain its key functions depends on the time scale chosen by the observer. Ecological resilience is therefore a time-dependent concept. This argument appeared within the context of system theory in chapter 4.

Another aspect Walker and Abel (2000) carved out is that the characterisation of a system as resilient depends on which function is defined as the key characteristic of this system. If, for instance, the function of a land-use system is to produce wool, a change from shrubland supporting sheep to grassland supporting sheep does not necessarily imply a loss of wool production, as Walker and Abel (2002) added. Therefore, whether a system is resilient depends not only on the timescale chosen but also on the function, goal or purpose that has been defined for that system, which, at least for ecological systems used by humans, depends on the observer.

In conclusion, should Holling's (1973) notion of resilience as outlined above entail only changes between different stability states within one domain of attraction, there would be no contradiction to his first argument which is basically changing to persist: the degree of absorbing, of altering between different stability states within one domain of attraction or

functional state would then indicate which magnitude of disturbance is buffered before a switch to another domain occurs. Switching between different domains of attraction, i.e. between functional states, however would not meet the criteria of a resilient system since the key system function ceased to exist. As Holling and Gunderson (2002: 26) stated: '*multiple equilibria* [i.e. domains of attraction] *define functionally different states*'. Only on a long time scale, where the system fluctuates between different domains and has therefore the chance to regain its defining state, e.g. grassland turning into trees and shrubland, and converting back to grassland, can such a fluctuation be interpreted as resilient, but not during a much shorter time span within which it has lost its key function. From Holling's (1973) overall resilience notion, only alternating stable states within one functional domain, where the degree of resilience manifests as the amount of disturbance that can be absorbed while maintaining its function within that domain, is supported here. Subsequent authors appear to restrict the notion of resilience anyway to changes between different stability states within one domain, not necessarily between different domains (e.g. Carpenter et al., 2001; Walker and Abel, 2002; Walker et al., 2006).

Holling's (1973) overall argument leads to his key proposition that focussing on stability, which is associated with states of equilibrium, does not reflect the reality of ecological systems which are subject to changes. This proposition is channelled into later works where 'ecological resilience' is contrasted with 'engineering resilience'.

Holling (1973) defined stability as '*the ability of a system to return to an equilibrium state after a temporary disturbance*' (p. 17). He continued that stable systems return quickly to a state of equilibrium with a minimum of fluctuation. Defined this way, stability concurs with the notion of 'engineering resilience'. As Holling (1996) and Holling and Gunderson (2002) stated, 'engineering resilience' focuses on the amount of time a system needs to regain its equilibrium after it has been disturbed – the faster it recovers, the more resilient it is. Holling and Gunderson (2002) criticised that 'engineering resilience' concentrates on systems at equilibrium or near equilibrium. 'Engineering resilience' in the context of ecosystem management would therefore imply the re-establishment of the desired status quo, which is for example the maximum harvest of lake trout, by means of control and prediction. This leads on from Holling (1973) who, arguing from experience with equilibrium oriented mismanagement of ecosystems, criticised the focus on equilibria. Against a background of increasing demand for economic development and consequences such as pollution and species endangerment, he doubted that concentrating on equilibria and near-equilibrium conditions is an adequate reflection of the world. If one assumes 'predictable' conditions which are free of surprises, and as a result not influenced by enhanced external variability, then inconsistency can be measured and quantified. It is not only possible to identify those situations where a constant goal (e.g. a certain level of harvest) is not met, but also to quantify the amount by which the goal is not met. However, if one incorporates non-linearity and unpredicted and external changes, constancy of performance is not so much the focus, but rather the persistence of a system as such. This implies a shift towards a qualitative approach where it is less an exact status quo, and more the

quality of the system and its persistence that is the goal. The notion of 'ecological resilience', in contrast to 'engineering resilience', does not necessarily imply the re-establishment of the status quo and underlines that the system can alternate as long as it persists in its function: it can switch between different stability states (e.g. varying numbers of trout in a lake) within one domain of attraction.

Holling (1973) concluded that a system can either be very resilient but unstable, or it can be very stable but has lost its resilience. Conditions characterised by changing extremity, for example variable extreme climatic conditions, tend to produce unstable but resilient systems with a high ability to absorb extreme fluctuations while system variables fluctuate. In contrast, systems operating under more stationary conditions tend to be less diverse and more stable but are less capable of absorbing climatic extremes, hence they are less resilient. At this point Holling (1973) refers to evolutionary history as a generator for resilience in natural systems.

In this context, diversity, for instance of external conditions, is seen as a key to ecological resilience. Resilience is, for example, fostered if the level of biodiversity is high. High biodiversity is an insurance mechanism (Folke et al., 1996 in Berkes and Folke, 2002) because it creates what is sometimes titled as 'redundancy'. Redundant species provide overlapping functions, which is enormously important for recovery after a disturbance because a larger pool of possible responses can be tapped and support the opportunity for innovation. Similar to ecological systems, manifold (seemingly redundant) adaptive or coping options within social systems are related to a high level of resilience (Berkes and Folke, 2002; Folke et al., 2002). Without drilling deeper into this discussion, exceptions to rather linear relationship of high diversity and high resilience in ecosystems have been identified (Adger, 2000).

Holling (1973), with respect to ecosystem management, stressed the need to acknowledge diversity of adaptive strategies. By promoting the notion of ecological resilience, Holling argued for a worldview which emphasises the unknown, which does not aim to exactly foresee the future but which builds on the *'qualitative capacity to devise systems that can absorb and accommodate future events in whatever unexpected form they may take'* (p. 21). This call for a shift from 'command-and-control' to adaptive management is underlined again much later by Holling and Gunderson (2002) and Westley et al. (2002). Rigid methods of controlling change, for example by forcing natural and social processes into a desired direction which fixes overall system conditions, is regarded as corrupting resilience (Folke et al., 2002). As Folke et al. (2002) pointed out, flexible management which is open to learning and which faces uncertainty, unpredictability and complexity is better equipped to face crisis because it builds resilience. As a manager of a multinational company stated: *'The future is moving so quickly that you can't anticipate it. [...] We will continue to be surprised, but we won't be surprised that we are surprised. We will anticipate the surprise'* (Malhotra, 1999 in Folke et al., 2002: 11).

This focus of research on transient systems and the implications for their management is also shared by other disciplines such as geomorphology and discussed for example in Brundsen and Thornes' (1979) 'Landscape sensitivity and change'. Also, Warner (2003) observed signs of adaptive flood hazard management acknowledging non-linearity and uncertainty. These aspects are important for understanding risk, because they assist in understanding system behaviour as presented and discussed in chapter 4.

In summary, promoting a perception of transient rather than static systems, non-linear behaviour, surprises, focussing on diversity and functional redundancy, as well as adaptation as a driver for resilience, is certainly of high benefit when seeking a comprehensive understanding of resilience. Ecology based resilience research has therefore contributed to a great extent towards a broader and more dynamic conceptualisation of resilience, which for example precipitated in the ISDR's perspective on resilience.

This understanding of resilience can be adopted for social or 'social-ecological' systems. Within this thesis, a system (a community) is therefore regarded as very resilient if it can absorb, including changing of its inherent settings, larger natural hazard impacts while maintaining its community functions. A focus on changes and on how increasing diversity can foster resilience would then be a key element of risk management.

It has to be underlined that natural risk management, aimed at reducing overall loss and damage, operates at much shorter timescales than ecological timescales. A community might re-establish its functioning within fifty or more years after it had been adversely affected, however this cannot be acceptable when aiming at reducing risk and sustaining livelihoods on a human timescale. The long ecological time scale needed for eventually reaching overall persistence by reversing to a former system state is not applicable within a field where risk reduction should be as effective as possible, as soon as possible. This is not to say that sustainable solutions targeting long-term resilience are excluded. The difference of relevant time spans illustrates that caution is needed when transferring ecological to social applications – it can, in fact, become quite cynical.

6.2.1 Resilience – resistance – robustness

A term which needs to be distinguished from the concept of resilience is 'resistance'. 'Resistance' to change is a system attribute which implies that the system is immune and not affected by a disturbance: *'the extent to which a disturbance is actually translated into impact'* (Adger, 2000: 349). For example, if the element of interest within a rangeland system is the biomass underneath the surface, which say constitutes 80% of the total biomass, this 80% is resistant to grazing pressure while at maximum only 20% can be disturbed. In this case, the system is resistant rather than resilient. However, if the element of interest is the biomass above ground, 100% can be disturbed. In this case, the resilience of the system can be generated by utilisation of below ground, resistant biomass which can operate as a seed bank and enable recovery. Hence though they are different concepts, resistance and resilience are interrelated

(Walker and Abel, 2002). In the rangeland example, the resistance of the system is based on a lack of exposure: the underground biomass was not exposed to grazing and therefore could not be damaged. However, it could be argued that resisting something does only apply when actually being exposed to something – ‘avoiding’ might be the better term for the example above. By developing this example further, one could imagine that plants armoured with spikes or other defence mechanisms would resist grazing pressure. In this case they would be exposed, and exposed to the same extent as plants without a defence mechanism, but they would withstand the perturbation much better, hence resist. Against this background, including resisting as a defining feature of social resilience, as for example proposed by Dovers and Handmer (1992: 267) (‘resilience type 1’) seems deceptive.

Transferring the notion of resistance into the field of natural hazards and disasters, it appears that resistance is linked to structural mitigation. Structural mitigation measures such as reinforced housing designs can increase the ability to ‘withstand’ stressors such as a landslide or an earthquake. It is therefore very likely that the often used notion of ‘withstanding’ is interpreted in the sense of resistance. This, however, relates to vulnerability rather than resilience because the overall damage potential is altered. Nevertheless as will be fleshed out in greater depth in chapter 7, resistance/vulnerability and resilience are linked.

The term ‘robustness’, recently brought into the discussion in the context of ‘socio-ecological systems’, seems to concur with the notion of withstanding perturbations without changing system components (Anderies et al., 2004). However, as Young et al. (2006) stated, the discussion about the notion of ‘robustness’ is far from completed and sometimes heated. Gallopin (2006) also recognised the ongoing debates about robustness and used it as the opposite of vulnerability.

6.2.2 Resilience – adaptive capacity – adaptation

At least within the field of ‘Climate Change and Global Environmental Change’, resilience and adaptation, or adaptive capacity, are so closely linked that they are used interchangeably (chapter 5). However, this link appears to be interpreted as running in two different directions: from resilience towards adaptive capacity, or vice versa as discussed in the following paragraphs.

Within ecology, resilience is often regarded as a component of adaptive capacity (Manyena, 2006), hence resilience would influence overall adaptive capacity. Klein et al. (2003), arguing from the context of climate change, concurred with this view, and criticised the application of resilience as an ‘umbrella concept’. This understanding of resilience and adaptive capacity is reflected by Folke et al. (2002: 17) who extend the notion of adaptive capacity from ecological to socio-ecological systems as *‘the ability of a socio-ecological system to cope with novel situations without losing options for the future, and resilience is the key to enhancing adaptive capacity.’* Also Berkes and Folke (2002: 146) reported experience with local institutions where small disturbances can foster ‘socio-ecological resilience’, which in turn promotes adaptive

capacity to deal with larger disturbances. Hence resilience appears to be a stepping stone towards the path of overall adaptive capacity.

The question of whether resilience influences adaptive capacity or adaptive capacity shapes resilience is tied to the question of whether resilience is an attribute of the overall system or refers to elements within the system as for example argued by Klein et al. (2003). For example, if one assumes that 'adaptability' equals 'adaptive capacity' (Smit et al., 2000; Gallopin, 2006; Smit and Wandel, 2006; chapter 5), Walker et al. (2006: 3) defined adaptive capacity as the *'capacity of the actors in a system to manage resilience'*. This definition implies that adaptive capacity influences resilience, not resilience adaptive capacity. Walker et al. confirm this interpretation later when pointing out that adaptive capacity depends on people managing these systems, and that these activities influence resilience. This comprehension does not appear to be an isolated perspective, since Walker et al. based their argument on Berkes et al. (2003). Also Folke et al. (2002: 13) in their definition of resilience based on Kaspersen et al. (1995a) imply that adaptive capacity influences resilience: *'resilience owing to adaptive measures to anticipate and reduce further harm'* – which, in fact, contradicts their position above. Resilience seems to be an overall system attribute or 'outcome' of an adaptive process, which is influenced by adaptive capacity and actual adaptation. This view concurs with Holling's (1973: 17) original understanding of resilience, which he saw as an overall system property. This matches also with the Resilience Alliance underpinning that adaptive management is the key to resilience and sustainability and the resilience definition supplied by Carpenter et al. (2001).

Finally from a human ecology perspective, Burton et al. (1993) argued that adaptation and adjustment influence what they call 'absorptive capacity'. This is interpreted here as resilience, considering that absorbing is associated with resilience (chapter 5, section 5.3). Hence the ability to adapt (and adjust), i.e. adaptive capacity influences resilience.

6.3 Models of resilience

6.3.1 Tobin

Tobin's (1999) conceptual framework of resilience combines three different models: the mitigation model (Waugh, 1996), the recovery model (Peacock and Ragsdale, 1997), and the structural-cognitive model (Tobin and Montz, 1997) (figure 6.1). By linking these three models, Tobin underlined the interconnectivity and complexity inherent in resilience studies. Tobin referred to Bates and Pelanda (1994) and Hewitt (1983) as the source of ideas related to ecology and political economy and human ecology as the basis for his conceptual framework, respectively.

By including mitigation as a process during the pre-impact phase, the possibility to reduce risk through reducing exposure, which is a form of adjustment, is included within the mitigation model. Structural mitigation measures such as levees provide protection for communities up to the level for which they are designed. Tobin referred to Waugh (1996) who draws on

Mazmanian and Sabatier's (1983) guidelines to prevent mishaps with such mitigation efforts. For example, to successfully implement the guidelines, Mazmanian and Sabatier recommend that skilled agencies with sufficient resources should guide mitigation programmes, and that clear policy objectives should be identified, without them being undermined over time.

Figure 6.1: Tobin's framework of analysis (1999: 14)

As Tobin pointed out, since in many situations hazards cannot be modified, a fast recovery plays an important role in generating sustainable and resilient communities. Recovery should not imply a simple re-establishment of pre-disaster conditions (getting back to 'normal'), but should foster local participation and aim for long-term recovery which takes into account the socio-economic and structural situation of a community. According to Peacock and Ragsdale (1997), recovery should focus on '(1) re-accumulation of capital and physical infrastructure; (2) policies and programs of governmental agencies, private organizations, and businesses among others; and (3) resource distribution' (in Tobin, 1999: 15). One element Peacock and Ragsdale stressed within the recovery process is the role of social networks, which can improve re-accumulation of capital. The recovery process should acknowledge the often inhomogeneous distribution of resources within a community, which can be rooted in socio-economic

marginalisation of some groups – which will have more difficulty to recover than groups which are not marginalised (chapters 5, 8).

The third model which Tobin includes in his resilience framework aims to capture alterations in a society's structure with time, and also in the way a society perceives hazards on a daily basis. This 'structural-cognitive' model acknowledges that the cultural, political, social and economic settings within a society can hinder or encourage actions of risk mitigation and the development of sustainable, resilient communities. Additionally factors such as age, household structure, economic status, gender, ethnicity, education, and neighbourhood characteristics will lead to differences in building resilient communities (Tobin, 1999: 15) (chapter 8).

By joining the three models, Tobin (1999) underlined that only planning, which incorporates risk mitigation (structural and non-structural) and long-term sustainable recovery can build resilient communities. Furthermore, only planning which takes into account the structural and cognitive settings of a society or community, and how they influence the success of recovery, is advisable.

Tobin accomplished his rather general model with seven concrete suggestions of how a resilient community should be characterised. Among these, he listed reducing vulnerability by tackling social inequities and support for marginalised groups, as well as knitting strong horizontal and vertical social networks. He also addressed the links between different scales by incorporating multi-scalar planning in order to accommodate implications of global processes influencing the local scale – for example the implications of multi-national or global companies with establishments on the local scale.

Tobin's framework is an effort to capture the complexity and interconnectivity of the factors and processes which constitute a resilient community. By strongly linking resilience with sustainability, he stressed the importance of a long-term perspective, therefore underlining the need for incorporating the element of time. Furthermore, Tobin differentiated between two time periods: the pre-disaster mitigation phase, and the post-disaster recovery phase. Their linkage is not explicitly incorporated in the model, however implicit in underlining that recovery should not be aimed at re-establishing the pre-disaster status quo.

Tobin's framework clearly displays the heritage of the human ecology school of hazards research by incorporating in his mitigation model a combination of structural and non-structural measures, combined with an understanding of the physical processes, as a key element. In the model, this is accomplished by political actors and agencies operating within the field of mitigation. The mitigation model addresses the ability to 'withstand', which is a constable element in Tobin's resilience definition and intersects with the notion of vulnerability and its opposites resistance/robustness (section 6.2.1).

Equally influenced by structuralist vulnerability research, as well as sustainability research, is the recovery model, which incorporates the notion of social networks. This model accounts for the 'quick recovery' element in Tobin's resilience definition. Again, a possibility to carve out similarities with already existing approaches in vulnerability research is not realised; although Tobin explicitly refers to Hewitt (1983) (for example) as one source of ideas underlying his overall framework.

A combination of different paradigms is the 'structural-cognitive' model, which brings together elements of structuralist vulnerability research and perceptive and 'behavioural' elements of the human ecology school. Tobin's resilience framework therefore combines the insights gained from several schools of thought which traditionally deal with vulnerability: the human ecology school with some of its principles influencing Hewitt's socio-political interpretation, and the structuralist paradigm predominately related to more recent vulnerability and development research. The benefit is a more holistic, balanced view on how disasters can be mitigated.

This benefit is limited to some extent because it does not explicitly explain the relation between vulnerability and resilience, and seems to assimilate elements of vulnerability into the resilience notion. The way vulnerability is incorporated into the notion of resilience is therefore a central point of criticism. In the model, resilient communities are characterised by 'low' vulnerability. However, this linear assumption is not necessarily valid since vulnerable communities can be resilient and non-vulnerable communities can be non-resilient, as for example Paton et al. (2006: 195) and King (2006: 298) stressed. Generally, within Tobin's model, the difference between resilience and vulnerability is somewhat fuzzy: while a combined approach is generally beneficial, it is not quite clear how for example the situational factors manifest as resilience rather than as vulnerability.

In addition it is not evident how the 'situational factors' influence the policy levels of the mitigation and recovery model. The role of infrastructures is only potentially mentioned but not explained by referring to Peacock and Ragsdale's recovery model (point one 'physical infrastructure'). A final point of criticism regarding Tobin's resilience framework is the way scale is incorporated. Generally, although Tobin refers to the important link between global/national and local scales, this is not well implemented. The framework operates either solely on the governmental/agency level (mitigation model), or is intermixed with the household scale (recovery model). Hence a clear structure of the scales themselves, and how local, regional and national/global scales interact, is not supplied.

6.3.2 Paton

The differentiation between scales, as well as their linkages, is discussed with more depth in Paton's (2006) resilience model (figure 6.2). He distinguished between three scales. Firstly, the personal level which is characterised by resilience factors such as specific experience, skills and self efficacy. In addition, a commitment to the community can operate on this level if the personal sense of community is high. On the second level, the community, cooperation between individuals can increase overall resilience, for instance through 'collective efficacy', as well as

combined capacity and social support. If structures enabling communal decision making and organisation of task exist, participative processes are encouraged which can foster resilience. Ideas can be more easily communicated within the community and transferred to higher levels of institutional hazard management, as compared to a lack of mechanisms of communication and decision-making. Finally, on an institutional level the appreciation and support for community action can foster resilience.

Figure 6.2: Paton's resilience model (Paton, 2006: 311)

Paton's resilience model is guided by the differentiation between these three spatial scales, while illustrating the linkages between those scales and how they apply according to the pre- and post-impact phase, as well as the period during immediate impact (the first three days or so, or even longer). Paton aimed at illustrating that these three temporal scales are interrelated: the pre-impact phase, where for instance mitigation measures have been implemented, influences what happens during immediate impact: whether a house has been reinforced or not will play a role in the well-being of its inhabitants, and consequently their response and recovery. Household preparedness during the pre-impact phase, such as stocking up emergency supplies and designing an emergency plan, will equally play a role with respect to what happens during the impact and with respect to people's self-reliance. Here, Paton touches on the possible interrelations between vulnerability and resilience, however without exploring this further.

According to Paton, adaptation occurs before, during and after a community has been impacted by a hazard. In this sense mitigation measures, such as structural strengthening of a house, are part of the adaptation process. According to Paton, preparedness as an adaptive action highly influences coping capacity during an event, and can be undertaken at a personal and community level. Shortly after an event, communities will rely on their adaptive capacity in order to deal with the impact. 'Collective capacity' can support dealing with damage and loss, which involves mutual support through skills and knowledge, and which can be fostered by risk management, for instance when organising volunteers. During the post-impact phase, Paton

regards a growing interaction between the community and risk management agencies as a key to enhancing adaptive capacity, and as a result resilience.

Paton's model is therefore multi-scalar and multi-temporal, with relations not only within different spatial scales and temporal scales but between spatial and temporal scales - although the temporal implications are not included in the graphical translation of figure 6.3. In an overall overview model including hazard and risk, both resilience and vulnerability follow this structure (figure 6.3).

Figure 6.3: Paton's model of risk (2006: 308)

When explaining resilience (figure 6.2), Paton emphasised the linkages between the spatial scales where resources, such as self-efficacy and local knowledge, are generated and exchanged in order to enhance cooperative action, hence adaptive capacity. Such 'collective efficacy' (p. 310), by exceeding the sum of individual resources, can be stimulated by risk management which facilitates such exchange of resources, addresses inequality and fosters social justice. Risk management can also empower communities by involving them in decision-making processes. For instance empowerment can occur when settling on which level of risk is acceptable and which mitigation strategies should be implemented. Emergency managers can play an important role as facilitators implying that they guide and support bottom-up engagement rather than command and control activities.

Paton equated adaptive capacity with resilience, which concurs with what Tobin (1999) categorises as mitigation and recovery. However, while from this perspective Tobin's model can be interpreted as a risk and risk management model, Paton restricts his framework to factors which influence resilience. By doing so, his model introduces factors which explain resilience in greater depth compared with Tobin's framework.

Additionally, Paton puts resilience in the context of vulnerability and risk. Both, resilience and vulnerability are represented by similar temporal and spatial scales, which is very beneficial when seeking a comprehensive understanding of both, resilience and vulnerability. Paton defined risk as the product of likelihood and consequences. This concurs with the understanding of risk in this thesis. According to Paton, consequences are the product of resilience (gains) and vulnerability (losses). He pointed out that originally, the notion of risk does not only imply potential loss but also potential gain (chapter 3). Although strictly speaking resilience does not account for 'gains' as such but rather limited loss, the mutual comprehension of how resilience and vulnerability shape risk is very beneficial and will resurface in chapter 7. As will also be seen in chapter 7, the relationship between vulnerability and resilience can be looked at in a more differentiated way, meaning with respect to the magnitude of the natural processes.

The graphical translation of Paton's resilience model illustrated a nested structure, demonstrating that the scale 'personal' rests within 'community', and both rest within the 'institutional' level. This indicates scale linkages independent of a certain time frame (before, during, after an event) which certainly exists: for instance the influence of institutional and environmental settings on household or community characteristics. This would address the deeper causation of people's resilience. Paton only touches on this level of explanation when stating that adaptive capacity is exhausted once the resources a community relies on are depleted. Hence, it appears that scale linkages independent of disaster phases are sacrificed for the benefit of an eminent linkage between spatial and temporal scales, which nevertheless, is quite helpful.

Unfortunately some of the terms in Paton's model (figure 6.2) are not explained in the accompanying text ('procedural and distributive justice', 'protective factors', 'power', 'environment - behaviour links'). In particular, it is unclear whether 'environment' carries an ecological meaning: while the model emphasises the social and institutional environment, the role the 'natural' environment plays in resilience is not addressed. Equally, the role of infrastructure is not covered within the model.

In conclusion, Paton's resilience model has much to offer: it is multi-scalar and multi-temporal, underlining the dynamic nature of resilience. The variables influencing resilience carry much explanatory potential (chapter 8). Adaptive capacity features as a prominent factor within Paton's model, which is a very valuable approach. Furthermore, the model's design is open to different contexts, which assures its applicability for different hazards and cultural backgrounds. However, the role of the 'natural' and built environment, especially in terms of a sound ecological base for livelihood, the quality of natural resources and the role of infrastructure with respect to resilience, is not incorporated. Paton's risk model displays first steps towards a holistic comprehension of both resilience and vulnerability, which is however not explored further.

6.3.3 Buckle

Not designed as a model as such, but carrying much explanatory quality is Buckle's (2006) 'functional resilience assessment'. Buckle (2006) characterised resilient communities as being able to adapt to changes and as having mechanisms in place to monitor and assess these changes, such as community consultation, audit and feedback. In his assessment design, resilient individuals, groups and communities are identified according to how well they 'own' the following attributes or functions (p. 96):

- Information and advice on preparedness and assistance measures, and how to access them; dealing with the event physically and mentally
- Resources: financial capital for prevention, preparedness and recovery; physical goods such as household items, alternative accommodation, transport or tools
- Management capacity: time and opportunity to manage activities which generate resilience, and the physical capacity to do so; access to services and support systems such as building and financial services, counsellors, and interpreters
- Personal and community support: post-event support such as counsellors, specialist support services, and community support
- Involvement: social networks; participating in disaster management programs and policies

Buckle (2006) favoured an approach which diverges from focussing on socio-economic variables, such as age, gender and income, towards targeting these five categories. He argued that in order to enhance resilience, the extent of 'owning' these categories can be modified, while individual attributes such as age and gender cannot be changed at all. Buckle underlined that although the root causes cannot always be readily altered, access to these five categories can be improved. This argument concurs with a new focus within the structuralist vulnerability paradigm, which recognises the root causes but also the opportunities on the local or community scale without perceiving people as 'victims'. Furthermore, Buckle argues that identifying non-resilient and vulnerable people or groups only based on whether they fall into certain socio-economic categories can lead to an incorrect assessment and stigmatise people. People who are vulnerable and not resilient might be overlooked and not receive the support they need.

Buckle emphasised the need for establishing the context for resilience assessment, and the dynamic nature of changing communities, hence changing levels of resilience. His functional assessment targets individuals or groups. However, he underlined that his functional categories are relevant for communities as well, only in a different way. Communities possess characteristics dissimilar to individuals, such as networks, a shared history or culture.

Buckle's general plea for focussing on 'owning' certain 'functions', which resembles quite strongly the concept of 'access to resources' as proposed for vulnerability by Wisner et al.

(2004), is certainly a valid claim. However, Buckle's approach does not recognise that individual socio-economic characteristics translate into access to these five functions. His approach is therefore difficult to evaluate, since it aims to operationalise resilience assessment while at the same time providing some level of explanation, but not enough to really confirm this approach.

As already observed in the models discussed so far, the relationship between resilience and vulnerability is, again, unclear. While Buckle, just as Paton, generally underlines that both are separate but related concepts, the nature of that relationship is not fleshed out to a satisfactory degree. For example, being physically able to manage activities that create resilience is a link where vulnerability and resilience interfinger: being wounded during a manifest natural hazard would certainly limit such activities (chapter 7). Likewise, those aspects listed under 'information' and 'resources' carry as much implication for vulnerability, which is not addressed.

Buckle's assessment implicitly draws on different scales when categorising the five functional groups. However, his is not a multi-scalar approach explicitly carving out different scales. Finally, the role of infrastructure for community resilience is not addressed.

6.4 Conclusion

None of the three models is specifically designed to suit a specific context, either with respect to hazard type or society, i.e. cultural background (table 6.1). This ensures their applicability across various settings. While Tobin and Paton target the community level, Buckle extends his approach to suit the individual as well as groups of people, although he underlined that his model is applicable for communities. None of the models includes the role of infrastructure as part of the built environment surrounding people and their communities. However, all three authors underline the dynamic nature of resilience, either in terms of changing conditions or with respect to a harmful event or disaster which can actually change these conditions – this occurs when activities in the post-impact phase directly influence and overlap with the pre-disaster phase. Tobin and Paton especially demarcate different temporal scales. Tobin and Paton draw on adaptation as a key process to explain resilience, while Buckle only mentions adaptation in the accompanying text without defining adaptation further. He might think of the five functional groups as adaptation functions, but this is not made explicit. All three models refer to several dimensions such as the economic and institutional. The 'natural' environment as a source for sustainable livelihoods and resources such as clean water and food, is not included. Paton provides the most precise understanding of how different spatial scales are related, and how this translates into resilience, while Buckle does not address the issue of scale as such.

Finally, explicitly in Tobin's model vulnerability is regarded as an element of resilience. All three resilience models hint at relationships between vulnerability and resilience, and with various degrees draw on existing work and terminology developed for vulnerability. Generally, this is to be welcomed because it acknowledges previous work aimed at reducing risk. However, rather than providing a precise explanation of resilience which shows where resilience and vulnerability differ and where they are interrelated, explanations remain partly fuzzy with respect to the three processes of mitigation, of dealing with the immediate impact, and of recovery.

Frequently one is prompted to wonder whether a certain aspect related to resilience is not equally associated with vulnerability.

Table 6.1: Comparison of selected resilience models

		Tobin	Paton	Buckle
context-specific	hazard	-	-	-
	society ¹	-	-	-
	scale ²	✓	✓	✓
infrastructure ³		-	-	-
dynamic		✓	✓	✓
adaptation		✓	✓	implicit
multi-dimen. ⁴		✓	✓	-
multi-scalar ⁵		unclear	✓	-
vulnerability part of resilience		✓	-	-

¹ = i.e. if a bias towards specific types of societies/countries is translucent

² = targeting the community

³ = the role of infrastructures for social resilience

⁴ = including at least three of the social, economical, environmental, political and institutional spheres of resilience

⁵ = a model structure which accommodates different spatial scales

7. Vulnerability and resilience: a synthesis

Vulnerability and resilience are ‘concepts’ or ‘constructs’ (chapter 3). Defining a concept aims to communicate its meaning without necessarily claiming that this definition is the ultimate ‘truth’ (Lewis-Beck, 2004: 162). As has been demonstrated in previous chapters (2, 5, 6), while some agreement exists *within* several streams of natural risk research, conceptualisations of vulnerability and resilience *between* these streams differ to various degrees. This does not necessarily lead to greater insights but definitely creates terminological and conceptual confusion amongst the different research streams. With respect to the operationalisation of both concepts, their different conceptualisations, context-specific nature related to hazard type, temporal and spatial scale as well as societal context increases the spectrum of factors and explanations which precludes a simple ‘one-fits-all’ approach. In comparison, today the concept of ‘hazard’ as a potentially harmful event of a specific frequency and magnitude is widely accepted as a standard, although exemptions can be found (‘biophysical vulnerability’, chapter 5), and frequency-magnitude analysis bears some problems as addressed in chapters 4 and 10. One step towards conceptualisation is to identify unifying elements within and between the vulnerability and resilience concepts developed in different fields. Such a synthesis does not only ease communication, minimise misunderstandings and therefore maximise the sharing of knowledge, but helps to find the most effective and sustainable strategy of risk reduction. So far, such synthesising approaches are missing.

The synthesis developed in this research recognises vulnerability and resilience as independent but related constructs. Based on this synthesis, a model for vulnerability and resilience each is developed. These models, in turn, guide the methodology developed for measuring vulnerability and resilience (chapter 11).

While aiming to develop a conceptual and operational synthesis of vulnerability and resilience, it is clear that due to the selection of research fields and models discussed in chapters 2, 5 and 6, a warrant of completeness is not given. Therefore, the contribution towards overall vulnerability and resilience theory building is restricted, although some of the most influential approaches towards vulnerability and resilience are included here. Both concepts are tied into the wider theoretical context of risk detailed in chapter 3.

7.1 Observations towards a synthesis

Against the background of the history of natural hazards and risk research (chapter 2) and, to a lesser extent, the theoretical approaches towards risk (chapter 3), as well as the comparison within and between models of vulnerability and resilience (chapters 5, 6), similarities between the conceptualisations of vulnerability and resilience emerge.

7.1.1 Similarities

Firstly, most vulnerability and resilience models include human-nature interrelations. This means human dependency on an intact environment as a resource and base of livelihood, as for instance described by Kasperson et al. (1995) and Kasperson et al. (2005). To varying degrees topics like depletion, contamination and destruction of the environment are included, especially when addressing 'socio-ecological' resilience.

Secondly, there appears to be a substantial intersection between variables used for analysing and explaining vulnerability and resilience. This observation initiates a combined discussion of these factors as provided in chapter 8. A clear example of variable intersection is found in Handmer (2003) who relied on indicators typically chosen to measure vulnerability (wealth for livelihood security, house age for housing quality) for analysing resilience. Such an approach dilutes the meaning of both, vulnerability and resilience. The intersection needs to be addressed in a more differentiated way, which is the purpose of the synthesis developed here.

Thirdly, and perhaps most importantly, explanations of vulnerability and resilience both draw mainly, though not exclusively, on the process of adaptation. In the field of 'Climate Change and Global Environmental Change', 'adaptation' and 'adaptive capacity' are usually strongly associated with resilience and used interchangeably (chapters 5, 6). From an ecological and 'socio-ecological' perspective on resilience, diversity (which can entail functional redundancy) is a key element of resilient ecosystems or communities (chapter 6). Diversity implies a wider spectrum of accessible resources and available adaptive strategies, and this spectrum is associated with higher adaptive capacity, hence higher resilience.

By transferring this approach into the field of natural hazard and risk research, much of the findings of previous vulnerability research are ignored. In particular, the work of the human ecology school underlining the importance of adaptation and adjustment for risk reduction, as well as the structuralist perspective illuminating how people's access to resources can limit the implementation of adaptive measures, this means their overall adaptive capacity.

Explanations of both concepts, vulnerability and resilience, include adaptive capacity, as an expression of the diversity of adaptive strategies. However, only few authors associated with the 'Climate Change and Global Environmental Change' stream such as Klein et al. (2003), acknowledged that the concept of adaptive capacity does not play a central role in resilience research, but is deeply embedded in vulnerability research.

Now that the central role of adaptation (and adjustment) within vulnerability and resilience research has been established, it is suggested that adaptive capacity, the potential to implement adaptive strategies, should play a central role in a model of vulnerability as well as resilience. Across the disciplines, however, the meaning of the term 'adaptation' differs (appendix A).

Recalling characteristics of adaptation from a human ecology perspective (chapter 3), adaptation is:

- a process of mutual modification between two or more elements, ideally aiming at a favourable outcome for all,
- specialisation or generalisation,
- a collective rather than an individual process.

These three characteristics are underlined here within the context of natural risk. This is because such an understanding of adaptation concurs with:

- 1.1. the overall aim of risk reduction,
- 1.2. the aspect of co-evolution (hence time),
- 1.3. different strategies of adaptation, and
- 1.4. the role of communities and the aspect of scale within the field of natural hazard and risk.

How can these general characteristics of adaptation be specified in the context of natural hazard and risk? Again, opinions differ. Pelling (2003) noted that 'learning' facilitates improved adaptation to future events. King (2006: 296) identified 'preparing' as characteristic of a resilient community adapting to hazards. Klein et al. (2003: 43) regarded 'preparing', 'planning' and 'implementing technical measures', which can be interpreted as structural mitigation measures, as adaptive strategies. The field of 'Climate Change and Global Environmental Change' usually clearly separates adaptation from mitigation, while especially from a human ecology perspective hazard mitigation is seen as a form of adjustment or adaptation (chapter 2, 5, appendix A). Adger et al. (2005: 1037) referred to 'anticipating' and 'reacting' to coastal hazards as adaptive measures. Also Folke et al. (2002: 13) listed adaptation and anticipation as two separate activities influencing resilience. Anticipation does not necessarily prompt adaptive measures, which may explain why the two terms are listed separately. Anticipation, however, is just like learning a prerequisite for any adaptive activity. Therefore it seems more coherent to include anticipation within the notion of adaptation.

Summarising these interpretations of adaptation and recalling the reviews in chapter 3, 5 and 6, it is suggested here that the process of adaptation includes **learning, anticipating, modifying, preparing** and **planning**. These processes can be channelled into **mitigation, preparation** and **recovery** activities, provided risk is recognised and the willingness and/or opportunity to implement these activities exist (chapters 2, 5). Recovery, if envisaged as sustainable, should include adaptation activities based on learning from previous experience and anticipating future hazards.

Furthermore, the processes of mitigation, preparation and recovery concur with the overlapping **pre- and post-event phases** (chapter 6), which have also been identified by Etkin (1999), Alexander (2000), Alexander (2002) and Dore and Etkin (2003). These authors further include 'response' as the period of immediate emergency. 'Response' is also applied by Gallopin (2006)

in the sense of coping or immediate reaction. However, response is often used as a bracket term subsuming all forms of adaptation and adjustment. '**Reacting**' can be used instead to delineate the period during crisis and is used here in the way 'coping' or 'coping capacity' are defined, as for example by the ISDR². This usage of 'reacting' concurs with Chambers and Conway (1992: 14), who underlined that coping is reactive, while adapting is proactive (chapter 5). Hence reacting is clearly separated from adapting, which is a different approach compared to the 'Climate Change and Global Environmental Change' stream as indicated above (see Adger et al., 2005). The term 'reacting' is preferable to the term 'coping' since 'coping' implies that the degree of damage can be dealt with, which is not necessarily the case.

While recognising the temporal distinction between the human ecology-based conceptualisation of adjustment and adaptation (chapter 3, appendix A), the term adaptation as used here includes both notions of time. This is because adjustments can evolve into adaptations. When considering risk as a process it is difficult to pinpoint when to speak of adjustments and when to speak of adaptations. Such differentiation would be an interesting study in itself. Adaptation as used here therefore encompasses mitigation measures such as summarised by the human ecology school as 'modify the cause', 'modify the loss' and 'distribute the loss' (chapter 2). It should be noted that adaptation activities aiming at 'modifying the cause' target hazard or exposure, not vulnerability or resilience. This is why these are excluded from table 7.1, which gives a summary of adaptation activities for reducing vulnerability and increasing resilience.

Adaptive capacity and adaptation as the implementation of adaptive activities are the key to both vulnerability and resilience – although the outcome is different: on the one hand, it is the potential degree of being wounded, on the other hand the potential degree of absorbing the adverse effects inflicted by this 'wound' while still functioning. Because adaptation strategies target different outcomes their specific activities differ, as summarised in table 7.1. Furthermore, activities that influence vulnerability aim to reduce the immediate impact, cost or damage, which influences vulnerability in the long-term. Activities that influence resilience are aimed at what happens after the immediate impact, and similarly affect long-term resilience. The reasoning behind this conceptualisation is discussed in section 7.1.2.

Another shared aspect in explaining vulnerability and resilience is that they tap into similar resources in order to implement adaptive activities. Klein et al. (2003: 38), discussing resilience to climate change and referring to Smit et al. (2001), rated economic wealth of a country or community, the inventory of technology and infrastructure, information, knowledge and skills, its institutions, endeavour for equity, and its social capital as factors influencing the country's adaptive capacity.

² <http://www.unisdr.org/eng/library/lib-terminology-eng.htm>, accessed 2.10.2007

Walker et al. (2006) proposed that adaptive capacity depends mainly on the amount of all sorts of capital and the system of institutions and governance. All of these factors (one could call them generously 'resources') overlap greatly with those resources identified under a structuralist perspective on vulnerability (chapter 5). Table 7.2 provides a summary of resources discussed below and included in the explanation of vulnerability and resilience developed in this thesis.

Tab. 7.1: Adaptive activities for households and communities

Household/ community	Vulnerability	Resilience
Mitigation	Structural and non-structural: hazard-proof or re-enforced housing, emergency planning, receiving information on hazards, warning and evacuation announcements, securing dependants	Insurance ¹ ; volunteering for civil defence work, building and facilitating social networks and cohesion, developing effective decision making and monitoring structures
Preparation	Immediate effect on well-being: stocking up emergency supplies and materials, designing emergency plan	Level of self-reliance, i.e. skills and resources that maintain functioning with a certain degree of damage
Recovery	Mutual emotional and financial support and care-taking; recover in a sustainable way, i.e. by implementing mitigation and preparation strategies	Mutual emotional and financial support & care-taking, sharing skills for rebuilding livelihoods, recover sustainably, i.e. by implementing mitigation and preparation strategies

¹ Insurance, in the tradition of the human ecology school a measure to spread the loss, is sometimes regarded as an aspect of vulnerability. However, insurance cannot limit or even prevent damage and is instead a tool for a quick recovery (chapter 8).

Social capital

Social capital is a rather fuzzy term which appears frequently in the literature on vulnerability and resilience. According to Cannon (2000) 'social capital' includes a variety of skills such as dealing with bureaucracies. The term 'social networks' often falls in the category of 'social capital'. In this context, 'social capital' can be defined as *'trust, norms and networks'* enabling cooperation and coordination aiming towards overall benefit (Putnam, 1993: 167 in Pelling, 1998: 470). Social networks established by disaster survivors promoted the recovery process by providing physical and emotional support (Echterling, 2001 in Jang and Lamendola, 2006).

Social networks are often based on friendships and family. As reported in the aftermath of Hurricane Andrew, 41% of people residing in the most severely hit zone identified family help from outside this area as fundamentally important (Morrow, 1997). It has also been observed that people affected by natural hazards prefer to source loans from family, friends and neighbours rather than the banking system (Birkmann et al., 2006).

The benefits of accessing social capital not only translate into recovery, but into adaptive measures of mitigation and preparation, mainly by sharing information and financial resources which is a form of mutual support. Being part of a social network can prevent dependants such as the elderly, the very young, the ill or disabled from being harmed (chapter 8).

Table 7.2: Vulnerability and resilience: resources

Resource	Description	Author
Social capital	Cooperation between people: networks of relationships such as friendships and kinships; skills	Pelling, 1998; Cannon, 2000; Smit et al., 2001
Financial capital	Savings, loans, assets, insurance	Chambers and Conway, 1992; Buckle, 2006
Information	Information, e.g. about hazards, relief, financial support, receiving (early) warning	Pelling 1998; Buckle, 2006
Institutions provided by the state	Provision and distributive structures of welfare, health care, relief;	Bolin and Stanford, 1998; Cannon, 2000; Wisner et al., 2004
Environment	Base of livelihood: income opportunity related to ecosystem functions	Chambers and Conway, 1992

Financial capital

Financial capital such as savings, assets and loans can be utilised during the pre-impact phase for implementing mitigation measures which aim to reduce the potential degree of damage. Similarly, financial resources spent on preparation, such as stocking up food and materials, exert a direct influence on vulnerability. Financial capital is also needed for purchasing insurance, which will influence people's ability to recover in the post-impact phase (Chambers and Conway, 1992; Buckle, 2006). With respect to the recovery process, financial resources are best used when targeting sustainable recovery which includes both, vulnerability and resilience, in order to reduce negative consequences in the onset of a future natural hazard.

Information

In our day and age, information has become a highly sought after resource. Against a natural hazards background, the resource 'information' as used in this thesis includes a wide range of knowledge related to the environment, hazardous processes, obtaining relief and government aids such as loans, as well as (early) warnings. All of this information is crucial for the decision-making process not only on the national or regional, but also on the local scale (Pelling, 1998; Buckle, 2006).

A form of information is what is often labelled 'local knowledge'. A precise definition of 'local knowledge' is not readily available, but referring to Wisner (2004) the term seems to describe knowledge related to the surrounding ecosystem and traditional adaptation strategies. For example, indigenous people of the Andes adapted to earthquakes and other perils by scattered settlement patterns, ecological tiers, certain building materials and techniques and preparations (Oliver-Smith, 1994; chapter 2).

It is most likely that previous experience as a form of information carries the most contradictory implications for vulnerability and resilience. As behavioural research shows (chapter 2), people's past experiences and expectations influence their risk perception and decision-making.

These decisions are basically concerned with adapting to a particular situation of endangerment, with the ultimate aim of reducing vulnerability or exposure, and increasing resilience. However, people's decisions are not always rational and might provoke increased vulnerability and exposure, and decreased resilience despite previous experience.

Institutions

An institutional resource subsumes the opportunities governments can have in supplying goods and services to their citizens. Whether or not the state provides welfare and an affordable health service influences people's wellbeing, independent of any hazard, and as much before as after a disaster. Especially those unable to afford private health care benefit from such structures (Cannon, 2000). State-inherent financial capital to cover people's losses can be an important resource and provided in the form of relief and state loans. An example of the state interfering with the recovery process was when after Hurricane Andrew the U.S. government covered liabilities of insurance companies which were unable to pay out claims (Powers, 2006). Relief as a resource provided by the state directly influences people's well-being in the short and long run after they have been adversely affected (chapter 8).

Environment

The environment is the source of peril but also the basis for a wide spectrum of income opportunities. Landownership does not only guarantee a place to live, but can be a back-up for bank loans, can be sold if financial capital is urgently needed, and generally serves as the base of livelihood (Birkmann et al., 2006). Livelihoods based on natural resources, apart from mining, oil and gas exploration, depend on the quality and functional persistence of ecosystems. Natural hazards can destroy or reduce the quality and functions of these ecosystems. Industries extracting resources and producing new goods, such as fishing, farming and forestry, are directly linked to the sustainability of the ecosystems utilised. Subsequently, industries refining and distributing these goods are equally dependent on and affected by the state of the environment. Therefore, whole industries and a wide range of livelihoods from the local farmer to the workers in a food processing factory, freezing works or shearing sheds, to the manager of logistic companies, just to name a few, are interlinked with the ecosystem they rely upon.

The environmental dimension of vulnerability is included in most of the vulnerability models discussed in chapter 5. Similarly, ecological resilience and 'socio-ecological' resilience are the basis and further development of work under the auspice of the Resilience Alliance. Hence it appears that vulnerability and resilience share another aspect: the strong human-nature interrelation as outlined at the beginning of this section. Entitlement to the environment as a resource and base of livelihood is a culturally and politically determined aspect which can restrict access to this resource for some and allow access for others. This has also surfaced when discussing vulnerability models in chapter 5, and has surfaced in chapter 2. Table 7.3 summarises the role resources play for adaptive activities.

A conclusive and final similarity between explanations of vulnerability and resilience is that **access** to the resources listed above translates in adaptive capacity. Access to resources is filtered by the socio-economic **profile** of a community, as well as the characteristics of the built environment with respect to infrastructure (chapter 8). What is called here a '**frame**' influences the way the profile of a community filters access to resources, which has implications for adaptive capacity, hence vulnerability and resilience alike, as discussed above.

The frame delineates the political, economic, cultural and environmental structures of a society. The political sphere encompasses aspects such as the type of the state system, whether a strong civil society is supported, or human rights are safeguarded. The type of economic system and its functioning tailor how financial resources are accumulated or depleted and how streams of capital and goods operate. A society's culture is expressed by the dominant customs and beliefs, including attitudes towards risk, hazards and technology. Religion can be subsumed under the cultural sphere.

People's ability to develop and sustain a livelihood is partly pre-conditioned by the frame. For instance, questions of gender equity will be answered differently in different cultures. Apart from physical weakness, amplified by pregnancy, women are not more vulnerable than men because they are woman. As Wisner (1993) clarified it is often their role, which depends on the cultural context, which makes them vulnerable. Likewise, higher mortality rates often correlate positively with age – but apart from diminishing physical strength and health, other factors such as poverty and isolation are shaped by the way a society treats its elderly, in terms of pension systems and the social status elderly enjoy or do not enjoy. Additionally, the environmental settings reflect the physio-geographic and climatic conditions which do, to some extent, influence the economic and cultural spheres of a society.

The concept of framing conditions as used here is based on the PAR model's 'root causes', which also appeared in a modified way in Cannon (1994). However, the term 'frame' is introduced in this research as to illustrate a perspective which recognises scale linkages and the translation of the overall living conditions into vulnerability and resilience, while simultaneously realising that these conditions are not the sole cause for vulnerability or resilience, but are matched by individual agency.

The frame is situated on the society scale and as such on the national scale which according to Pelling (2003) is strongly interlinked with the global scale: globalisation implies consequences for a range of different scales, with diverse consequences for disaster and risk. Also Wisner (2003b) emphasised and illustrated this scale linkage. The scale link runs like a red thread through the structuralist paradigm of vulnerability research and has been discussed accordingly (chapters 2, 5).

Table 7.3: Linking adaptive activities and resources for households and communities. Depending on the base of livelihood, **environmental resources** are closely linked to financial capital.

Adaptation	Vulnerability - adaptive activity	Resources	Resilience - adaptive activity	Resources
Mitigation	Structural and non-structural: hazard-proof or re-enforced housing, emergency planning, receiving information on hazards, warning and evacuation announcements; securing dependants	Financial capital, information, social capital, institutions	Insurance; volunteering for civil defence work, building and facilitating social networks and cohesion, developing effective decision making and monitoring structures	Financial capital, social capital, information, institutions
Preparation	Immediate effect on well-being: stocking up emergency supplies and materials, designing emergency plan	Financial capital, information	Level of self-reliance, i.e. skills and resources that maintain functioning with a certain degree of damage	Financial capital, social capital
Recovery	Mutual emotional and financial support, care-taking; recover in a sustainable way, i.e. by implementing mitigation and preparation strategies	All of the above	Mutual emotional and financial support & care-taking, sharing skills for rebuilding livelihoods, recover sustainably, i.e. by implementing mitigation and preparation strategies	All of the above

7.1.2 Differences and linkages

As demonstrated so far there are a range of similarities between the different approaches of explaining vulnerability and resilience which lead to a similar path of explanation in this thesis. Simultaneously, it is illustrated how vulnerability and resilience differ conceptually and practically.

As concluded in chapter 5, conceptualisations of vulnerability in the fields 'Climate Change and Global Environmental Change' and 'Development and Livelihood' include resilience as a component of vulnerability. Similar conceptualisations of vulnerability can be found in Cannon (1994), Emergency Management Australia (1998), King and MacGregor (2000) and Cardona (2005). With this conceptualisation vulnerability and resilience are interpreted as two ends of one spectrum, with vulnerability as the opposite or 'flipside' of resilience (Folke et al., 2002; Holling and Gunderson, 2002; Adger et al., 2005). Resilience as one side of the equation is linked with a direct increase or decrease of vulnerability. Likewise, resilience models reviewed in chapter 6 tend to include vulnerability as a component although this partly conflicts with accompanying definitions. As a result, contradictions between the research streams and diffusiveness unfold.

The 'Human Ecology' stream of vulnerability research considers vulnerability and resilience as independent constructs (chapter 5). This is most likely related to its application of UNDRO's (1982) vulnerability definition. When defining vulnerability simply as the potential degree of loss due to the susceptibility to be damaged (UNDRO, 1982), the distinction between the two concepts is clear. Also King (2006: 298) emphasised that vulnerability and resilience are not opposite ends of the same spectrum, but *'two separate, occasionally interconnecting scales from low to high vulnerability and low to high resilience'*. Paton (2006) and Gallopin (2006) stated that resilient communities operate in a way which is independent of their vulnerability. If vulnerability is defined as the 'flipside' of something else, human security is a candidate: according to Hewitt (1997: 143) vulnerability is about the *'human ecology of endangerment'*. This link between vulnerability and human security is also underlined by Birkmann (2006b). Alternatively, notions of resistance or robustness can be seen as the 'flipside' of vulnerability along a spectrum of potential damage (chapter 6).

Within this thesis, resilience and vulnerability are interpreted as two independent but linked concepts. While vulnerability refers to the potential degree to which someone or something might be initially 'wounded', resilience is the ability to still function despite this wound and to recover quickly. This recognises the main findings during the relatively long history of natural hazards and risk research as summarised in chapter 2. Consequently, such a conceptualisation prohibits an interpretation of vulnerability and resilience as reciprocals. Low vulnerability levels can in fact be accompanied by low or high resilience. Resources (table 7.2) channelled into adaptive activities solely targeting vulnerability will not automatically increase resilience. In contrast, if resources are distributed more evenly between the two, lower vulnerability can be accompanied by higher resilience. As discussed in chapter 3, specialisation and generalisation are two forms of adaptation which can reduce risk. However, a fallacy is lurking when it is assumed that decreasing vulnerability only (as a form of specialisation) automatically increases resilience.

It is suggested here that the relation between vulnerability and resilience is rather indirect, with the pool of resources as the linking element as will be detailed shortly (figure 7.1). In addition, one aspect shapes this relation: the magnitude of the geophysical process.

1. *Low vulnerability/small magnitude of geophysical process*

The less a community is wounded, i.e. adverse effects on people's physical and mental health and livelihood (income opportunities, assets, savings) are incurred due to low vulnerability or a small geophysical process magnitude, the less resources are depleted. The fewer assets and buildings are destroyed, the fewer resources such as skills, materials, or financial capital, need to be utilised and the more are available during the recovery process. For example, a low number of injured people enables the majority of community members to play an active role within social networks and to participate in recovery

activities, from which the whole community, including those injured, benefits. This is assuming that social networks exist before the crisis unfolds. Infrastructure still functioning enables communication, evacuation, transport and access to water and electricity, which means that resources which are needed to maintain functions are available, which in turn accelerates the recovery process.

An important aspect is that the low depletion of resources based on low vulnerability does not automatically entail initial high resilience. Low vulnerability does not imply that people have actually built strong social networks, purchased insurance or that community wide planning for an emergency has actually taken place in order to 'bounce back'. Low vulnerability entails that if adaptive strategies targeting resilience have been implemented, they can enfold their positive effects and reduce risk. Only then the pool of resources, on which both vulnerability and resilience rely, is less strained and can be easily replenished and utilised for adaptive strategies targeting both vulnerability and resilience.

2. *High vulnerability/large magnitude of geophysical process*

In contrast, the more wounded a community is either due to high vulnerability, a large geophysical process magnitude or, in a worst-case scenario, both, the fewer resources will be usable overall. The availability of people, skills, knowledge and materials will be severely limited due to damage and loss, as well as infrastructure needed for communication, transport, water and electricity. If skilled people are affected themselves, the resource 'social capital' is drained, which has negative effects for those who survive (Buckle et al., 2000; North, 2003). If community assets are damaged or destroyed, their functioning will be impaired (Buckle et al., 2000). The draining of resources hampers the ability to maintain social networks and functions, and depletes other resources needed to recover quickly.

This, however, does not imply that initial resilience levels were low. Despite potentially many adaptive activities that were implemented and aimed at increasing resilience in the forefront, their positive effects simply cannot manifest when resources are depleted. Overall, few resources will be left, hindering the recovery process and the implementation of adaptive strategies used for concentrating on both vulnerability and resilience.

It is concluded that the ability to realise adaptive activities which foster resilience is compromised mostly in cases of high vulnerability or large process magnitudes exceeding even low vulnerability. If the vulnerability is so high or the process magnitude of such a level that resources are greatly depleted, community-inherent strength is lost: help from the outside is needed and disaster strikes. This is independent of an initial high or low resilience level. Therefore, with respect to geophysical processes of high magnitude, it is advisable to prioritise vulnerability reduction.

In cases of low vulnerability or medium to small process magnitudes, the benefits of initial high resilience can be realised, and overall risk can be reduced depending on the level of resilience. For example, initially very self-reliant communities with tight social networks and a large communal pool of knowledge, skills, materials and financial capital can still abate negative effects for health and overall well-being that have been encountered. This reduces the overall damage level, but not initial vulnerability as such. A high level of resilience has not reduced pre-existing vulnerability (before the event). Despite of community engagement or purchased insurance people might not necessarily have reduced their vulnerability by stocking up emergency supplies or by modifying their house or. Limited physical strength of the elderly or children has not been miraculously increased, nor have the cognitive and sensory abilities of the disabled been altered (chapter 8). The bonus of higher resilience is that further loss is limited and resources are spared which speeds up the recovery process, and – when adaptive strategies are included – future vulnerability as well as future resilience.

Since high resilience does not equal low vulnerability, or low vulnerability high resilience, risk management should target both concepts; when planning for large magnitude processes prioritising vulnerability is advisable. It is in fact necessary to positively alter both conditions so they can positively influence each other. This is another reason for why a combined approach is beneficial. In addition, a combined approach prevents people from easily being ‘victimised’ without a realisation of their strength, as Cannon (2000) pointed out (see also Cuny, 1983; Bankhoff 2004a; Fordham, 2004, chapter 2).

When aiming to understand the relation of vulnerability and resilience, the notion of time is important. The key point of the interrelation between vulnerability and resilience as described above is that they positively or negatively affect the overall pool of resources, hence the source for recovery and future adaptive activities (figure 7.1).

Within the overall societal context the community profile determines access to this pool of resources (this path is simplified in figure 7.1). This is the point where access to resources and the overall societal context need to be recognised within local vulnerability and resilience analysis. Injections of resources from outside the community are also possible, increasing the overall contingency. It should be noted that, however, resilience is usually associated with self-reliance, i.e. independence from external sources.

While social vulnerability and social resilience do not directly influence each other, ecological resilience does directly translate into social vulnerability and social resilience by affecting the source of livelihood (section 7.1.1). This connection is often included when speaking of ‘human-nature’ relations, which can exacerbate or abate overall risk.

Figure 7.1: The relation of vulnerability, resources, and resilience

7.2 Similarities & linkages: a synthesis

In the absence of an overall theory of natural risk, the synthesis developed here is influenced mainly by the 'Human Ecology' and the 'Development and Livelihood' stream.

Another framework which inspired the 'Development and Livelihood' stream as well as this synthesis is Anderson and Woodrow's (1998) 'Capacities and Vulnerabilities Analysis'. Originally developed for the context of development and relief aid, Anderson and Woodrow's basic framework is applicable in different contexts. Capacities are 'strengths' which include the ability to withstand, recover and limit suffering from harmful events (Anderson and Woodrow, 1998: 12-13). Their comprehension of capacities therefore partly overlaps with the way resilience is defined in this thesis (chapter 6). According to Anderson and Woodrow, community capacities and vulnerabilities both arise from the productive resources and skills (physical/material), social relations and social organisation (social/organisational) and attitudes a society or community has towards modifying unfavourable conditions (motivational/attitudinal). The general matrix is accompanied by a range of factors such as gender, economic status and age which disaggregate this matrix in order to reflect the rather diverse reality (Anderson and Woodrow, 1998: 15-20). The benefit of Anderson and Woodrow's framework is the combined analysis of 'capacity' and vulnerability as compared to the usually separate perspective, and the disaggregation of both due to several other factors. Fordham (2003) rated the 'Capacities and Vulnerabilities' approach within the developed world as a radical transformation of disaster management, because it takes on a long-term perspective, regards mitigation as embedded within the social and economic dimensions of day to day life, and fosters capacities of local communities. Hence the developed world can learn from research and insights gained in the context of the developing world.

Finally, the 'Climate Change and Global Environmental Change' stream enters the synthesis through the interpretation and key characteristics of resilience as discussed in chapter 6.

The synthesis of similarities and linkages between vulnerability and resilience is summarised as following and mapped out in the models presented in the following section:

- Vulnerability and resilience can be traced back to the same **framing conditions** from where they follow similar paths until eventually manifesting in their distinct ways during and after a harmful event.
- Along these paths, vulnerable and resilient people or communities are equally dependent on **access** to largely the same **resources**. Access to these resources generally depends on the socio-economic **profile** or characteristics of households or a community influenced by the framing conditions. Access to resources shapes adaptive capacity.
- **Adaptive capacity** then translates resources into the process of adaptation, which for both vulnerability and resilience, encompasses activities of mitigation and preparation. Recovery, if anticipating future natural processes to occur, will include adaptation activities in order to build sustainable communities and reduce risk (see ISDR definition of 'recovery'³).
- While vulnerability expresses the potential degree to be wounded, resilience captures dealing with this 'wound' while maintaining social structures and functions, and recovering quickly. This is why adaptation strategies vary depending on whether vulnerability or resilience is targeted.
- Vulnerability and resilience are related in the sense that initial damage potential is mainly influenced by vulnerability, in the sense that resources can be depleted. High levels of resilience can abate the drainage of resources, which in turn affects both vulnerability and resilience.
- While vulnerability manifests immediately during a harmful event or disaster, resilience manifests in the aftermath, although a temporal intersection is likely. Both, however, are pre-conditioned (pre-impact phase) as well as influenced by the post-impact phase, which is potentially the next pre-impact phase.

One aspect that needs to be included here is that **risk perception** and **willingness to adapt** play an important role for implementing adaptive strategies as indicated previously. Ronan and Johnston (2005) placed much emphasis on willingness or what they called 'motivation', since without motivation skills and resources remain unused. The socio-economic profile of a community not only reveals differences in adaptive capacity, but also in risk perception. For instance, depending on a person's gender a diverse range of environmental risks are possibly perceived differently. For a small fraction of the existing wide-spanning literature, see Gustafson (1998), Bielders et al. (2001), Johnson (2002), Siegrist (2003), and Slovic (2004). Although risk

³ <http://www.unisdr.org/eng/library/lib-terminology-eng.htm>, accessed 2.10.2007

perception plays an important role for implementing adaptation activities and reducing risk, this aspect cannot be included within this thesis in a more differentiated way⁴.

The process of adaptation underlines the factor of time inherent in the explanatory path of vulnerability and resilience as proposed here. Not only do the frame and profile, hence access to resources and adaptive capacity as such, change in time. Interpreting vulnerability and resilience as processes is also related to changes inflicted on these dimensions by a harmful event or disaster itself. As addressed above and in chapter 2, depending on the degree of vulnerability and resilience the crisis itself may not only alter the profile of a household or community, but the overall resources available, and potentially the framing conditions. Adaptation during the post-impact phase can also modify the frame, the profile or, more perhaps most likely, access to resources, hence people's adaptive capacity before another potentially harmful natural process such as an earthquake or landslide occurs. Therefore, the temporal scale influences the spatial scale. Another temporal aspect is that the post-impact phase intersects with the pre-impact phase. In conclusion, there exist an interdependency of spatial and temporal scales inherent in the concepts of vulnerability and resilience.

7.2.1 Models of explanation

A conclusion drawn from the synthesis developed is that vulnerability and resilience models should not be designed and applied separately and subsequently linked by operators or arrows. They should already complement each other by revealing their characteristics and similar paths to explanation. Accordingly, this section presents a model for vulnerability and resilience each based on the synthesis as discussed so far. This is not to say that these models can only be applied in tandem. Each is applicable individually, but both should be used for risk analysis.

Based on the comparison of several vulnerability and resilience models (chapters 5, 6), expectations of models explaining vulnerability and resilience include two major aspects: a concise representation within one model, and a strong hinge for a combined vulnerability and resilience understanding and analysis. Additionally, a set of key characteristics condensates from the comparison of vulnerability and resilience models which should be included:

1. Provide a multi-scalar approach towards explanation.
2. Include temporal variability of all elements within the model and the notion of adaptation, to accommodate for the dynamic nature of vulnerability and resilience.
3. Recognise the multi-dimensional nature of vulnerability and resilience: this includes not only social, economical and political but also environmental dimensions.
4. Allow for a design which is open to different contexts (e.g. cultural, political), while including 'inherent' or 'generalised' elements of vulnerability.
5. Include the built environment with respect to the characteristics of infrastructure.
6. Keep it simple.

⁴ See Finnis (2006) for an example of a detailed analysis of perception in the context of volcanic hazards for several communities of the Taranaki region, New Zealand.

Though all models reviewed in chapters 5 and 6 display some very useful explanations of vulnerability and resilience, they miss out on some of the above expectations. More importantly, the link with vulnerability or resilience is either factored out or only hinted at by either including one concept completely as a variable of the other, or by transferring aspects usually associated with one concept into the other.

The following synthesising models acknowledge and build on some of those approaches previously discussed, especially PAR/Access/BDW, Turner et al. and BBC in the case of vulnerability, and Paton and Buckle in the case of resilience. The work of the Resilience Alliance has also influenced the understanding of adaptive capacity, not only with respect to resilience, but also vulnerability.

According to the synthesis developed in this chapter the models proposed here (figures 7.2, 7.3) follow the structure of **frame, profile, access to resources, adaptive capacity** and successive **adaptive activities**. These are either aimed at reducing vulnerability or building resilience.

7.2.1.1 Vulnerability

Shaped by the frame, the individual's socio-economic profile filters access to resources such as social and financial capital, information, the state with its institutions, and the environment (figure 7.2). In addition, infrastructure plays a role in enabling or limiting people's access to resources such as information, institutional resources and environmental resources. In the case of resources supplied by the state, it needs to be established whether these items listed under 'institutions' are present in the first place. Access to these resources is once again influenced by the profile. Chapter 8 elaborates on the manifold ways in which the profile filters access to resources.

This path of explanation crosses several spatial scales. While the focus in this thesis is on the community, the model can be applied for other scales such as a single household, a region or a country.

As touched on previously, scale interdependencies pose one of the greatest challenges in vulnerability research, and one might assume in resilience research as well. The path of causation in the model offered runs into one direction only: from overarching framing conditions towards what happens at the community scale. While this provides a clear structure for explaining vulnerability, it simplifies scale-interdependencies. The link between different scales is indicated to acknowledge that processes at the local scale, especially during and after a harmful event or disaster, can influence the higher scale levels up until the frame.

Figure 7.2: A model of social vulnerability

At the final stage of the model, adaptive capacity can manifest as adaptation before and in the aftermath of a harmful event or disaster. Adaptive capacity functions like a bottleneck where all the characteristics of different scales are bundled and manifest.

During the **pre-impact** phase, adaptation manifests through learning, anticipating, modifying, preparing and planning and can precipitate within the private realm as structural and non-

structural mitigation measures and as preparedness, for example by stocking up emergency supplies. Mitigation measures can include reinforcing outside and inside structures of dwellings (table 7.1). Pre-impact adaptation influences people's **immediate** reaction during the impact and the degree of damage inflicted by a natural process. This is when the potential degree of damage translates into actual damage. People's reaction and the degree of damage finally shape the **post-impact** period, when recovering is ideally accompanied by sustainable adaptation. The process of recovering should include learning, anticipating, modifying, preparing and planning – hence overlaps with the pre-impact phase.

Following the model's line of explanation, adaptive capacity plays a major role in explaining vulnerability. However, additional variables influencing vulnerability are fragility and mobility (chapter 8). Moreover, within the state or public realm risk management includes implementing structural and non-structural mitigation measures as well as preparing for harmful events (table 8.1).

7.2.1.2 Resilience

The explanation of resilience in the model presented in figure 7.3 draws on similar aspects and processes as vulnerability, but the key point is a different outcome: now the path of explanation diverts from that of vulnerability in the sense that adaptive capacity is channelled into different forms of adaptation. Learning, anticipating, modifying, preparing and planning are not aimed at reducing the degree of damage but the ability to deflect under this damage while maintaining functioning. These adaptive activities are summarised in table 7.3. The 'pressure', i.e. the degree of damage, is firstly and mainly dependent on vulnerability, while the ability not to 'break' under that pressure is captured by the concept of resilience.

Three additional aspects to consider are 'risk management', 'community network' and 'self-reliance'. Risk management, just as in the vulnerability model, can guide and support adaptive activities. While 'community network' is a phrase which subsumes facilities building cohesion on the community scale, the self-reliance of community members is a characteristic associated with the individual scale, which may, however, exert an influence on the community scale. Self-reliance describes some form of internal resourcefulness that implies independence from external resources. All three aspects are discussed in chapters 6 and 8.

Like the vulnerability model, the resilience model is dynamic in the sense that adaptation during the post-impact phase can target the frame, the profile, or more likely, people's access to resources in order to increase their adaptive capacity before another potentially harmful natural process such as an earthquake or landslide occurs. Risk management during the post-impact phase further overlaps with the pre-impact phase considering future harmful natural processes are possible.

Figure 7.3: A model of social resilience

7.2.2 Scale links

The vulnerability and resilience models presented differentiate between two different scales of explanation: the 'frame' which contains wider political, economic, cultural and environmental settings and is globally connected, and the 'profile' encompassing socio-economic characteristics as well as the infrastructural setup of a community. While the framing conditions are non-specific to an individual, a household or a community, the profile is specific to such an 'element at risk'. The combination of frame and profile determines access to resources.

Resources, i.e. social and financial capital, information and the environment are 'stored' on both scales: the frame and the profile. For instance, information about hazards can be generated outside the community by research institutions and transferred by governmental institutions, while local knowledge about hazards can grow out of the community and is shared between its members. Social and financial capital exists outside the community, e.g. when purchasing insurance, as well as inside the community in the form of friendships, kinships and assets. And a community's environmental resources are interlinked with various processes operating outside this local scale. Spatially, vast distances can be crossed, with global environmental change at the far end of this scale linkage. A similar scale linkage applies to a community's infrastructure which governs the availability of water, gas, electricity and telecommunication while connected to a region or nation wide network as described in chapter 8.

More specifically, framing conditions and profile characteristics display two levels of interconnectivity: between each scale and within each scale, which is summarised below and illustrated in figure 7.4.

1. Frame and profile dimensions are interconnected (indicated by a porous boundary). The framing conditions influence the way the profile of a community filters access to resources, and processes on the frame scale influence processes on the local scale. Similarly, processes at the local level influence the framing level. Especially after a disaster manifested on the local scale, changes are implemented or promised, such as (stricter) building codes, which are however not mandatory. In the short and long term, practical risk reduction strategies should rely on both, frame and profile levels of understanding vulnerability and resilience.
2. Different dimensions within the framing level are interconnected. Environmental and political dimensions infuse each other, just as they influence and are influenced by economical, political, cultural and institutional dimensions. On the profile level social and economical factors may be interconnected, such as the level of education and income, or age, gender and disability and income (chapter 8). Socio-economic factors can reflect on demographic structures, such as the number of children or elderly in households or communities. In addition, the nature of the built environment with respect to housing is influenced by socio-economic variables.

Figure 7.4 summarises aspects related to the frame as discussed in this chapter, and provides an introduction to the following chapter which depicts the focus of this thesis: the community or profile scale.

Figure 7.4: Interdependencies within and between the scales 'frame' and 'profile'

8. Vulnerability and resilience: a close-up on the 'profile' scale

One approach to analysing vulnerability is to compile a set of variables which, ideally based on empirical studies, are associated with high levels of vulnerability. King and MacGregor (2000) concluded that there is considerable agreement upon which variables should be included in vulnerability analysis. For instance, age and income are associated with aspects such as isolation, limited mobility, or poor housing. Such key variables can serve as indicators of vulnerability (chapter 11).

The variables discussed in this chapter constitute what is commonly regarded as the core of a 'laundry list' which, however, is not exclusive. Compilations of variables, accompanied by varying explanatory value, can be found in King and MacGregor (2000) (based on Keys, 1991; Smith, 1994; Blaikie et al., 1994; Salter, 1995 and Buckle, 1995), as well as in Cannon (1994), Hewitt (1997), Morrow (1999), Buckle et al. (2000), Cutter et al. (2003), Granger (2003a), Smith (2004), Wisner (2004), Wisner et al. (2004) following up on Blaikie et al. (1994), Buckle (2006) based on Marsh et al. (1999), Schneiderbauer and Ehrlich (2006), and Gall (2007).

The summary presented here contains some of the most frequently appearing aspects of vulnerability. The depth of research committed to many of these variables is considerable with some being research arenas of their own. This depth cannot be included here to the full extent. Hence the following summary seeks to cover the most frequent and empirically best documented aspects of each variable discussed. These aspects usually illustrate 'negative' examples; implicit, however, are positive examples and lessons learned. Comparable literature on resilience is sparse.

Viewed from a different cultural standpoint, some aspects discussed here will be interpreted in a different way and will lead to different conclusions, while others will apply against many backgrounds. Likewise, depending on hazard type implications for vulnerability and resilience differ to some extent. Many aspects, however, are essentially hazard-independent. For example, Morrow (2000) identified 26 variables which are related to storm vulnerability in the United States, of which 25 would apply for many other hazards, and not only in the more developed countries.

Since it is neither possible nor necessary to elaborate the full spectrum of various implications within the limitations of this thesis, this chapter contains a mix of different economic, political and cultural contexts, as well as different hazards, without discussing the context specifically. Although this may resemble a vendor's tray, such a (already selective) mix provides a broader entrance into the topic. What is more, this approach acknowledges the widespread research that has been undertaken so far. The context-specific implications which apply for this thesis precipitate within the context of vulnerability and resilience analysis (chapter 11).

Aiming for an accessible display of how a community profile translates into access to resources, aspects covered for each variable are accompanied by keywords in brackets throughout the text. The first item in brackets symbolises the relevant type of resource (table 7.2). The second item reflects whether this bears implications mainly for adaptive activities targeting vulnerability, resilience, or both: For example '*(information: vulnerability)*' implies that access to the resource 'information' carries explicit explanatory power for the construct of vulnerability. In addition, where interrelations between different variables emerge, the variable in question is added in brackets.

In some cases aspects covered for a certain variable are not directly associated with access to resources, for instance the fragility of the elderly and children. These appear as additional variables in chapter 7 (figures 7.2, 7.3) and chapter 11.

8.1 Economic status

For a number of reasons, low economic status is often the most 'visible' element of vulnerability (Anderson and Woodrow, 1998: 11). Destitute households are less apt to spend money on stocking up emergency supplies and materials (Wisner, 1993; Morrow, 1999; Buckle et al., 2000). This preparation activity directly influences the potential to be adversely affected, i.e. general well-being depending on whether enough food, water, medication and other supplies are available (*financial capital: vulnerability*). A supply of materials to build at least temporary shelter can decrease the degree of becoming wounded (*vulnerability*). Few or none possibilities to prepare and rebuild are associated with higher mortality rates, as well as higher damage to dwellings (Cochrane, 1975; Morrow, 1999, after Blaikie et al. 1994.). In addition, individually implementing mitigation measures such as protective structures, for example against landsliding, might be too costly (Wisner et al, 2004), although they directly affect the probability and extent of being wounded (*vulnerability*).

Even though for the poor material and economic loss is small in absolute terms, livelihoods can be endangered substantially when all possessions are lost (Tobin and Montz, 1997; Morrow, 1999; Cross, 2001; Wisner, 2003; Wisner et al. 2004). In this sense, a \$80,000 home is as valuable as a \$1 million home – in fact, the former may be of more value to the residents if they lack other financial resources, especially when no insurance covers the loss (Buckle et al., 2000). For an economic derivation of relative damage and loss levels, in the sense that low levels can be disastrous, see Plate (2006).

Not being able to afford private transport is likely to reduce access to relief and general support during and after a disaster. This is especially the case for isolated communities (Morrow, 1999). Lack of relief directly influences well-being and the chances of suffering harm (*vulnerability*).

Non-affordability of insurance can severely affect the recovery process, when savings (if available) or the first incomes in the post-impact phase are likely to be spent on replacing the lost goods, while simultaneously spending money for the basic needs of living (Cannon, 2000) (*resilience*). Accordingly, the recovery process of poor people usually takes longer than compared with households of higher economic status (Morrow, 1999 after Bolin, 1986; Bolin, 1993, Bolin and Bolton, 1986), and sometimes never reaches pre-impact economic status. After the 1977 cyclone hit the Bay of Bengal in India, the poorest people in Andhra Pradesh could not rebuild their homes and were rendered homeless (Winchester, 1992). In addition, the period of time spent in refugee camps and temporary dwellings is prolonged compared to economically better off people (Morrow, 1999). From the 19,000 people evacuated from the suburb of Lower 9th Ward in New Orleans during Hurricane Katrina in 2005, only 500 have returned in 2007, and most of these live in mobile homes on their properties. Electricity is just being reinstalled. Of those who are willing to return, most cannot afford a new beginning (Heide, 2007), probably because they would have to literally start with nothing and face the risk of losing their assets again during the next hurricane. The few people who are able to move back into a rebuilt home were covered by insurance (Heide, 2007). Before Hurricane Katrina, Lower 9th Ward had an African-American population of 98%. Low and inadequate insurance cover amongst African-Americans was also reported after Hurricane Andrew (Girard and Peacock, 1997 in Tobin, 1999) (*ethnicity*).

Low economic status often correlates with poor-quality and ill maintained dwellings. In their 'Pressure and Release (PAR)'-model, Wisner et al. (2004) refer to 'unsafe conditions' in this respect. In the U.S. for example, poor people often live in mobile homes, which are less able to withstand storms. After Hurricane Andrew reached Florida in 1992, out of 6,600 mobile homes only nine were not destroyed (Morrow, 1999).

While early warning saved most lives, this example illustrates the role housing plays, in particular if no warning systems exists or the hazard occurs suddenly without adequate time for evacuation, for example in the case of earthquakes. The quality of housing directly affects the likelihood of being wounded: whether a building remains intact or collapses during an earthquake directly affects survival chances of those located inside (*vulnerability*). The lack of storm shutters or a solid dwelling structure are generally seen as the causes of damage and loss to wind storms. However, limited ability to choose and to afford better, more protective housing remains an underlying factor (Morrow, 2000). The quality of housing is discussed in the context of the built environment at the end of this chapter.

In the face of evacuation, people with limited financial resources are likely to lack sufficient options for transport. Therefore they cannot leave, or might be delayed in leaving the area which increases their exposure and potential to being harmed (*vulnerability*). With Hurricane Andrew approaching Florida, some people had to walk or hitchhike in order to leave the danger zone and reach safety (Morrow, 1997, 1999). In the pre-Katrina New Orleans about 27% of the

adult residents did not own a car (Cutter and Emrich, 2006). Though this at first does not seem like a large proportion, the lack of planning and preparedness to assist these people (in total about 50,000) in leaving the city exacerbated their situation. Those who could afford to leave left, those who could not were left behind.

The location of dwellings can increase people's exposure to hazards, which is referred to as the second factor of 'unsafe conditions' in the PAR-model (Wisner et al., 2004). People of low economic status often reside in unsafe locations, such as floodplains (Quarantelli, 1993; Sidle et al., 2004), which in turn increases their potential to suffer harm (*vulnerability*). As opposed to those higher income households that choose to live in a unsafe location, poor people often do not have the choice since they need to be close to their source of income, for example in the case of fishing or tourism (Wisner, 1993 after Allan, 1991; Morrow, 1999, Wisner et al., 2004). This illustrates the concept of voluntary risk (for the rich) and involuntary risk (for the poor) (Smith, 2004; Alexander, 2005).

In the literature referred to in this section, 'unsafe location' is directly and consistently equalled with higher vulnerability. This is not quite correct, since in fact it is exposure to a natural hazard that is increased (chapter 2). In terms of exposure, consequences for vulnerability arise due to the specific economic status: while the rich and poor can be exposed to the same degree living on a steep slope, the different foundations, strength of materials and protection of their houses will entail different degrees of vulnerability at an equally unsafe location.

Therefore, it is often the combination of unsafe housing and unsafe location which renders economically, and often spatially, marginalised people more vulnerable (Wisner, 1993 after Parker and Thompson, 1991, Tobin and Montz, 1997). In Bangladesh, it is often the poor households with *'the flimsiest houses and least economic resources who suffer most'* during and after floods (Brammer, 2000: 109). Settlements around Kuala Lumpur, Malaysia, spread into floodplains of the Kelang River. Of these, one fifth is residential, which is mostly occupied by the poorest living in squatter settlements (Chan and Parker, 1996 in Montz, 2000). Examples for combined unsafe housing and unsafe location with respect to threatening landslides are the barrios of Caracas, the favelas of Rio de Janeiro and bidonvilles of Ponce (Puerto Rico) and Cuzco (Peru) (Alexander, 1989 in Alexander, 2005).

A feedback between erecting dwellings on marginal land such as steep hillsides and the occurrence of landslides has been observed in many cases (chapter 2). The often illegal building activities of the economically marginalised (or the rich for that matter) can decrease overall slope stability and foster landslides – a situation also often emerging due to limited access to farm land (see later in this section). In addition, the lack of or the only poorly constructed and maintained drainage of waste or storm water in these areas can trigger flooding and landslides (Wisner, 1993; 2000). Uncontrolled building activities in San Salvador, in this

case by developers, increased surface run-off and resulted in flash flooding in lower lying poor communities in September 1989 (Lavell, 1994).

The poor often rely on jobs which are likely to be eroded by a disaster. These low-paid 'informal sector' jobs, such as house cleaning, gardening, childcare, catering or other home-based enterprises, can disappear with the employer's home, or when the employer has left the danger zone (Morrow and Enarson, 1996; Morrow 1999; Cannon, 2000), is displaced or has died. Temporary jobs in the agricultural sector are endangered when a flood destroys employment opportunities along with crops (Cannon, 2000). Similarly, permanent jobs as the source of livelihood can be endangered (Brammer, 2000). Other hazards such as landslides, storms and droughts threaten the agricultural sector accordingly. Low-paying jobs in this sector are more likely to be lost first, because they are directly related to comparatively unskilled activities such as harvesting. These examples illustrate a feedback between low wages and job security. This is a double negative situation, with implications for adaptive activities targeting vulnerability and resilience. Furthermore, the examples reveal the link with the resource 'environment' and economic well-being.

Poverty is often not quantifiable in terms of financial resources, but constitutes itself as limited access or the loss of access to other resources. Worldwide, the poorest suffer from lost access to fresh water, marine and terrestrial wildlife and land to grow crops and trees (*environment: vulnerability, resilience*). Attempts to regain access to these resources are often accompanied with relocation and increased exposure to hazards on marginal land as indicated previously (Wisner, 1993). For example, small scale farmers in Nicaragua and Honduras have been replaced by multinational companies establishing coffee and banana plantations. Consequently, these farmers have been driven further into the mountainous terrain, subsequently cutting down forests for their crops. This practice, recently more widespread by dislocated farmers aiming to sustain a livelihood, has led to substantial losses of topsoil in these areas. When Hurricane Mitch struck Central America in 1998, widespread massive landsliding not only destroyed crops, but also infrastructure and whole villages (Comfort et al., 1999, Wisner, 2000).

Communities with a large proportion of low-income households will have to support these households more and longer than higher-income households (Morrow, 1999). If such support mechanisms exist (either institutionalised or privately organised), such a community is affected as a whole and might not have the capacity to provide additional people with the assistance required.

Poverty is an important factor influencing adaptive capacity. Simultaneously, it is one of the most difficult variables to modify. Poverty reduction is a long-term process which needs to be based on a more equal distribution of power and resources, and social justice (Wisner, 1993). It should be noted that the above examples illustrate relative poverty, meaning that levels of

poverty are not absolute but depend on social and cultural context. Furthermore, despite the above summary illustrating the profound implications that poverty bears for vulnerability, the often cited equation 'vulnerability = poverty' is far too simple (Wisner, 1993, Anderson, 2000). Simultaneously, a range of other factors play a role, or even a larger role, for people's resilience.

8.2 Age

With respect to vulnerability studies, one often cited variable is age with respect to the elderly and the young. It should be noted here that resilience literature usually does not refer to the variable 'age', although there are clear implications as will be seen shortly.

The age boundaries defining these two groups are inconsistent throughout the literature. Eldar (1992) for example refers to a body of literature using the age of 60 as a threshold for the elderly. This benchmark is somewhat arbitrary, and vulnerability studies often utilise census data and have to apply the age boundaries dictated by the census.

8.2.1 The elderly

After the 1995 Great Hanshin earthquake in Kobe and surroundings, 30% of all fatalities were in people aged between 60 and 74 and a further 30% were older than 75 years. Therefore about half of those who died were older than 60 years (United Nations Centre for Regional Development, 1995: 45 in Wisner, 1998). Similar figures have been assembled for Hurricane Katrina (Gullette, 2006). Klinenberg (2002) reported that 73% of all casualties of the 1995 Chicago heat wave (in total 521) were older than 65 years. A case study carried out in several areas in Sri Lanka after the 2004 Asian Tsunami revealed that the proportion of the elderly amongst the overall number of dead and missing people was the highest (Birkmann et al., 2006).

The physical strength of elderly people is likely less compared to younger people (Buckle et al. 2000). Many of those victims of the Kobe earthquake older than 60 years did not have the physical strength to free themselves from collapsed buildings (United Nations Centre for Regional Development, 1995 in Wisner, 1998). The elderly are less able to withstand external stresses such as falling debris or high-speed water masses. Nor can they climb onto roof tops to escape flooding or leave the hazard area by foot burdened with supplies (Gullette, 2006). During the Chicago heat wave of 1995, the elderly had to be carried down from their hot high level apartments once lifts in high rise buildings stopped working (Klinenberg, 2002). The elderly are also more likely to be disabled and suffer from diseases for which they need special medication, and have special needs emergency workers need to be aware of. For instance the elderly have a higher risk of dehydration than younger people (Gullette, 2006) (*age: vulnerability*).

The elderly's sensory or cognitive abilities are likely impaired compared to those of younger people. During and in the aftermath of a natural hazard manifesting, the elderly are therefore

less likely to cope with the changed, disrupted environment. For example, as occurred during the Chicago heat wave, lifts might not be usable anymore, or a well accustomed pathway which is practicable with impaired sight might be blocked, resulting in disorientation (Eldar, 1992). The elderly are therefore more likely to be wounded in the immediate onset of a hazard (*vulnerability*).

In the aftermath of a manifested natural hazard the proportion of disabled persons within the age group over 65 is generally very high (Eldar, 1992). Also, when evacuated and sheltered in refugee camps or other temporary shelter, the elderly are more likely to rely on medication or special aids which might not be available (Eldar, 1992), as observed after Hurricane Katrina had hit New Orleans (Gullette, 2006).

Although there is a debate about the proneness of the elderly towards posttraumatic stress disorder (PTSD), there is some indication that they are more likely to suffer from this sort of psychiatric problem in the aftermath (Ticehurst et al., 1996; Chung et al., 2004). Morrow (1999) refers to authors who have demonstrated slower recovery and a higher probability of impacts on their health, compared to younger people, after a disaster occurred.

The elderly are likely to be less mobile, hence less able to escape a hazard zone or find shelter within a building (Eldar 1992; Buckle et al., 2000). They also tend to be reluctant to leave their homes in the case of an evacuation (Gladwin and Peacock, 1997). As reports from Hurricane Katrina revealed, the elderly in particular refused to be evacuated once they were told they could not take their pets – the pet being their only family (Hartman and Squires, 2006). Compared to younger people, the elderly are therefore more likely to remain in the endangered zone and therefore in an unsafe location (*indirect through exposure: vulnerability*).

This set of aspects is probably what generally is subsumed under the statement that elderly are likely to be more 'fragile' (Morrow, 1999; Buckle et al., 2000), or captured in statements that the probability of injury is higher for the elderly (Quarantelli, 1993). Furthermore, in the case of reduced sensory and cognitive abilities, the access to information, such as warnings and where to receive relief is limited (Eldar, 1992; Mayhorn, 2005; Guha-Sapir et al., 2006) (*information: vulnerability*).

In the U.S. of the mid 1990s, of all people living alone, 40% were aged 65 and older. This is only a snapshot of a trend which firstly sees the number of people living alone, and secondly the proportion of elderly people living alone spiralling since the 1950s (Klinenberg, 2002 referring to the U.S. Bureau of Census). This general trend, which might be representative of many other industrialised countries, bears some profound implications for disasters. Especially for the elderly, living alone often comes with a range of adverse effects: they are more likely to suffer from depression, to be impoverished, to hurt themselves unnoticed, and to be disconnected from social networks which supply care, emotional and material/physical support (Klinenberg,

2002: Busuttil, 2004; Buckle, 2006). Therefore, isolated elderly people cut off from social networks are more likely to lack the benefits of social capital for implementing adaptive activities targeting resilience, such as emotional or financial support or sharing skills (*social and financial capital: resilience*). The role of social networks for building resilience is underlined by Ronan and Johnston (2005). They see youth, schools and family as major components of a community, which are linked amongst each other and with other networks (see also Witten et al., 2007). Elderly people are usually excluded from these networks if not connected by kinship. Generally, people tend to rely more on family and friends rather than official support, which underlines the role of family networks. The quality of social networks is crucially important for the mental health of those who survive: psychologically they respond far better when believing they will get help and care if needed, compared to survivors who feel left alone (North, 2003) (*social capital: vulnerability*).

Each one of the above factors and their combination reveal the explanations for reports like the one of the high number of Kobe earthquake victims being older than 60 years and living alone (United Nations Centre for Regional Development, 1995 in Wisner, 1998). During the 1995 Chicago heat wave with 73% of the fatalities older than 65 years (see above), hundreds died alone, which led Klinenberg (2002) to conclude that the heat was not a natural, but a social disaster.

In general terms, the elderly are more likely to be disadvantaged financially due to a lack of or a reduced income (Quarantelli, 1993; Bolin and Stanford, 1998; Buckle et al, 2000, Eldar, 1992, Busuttil, 2004). For example, during a heat wave which struck the U.S. in 1979, thousands of elderly were killed because they could not pay for air conditioning, or were financially unable to vacate to a cooler climate (Wisner, 1993 after O'Riordan, 1986). Furthermore, they are unlikely to have the same opportunities, with respect to available time, to regain financial resources than younger people (Buckle et al., 2000). A lower economic status bears all those implications summarised in section 8.1 (*financial capital: vulnerability, resilience*).

A correlation between unsafe housing and higher age is likely. For example, one of several factors which contributed to the high death toll amongst people older than 60 years during the Kobe earthquake, was that they tended to live in old houses which collapsed and, when wooden, burned (United Nations Centre for Regional Development, 1995 in Wisner, 1998) (*age: vulnerability*).

Elderly can utilise experience with previous crisis to help them to minimise adverse effects resulting from a manifested natural hazard (*information: vulnerability, resilience*). For example, during a gas shortage in Victoria, Australia, in 1998 elderly who had experienced the Great Depression and WW II could tap back into coping strategies they had developed (Buckle et al,

2000). This can be valuable in the event of a natural disaster, when gas supply is cut and alternatives for cooking and heating need to be found.

However, while having lived through a hazardous event in the past can increase preparedness and improve the way of response in the case of an emergency, the opposite is also observed. Especially when the past event was of small or medium magnitude, people can be blasé and act in a way that reflects a 'we've dealt with it before, we'll cope now' attitude (Morrow, 1999). In addition, better preparation and response cannot be directly related to prior experience because other factors, such as the socio-economic status, can be restrictive. Also the time lapse between a previous event and a potential future hazard is likely to play a role in disaster preparedness. If the event occurred a long time ago, the memory of useful experiences might be lost or skewed (*information: vulnerability, resilience*).

8.2.2 Children

Compared to adults, children's mortality rates from disasters indicate a generally higher degree of suffered harm. For example, over half of the deaths related to the Bangladesh cyclone disaster of 1970 were suffered by children younger than ten years, although they only comprised only one-third of the overall population (Smith, 2004). Following the 1991 Bangladesh Cyclone, 60% of fatalities were children (Brammer, 2000). A study conducted in the Indian state of Tamil Nadu showed a disproportionately high number of deaths amongst children of both sexes following the Asian Tsunami of 2004 (Guha-Sapir et al., 2006). Concluding from several reports in India and Sri Lanka generated after the tsunami, Rohde (2005) stated that in fact a third of all fatalities were children (in Wisner, 2006).

These death tolls indicate that for a number of reasons, children are more vulnerable than adults. Due to their reduced physical strength, they are less likely to withstand natural forces. The very young are less mobile: infants cannot run away and older children cannot use other means of transport, which increases their exposure (*indirect through exposure: vulnerability*). When sensory and cognitive abilities are not fully developed, 'sensible' behaviour and receiving information such as warnings cannot be expected, and due to their young age they are less likely to have experienced a similar crisis (*information: vulnerability, resilience*).

Morrow (1999) pointed toward a body of literature which demonstrates the adverse psychological effects such events have on children. As North (2003: 63) summarised, children's perception of the world can substantially change when exposed to destruction, which influences their future development and can have adverse effects on their relation to trust, their sense of 'safety, self-esteem, self-efficacy, interpersonal relations and more development'. North (2003) further reported cases of guilt or responsibility for what has happened. For example, after the 9/11 tragedy a boy aged 11 feared the towers collapsed and his father died because he had lied about brushing his teeth. Moreover, North stated that the young generally have reduced coping abilities hence they are more likely to be overwhelmed and traumatised. Children also require special care and services while staying in refugee camps and other institutions of relief

provision (Morrow, 1999). In times of crisis, they are often 'invisible' or their needs are subordinate (Hewitt, 1997). Children are also very likely to suffer from PTSD. For example, after Hurricane Andrew had stricken southern Florida and Louisiana in 1992, 86% of children were diagnosed with PTSD three months afterwards, and 69% were still diagnosed with PTSD 10 months afterwards (LaGreca et al., 1996 in Lubit et al., 2003). One and a half years after the 1988 earthquake in Armenia, of all children living close to the epicentre 90% showed symptoms of PTSD (Pynoos et al., 1993 in Lubit et al., 2003: 66).

Hence partly due to similar, partly due to different factors children are like the elderly more 'fragile' with respect to their physical and mental health (*vulnerability*).

Because of their shorter life span compared to adults, it is less likely that children have experienced a previous disaster and can profit from familiar reaction patterns (*information: vulnerability, resilience*).

Children's overall higher probability of being adversely affected during and in the aftermath of a manifested natural hazard is strongly related to their dependence on family networks or other people outside the family (North, 2003; Buckle, 2006) (*social capital: vulnerability, resilience*). A lack of access to social networks directly translates to a lack of other resources, such as finances, information, institutions and environmental resources. If access to social networks exists, the type of network shapes the degree of children's access to other resources (*vulnerability, resilience*).

8.3 Gender

As Enarson and Morrow (1998) underlined, disasters occur in social systems which are gendered to various degrees. As many studies have shown, for a number of reasons women are more likely to be adversely affected by manifested natural hazards than men (Morrow, 1999).

8.3.1 Women

After the 2004 Asian Tsunami, twice as many women than men were reported dead or missing in the Galle Municipal Council in Sri Lanka (Birkmann et al., 2006). As earthquake disaster studies have shown, females are more likely to suffer from severe physical injuries (Ticehurst et al., 1996; Smith, 2004). Moreover, North (2003) stated that there is evidence for women being more prone to posttraumatic stress disorder (PTSD) and major depression after a disaster as compared to men. Increased susceptibility to suffer harm can also be due to biological reasons, for example less physical strength compared to men (Bradshaw, 2002). Furthermore, pregnancy decreases mobility and increases the need for food and water. Pregnant and lactating women are listed as a vulnerable group by Emergency Management Australia (1998). Multiple reports speak of increased domestic violence against woman during and after crisis (Morrow, 1999). For example, after Hurricane Andrew hit Florida in 1992, the level of domestic violence during the following months had risen, and divorce rates had increased by 30%

(Morrow, 1997 in Tobin, 1999). Moreover, violence against women during the relief process organised by official disaster management institutions has been observed (Fordham, 2003). Because of a combination of these factors, similar to the elderly and children women can be more 'fragile' than men (*vulnerability*).

A woman's vulnerability and resilience to hazards can be strongly influenced by an unequal distribution of responsibilities. Women traditionally and often still are usually responsible for care-giving, bearing most of the burden to supply daily needs of their dependent family members (Hewitt, 1997; Morrow, 1999, Tobin, 1999, Enarson and Morrow, 2001; Cutter et al., 2003; Poole, 2005 in Cottrell, 2006; ERRA-INFOCH, 2007). In New Zealand at the turn of the millennium, women were, compared to men, still more engaged with family care (Magee, 2001). In case of caring facilities for children and the elderly being closed after a disaster, within the family it is usually the woman's commitment which increases (Cutter et al., 2003). Carrying the sole care-giving responsibilities puts extra stress on women, and can lead to a mentality where children and other dependants, such as the elderly, come first, while the woman's needs comes second. This can directly affect their well-being (*vulnerability*).

As Cannon (2000) argued, not only relief but also rehabilitation programmes often target the head of the household. When accessing relief goods, women are often disadvantaged because they are to stay with the children and elderly, while the men leave to receive goods which are to be shared with the family – however, examples from several countries around the world illustrate that sharing is not necessarily what happens in practice (Morrow and Enarson, 1996, WHO, 2002) (*institutional (relief): / vulnerability*).

Women 'invisible' within family power relations, as often the case in men-headed households, experience limited decision-making (Hewitt, 1997; Fordham, 2003). It has been shown that oppressed women suffer disproportionately since decisions do not reflect their needs and susceptibility to be harmed (Hewitt, 1997) (*financial and social capital, information, environment: vulnerability, resilience*). This has been observed for example after Hurricane Mitch, when larger proportions of households relied on one income supplied by the male, which restricted women's access to and control over the resources available (Bradshaw, 2002). After Hurricane Andrew devastated southern Florida in 1992, it has been reported that many women wanted to improve the safety of their homes, but were unable to realise this safety measure against the will of their husbands (Enarson and Morrow, 1998).

When the male partner has not survived, women can face new roles which they are not accustomed to and which makes it even more crucial that they have access to economic and social services, as observed after the 2005 earthquake in Pakistan (ERRA-INFOCH, 2007) (*vulnerability, resilience*).

Outside the household context, Fordham (2004) criticised an often gendered disaster management, with no understanding of women's situations, needs, capacities and vulnerabilities (see also Rashid and Michaud, 2000; WHO, 2002). This can be related to poor acknowledgement of women's opinions and needs at various levels of decision-making (Wisner, 1993) (*vulnerability, resilience*).

Behaviour patterns indoctrinated by a society can increase women's likelihood of suffering harm (*vulnerability*). For example during a flood in Bangladesh, a woman died because she did not dare to leave the house without a male, or even seek shelter where predominately men gathered. Her husband later stated that she '*was a good woman*' since she did not breach the behavioural code (Hossain et al., 1992: 54 in Enarson and Morrow, 2001: 133). Many other examples have been reported where women did not leave a dangerous area alone or did not receive vital information due to their culturally engraved role of not appearing alone in public or staying inside or close to the home (WHO, 2002; Mehta, 2007). Women often suffer from a lack of access to health systems (Cannon, 2000), which does not only potentially render them less healthy before a hazard manifests, but also in the aftermath (*institutional (health): vulnerability*). As these examples show, a culture ingraining male life as more valuable than female life generally disadvantages women in their struggle to survive the immediate threat and the aftermath of crisis. A drastic example was reported from a tidal surge in Bangladesh, where a father could not hold on to his two children. Realising the son would carry on the family line, he let go of his daughter (WHO, 2002). Certainly a horrible and painful decision for any parent in any society; the cultural norm decided in favour for the boy.

Single-woman and women headed households are likely to be amongst the low income groups (Bianchi, 1999; Morrow, 1999). This rendered these families amongst the ones with the least resources to leave New Orleans after Hurricane Katrina (Jones-DeWeever and Hartmann, 2006). This is partly because for a number of reasons women's opportunities pursuing a career are still restricted compared to men, and wages are still generally lower than those of men, as can be for example observed in the U.K. and U.S. (Rutherford, 2001; Cutter et al., 2003, Jones-DeWeever and Hartmann, 2006 based on U.S. Census Bureau, American Community Survey, 2005; Roth, 2004), and in New Zealand (Magee, 2001). Also, women's access to loans is generally lower, even if not affected by a crisis (Wisner, 1993; Morrow, 1999). Furthermore, the types of jobs occupied by women are more likely to be in the informal sector and of generally lower income and status than those of men. This implies the disadvantages of employment in the informal sector as described previously. For example, women in the U.S. Gulf region affected by Hurricane Katrina were amongst the most likely nationwide to be trapped in a cycle of low-income jobs, especially those women of colour (*ethnicity*). On a national scale, the majority of minimum-wage workers in the U.S. (60%) as well as those caught up in low-income jobs during their prime earning years (90%) are women (Jones-DeWeever and Hartmann, 2006: 87 based on Lovell (2004) and Rose and Hartmann (2004)).

As opposed to men, immediate job opportunities after a disaster are limited (Morrow and Enarson, 1996). In the case of an unbalanced care-giving pattern, women are more likely to give up their income-generating job – probably also because female wages often are still generally lower (*financial capital: vulnerability, resilience*).

Worldwide, compared to men women's access to education is reduced (Enarson and Morrow, 2001). As the UNESCO Institute for Statistics reports, as of March 2007, 64% of the 781 million illiterate adults worldwide are female¹. Illiteracy or low education levels do not only imply that higher skilled jobs are less accessible, with all consequences for the economic status as illustrated in section 8.1. It is also the ability to access information about hazards, about relief and longer term support such as loans which is limited. For example, as Morrow (1999) stated, vulnerability is increased when application forms necessary for receiving relief cannot be not be filled in, and experience in dealing with bureaucratic processes is low (*information, social capital: vulnerability, resilience*).

A combination of poverty with other factors such as ethnicity and age can exacerbate a woman's vulnerability (Morrow, 1999). The proportion of female elderly killed during the Kobe earthquake was very high (Ishii et al., 1996: 561 in Wisner, 1998). In addition, on average longer life spans can pronounce economic marginality of elderly females (Enarson and Morrow, 2001). These figures speak for themselves: in the Gulf region struck by Hurricane Katrina, the rate of poor women older than 65 exceeded the national rate and was about twice the rate of poor men in that age group (Jones-DeWeever and Hartmann, 2006, based on Gault et al, 2005) (*age, economic status: vulnerability*).

8.3.2 Men

Finding literature explicitly devoted to male vulnerability or resilience is problematic. Usually studies illustrating women's vulnerability refer to men as the 'better-off', the 'opposite' or even the cause of their vulnerability. Indeed, from the summary of gendered vulnerability above it can be concluded that due to various aspects men are less vulnerable than women. In order to avoid repetition with section 8.3.1, it is assumed here that men's access to resources such as financial capital, information and environment is generally better than compared to women. This implies that men are usually less vulnerable and more resilient. In addition, some other factors can favour men. For example, in terms of economic status after a manifested hazard or a disaster new employment opportunities likely arise in the fields of cleaning up and reconstruction. Jobs in this area often favour young men who are physically capable and have building skills (Morrow, 1999) (*financial capital: vulnerability, resilience; age*). Men are also generally physically stronger, and never weakened by pregnancy. They usually are less involved in care-giving activities (*vulnerability*).

¹ http://www.uis.unesco.org/ev.php?URL_ID=6401&URL_DO=DO_TOPIC&URL_SECTION=201, accessed 16.5.2007

Although many aspects illustrate that men are less vulnerable and likely more resilient than women, this is not to say that men are not vulnerable at all. Just as women have to deal with extra responsibility when their male partners have disappeared, men will be under more stress when suddenly confronted with care giving and household responsibilities.

Men can become susceptible to harm when their profession, for instance as fishermen, implies being close to natural resources and hence natural hazards. They might also put themselves more at risks than women, for example they are likely to try and rescue their family members or other people (WHO, 2002), although it has also been reported that women have died trying to rescue small children and elderly family members, for example during war (Hewitt, 1997). However Jonkman and Kelman (2005), analysing flood related deaths in Europe and the U.S., found that within all the cases compared, the majority of deaths were males, sometimes even rising up to 70% of reported deaths. This is associated, at least in the western context, with more men driving cars (most people during floods die driving a vehicle), risk-taking behaviour and a higher proportion of males active in emergency services. Men are more likely to be working as rescue workers or volunteers, which exposes them more towards dangerous situations after the immediate impact (WHO, 2002). In health systems dominated by female staff, men might hesitate to seek help (Fordham, 1998, Fordham and Ketteridge, 1998 in Cannon, 2000). In addition, men's mental health can be affected if their culturally imposed role as the main family's income earner is disrupted after a disaster (WHO, 2002). In extreme cases, this can lead to suicide, as reported after flooding in Australia in 1993 (P. Buckle personal communication to T. Cannon, in Cannon, 2000). Furthermore, men are more prone to substance abuse after a disaster, which affects their health and well-being (North, 2003) (*vulnerability*). Klinenberg (2002) identified the group of older men, especially those without children, as socially isolated, this means cut off from social networks which supply care, emotional and materialistic support (*age, social capital : vulnerability, resilience*).

Considering the above summary of aspects which make men less or more vulnerable or resilient than women, it seems it is rather the comparison between both which is the key to understanding gender roles with respect to vulnerability and resilience.

8.4 Household structure

The type of household, with its number of income-generating members in relation to the number of dependants (elderly, children, the disabled), generally influences and at the same time is influenced by economic status. Large families with a higher ratio of dependants (children, elderly or disabled) to income-earners are under increased pressure to obtain or sustain a certain economic status (Morrow, 1999, Buckle, 2006). This can lead to excessive demand when responsibility for dependents exceeds the financial resources available. Families are the still dominant type of households, also in western industrialised countries (Morrow, 1999). In New Zealand, the proportion of families (couple and one parent) is 60% for the year 2006 (New Zealand Census 2006). Because the costs of raising children are basically the same for every

income group, households earning less are disadvantaged. Especially single-parent households are less likely to obtain the living standard two wage earners can obtain, and become economically marginalised (Buckle, 2006). This is more likely the case of woman-headed single-parent households (Morrow, 1999) (*gender*). The type of household with respect to the number of dependents therefore plays a role for the affordability of adaptive activities targeting vulnerability and resilience (*financial capital: vulnerability, resilience*).

The type of household also bears implication for caring responsibilities during and after a crisis. Within a community, families are social networks (Ronan and Johnston, 2005). Generally families are a source of social capital: married couples or couples with children constitute a social network from which its members can profit due to shared responsibilities and resources, as well as emotional support. People living alone, e.g. widowed or young single households, cannot fall back on this kind of network (*social capital: vulnerability, resilience*).

However, networks of larger families with a higher number of dependents are under higher pressure, not only economically but also in terms of emotional support. As empirical research spanning twenty years from 1981-2001 has shown, the level of stress for adults is higher when a child is living within a household, compared to households without children (Watson et al., 2003 in Ronan and Johnston, 2005). With respect to caretaking, it is more likely to be a female responsibility, as discussed above (*gender*).

Although families still dominate social structures, western societies have become more heterogeneous compared to the scheme of a two-parent nuclear family, for example due to the increase of single households, childless couples, single parents or un-related housemates (Quarantelli, 1993). In New Zealand in 2006, 40% of families are two-parent families, while already 20% are single-parent families (New Zealand Census, 2006). At the same time, changes in household structures are the result of processes such as migration (Morrow, 1999) - increasingly, cities in developed countries such as Germany, France, Canada or the U.S. are the final destination of migrants, contributing to a wider heterogeneity than in the past. However, this reshaping of societies and the related implications for vulnerability and resilience are only slowly being recognised by policy-makers (Morrow, 1999).

8.5 Education

As already discussed in section 8.3.1, illiteracy and poor education can reduce access to information and well paid jobs, which has implications for adaptive activities involving information and financial capital, with respect to both vulnerability and resilience (*information, financial capital: vulnerability, resilience*). Additionally, the lack of language skills can result in similar consequences, for example by limiting the access to information before a disaster occurs. Especially when coupled with cultural differences, misinterpretation of information after a disaster and hence problems in seeking help and relief can arise due to a lack of language (Morrow, 1999; Buckle et al., 2000) (*information: vulnerability*).

In contrast, education and personal skills can decrease vulnerability to natural hazards (Morrow, 1999). Higher education is generally related to better job opportunities and higher lifetime earnings (Cutter et al., 2003), even after an economy has been impacted by a disaster (Morrow, 1999) (*financial capital: vulnerability, resilience*).

8.6 Ethnicity

In many cases, ethnic minorities tend to rely more on kinship and social networks for information on emergencies (Quarantelli, 1993), as for example reported after flooding in Australia (P. Buckle personal communication to T. Cannon, in Cannon, 2000). This can be a strength: within their own ethnic group, they are likely to experience strong ties and assistance (Morrow, 1999). However, recent immigrants are likely to lack access to social networks (Morrow, 1999). Members of ethnic minorities can also show a high level of mistrust towards their host society, hence they are isolated from networks and 'invisible' (Quarantelli, 1993, Bolin and Stanford, 1998) (*social capital, information: vulnerability, resilience*).

Additionally in case of immigration, a lack of language skills is likely. This language barrier can be paired with a cultural barrier when crisis management does not necessarily match the host country's approach (Morrow, 1999). The latter potentially differs from the local approach to dealing with crisis, and can be shaped by former negative experiences in their own or their host country. These aspects are likely to dampen motivation to seek help (Cannon, 2000, Morrow, 1999) (*institutional (health, relief): vulnerability*). In addition, both language and cultural differences can limit the ability of filling in forms and understanding necessary information during the immediate crisis and the recovery process, as illustrated in section 8.5. Especially in case of recent arrivals, local knowledge will be non-existent amongst this group (*information, institutional (relief): vulnerability*) (Bolin and Stanford, 1998; Morrow, 1999; Cutter et al., 2003). These aspects are closely related to those discussed in section 8.11 under the category 'migrants'.

It is not only immigrant ethnicities that are likely to be disadvantaged by lack of communication, but also indigenous peoples within their own country. In 1999, officially 263 people within the Sierra Norte de Puebla (Mexico) lost their lives due to massive flooding and landsliding, and nearly 1.5 million people were affected (Alcántara-Ayala, 2004a). This region is characterised by an above-average rate of people speaking an indigenous language. In the aftermath of the catastrophe, specialists together with local civil protection authorities produced a booklet in Nahuatl, the Aztec language, aiming to improve preparedness, awareness and understanding of landslide and flood hazards which was received very well in indigenous communities (Alcántara-Ayala et al., 2004). The need for producing such a booklet reflects the deficits of hazard education in reaching indigenous people (*institutional, information: vulnerability, resilience*). On an international scale, the long-awaited and recently constituted United Nations declaration on the Rights of Indigenous Peoples (UN, 2007) covers many aspects which are

also related to vulnerability and resilience, for example the right not to be forcefully removed from their lands, the right of self-determination or the right to safeguard and pass on their culture and indigenous knowledge. Within the declaration, the dominant issue is stopping discrimination against indigenous peoples in every respect. It further addresses the responsibility of states to improve the economic and social conditions of indigenous peoples, especially '*elders, women, youth, children and persons with disabilities*' (UN, 2007, article 21, 2). Also article 22 emphasises the rights and special needs of these groups and states that states should take measures to prevent violence against indigenous women and children. The declaration, which is not legally binding but carries much moral weight, was accepted with 143 votes in favour and only four negative votes, including New Zealand.

Conflicts between ethnic groups in the aftermath of manifested hazards or disasters can increase stress levels and lead to problems in refugee camps and temporary shelters. Since often each group is economically marginalised, competition for restricted resources creates extra tension (Tobin, 1999) (*vulnerability, resilience*).

Generally speaking, ethnic minorities are more likely to be destitute. They are more likely to work in low-income jobs, such as Koreans and Chinese working in Japan (Wisner, 1998). Ethnic minorities such as the Latinos in California have a legacy of working in low paying agricultural jobs (Bolin and Stanford, 1998). In the U.S., major hurricanes revealed that ethnic minority groups with low incomes were most severely affected (Wisner, 1993). Like many metropolitan areas in the U.S., high levels of poverty characterised New Orleans before Hurricane Katrina fell on land. A close link between poverty and race was observed, with the black poverty rate more than three times the white poverty rate (Hartman and Squires, 2006) (*financial capital: vulnerability, resilience*).

In addition, an extreme level of racial segregation shaped New Orleans, with whites and blacks literally living in different worlds (Hartman and Squires, 2006). A positive 'spill-over' effect of resources from the more affluent towards those in need was impeded by a racial barrier. Racial segregation is a residential pattern also reported for larger urban areas in New Zealand, such as Auckland, Wellington and Christchurch. Maori, especially when combined with Pacific Islanders who also claim a Polynesian identity, are clearly separated from other New Zealanders with European or Asian heritage (Johnston et al., 2005).

Ethnic minorities are likely impaired by limited access to relief and health provision (Wisner, 1993), and discriminated ethnic groups are likely to display lower nutritional and health statuses (Cannon, 2000) (*institutional (health, relief): vulnerability*). Discrimination is often a factor generating these unequal opportunities. In the U.S. for instance, there is a history of charges that claim discriminating practices towards African-Americans in the aftermath of hurricanes, for example after Hurricane Camille (1969, coastal Mississippi, Popkin, 1990 in Wisner, 1993), Hurricane Andrew (1992, Florida, Girard and Peacock, 1997 in Tobin, 1999) and Hurricane Katrina (Stein and Preuss, 2006). Media coverage during the Katrina disaster revealed

underlying race-biased perspectives on the tragedies that evolved: *'[...] black survival behaviour was treated as criminal behaviour, while similar acts by others were celebrated. African Americans searching for food, water, childcare necessities, and basic medical supplies were selfish looters, but doctors, police, and white tourists doing the same selfless heroes'* (Powell et al., 2006: 63).

Rooted in the history of slavery in the U.S., discrimination has and still does prevail within institutional structures such as justice and health systems, limiting opportunities for black people (Hartman and Squires, 2006, Powell et al., 2006). In this sense, the Katrina disaster was not triggered by a hurricane but began 250 years ago.

Institutionalised and underlying discrimination against certain ethnicities creates generally fewer opportunities and limited quality of life as well as less access to resources crucially important for mitigation, preparation and recovery after a disaster. Hurricane Katrina was a tragic example. Will it repeat itself? And, will similar tragedies unfold in countries with high ratios of immigrants, such as Germany and New Zealand?

8.7 Occupation

One aspect of the variable 'occupation' is the direct translation of occupation type into earnings, hence the economic status which in turn bears all the implications for adaptive activities targeting vulnerability and resilience as discussed in section 8.1. Higher education is generally related to better job opportunities and higher lifetime earnings as mentioned in section 8.5.

Additionally, occupations tied to a natural resource are endangered directly if this resource is destroyed by a manifested natural hazard. For example, shrimp farming in Bangladesh, which has expanded quickly in some coastal zones, is threatened by storm surges and floods. Likewise, crops are frequently destroyed by floods, hence eroding the basis of livelihoods (Brammer, 2000) (*environment: vulnerability, resilience*). This interrelation between environment and livelihood has been touched on in section 8.1.

Birkmann et al. (2006) reported that after the 2004 Asian tsunami in several areas of Sri Lanka, a high proportion of jobs were lost in the lowest income category. These jobs were mostly daily paid labour, for example fishermen, fish vendors or otherwise low-income self-employees. In the higher income group fewer jobs were lost, which were of a more permanent nature and more frequently related to government or the private sector. Birkmann et al. (2006) could also relate faster recovery rates for people working in these kind of professions compared to those working in daily paid labour. Therefore it seems that job security is higher for such sectors as government or the private sector, which is further coupled with generally higher earnings and faster recovery (*financial capital: vulnerability, resilience*). This aspect has also surfaced in section 8.1.

People working in jobs directly related to a natural resource can not only be adversely affected by the loss of the job, but also by direct physical harm and loss of life, for instance fishermen, as covered in section 8.3.2 (*vulnerability: gender*).

Seasonal, migrating agricultural workers are unlikely to be part of community networks, hence are 'invisible' to planners and relief providers (Morrow, 1999) (*resilience: migrants*).

Generally, occupation is strongly interlinked with the variables age, ethnicity and gender. For example, politically or socially marginalised people often do not have equal employment opportunities and restricted access to education (Anderson, 2000).

8.8 The disabled

Impaired sensory and cognitive, as well as physical abilities have been discussed with respect to the elderly and children, but apply even more strongly for the disabled. Hence they are likely to be more fragile than people not suffering from a disability. Receiving and responding to hazard warnings and information generally is likely to be limited by mental or physical disability such as deafness, blindness or paralysis (Wisner, 1993; Morrow, 1999) (*information: vulnerability, resilience*).

The physically disabled are likely to be less mobile, for example when dependent on a wheelchair. This affects their ability to leave the endangered zone before, during and after an event (*indirectly by exposure: vulnerability*).

The disabled are likely to be at the periphery of a community, and 'invisible' to planners and responders. This isolation or 'invisibility' implies reduced access to crisis support (Handmer, 2003). As reported during the disaster unfolding in New Orleans, the disabled were ignored, shut off from transport, communication and special medication and treatment (Gullette, 2006) (*risk management; vulnerability*). Suffering from a disability is also likely to restrict earning opportunities, hence those implications for adaptive activities, as discussed in section 8.1, are likely to apply for the disabled (*financial capital: vulnerability, resilience*).

The disabled are also likely to depend on social networks: whether they have access to such networks, as well as the type of network, influences their access to other resources (*social and financial capital, information, institutional, environmental: vulnerability, resilience*).

Depending on the cultural context, suffering from disability is related to other variables discussed here. For example, basic hygienic standards can prevent an eye disease which is transmitted by flies and causes blindness. And low hygiene environments are often the reality of the very poor (Wisner, 1993) (*economic status*). Gender issues can prolong or prevent medical treatment of women and cause disabilities. In some societies, disabled women are less likely to find a husband, which has consequences for their economic status (*gender*). A general lack of access to health systems by the often ethnically distinct minority groups increases their risk of developing disabilities (*ethnicity*).

8.9 The ill

Ill people are already weakened before the onset of an emergency: they might be immobile and their sensory or cognitive capacities can be reduced. Especially the seriously ill and people

relying on life support systems are more 'fragile' than healthy people (Buckle et al., 2000). Relying on special medication which might not be available during and in the aftermath of a crisis can be fatal. As an eye witness trapped in New Orleans three days after Hurricane Katrina reported: '*Four people died around me. Four. Diabetes. I am a diabetic and I survived it, by the grace of God [...]*'. (Alive in Truth 2005 cited in Stein and Preuss, 2006: 38). With various degrees of illness, people are dependent on social networks or public care giving facilities to various degrees. Hospitals are places where many ill people are located and therefore 'hot spots' of vulnerability, which need special consideration by risk and emergency managers (*vulnerability*). Long-term illness can lead to reduced income and eventually lower economic status, which bears a range of implications for resilience and vulnerability as discussed in section 8.1 (*financial capital*).

8.10 The homeless

Generally, homeless people are likely to suffer more from manifested natural hazards and disasters. One factor is their inability to afford safe housing, apart from those voluntarily choosing a life on the streets (who are likely to be a minority). Should the homeless construct some sort of shelter, it is likely to be flimsy and will not provide any protection (Morrow, 1999) from perils such as storms or landslides, although this can be an advantage in the case of earthquakes (*financial capital: vulnerability*). In addition, their location can be very unsafe, for example when staying under bridges close to rivers. People who are homeless before a disaster strikes are less likely to find a home afterwards, and their number is likely to increase in the aftermath (Morrow, 1999), since the overall availability of housing can be reduced by the impacts of the natural hazard (*vulnerability*). As exemplified by the homeless in Tokyo, they are generally characterised by a low income, an overall lack of financial buffers or insurance (Wisner, 1998), hence those factors related with economic status as discussed above apply (*financial capital: vulnerability, resilience*).

Like the disabled, homeless people are generally or even more so 'invisible' to the community. Marginalised people in general, especially in big urban centres, are not visible to the public (Wisner, 1998) – either because of the public's tendency to ignore them, or because they live in areas away from busy places. While the disabled are not necessarily socially isolated, the homeless often are (*social capital: resilience*). Their whereabouts are often unknown. Hence, it is likely nobody will note they are missing and search for them, which in turn increases their chances of suffering harm. Moreover, the homeless are more prone to suffering from health problems (Wisner, 1998), hence their ability to withstand physical impacts is likely to be impaired (*vulnerability*).

There are likely to exist several links between homelessness and other variables listed here. For example in Tokyo, nearly 70% of the homeless are older than 50 years (*age*), and the majority of the homeless are men (*gender*) (Tokyo Metropolitan Government, 1995 in Wisner, 1998).

8.11 Transients

Transients such as seasonal migration workers are people usually at the periphery of a local community. Hence they are less likely to have immediate access to social networks, and as Cannon (2000) argues in the case of Mexican migrant workers in California, to social and medical care (*social capital, institutional: resilience, vulnerability*).

In the case of foreign transients, the lack of language skills can bear similar consequences, for example when limiting the access to information before a disaster occurs (section 8.5). Especially when coupled with cultural differences, misinterpretation of information during and after a disaster and hence problems in seeking help can arise due to a lack of language skills (Morrow, 1999; Buckle et al., 2000) (*information: vulnerability, resilience; ethnicity, education*). Foreign migrant workers might also avoid official institutions assisting with disaster relief, because of prejudices or the fear of discovery if their presence is illegal (Wisner, 1998; Tobin, 1999; Cannon, 2000). For instance, after the 1986 floods in California, many immigrants did not apply for relief due to their fear of the government (Tobin and Montz, 1997). The same pattern was observed after the 1994 Northridge Earthquake in California (Bolin and Stanford, 1998) (*institutional (relief): vulnerability*).

Tourists might be completely cut off from their social networks (Buckle, 2006), when for example airports are closed and telecommunication is disrupted (*resource: social capital: resilience*). Even if access to financial resources was secured before a disaster, this might be not the case after a disaster, when financial services have ceased. In this case, tourists have no resources to fall back on (*financial capital: vulnerability, resilience*). Tourists are likely to lack or possess only fragmentary language skills and cultural knowledge, which influences their access to information (*information: vulnerability, resilience*). Tourists are likely to be in 'unsafe conditions', though for different reasons than the poor. They often seek beautiful surroundings within nature, which often are quite hazardous, such as high alpine settings or beaches (Morrow, 1999) (*vulnerability*).

Compared to locals, transients are less likely to have faced the type of natural hazard they might encounter. Relocation, for example due to economic pressure, implies a loss of local knowledge, not only when shifting between rural or urban areas but also from rural to urban areas and vice versa. Migrants and tourists alike are often unfamiliar with local circumstances and assistance. This means they cannot rely on tested mechanisms to mitigate, prepare, react and recover. It is unlikely that they are familiar with their environment (Buckle, 2006) and the magnitude of processes which can be encountered, even if they have been at their temporary location before. Hence a lack of local knowledge can also be a disadvantage with respect to anticipating a potentially harmful situation. For example, many of the survivors of the 2004 Asian tsunami where locals who knew about the tsunami danger and indicators of an approaching wave (Adger et al., 2005) (*information: vulnerability, resilience*).

Expanding communities are more likely to lack a high level of local knowledge, unless this is shared amongst the members of the community. Quickly expanding communities or those with a high rate of transients or tourists are likely to have a high proportion of vulnerable and non-resilient people, which could be a disadvantage for the community as a whole.

8.12 The built environment: infrastructure

'Critical' infrastructure such as telecommunications, roads, bridges and sewage, and such infrastructure delivering water, gas and electricity provide individuals, communities and countries with services which are fundamentally important for their functioning and wellbeing (Tierney, 1992; Buckle et al., 2000; Cutter et al., 2003; Dore and Etkin, 2003). Not only a society's prosperity, but also the authority of public administration can be jeopardised by a failure of critical infrastructure (Newlove et al., 2003). The lack of services impedes on people's well-being in many ways, for example by cutting people off from basics such as clean water. If not prepared for such a situation, people will suffer and become ill or even die due to dehydration. An example for how much social systems rely on technical systems is the two-month electrical blackout that struck central Auckland in 1998. It coincided with a heat wave which rendered all offices, hotels and residents without air conditioning, and had profound negative influences on the businesses operating in the CBD. Luckily no deaths resulted from this failure, which was the result of human error and a frail electricity system (Newlove et al., 2003) (*vulnerability*).

In addition, not only the lack but disruption of infrastructure can pose a secondary threat to people's well-being. For example, bursting gas pipelines after the 1906 earthquake in San Francisco led to wide spreading fires, which were a powerful accomplice for the devastation that occurred (Powers, 2006; Bradford and Carmichael, 2007). Disrupted infrastructure and the intermixing of flood water, excrement, dead bodies and debris increased the health risk of those people trapped within the flooded city of New Orleans long after Hurricane Katrina had moved on (Franklin, 2006) (*vulnerability*).

The negative effects of service disruption were also felt during Hurricane Mitch, when landline communications and road networks were massively destroyed by mudslides (Comfort et al. 1999). After the 1987 earthquake in Edgecumbe, New Zealand, landslides blocked all major roads leading in and out of the area (Johnston et al., 2006). In 1993 a massive landslide in Ecuador dammed two rivers, and when the accumulating water volumes combined into one big lake, Cuenca City was cut off from Quito and lowlands to the east and west (Morris, 2003). In the case of Hurricane Mitch, the disruption had profound impacts since 90% of trading in Central America depended on damaged infrastructure. Farmers could not access markets due to the loss of bridges and roads, and within cut-off areas prices increased threefold. This adversely affected people by threatening their livelihood (Comfort et al. 1999), with implications for their vulnerability and resilience. The eruptions of Ruapehu during 1995 and 1996 caused

widespread ashfalls across much of New Zealand's North Island. Though only a few millimetres thick, communities were left with bills to pay for cleaning-up work, as well as disruptions to air travel and the failure of electricity transmission impacted on New Zealand's North Island. Especially the skiing industry was seriously hit, and the overall costs are estimated to be more than NZ\$ 130 million (Johnston et al., 2000).

Nodes within international trade, once dysfunctional, can interrupt and adversely affect trading partners and the economies of countries. This can radiate into regional and local levels of vulnerability, since the micro-level scale is interrelated with macro-level processes (see vulnerability network model). As Comfort (1999) observed after the 1995 Hanshin earthquake, Japan's trade with Asian partners was disrupted by damage to the port of Kobe, which adversely affected the economies of these countries (Comfort et al., 1999). In the period after the earthquake, the port was closed for two years, which resulted in a loss of 40,000 jobs in Kobe (Chang, 2000 in Cross, 2001) – hence had an additional impact on the local economy (*financial capital: vulnerability, resilience*).

Because of the network character of infrastructure, people might be affected by a natural hazard occurring in their neighbourhood, despite otherwise not suffering any harm. Damage to community facilities, businesses and services directly influence people's livelihood (Buckle et al., 2000). This is an example of how different scales are interlinked, meaning the national, or regional, supply of resources such as electricity directly impacts on a community and the individual members of this community. This aspect of scale is interesting for another reason, and that is remoteness. People might be affected by infrastructure failure which was triggered far away from their residence.

Failure of infrastructure can affect the poor disproportionately. For example, failure of public transport networks impacts more severely on those without access to private transport (Buckle et al., 2000; Hartman and Squires, 2006) (*economic status*).

There are a range of factors that can make infrastructure more or less 'vulnerable' or 'resilient'. Engineering and other fields have devoted themselves to in-depth research on the performance of 'lifelines', which has developed into a field of its own (e.g. Robinson et al., 1998; Macwan, 2004; Grubestic and Murray, 2006; Rauscher et al., 2006; Ezell, 2007; Hellstroem, 2007; Min et al., 2007). Generally, there is a bundle of factors influencing infrastructure performance. For example, in countries of rapid urban growth with high levels of urban sprawl critical infrastructure can be prone to hazards since constructed quickly and hence not able to withstand external pressure. In addition, resources must be available to maintain new infrastructure (Parker and Tapsell, 1997 in Montz, 2000; Wisner, 2003b). In general, aging infrastructure can increase the probability of failure, when for example a pumping station or another critical element of a water supply system collapses. These deteriorating structures are increasingly found in older cities throughout the world (Quarantelli, 1993). London for example

is characterised by an aging infrastructure which, due to neglect of maintenance, is more vulnerable to, for example, flooding (Parker and Tapsell, 1997 in Montz, 2000). In the U.S., an investment of U.S. \$ 1.6 trillion over the next five years is necessary to counteract the poor state of key infrastructure such as highways, bridges and waste water systems (American Society of Civil Engineers, 2005 in Hartman and Squires, 2006:5).

On the one hand, tightly woven infrastructure can be advantageous. A so-called 'redundancy' implies alternative access ways if a bridge collapses, a road is blocked or a lifeline is broken (O'Rourke, 2007). After the Loma Prieta earthquake in California the San Francisco Bay Bridge was closed. However, this did not completely disrupt traffic flow because of a high level of redundancy due to alternative freeways, bridges and the tunnel underneath the bay serving the public transport system BART. In comparison, the smaller city of Santa Cruz was isolated from help due to a lack of redundancy (Webber, 1990 in Cross, 2001). A high number of access roads implies that alternative routes can be used, where a low number increases the probability that the community is cut-off when one or several access roads are impassable. Low access to a community implies the need for helicopter-based evacuations or import of rescue staff and relief goods, which as such is possible but temporally deferred as compared to road access. D'Andrea et al. (2005) underlined the role of the road network in quickly reaching affected areas with respect to seismic hazard, which regardless applies to any other hazard. Lack of access, particularly relevant in mountainous terrain, can therefore impose a great barrier towards timely emergency relief (*institutional (relief): vulnerability, resilience*).

On the other hand, highly industrialised countries with a tight network of infrastructure are more likely to bear high economic costs in the case of natural hazards (Comfort et al., 1999 after Mitchell, 1999). In tight networks, investment into infrastructure and buildings in general is high, hence the potential loss should they be destroyed. For example, after an ice storm in Quebec, Canada in 1998, costs of \$1.5 billion had to be faced which were mostly related to repairing the electricity grid and transport systems (Comfort et al., 1999 after Statistics Canada, 1998). Ten percent of the US\$ 20 billion damage after the 1993 Midwest floods in the U.S. arose due to damage to transportation (Pielke Jr, 2000).

Interdependency of infrastructure can entail the failure of one system as a consequence of a failure or disruption of another system, which is also described as a 'cascading effect' (O'Rourke, 2007). For example, telecommunication relies on electricity (Centre for Advanced Engineering, 1991). Interdependency was observed for example after the eruptions of Ruapehu in the central part of New Zealand's North Island. After ash had been washed into a power transformer, an explosion occurred which cut the electricity supply needed for water pumps. In addition, residents' cleaning-up efforts increased water usage, draining the available supply and cumulating into a water shortage (Johnston et al. 2006). During major flooding in 2004 in the Manawatu-Wanganui region, this time on the west coast of New Zealand's North Island, more than 20 bridges were destroyed or seriously damaged (Ministry of Civil Defence and Emergency

Management, 2004 in Johnston et al., 2006), including one routing a gas pipeline. Amazingly, while the bridge collapsed, the pipeline did not rupture. However, the impacted section had to be maintained and the cut-off in gas supply subsequently entailed gas shortages to regions as far away as the Hawke's Bay on the east coast (Johnston et al., 2006).

8.13 The built environment: quality of housing

Dwelling structures influence people's probability of being wounded when natural hazards strike (Heinz Centre, 2002 in Cutter and Emrich, 2006). Housing design can be a very effective way of adjustment to a specific natural hazard. For example in Bangladesh, traditional housing patterns are adapted to seasonal 'normal' flooding by not only being located on the crests of floodplain ridges, but also by being constructed on raised mounds and with plinth levels based on previous flooding experience. On river 'chars', which is land between river channels temporarily alluvial, houses are designed to be deconstructed easily and reconstructed elsewhere (Brammer, 2000).

However, there are other examples where the construction of a dwelling can increase the vulnerability of its inhabitants. For example, loam and stone houses are known to not perform well during earthquakes (Schwarz et al., 2004). During the 7.8 magnitude earthquake in Napier and Hastings located in the North Island of New Zealand in 1931, most of the cities' unstrengthened brick buildings, and a poorly constructed concrete building (a nurses home), collapsed. This was the major reason for fatalities (Johnston et al., 2006). The quality of the construction can severely limit the robustness towards earthquakes, which explains different degrees of damage to school buildings after an earthquake struck the city of Bingöl, Turkey, in 2003 (Schwarz et al., 2004). During the 1999 Marmara earthquake in Turkey, 43 schools collapsed (Oezerdem, 2003) – exposing especially children and teachers to higher probabilities to be wounded (*age, occupation*). Most houses destroyed by the 2004 Asian Tsunami in the Indian Region of Tamil Nadu were of poor construction quality (Guha-Sapir et al., 2006). Heinemann (1999) provides a general overview of different resistance levels to landslides according to the building structure. For example, light timber dwellings are overall less resistant than mixed structures of concrete and timber, which again are less resistant than brick walls or pure concrete designs (Glade, 2003). The 1999 Marmara earthquake left 75,000 buildings collapsed or heavily damaged and about 17,000 people dead – both numbers are peak values for all major earthquakes in Turkey since 1970. While poor building quality was the direct explanation for the peaks, underlying factors such as a high level of corruption paired with slack supervision of building codes and a fast migration from rural to urban areas since the 1980s urging to meet growing accommodation needs influenced the death toll (Oezerdem, 2003). Buildings are human-made, and the type of structures and their quality are constructs of political, economic and social processes – the Marmara earthquake is a sad example of such a socially constructed disaster. Wisner (2003b) linked the catastrophic consequences of the 1988 earthquake in Armenia to poor building quality which can be traced back to similar causes as revealed for Turkey.

Renting usually limits the influence a tenant has on the condition and maintenance of the dwelling. This includes aspects such as a sound structure and hazard protection elements like shutters for storms (Morrow, 1999), or reinforced concrete for earthquakes, or a retaining wall in the case of landslides. The maintenance of a building can be substantially neglected, due to a higher short-term cost-benefit ratio based on rental income but no expenditure on repairs (as own experience showed). Furthermore, the house owner is more likely to ignore the poor structure and/or maintenance since he or she is not exposed to them on a daily basis. These aspects can entail unsafe housing with implications for vulnerability as discussed previously.

After a manifested natural hazard or disaster, within a depleted housing market landlords may expect full rent payment while repairs have not been carried out. In the case of insured property, the money can also go towards renovations which, when finished, are followed by a rent increase. This, in turn, can mean that the current tenants are not able to afford living there anymore (Morrow, 2000), which puts extra stress on their situation.

8.14 The built environment: location of housing

Where people are located when a hazard strikes influences their exposure, i.e. the potential degree of impact on their well-being. This has already been discussed in the context of 'unsafe location' in section 8.1. However, another aspect is the location of people within their houses. In the case of landslides, people sleeping in rooms which face the slope, especially when the room has a window which is not secured by shutters, are exposed to debris potentially entering the house. Although Fell (1994) and Fell and Hartford (1997) referred to this as increased vulnerability, it is strictly speaking, increased exposure due to location. A similar principle applies for day time-night time presence. During the day, children will be at kindergarten or school, and employed household members will be at their work place. Hence their exposure resulting from a landslide threatening their home is lower during the day, but higher at night (Glade, 2003).

So far, socio-economic variables characterising the profile of a community and their implication for access to resources, hence adaptive capacity, have been discussed. A few additional aspects which do not directly translate into adaptive capacity but bear implications for vulnerability mainly have been included, namely fragility, immobility, and benefits from welfare and health systems. Furthermore, the way infrastructure influences vulnerability and resilience of communities has been sketched out.

The next variable introduced here, 'community life' is mainly concerned with resilience. It is as such not filtered by the socio-economic profile of a community, which is why it is listed separately at the bottom of figure 7.3. This variable is however strongly related to the resource 'social capital', and to a lesser degree 'financial capital', as discussed in the following.

8.15 Community network

This variable combines a range of aspects that only apply on the community scale, mainly cohesion, participation, and social infrastructure. One of these aspects is the sense of community which can foster participation in community activities and volunteerism, therefore help building networks (King and MacGregor, 2000; Buckle, 2006; Paton, 2006) (*social capital: resilience*). This relation works in the other direction as well: a sense of community is likely to be the product of participation in community activities. In any case, it is the beneficial effect on social networks which is the central point here. The positive effects of social networks surfaced in some of the previous sections, for instance ethnicity or household structure, and are discussed in relation to social capital (chapter 7). A sense of community can emerge due to shared values and goals and a common future (Buckle et al., 2000; King and MacGregor, 2000). Closely related is also a sense of belonging which positively influences community cohesion (King and MacGregor, 2000).

Importantly, communities can also possess structures of decision making which foster participation and communication (Alcántara-Ayala et al., 2004; King, 2006; Paton, 2006) with respect to mitigation, preparation and recovery activities. Bolin and Stanford (1998) and Pelling (1998) for instance underlined the role of 'Community Based Organisations' (CBOs) which are non-profit organisations growing out of the community. Pilgrim (1999) reported of a community in the Indian Himalayas, successfully articulating their needs after a landslide had cut the village off. Community structures can also be organised to monitor and assess changes within the community through consultation and auditing processes (Fordham, 2003; Buckle, 2006), which favours mitigation and preparation activities. Moreover, community inherent structures providing support for community members, for instance through counsellors or specialist support, can foster resilience (Buckle, 2006), mainly through assisting with recovery, mitigation or preparation activities. Community centres are a vital element enhancing the implementation of community activities (Fordham, 2003). Finally, community organisations (sport and social clubs) generally foster the exchange of information, skills, materials as well as spending time for planning and preparing (Buckle et al., 2000). Granger (2003a) in an attempt to operationalise vulnerability, also lists under the factor 'society' elements that can be used to describe the community, such as social and cultural services that support the community, churches, schools, libraries, sporting clubs and social clubs. Witten et al. (2007) underlined and exemplified for communities in New Zealand the central role schools and pre-schools (and supposedly kindergartens and playcentres) play for the parents' sense of belonging, source of information, friendship networks as well as mutual child care and support.

8.16 Crossing scales: risk management

Similar to 'community network' risk management is not factor-specific to elements at risk, but can influence vulnerability as well as resilience by supporting and guiding adaptive activities. It

is therefore discussed here and included in the models of vulnerability and resilience as a separate aspect.

While it is often the self-reliance or self-efficacy of people and their communities which is associated with resilience (chapter 6.), the nature and quality of risk management implemented by authorities can play a vital role in enhancing people's adaptive capacity. Risk management can, of course, profit from community inherent capabilities and surface through formalised decision-making bodies, a sense of community involvement and volunteerism. These community inherent aspects of risk management, however, manifest as adaptive activities and have been discussed above.

Risk management can not only influence exposure to hazard, for example in terms of land use planning (Paton, 2006; Paton et al., 2006) and (early) warning systems. As touched on in chapter 2, options of non-structural risk management targeting vulnerability and resilience are emergency preparedness, building codes and their enforcement, fostering education and public awareness and promoting insurance (Oezerdem, 2003 based on Barakat and Davis, 1998) (*vulnerability, resilience*). With the onset of the massive flooding of 1993 in Europe, German, Belgian and Dutch authorities were caught unprepared and emitted delayed warnings. The 1995 floods revealed better preparation and usage of warning time (Rosenthal and Bezuyen, 2000) – hence demonstrating that government agencies can improve their performance if the will and resources are available. Non-structural or 'soft engineering' methods can also entail less destructive forms of land use (Morris, 2003). Structural mitigation measures usually aim at keeping the hazard away from people, for instance by constructing windbreaks or dams (Oezerdem, 2003). The way risk management can positively influence a community's vulnerability and resilience by targeting adaptive measures is summarised in table 8.1.

Risk management also involves managing resources provided by the state, such as relief in the form of directly addressing urgent needs and financial capital for recovery. After the 1994 Northridge Earthquake in California, the federal government provided billions of dollars for loans (Bolin and Stanford, 1998). However, access to loans was not equal, partly because the loans were designed for middle-class homeowners, partly because of unequal access due to cultural and educational differences (Bolin and Stanford, 1998; see also above ethnicity).

In contrast, when facing strained internal resources and dependency on foreign aid the state's decisions are not necessarily best for its citizens. With respect to relief as part of the recovery process, risk management can be diluted by the state when restricting external help and preferring to deal with the crisis internally, in order to display strength and capability. This, however, is not necessarily the reality. For example, after the 1995 Neftegorsk earthquake, Russia refused to accept foreign aid although it had problems dealing with the situation internally (Tobin and Montz, 1997). Food deliveries to North Korea are still difficult, while China permitted some degree of foreign assistance after disasters (Cannon, 2000), with for example Japan sending food in 2000 (Kelman, 2003). This kind of political farce is not restricted to

communist regimes, and was observed for example during the evolving disaster of New Orleans after Hurricane Katrina fell on land. An offer of foreign aid coming from Cuba was ignored by the U.S. State Department (Hartman and Squires, 2006). Likewise, Cuba had refused to accept U.S. aid, for example during a drought in 1998, and only accepted U.S. food aid after in 2001 Hurricane Michelle had left a path of destruction in Cuba. These political tactics are what Kelman (2003) called 'disaster diplomacy' and, as stated above, are not always guided by a prime concern for the well-being of citizens.

Powers (2006), after reviewing several disasters in the history of the U.S., underlined the need of 'revitalization' disaster stricken regions rather than simply rebuilding them, for example by promoting improved housing options for low-income families, and utilizing the labour force to move people to self-sufficiency. Anderson and Woodrow (1998), arguing from a development perspective, observed that immediate disaster responses frequently overrule sustainable recovery and development. Fordham (2003) emphasised this observation and called for experience and knowledge transfer from the 'South' to the 'North' in order to prevent simple 'returning to normality' philosophy of risk management.

Tab. 8.1: Risk management opportunities for promoting adaptive activity and other aspects influencing vulnerability and resilience

	Vulnerability	Resilience
Mitigation	structural and non-structural: modify hazard, land use planning, implement building codes, enforce building codes, warning systems in place, evacuation facilities in place, facilities for search and rescue operations	strengthen civil society, foster volunteerism, foster community inherent structures of decision making, organisation and mutual support, foster participation
Preparation	foster hazard education to promote people's adaptation to short term impact; risk management itself: emergency planning, skilled people and resources	foster hazard education to encourage social networks and accumulation of resources and skills for enhanced self-reliance
Recovery	manage relief, support sustainable recovery i.e. by implementing mitigation and preparation strategies	provide long-term support for rebuilding livelihoods, include mitigation and preparation strategies for sustainability

Risk management and government systems and policies are interrelated. Generally the type of state system can positively influence civil society in a sense that people's capacity to deal with an emergency can be strengthened by a higher moral, good nutrition, healthy conditions, freedom of press and speech (Cannon, 2000) (*vulnerability, resilience*). This relates to the framing conditions as discussed in chapter 7. Civil societies can be characterised by a dominant attitude of self-reliance and 'do it yourself' such as in New Zealand. In contrast an attitude of 'asistencialismo' has been observed in Latin America, at least in the past, and in some areas. 'Asistencialismo' accounts for dependency on others, such as the state or foreign aid, combined with an expectation of receiving financial or material help (Morris, 2003). This is associated with

a 'weak' civil society rooted in the legacy of colonialism and following corrupt and dictator governments (Fukuyama, 1995 in Morris, 2003).

Restrictions in government spending on sectors such as infrastructure, health and other public services can severely limit the ability of municipalities to prepare and react to natural hazards, which directly translates to the vulnerability and resilience of the people and can influence their adaptive capacity (Hartman and Squires, 2006). Cutbacks in government spending can be caused by a variety of reasons, for example a low tax income due to low productivity. The huge losses after Hurricane Mitch which struck Central America in 1998 are partly explained by the already weakened state municipal and national governments (Comfort et al., 1999, Wisner, 2000). Lack of political will or ability to provide alternatives can render people in unsafe conditions. Examples are the slum settlements around Rio de Janeiro, usually located on very steep slopes (Allen, 1994 in Cannon, 2000). The squatters and shack dwellers in South Africa that mushroomed during and after the apartheid generally lack safe water, electricity, sanitation or drainage of rainwater, hence overall creating unsafe conditions in areas affected by natural hazards such as floods (Wisner, 2000).

A resourceful state can provide welfare and health systems. However, in developed nations such as the U.S., for various reasons access to for example the health system is often not equal, depending on income, education, and ethnicity (Franklin, 2006 after Institute of Medicine, 2003 and Franklin et al. 2005).

Generally, the state's contribution towards reducing natural risk can be impeded by not only lack of political will or lack of resources, but also by inability to face the complexity of the problem, by corruption, by failure to implement and re-enforce building codes, and by failure to cooperate between different agencies (Montz, 2000; Oezerdem, 2003). In contrast, legislation such as implemented in New Zealand (Resource Management Act, building act) and specific institutions, such as the New Zealand Ministry of Civil Defence and Emergency Management, and the Earthquake Commission can reduce natural risk.

8.17 Variable interrelation

While the link between frame and profile is discussed in chapter 7, links within each level have not been addressed as yet. Of special interest for this thesis is the profile level, since this is where the vulnerability and resilience assessment is anchored. Figure 8.1 summarises socio-economic variables which shape the profile of a community as discussed in this chapter, and their implications for vulnerability and resilience.

The profile level of explanation does not only provide insights with respect to access to resources and translation into adaptive capacities but has immediate practical value for hazard

and risk management, for example in planning evacuation and targeting special groups such as the elderly, patients in hospitals or kindergartens.

As figure 8.1 illustrates, several variables, namely age, gender, ethnicity and disability, are linked by the variable 'education' and 'occupation' and cumulate in 'economic status'. Mapping out this path enhances the visibility of consequences stemming from alternations of one or more variables. For instance, improving language skills of immigrants will not only improve their access to information and potentially lower cultural barriers, but also improve their job and economic status. Such a map shows where strategies for reducing vulnerability and increasing resilience can start, or which aspects should be prioritised. Hence such map, which can be designed at the household or community scale, is a useful tool in risk management. One result of this research is the quantification of the strength of these relationships on the community scale (chapter 13).

As Wisner (1993) pointed out, although identifying socio-economic variables is a necessity for vulnerability analysis, simple correlations of individual factors with, for example mortality rate, do not necessarily reveal the causation of vulnerability. Such a procedure may be favoured when aiming to reduce the number of variables included in vulnerability and resilience analysis. In addition, despite the possible interrelations between variables, one variable cannot necessarily operate as a substitute for various other variables. For example, from a South Asian perspective several variables combine to increase women's vulnerability because they account for different aspects, such as high illiteracy levels, low assets or land ownership, limited mobility outside the home, low social status and a dependency on male family members which is defined by social norms (Ariyabandu, 2000 in Fordham, 2003). A 'young, low-income, illegal immigrant, single-mother' combination has been found to increase women's vulnerability to a variety of processes, such as earthquakes, fires or storms (Wisner, 2003a:11; Wisner, 1999).

This is just one of many examples for why variables are generally assumed to be cumulative, which can subsequently amplify disadvantages. If detailed census data is available, the combination of aspects lowering adaptive capacity can be mapped out specifically.

Before the methodology and results of the hazard, vulnerability, resilience and risk analysis are presented, the following chapter introduces the three study sites 'Western Hutt Hills' (WHH), 'Te Arai' and 'Aoraki'.

Figure 8.1: Variable interrelations on the profile scale, simplified

9. Study sites

The aim of this research, to identify and interpret the evolution of risk, is based on the thesis that risk is a product of interacting social and geophysical processes (chapter 2). This chapter summarises processes which shaped and still shape New Zealand's society and landscape alike. Three processes are the focus of this research: suburbanisation, rural development, and tourism. The three locations included in this research represent these processes: the suburbs of the Western Hutt Hills, the rural communities of Te Arai, and Aoraki as a hub of tourism in New Zealand (figure 9.1). The geographical settings of the three sites are presented here and discussed under special consideration of landslide risk.

9.1 Shifting New Zealand

New Zealand's era of settlement is relatively short. Human history began with the first Polynesian canoes landing on the shores of the North Island, about 800 years ago (King, 2003). These first inhabitants, the Maori, entered a densely vegetated environment, which they altered by clearing forest with fire, by hunting and introducing exotic species (Williams, 1980). Those activities led to significant extinction of native wildlife, as well as to locally increased rates of sediment mobilisation and deposition (e.g. Lake Tutira, North Island) (Page and Trustrum, 1997; King, 2003). However, the impact was relatively low since Maori preferred flat areas, hence the more erosion-prone hill country was not destabilised (Glade, 2003b). Additionally, the alterations spanned a period of several hundred years and regeneration of vegetation cover was possible (Williams, 1980).

From 1840 on, things changed dramatically. While the pre-1840 Europeans in New Zealand tended to live at the coastal fringes, the waves of settlers coming into the country after 1840 were immense. Their numbers, mainly triggered by private enterprise immigration, rose from ca. 300 in 1830 to 2000 in 1840 to ca. 500,000 in 1881 (Robinson et al., 2000; Statistics New Zealand, 2006). Urban centres were established and expanded, consuming land for housing, businesses and infrastructure (Robinson et al., 2000).

The strong orientation towards farming and agriculture as the main export products from the beginning of the nation shaped New Zealand's development during the last century until today. The early colonial vision was to create a 'Neo-Europe' by altering the landscape and introducing domestic animals. Clearing the native forest, 'breaking in' the land was a (harsh) process of building a livelihood and at the time, and still today, is associated with building a nation (Roche, 1997).

Increasingly, the resources of the interior were made accessible, more forest cleared and sheep numbers rocketed from 1.5 m in 1858 to 13,1 m in 1878 (King, 2003). Premier Julius Vogel's vision of a 'Britain of the South' was well alive during the following century: of the 18 m hectares of native forest left in the middle of the 19th century, another two-thirds has since been removed for pastoral farming and agriculture (Williams, 1980).

Figure 9.1: The study sites Te Arai, Western Hutt Hills and Aoraki.

Currently, land is used predominately for pasture and arable land (44%), followed by other usage (e.g. urban, 26%), native forest cover (23%) and plantation forest (7%) (Statistics New Zealand, 2006).

Sheep numbers continued to spiral and reached 70 m in 1982, while cattle numbers were up to 8 m in 1982 from 850,000 in 1886 (Statistics New Zealand, 2006). In 2005, sheep numbers are

down to 40 m, beef cattle decreased to 4.4 m, while dairy cattle increased to about 4 m from 3 m in 1982 (table 9.1)

Table 9.1: Livestock numbers for 1982 and 2005, in million (Statistics New Zealand, 2006).

	1982	2005
Sheep	70	40
Cattle	8	4.4
Dairy	3	4

Between 1901 and 2004 the population of New Zealand quickly climbed from 800,000 to just over 4 m in 2006 (New Zealand Census 2006). After World War II until the end of the 1960s birth rates increased significantly, and this period of economic wealth became known as the 'long boom' or 'baby boom'. Since the late 1960s, the growth rate was subject to pronounced fluctuation due to negative net migration during less favourable economic phases, mainly throughout the later 1970s with a peak in 1980. In contrast, net immigration led to a 40% population growth from 1991 to 1996.

In New Zealand from 1950 until the 1970s the 'prosperity consensus' governed all divisions of society and rooted in a welfare state without great division in socio-economic classes, but with a large middle-class. Security of jobs and the assurance of high living standards were at the centre of the welfare state, besides free education, state housing for those who could not afford private rents, and health service of low or no costs. The welfare state was based on pastoral farming. Free usage of scientific innovation and labour, mostly the farmer's family, and aerial application of fertiliser in remote areas ('topdressing') resulted in high productivity of the pastoral output (James, 1992). This intensive effort for productivity increase became known as the 'grassland revolution' (Brooking et al., 2002). The farmer's central position in New Zealand's economy guaranteed the farmers stable price schemes, subsidies for interest rates on loans or when applying weed-combat and fertiliser, and tax concessions for public services in remote areas. Import licensing protected the manufacturing industry which was supported by pastoral exports to Britain and still was in its infancy. Hence, jobs in the manufacturing industry were indirectly dependent on pastoral farming. Gradually, tight export and import bonds to Britain loosened, with more than 70% of exports to Britain in 1940s and 53% in 1960. However, the export contingent of pastoral products decreased only slightly from 96% in 1950 to 93% in 1960, making little room for a starting diversification of the product palette. Clearly, New Zealand was still 'Britain's farm in the South' (James, 1992). In the three decades after 1945 agricultural exports increased, the gross domestic product grew by 40 to 50% per year and unemployment was less than 1%. Pastoral farming required a concentrated investment, especially in the hill country and lowland wetland areas (James, 1992; Le Heron et al., 1992).

The welfare state was not sustainable, and its growing financial burden collided with Britain joining the European Community in 1972, cutting the bond to New Zealand, and international economy changes of globalisation (James, 1992). The supplementary minimum prices (SMP)

for sheep farming, meaning the difference between the price set by the government at the beginning of the year and the lower world market price at the end of the year, peaked between the Muldoon-Government (1978-1984). Most subsidised pastoral farming was not based on a sound sustainable productivity. Farmers turned towards a wider spectrum of products, e.g. deer farming, grapes and kiwifruit. Kiwifruit exports shared 30% of the value of all fruit and vegetable exports in 1984. However, the kiwifruit 'revolution' declined in the 1990s and less land was under production (Robinson et al., 2000). The slipping economic welfare manifested itself for many New Zealanders in losing their jobs and a drop of living standards (James, 1992); Maori were represented disproportionately in this group (Douglas, 2001).

Responding to deteriorating economic productivity, the Fourth Labour Government initiated a plethora of measures soon after its election in 1984. The economy was deregulated and opened, and the historically always centred and protected primary sector was faced with prices of the world market and a cut in agricultural subsidies (Le Heron et al., 1992). SMPs were eliminated after 1984 (Robinson et al., 2000). Every level of the agricultural system was affected, from the producer to the processing industry. Reduced governmental assistance was noticeable immediately, for instance with plummeting land values, and adjustments became a matter of survival for many farmers. Adjustment strategies were, for example, the substitution of hired labour by family labour, tenure change and diversification. Percentage of fertiliser used, livestock numbers and expenditure for farm business maintenance and development dropped significantly in many regions. Freezing Works suffered from decrease of government farm support and a collapse of international meat prices in the early 1980s. With the beginning of the 1970s, areas under new forest plantation climbed until 1989, with both state and private share. With over nearly thirty years of employment gain in the forestry sector between 1950 and 1980, employment declined within the next five years, due to an internationalisation of the market (Le Heron et al., 1992).

In a period which witnessed Cyclone Bola (1988), one of the worst recorded rainstorms devastating the East Coast of the North Island, the fourth Labour Government restructured the environmental institutions, amongst others the disestablishment of the Forest Service and the Department of Lands and Survey. Their commercial sections were turned into state-owned enterprises. Native forest clearing and land development subsidies were stopped and in 1991 the Resource Management Act (RMA) was passed, with a key concept of sustainable management. The RMA replaced more than 60 other laws and imposed duties of environmental monitoring and managing upon the District Councils (Pawson et al., 1992; King, 2003). Because of the economic changes starting in the mid 1970s and the responsive reforms of the 1980s affecting all sectors of society, this period is known as the 'restructuring' phase (James, 1992).

The phase of drastic changes affecting all sectors of society however did not stop with the beginning of the 1990s. The neo-liberal reforms which became known as 'Rogernomics' were

continued: deregulation of the labour market, privatisation, cuts in welfare, and increasing pressure from globalisation (Willis, 2001a). In 1991, unemployment reached its peak in 50 years and while profits were in line for some, the financial drought continued for many. Income disparity grew as the demand for unskilled labour declined, while higher levels of education became increasingly vital for employment (Morrison, 2001). Simultaneously, during this decade the net migration gain is recorded as the largest since 1900 for a ten year period. Numbers of Northeast Asian immigrants in particular increased and reached peak values. In comparison, net migration loss was highest between 1977 and 1985 since the beginning of the 20th century (Bradford, 2001).

The 1990s witnessed intensive land-use changes rooted in the processes of the 1970s and 1980s. Agricultural production shifted from sheep and beef farming to dairy farming and forestry. Dairy products became export earner number one in 1999. The land-use change was a reaction to the continuing situation of facing world market prices, a successive reduction of government support in general, combined with an increase of profits for dairy and timber products (Willis, 2001b). Since 2001, the increase of exotic forest plantation has come to a halt and stabilised during the subsequent years (Ministry for the Environment, 2007).

Apart from the overall economic development with a focal point on primary production as summarised so far, urbanisation and tourism are processes contributing to the shape of New Zealand's social and natural landscape.

As early as 1911 urbanisation reached 50% and rose to 85% in 2001 (Statistics New Zealand, 2006). In fact, in 1996 New Zealand was the third most urbanised country worldwide, after Hong Kong and Australia. Maori, traditionally based in rural communities, migrated into the cities: while in 1945 75% were non-urban dwellers, this picture was reversed in 1981 with 80% living in urban areas, stabilising afterwards (Robinson et al., 2000). The growth and style of urbanisation and suburbanisation in particular continued to be comparatively high-demanding in terms of land. Low density of housing has and still is one of the key elements of a New Zealand lifestyle. While favourable in many ways, the downside is a high consumption of land. The Western Hutt Hills are a prime example for fast and extensive suburbanisation, turning native bush or pastures into sealed surfaces in a steep terrain – with drastic consequences as will be seen shortly.

Tourism increased quickly in New Zealand: the number of international tourists in 2000 compared to 1990 has more than doubled; a trend continuing from the 1980s. Domestic tourism, however, stagnated in the 1980s (Pearce, 2001), which probably related to the economic hardship encountered by many New Zealanders at that time. In 2003, international visitor numbers were up to 2 m from 690,000 in 1986 (Statistics New Zealand, 2004a). International and domestic tourism expenditure directly contributed 9.6% (NZ\$ 16.5 bn) to the GDP as of March 2003. This is 34% higher than 1999 (Statistics New Zealand, 2004b). Figures for 2006 suggest a steady increase of tourism expenditure compared to 2003, especially with

respect to domestic tourism (Statistics New Zealand, 2007). With a share of 19.2% of the country's total export earnings in March 2006, international tourism expenditure plays a significant role in overall export earnings. For the first time in 2003 international tourism's share of total exports exceeded the share of the largest export contributor, the dairy industry, and has been higher since (Statistics New Zealand, 2007). Overall, the economic activities associated with tourism trickle into various sectors: from the production of goods and services, to generating jobs in accommodation, transport, retail and gastronomy (Statistics New Zealand, 2007). The mixed blessings of tourism development in a geomorphologically active alpine environment are discussed at the end of this chapter.

9.2 The Western Hutt Hills (WHH)

The study area (28.2km²) of the Western Hutt Hills is located within the Greater Wellington Metropolitan Area, a region comprising Wellington City and its surrounding urban centres (e.g. Tawa and Lower Hutt), which are linked by a stream of commuters in and out of the capital. Several smaller communities, namely Korokoro, Maungaraki, Normandale, Tirohanga, Belmont and Kelson or located in the study area 'Western Hutt Hills' (figure 9.2). The terrain in this area is deeply dissected with steep slopes exceeding 30 degrees in many places, as an analysis of a DEM (Digital Elevation Model) within this study revealed. The WHH area can be classified as 'steep-land low country' on greywacke with altitudes less than 460 meters a.s.l. (Eyles and McConchie, 1992). From Belmont Hill, elevation decreases both towards the east and the west. Distinct features are broad and very broad rolling interfluvies occurring at a range of different altitudes (Gee, 1992).

The hills in this region are bounded to the east by the Wellington fault, which is one of the several major active dextral shear faults in the Wellington Region. These faults link at the subduction zone of the oceanic Pacific Plate beneath the continental Indian-Australian plate at a depth of 20-30km at this locality. Plate movement has caused three earthquakes of Modified Mercalli scale VII-IX within the last 150 years, and leads to uplift rates of at least 2 mm/year, for instance in the nearby Tararua Ranges (Crozier and Aggett, 2000). A period of quiescence separates the current Kaikoura Orogeny, which began in the late Pliocene, and the previous Rangitata Orogeny (141-118 m ago). During this quiescence, denudation was the dominant process and the greywacke bedrock, which is comprised of sandstones, siltstones and mudstones, was reduced to an erosional surface (Eyles and McConchie, 1992, McConchie, 2000).

Figure 9.2: Study site 'Western Hutt Hills', with boundaries demarking the statistical area units. The boundaries are adjusted to represent the aerial photo coverage used for the landslide analysis; Belmont and Kelson would extend further into uninhabited hinterland. Residential areas are coloured in grey, roads are coloured in orange.

This surface was lifted and tilted again during the Kaikoura Orogeny, but some remnants persist even today as the broad and very broad rolling interfluvies, which were named by Cotton (1957) as 'K-surfaces' (K for 'key' and 'Kaukau'). During the Pleistocene, unlike the upland areas of the South Island, the Western Hutt Hills were not covered with ice, but existed under periglacial conditions with active freeze-and-thaw cycles breaking down the greywacke outcrops. Solifluction transported erosional material down the slopes and this material accumulated in depressions and old drainage channels, referred to as 'fossil gullies', 'colluvium-filled bedrock depressions' (CBDs) or '0-order basins', if they have a surface expression (Cotton and Te Punga, 1955; Stevens, 1957; Crozier et al., 1990). During interglacials and the Holocene, which currently has warmer and moist conditions with average annual rainfall between 1200mm and 1400mm (Goulter, 1984; Tait et al., 2002), the process regime changed to become dominated by fluvial erosion, enhanced by the continuous uplift. The landscape of the Wellington Region was described by Cotton (1964) as 'feral', a term which accentuates the changes between

different landforming process regimes, originally involving the smoothening of the relief under periglacial conditions, but sharpening of the ridges and incision of the terrain by water during the interglacials and in the Holocene.

On the greywacke bedrock, which is partly mantled by loess and solifluction material, yellow-brown earths developed. They are predominately between 30 and 80 cm deep, in places up to 100 cm, and in very steep areas less than 30 cm. Rock outcrops are scattered throughout the areas of higher elevation (Page, 1995; New Zealand Land Resource Inventory NZLRI)¹. Within the CBDs, regolith depth typically ranges between 2.80 meters and about five meters (Vaughan, 1989).

This complex geomorphic terrain, located near the major population centre, soon became the object of suburban development. In the following, the Wellington metropolitan area (WMA) is defined as the Wellington plus the Lower Hutt urban zone into which the WHH fall, based on the introduction of the term in 1916 to mark the close relationship between the two cities (Evans, 1972). The hills surrounding the WMA were originally completely covered by vegetation. As one of the early settlers described the scenery: *'[...] it is supposed to be a succession of barren hills, but upon being approached they are found to be covered to the very summits with a dense matting of timber and scrub (ti-tree) [...].'* (Bishop, 1882). With the arrival of European settlers in the 1840s the hills were clear-felled to gain land for farming and residential areas (Mildenhall, 1994; Dunbar et al., 1997; McLean, 2000).

The suburbs have always been very important for New Zealand cities. New Zealand cities are characterised by a low density; housing ideals favour separate single-storey houses with spacious gardens which consumes large areas (Pawson et al., 1992). After World War II, the number of people owning a car increased substantially which favoured the rapid suburbanisation process (Robinson et al., 2000; Pawson, 2002). The Western Hutt Hills became dormant suburbs of Wellington, with in places 94% of the residents working in Wellington (Mathieson, 1960). Stereoscopic aerial photo analysis carried out within this study reveals that while settlement in the Western Hutt Hills in the early 1940s was still localised, occupying only 0.4 km², it had more than doubled by 1958, and increased substantially and gradually during the following years until reaching about 5 km² in 2005. This development is documented by a selection of aerial photos used in this research (figure 9.3).

¹ Land resource and soil data are derived from the New Zealand Land Resource Inventory and National Soils Database, and are reproduced with the permission of Landcare Research NZ Ltd. Landcare Research accepts no responsibility for any errors or omissions in the data supplied and shall not be liable for any loss or damage arising directly or indirectly from any use whatsoever of the data supplied.

Figure 9.3: Example of suburban development in the Western Hutt Hills for Maungaraki (left) and Normandale and Tirohanga (middle and right). Arrows and lines mark reference points. The figure is based on aerial photos SN 163, SN 3185 and SN 50037c for 1941, 1969 and 2001 respectively.

In addition, aerial photo analysis shows that today 20% of the WHH is covered with pasture, 20% with residential areas, and 60% by bush with patches of forest.

9.2.1 The landslide threat in the Western Hutt Hills

Preferred areas for settlement in the Western Hutt Hills are the broad interfluvies (figure 9.4). However housing, roads and infrastructure such as gas and water pipes are not confined to these flatter areas and especially the latter two, by necessity, traverse steeper slopes and gullies. Landslides impose a certain risk to health and life in the Western Hills, even though landslides are predominately shallow, for example where *'slips washed into the front and sides of two homes, filling the houses with soil, rock and trees'* (The Hutt News, 1.2.1977). Stereoscopic aerial photo analysis shows that frequently subdivisions extend right to the edges of the broad interfluvies, which are bounded by very steep slopes (larger than 35 degrees) and zero-order basins (figure 9.4).

Figure 9.4: View of housing on top of the broad interfluvies, Kelson, looking northeast (photo taken 26.8.2005)

Bedrock, altered by weathering accentuated when the erosional surface was formed, together with tectonically induced intense fracturing and shearing, has undergone a substantial reduction of rock mass strength (Page, 1995; McConchie, 2000). Additionally, blankets of loess and layers of solifluction debris provide a relatively weak mantle overlaying the bedrock (Eyles et al., 1978). Where this material accumulated in bedrock depressions, which simultaneously constitute areas of water concentration, it can reach depths above critical thickness for saturated conditions, which increases the weight and therefore shear stress. Without forest cover, critical depths vary between five and about one meter according to an increase in slope angle. Therefore, under the current process regime, the 'colluvium-filled bedrock depressions' are potential locations for landslides (Crozier et al., 1990), which can be deeper failures with a depth of about five meters (figure 9.5). Although many of the 'colluvium-filled bedrock depressions' are spoonshaped and therefore mimic the actual depression, some do not have a topographic expression. This makes it difficult to identify potential landsliding sites from topographic parameters alone (Vaughan, 1989).

In addition, 'cut-and-fill' slopes, which are created by road and housing construction, are usually zones of high susceptibility for landslides in the Wellington region (Eyles, 1979; Eyles et al., 1978; McConchie, 2000). Generally, freshly cut greywacke exposes less weathered rock and can maintain slopes at angles of 70 degrees. However, due to the unloading of the slope, the highly jointed rock mass expands and the joints open up (slope relaxation) thus reducing the effective strength of the rock. This process can be amplified by root-wedging. In Wellington, suburbs that have been subject to cut-and-fill development show a progression of slope adjustment. There is usually a rapid adjustment to initial cutting and a progressive development by shallow landsliding to a stable slope angle of around 47 degrees, which implies that in

general, older suburbs are less prone to failures (Eyles et al., 1978; Eyles and McConchie, 1992; McConchie, 2000).

Figure 9.5: The same view of Kelson as in figure 9.4, showing a landslide triggered on the 7.8.2006 at Vista Grove, which took out a carport. The residents of the house on the edge were not harmed, but the building had to be demolished (photo taken 8.8.2006; inlet courtesy of Phil Reid, Dominion Post).

According to Eyles et al. (1978) and own field observations, the types of landslides in the WHH are rock slide, debris flow and slide as well as earth flow and earth slide, all predominantly shallow, using Varnes' nomenclature (1978). In the period of 1968 to 1986, after flooding and wind, landslides accounted for the third highest annual cost in the Wellington Metropolitan Area (Gee, 1992). In 1998 claims worth more than NZ\$ 500,000 due to landslides were logged after one rainstorm in June in the Wellington region (Beattie, 1998). The worst and most widespread degree of damage, however, was reported after a rainstorm of the 20th /21st December 1976. As aerial photo analysis revealed, almost 800 landslides, mostly shallow earth flows, debris flows, and gully erosion, were triggered in the Western Hutt Hills alone. Nearby regions like Stoke's Valley were also severely affected, and the Hutt river was in high flood. Roads were blocked or washed out, houses completely destroyed, either by landslide material or houses from above or by sliding downhill (The Evening Post, 21.12.1976, The Hutt News, 26.1.1977). A four-year old boy was killed by a landslide on Crofton Downs (The Dominion, 21.12.1976).

In the Western Hutt Hill, suburbanisation accompanied by cut-and-fill building techniques and increased surface runoff in a landslide prone terrain produces a situation of landslide risk.

9.3 Te Arai (Gisborne District)

The communities of the Te Arai study area, Waingake, Waerengaokuri and Manutuke, are located about 10km west of Gisborne, at the East Coast of New Zealand's North Island. The Te

Arai area is the southern most part of the Waipaoa catchment which extends north along the Waipaoa river (figure 9.6).

Figure 9.6: Study area Te Arai, with the communities of Manutuke, Waerengaokuri and Waingake demarcated by their statistical boundaries. Land use classification is derived from the New Zealand Land Resource Inventory (NZLRI) mapping of 1996 (Landcare Research, 2000)

The Te Arai river follows the road which crosses the Waingake community from the south to the north, meanders along the boundary to Waerengaokuri and forms a floodplain as it comes out of the hill country onto the floodplain of the Waipaoa river at the Manutuke locality. The Te Arai floodplains are utilised for horticulture with crops of various sorts. These areas are mostly located in the Manutuke community, covering a substantial area in 1996 (figure 9.6). Waingake and Waerengaokuri are small farming communities where farms and dwellings concentrate in the two centres, but also disperse along the main roads and into the hill country. The dominant land cover in Waerengaokuri is grass for sheep and beef farming, with patches of exotic forest plantation. In Waingake, the proportion of grass and exotic forest is similar and stretches of indigenous scrub covers a much larger area than compared to Waerengaokuri. The large patch of forest (broadleaved, Kanuka, podocarp) is the 'waterworks bush' where the Te Arai river originates and which serves as a water intake.

As a comparison with recent aerial photography² shows, since 1996 horticulture has expanded and has replaced all the areas formerly mapped as 'grass' in the Manutuke community (figure 9.6).

² Aerial photography as shown in Google Earth; the area of interest is covered by several photos dating from 2003.

In contrast, land cover and use in Waerengaokuri and Waingake has not changed since 1996, with the same stands of forest and native bush still present³. The only difference is a patch of plantation forest in the block just south of Waingake which has been harvested. It is therefore concluded that sheep/beef farming and forestry, which are the main types of land usage in Waerengaokuri and Waingake, remain the main bases of livelihoods in these communities, while the area of Manutuke has witnessed a major expansion of horticulture at the expense of pastoral farming since 1996. For an impression of the Te Arai hill country, see figure 9.7.

Figure 9.7: Looking west into the Te Arai hill country. The road in the foreground is Waingake road which follows the Te Arai river and connects Waingake with Manutuke. Note the large slip in the middle of the picture, and horticulture along the river plains (photo taken December 2004).

In the Gisborne district, livestock (sheep and beef) numbers fell by 40-60% after the supplementary minimum prices were removed in 1984, leaving the Kaiti Freezing Works with overcapacity (Gisborne District Council, 2002). Subsequently, more erosion prone hill country in the Gisborne district was and is turned into exotic forest for timber production, mainly *Pinus radiata*, since maintaining erosion prone hill country compared to forest plantation was becoming less economic (figure 9.8).

The East Coast Forestry Project implemented by the New Zealand Government in 1992 was a major impetus for plantation of exotic forest. The project is set up to convert areas severely affected by landsliding into commercial forest as a measure of soil conservation. The Te Arai is

³ Aerial photography as shown in Google Earth; the area of interest is covered by several photos predominately dating from 2006.

within the area targeted for conservation forestry (Conservation Quorum, 1990). It has been reported that after cyclone Bola in 1988 plantation forests about eight years old protected the land from sliding, while considerable damage was still observed in stands three to five years old (Trotter, 1988).

Figure 9.8: Plantation of exotic forest in the Gisborne district, 1972-2002 (1972: 11,000ha, 1983: 9,000 ha; 1993: 89,249 ha; 2002: 146,415 ha; Statistics New Zealand, 1975, 1985, 1995, 2004a).

Since 2000, the project considers other treatment options, such as gully planting, reversion to indigenous species and poplar/willow planting which allows for continuous grazing. Recently, the interest in forestry is declining as revenue relative to farming is decreasing, which hampers the voluntary scheme of the East Coast Forestry Project targeting the conservation of erosion prone land (Bayfield and Meister, 2005). Figure 9.7 gives an example of forest plantation for soil conservation: the large slip in the middle of the picture, triggered by Cyclone Bola (7-9 March 1988, East Cape Catchment Board, 1988), has since been circled by exotic forest, although currently the scar is still partly bare, after twenty years.

A change of land use from agriculture to forestry affects the socio-economic fabric of communities. While the majority of people working in the farming sector work on the land and live on their farms or in nearby rural centres, most employees in forestry are involved in processing. Processing of timber is usually located in regional centres. Hence a shift from farming to forestry tends to induce a drain of workers out of the rural communities into regional centres (Barnard, 2001). Accordingly, Willis (2001b) noted that the 1990s' shift towards forestry on a national scale was contested by many: the conversion of sometimes entire sheep farms into forestry was criticised for the loss of rural population and social cohesion in many rural areas. Farming communities in the Waipaoa catchment have aired these concerns in the past (MAF, 1998).

While a drastic shift from sheep/beef farming to forestry is not recorded for Waerengaokuri and Waingake after 1996, shifts before 1996 are likely. Aerial photographs taken in 1945 (SN 1100, 1101, 1102 series) reveal that the hill country was almost completely used for pastoral farming, with no or only little forest cover. Aerial photography dating from March 1988 (SN 11485 series) show that small patches of forest had been planted in the meantime, and poplars were planted along gullies and river banks for land stabilisation purposes. The 1988 series does not cover the whole of the Te Arai, but it is recorded that the extensive plantations mapped in 1996 just north of Waingake are not establish yet. It is concluded that the shift in land use described for the Gisborne district include the Te Arai communities, in the sense that Te Arai hill country has undergone a partial shift from pastoral farming to forestry in the period 1988-1996.

Manutuke is much smaller in spatial extent, but has a much higher population (year 2006: 600), than Waingake (year 2006: 144) and Waerengaokuri (year 2006: 96) (New Zealand census 2006). However, population figures during the period of 1991-2006 are very stable for Waingake and Waerengaokuri, while numbers for Manutuke fluctuate and reach their lowest value in 2006 (as illustrated in chapter 12).

In the Gisborne district, between the 1970s until the early 1990s, depopulation of rural communities was high, with people leaving the region for further education or jobs in the urban centres, accompanied with declining employment opportunities in the rural sector (Blaschke et al., 1994). Whether this general trend is observed for the Te Arai communities cannot be verified due impaired data comparability. Population figures for the period 1991 to 2006 suggest some indication of depopulation in Manutuke and, to a far smaller extent, in Waingake, while the population in Waerengaokuri has grown during this period.

In the Gisborne district, unemployment reached 15% in the early 1990s, which was above national average, and more than 50% in some rural areas (Blaschke et al., 1994). Again, data for Te Arai before 1991 is not available which prohibits a comparison. Data for 1991 to 2006 is listed in figure 9.9. Unemployment is higher in Manutuke compared to Waingake and Waerengaokuri, but plummeted between 2001 and 2006 (New Zealand census years 1991-2006). This could be associated with a drop in population size, in the sense that people seeking work are leaving the community. Data for Waingake and Waerengaokuri varies to a greater extent during these years, but show similarly low levels in 2006⁴. If unemployment was much higher in the 1980s, recent figures indicate values below the national unemployment rate (3.4% in 2006) (New Zealand census 2006).

⁴ Interpretations of the magnitude of variation when using percentages for Waerengaokuri and Waingake should be considered with care: percentages for communities with a small population size are more sensitive to small changes compared to larger communities. This is discussed in more detail in chapter 12.

Figure 9.9: Unemployment for Te Arai and New Zealand, 1991-2006 (New Zealand Census, 1991-2006)

In summary, the Te Arai was not spared from the turbulences of the restructuring phase of the 1970s to the early 1990s. A change of land use, from sheep/beef to forestry, is documented for parts of the Te Arai between 1988 and 1996, and it is likely that the shift in combination with the already adverse economic situation entailed depopulation and an increase of unemployment. The shift towards forestry in large areas of the Te Arai hill country is also a reaction of the immense losses encountered after Cyclone Bola devastated large areas of the New Zealand's East Coast in 1988, which is exemplified shortly. From the beginning of the 1990s, land use and demographics have stabilised and employment improved slightly from 1991 until 2006. Manutuke has undergone substantial changes since 1996 with a shift from pastoral farming to horticulture.

9.3.1 The landslide threat in Te Arai

The Waipaoa catchment is one of the areas most severely affected by landslides in New Zealand (Ministry for the Environment, 2007). Already in the early 1940s Cumberland classified this area a part of 'Region III b' characterised by mass movements as the predominant process of soil erosion of serious degree, accompanied by sheet and rill erosion (Cumberland, 1943). More specifically, most of the Te Arai is classified as the 'Te Arai land system' characteristic for its severe degree of soil erosion due to landsliding. The dominant landslide types are earth slips and slumps, and shallow earth flows, accompanied by gully erosion (Eden and Trustrum, 1994). The physical setting of the region favours landslides: the lithic structure of the East Coast consists of weathering-prone Cretaceous and Tertiary sediments, mainly mudstones, argillites and sandstones. Additionally, uplift rates are about 1-4 mm/a (Ota et al., 1992), rainfalls can be extreme and steep to strongly rolling hills (20 to 40 degrees) are the main feature of the landscape (Page et al., 2000). Soils consist of 50% to 70% of silt, and a discontinuous tephra

layer is visible on uneroded sites. Soil depth varies and ranges between zero to two meters. Annual rainfall in the Waipaoa catchment ranges from 1000 mm near the coast to 2500 mm in the hill country (Reid and Page, 2002). Similar figures can be expected for Manutuke close to the coast and Waerengaokuri and Waingake in the hill country.

In July 1985 250 mm of rain within 24hrs, following a prolonged wet period, triggered shallow landslides on 35,000 ha of pasture of the steep hill country surrounding Waerengaokuri (Brown, 1991). The threat imposed by landsliding in the Te Arai is not only a threat to life, property and infrastructure, but also a threat to the base of livelihoods for farmers and horticulturalists in the hill country and on the floodplains alike. It is not only the direct loss of livestock, crops, gear or fencing, but also the loss of productive farmland which threatens economic viability of agricultural production (figure 9.10).

Figure 9.10: Devastated avocado crops at SH36 (connecting Waerengaokuri with Gisborne), after the flood of 25-26 July 1985 (photo courtesy of the East cape catchment board, 1985). The sediment in the foreground has been deposited by a large earth flow triggered to the right of the picture content.

Herbert Guthrie-Smith, an early farmer and environmental historian in adjacent Hawke's Bay, documented early impacts of landslides on infrastructure and livestock: *'Huge masses of solid hill have slid on to the larger flats. Fencing is buried, roads and bridges washed away, culverts destroyed, stock bogged or caught and buried in the displaced masses of earth.'* (Guthrie-Smith, 1926: 40). He asked himself: *'[Am] I absolutely happy [about]...my contribution towards more quickly melting New Zealand through erosion into the Pacific...?'* (cited in King, 2003: 437).

The losses and worries Guthrie-Smith described have since continued and are comparable to what farmers in the Waipaoa/Te Arai are facing. Staff of one of the most famous sheep stations of the North Island, the Waipaoa station, recalled '*occasions when fencing equipment has been placed ready for fencing the next day, but overnight it has disappeared downwards, along with much of the hill*' (Foster and Wright, 1983: 151). Surely, after two storms in 1980 and 1982, and after Cyclone Bola in 1988 with a maximum of 400-600 mm during 80 hours and an 24-hour maximum of 190mm (Phillips, 1989), the farm workers had to replace many kilometres of fences, since thousands of landslides had been reactivated or triggered throughout the whole catchment (figure 9.11).

This event is classified as a 'multiple-occurrence regional landslide event' (MORLE), describing the almost simultaneous triggering of vast numbers of individual landslides over large areas – the most common type of landsliding in New Zealand (Crozier, 2005). The December 1976 landslide event in the WHH is another example. Relief payments following Bola totalled NZ \$111 M (Blaschke et al., 1994). Buildings, crops, roads and bridges were destroyed, and some communities were cut off for weeks after the storm. This meant that products and livestock could not be transported out of the region and to the markets. It was also reported that some people intended to leave the region for good (Trotter, 1988). Pastoral productivity was severely impaired; Blaschke et al. (2000) reviewed studies on productivity loss in New Zealand and found that in general, productivity is reduced to about 20% of the initial productivity on recent landslide scars. Long-term productivity in landslide-stricken hill country is likely to never reinstate its original status. The Ministry of Agriculture and Fisheries estimated that loss of grazing area per farm ranged between 5% and 50% of grazing land (Singleton et al., 1989).

Figure 9.11: The impact of Cyclone Bola, aerial photo 28.3.1988 (SN 11485.E, run J). The road at the bottom is Gordon Road, half way between Waingake in the south and Waerengaokuri in the north. The large slide at the top of the picture is the same as captured in figure 9.7.

9.4 Aoraki

Aoraki village is part of the Mount Cook National Park, which is famous for New Zealand's highest peak, Aoraki/Mt. Cook (3750 meters a.s.l.), and listed as a World Heritage site. Located about 230 km south-west of Christchurch at the end of SH80, Aoraki is situated in the Hooker Valley within the central region of the Southern Alps. The Hermitage, one of New Zealand's most well-known hotels, was built in 1884 at Foliage Hill (Department of Lands & Survey, 1980), right in front of the Mueller Glacier's terminal moraine which nearly completely blocks the Hooker Valley. After the hotel was destroyed by a flood in 1913, it was rebuilt at its current site

(Innes et al., 1976), from which it provides direct views on Aoraki/Mt. Cook and surrounding peaks.

This site is located at the northeast facing side of the Hooker Valley, at the foot of the Sealy Range with peaks between 2000 and 2500 meters a.s.l. (figure 9.12). Greywacke (sandstone, siltstone and mudstone) and argillites, with some schist influence, form the Sealy Range, which belongs to the Torlesse group typical for the eastern Alps (Cox and Findlay, 1995; McSaveney, 2002). These Permian-Jurassic (280 to 140 m years) greywackes and argillites are closely jointed, and with the current climate (rainfall, frost) and tectonic activity produce large amounts of scree (Suggate et al., 1978). This scree, in some way or the other, finds its way into the bottom of the high lying catchments, from which it cascades eventually into the lower lying valleys, such as the Hooker Valley.

Figure 9.12: Aoraki village in the Hooker Valley, looking north-west over the Sealy Range forming the backdrop of the village (aerial photo 2.5.1997, SN 501130). The road extending to the right boundary of the picture leads to the camping ground and the Mueller moraine.

With the Hermitage as its initial starting point on the Glencoe alluvial fan (with moraine underneath, Skermer et al., 2002), the development of the village continued when in 1958 the first motels, a shop, the Visitor Centre and staff accommodation were built nearby. The petrol pumps were already present, servicing the Hermitage. A school was built in 1964 on the upper

part of Glencoe fan, and has since been moved to the lower, northern side of the Black Birch fan. During the 1960s the site became increasingly popular as a tourism destination, and in 1972 a proposal for a separate staff and servicing area was approved. Consequently, staff quarters were constructed on the Black Birch alluvial fan (Innes et al., 1974, Findlay, 1994). Oxidation ponds for sewage treatment were built on the Black Birch fan in 1969 (McSaveney et al., 1995). Today, the village spreads across the two alluvial fans, Glencoe and Black Birch; in addition the northern end is bounded by the Kitchener fan (figure 9.12). While the elevated position (about 20 meters) within the Hooker Valley yields some benefits in terms of flooding from the Hooker river, the location right underneath the geomorphologically very active catchments of the Sealy Range brings other problems as discussed shortly.

In 2006, Aoraki was home to 210 residents (New Zealand Census 2006). Key accommodation facilities, besides the high-end priced Hermitage, are the Youth Hostel, the Chalets, motel units and Glencoe Lodge. Aoraki village is a service point for visitors to the park which opened in 1953 (Findlay, 1994). The village does not only provide accommodation and other facilities (café, petrol station, Alpine Tour guides) but also hosts the Aoraki/Mt. Cook Visitor Centre run by DOC (Department of Conservation).

Although Aoraki has some characteristics of a village (the facilities, the cluster of buildings), it is not a village in the usual sense. It is better described as a resort village, with a substantial number of overnight visitors. Aoraki is also characterised by an influx of temporary staff staying for the peak tourism season in summer, during which about 75% of visitors arrive (Ernst and Young, 1997). These seasonal workers are predominately singles in their early to mid twenties (Findlay, 1994). With improved accessibility related to better quality of SH 80 since the mid 1970s, increasingly permanent staff considers living in the nearest town, Twizel, which offers a broader range of community and family facilities. Their community commitment is therefore likely to be directed towards Twizel rather than Aoraki. Generally, the variability in terms of a sense of belonging is high, with seasonal workers, permanent staff living outside and permanent staff living inside the community (Findlay, 1994).

New Zealand's natural parks have always been major magnets for tourists (Pearce, 2001). Visitor numbers per year climbed rapidly from 45,000 in 1963, to 168,000 in 1973 and reached 195,000 in 1975 (Innes et al., 1976). Most recent figures available (1997) show that about 240,000 people visit Aoraki per year, of which 70% are from overseas and 30% from within the country. Aoraki attracts a high amount of daily visitors (estimated at 67%) as compared to overnight visitors (estimated at 33%) (Ernst and Young, 1997). The proportion of Asia (especially Japan and China) as a source region for tourists has increased compared to the U.S., Australia, Germany and the U.K. (Ernst and Young, 1997); a trend which is confirmed by recent figures on a national scale (Statistics New Zealand, 2007).

9.4.1 The landslide threat in Aoraki

The village is exposed to high annual rainfall (4000 mm) and very strong winds (DOC, 2004). Peaks such as Aoraki/Mt. Cook and nearby Mt. Sefton demarcate the Main Divide which runs parallel to the Alpine Fault for most of its 500km length (Cox and Findlay, 1995). As Little et al. (2005) stated, the Main Divide in the Aoraki/Mt. Cook region is located only 15 km east of the Alpine fault. They further argued that this central region of the Alpine fault is characterised by especially high uplift rates which are estimated to range between 8 mm/yr and 12 mm/yr. Due to its close vicinity to this tectonically highly active environment, the village is also exposed to earthquakes (shaking and liquefaction of fan sediments). A magnitude 7.4 to 8.0 event is expected to occur within the next 100 years (McSaveney et al., 1995).

The major threat, however, comes from above: nestled just underneath the drop of the Sealy Range, the site is exposed to various types of landslides. In addition, while the raised position within the Hooker Valley reduces the exposure to flooding of the Hooker river, the settlement on alluvial fans introduces the exposure to flooding from the Kitchener, Glencoe and Black Birch streams.

As field investigation revealed, the slopes of the Kitchener and Black Birch stream catchments are characterised by talus sheets. Their surface is mostly covered by alpine scrub. Frequently, the talus sheets are incised by small tributary streams which are probably ephemeral. These incisions, however, cut into the sheets and expose the underlying material to erosion, which couples the talus sheet deposits with the stream channel. The thickness of scree stored within the talus sheets is variable but can reach several meters. Moraine deposits are also reported for the southern flanks of the Black Birch catchment (Lewandowski, 1970). The channels contain large rocks of about one to two cubic meters in size. Detailed geomorphological mapping is not available for these catchments, and could not be included within this study. However, it is concluded that a considerable amount of material is stored within these upper catchments which can be flushed out during a succession of rainfall events. Above the Black Birch stream, just after the point where it leaves a gorge and enters the fan, a gully has formed which exposes a sediment package of at least 4 m thick (figure 9.13).

A comparison of two oblique photos, which date from 1979 and 1980, shows that the gully must have formed either in 1979 or before April 1980. Indeed, a major flood event is reported for December 1979 when about 90,000 m³ of material was transported out of the catchment, which is considered as the largest magnitude observed in 70 years (McCahon, 1998). It is estimated that 70,000m³ of debris alone accumulated as a cone in the stream channel delivered from the gully above (McSaveney et al., 1995).

Figure 9.13: View downslope from the gully just above Black Birch stream. The stream itself is visible in the upper part of the picture, as is part of the staff quarters, and one of the levees (photo taken November 2004).

The Glencoe catchment is much smaller and steeper compared to Kitchener and Black Birch. Debris is not stored in talus sheets, however fresh debris enters the channel directly from the surrounding slopes. These are very steep, almost vertical, with bare rock faces and show signs of fresh rock fall activity (figure 9.14). According to Ray Bellringer, the park ranger, a rock fall had just been observed before the time of the visit in November 2004 (personal communication). The greywacke is shattered and weakened, and mass movements in the upper part of the catchment are associated with the fault (Great Grove Fault) (McSaveney et al., 1995). At the lower part of the catchment, a talus cone has formed which consist of fine debris and stones of various sizes. Its toe is cut by the Glencoe stream. Further down, rocks of about one cubic metre in size or more clutter the riverbed. Skermer et al. (2002) estimated the volume of debris stored in the Glencoe catchment at 30,000 to 40,000m³ for the year 2002, and another few thousand cubic meters were estimated to be released by rock fall at any point. The stream itself serves as a water intake for two tanks located above the stream, which store water for the sprinkler systems of the Hermitage. The Hermitage is located in close vicinity to the gorge where the Glencoe stream enters the Hooker Valley.

The Kitchener fan demarcates the northern boundary of Aoraki village. The position of the Kitchener stream at the time of visit (November 2004) is located at its northern end, away from the Hermitage. However, a secondary stream runs along its southern side as can be seen in

figure 9.14. In addition, figure 9.14 shows avalanche tracks, and according to Ray Bellringer avalanches are frequently observed to reach the end of the fan.

Figure 9.14: At the watershed boundary of the Glencoe catchment. Ray Bellringer, the park ranger, to the left, a Kea to the right. The rock outcrop obscures the view on the buildings on Glencoe fan. In the background to the right, the bridge crossing the Glencoe stream, connecting the Hermitage with the rest of the village. In the left of the picture the lateral side of the Kitchener fan is visible (photo taken November 2004).

In conclusion, field observation suggests that the backdrop of the village is formed by an active geomorphologic cascade system. The Black Birch and Kitchener catchments contain considerable amount of sediment storage, which is coupled with the drainage lines. Gully erosion increases the sediment delivered out of the Black Birch catchment. While the sediment storage volume is much smaller in the Glencoe catchment, debris is directly delivered into the channel via rock fall which results into the storage of debris in the riverbed. Rock falls of large magnitude are capable of delivering material directly into the Hooker Valley. Avalanches are reported to occur on the Kitchener fan.

Against the background of these conclusions, the sequence of floods and debris flows recorded in the history of the village is not surprising (table 9.2). Since the 1994 floods, no significant events occurred on either the Glencoe, Black Birch or Kitchener fan (Ray Bellringer, personal communication 26.5.2008). The sequence of response in terms of mainly structural measures is summarised in table 9.3. Hazard zoning based on existing structural measures and proposed structural measures was done in 1998 (CRC, 1998).

Table 9.2: History of geophysical events in Aoraki village

Where	When	Process	Magnitude/damage	Author
Glencoe	Boxing Day 1957 ¹	Debris flow	70,000m ² ; no damage	Skermmer et al., 2002
	Periodic intervals 1954 - 1986	Debris flow	n.a.	Skermmer et al., 2002
	December 1979	Flood	flooding of Glencoe staff quarters	McSaveney et al., 1995
	November 2004	Small rockfall within catchment	n.a./no damage	Ray Bellringer
Black Birch	1913	Flood/debris flow	'Large' aggradation	McSaveney and Whitehouse, 1988
	Boxing Day 1957	Flood/ debris flow	Shift of stream to northern side; landsliding in catchment, large volume of aggradation	McSaveney and Whitehouse, 1986
	October 1977	Flood	Minor damage to levee	McSaveney and Whitehouse, 1986
	May 1978	Flood	Damage to protective structures	McSaveney et al., 1995
	2 nd and 3 rd of December 1979	Flood/debris flow	90,000m ³ , 70,000m ³ debris cone built-up, aggradation of 7m underneath footbridge, excavation works, evacuation, breach of levee, debris flows in catchment	McSaveney and Whitehouse, 1986; McSaveney et al., 1995
	8th January 1994	Flood	7000m ³ debris cone built-up; residents evacuated; part of levees scoured and destroyed	McSaveney et al., 1995
	20-21 January 1994	Flood	Levees scoured, in combination with 8 th of January aggradation of 3-4m, footbridge destroyed	McSaveney et al., 1995; DOC, 1994
	Various events	avalanche		pers. communication Ray Bellringer
Kitchener	Various events	Debris flows, avalanches	n.a.	DOC, 1996

¹see figure 9.15

The initial measures of 1969 on Black Birch fan consisted of rock barriers built by 'rock raking' the fan and upper part at the gorge. In addition, the stream level was lowered by about 8m with the intent of creating a self-cleaning channel. This led to undercutting of the Sebastopol slope toe, which started to deliver debris directly into the river. The works themselves increased the likelihood of floods: undermining of the Sebastopol slope entailed an extra input of material onto the fan thus adding to aggradation of sediment. A similar effect is reported at the upper part of the fan, which adds material onto the fan, hence pushing the flow of the stream northwards and towards the residential area. In addition, the channel is narrowed allowing less sediment to be stored and increasing aggradation in the case of high magnitude events (Lewandowski, 1970; McSaveney and Whitehouse, 1986).

Table 9.3: History of mitigation measures

Where	completed	Style	Design magnitude	Author
Glencoe	1999	concrete wall, 3 dykes ¹ left and right of stream	100,000m ³ ; 1;200 yr return period	Skermmer et al., 2002;
Glencoe/entire village	1999	stream bed monitoring Glencoe, hazard zonation for entire village,		CRC, 1998; Hurley, 2003
Kitchener	1960-1974	2 levees	n.a.	Innes et al., 1976, Hurley, 2003
Black Birch	1969, upgrade 1986, 1990s	1969: 'rock-raking'; subsequently: 1 main levee with spillway and 2 levees along the spillway route; 1 levee parallel to stream southwards; 1 levee for oxidation ponds	1:100 yr return period, flood flow of 150m ³ /s, 100,000m ³ sediment	McSaveney and Whitehouse, 1988; Hurley, 2003; CRC, 1998
	1986	Warning system at footbridge		McSaveney and Whitehouse, 1988

¹earth embankment

Figure 9.15 gives an impression of the village encircled by debris flows and flooding occurring on the Glencoe and in particular on the Black Birch and Kitchener fans, December 1957.

Figure 9.15: Black Birch, Glencoe and Kitchener fans after the Boxing Day flood of 1957 (photo courtesy of DOC library, Mt. Cook Village)

Aoraki village is a prime example for a techno-fix approach where land use zonation is considered as a secondary option. This is because development on the fans was already in

place, and structural measures installed, before hazard zoning was considered as tables 9.2 and 9.3 reveal. Removal of buildings and infrastructure at this stage is not feasible. A main concern of the village development was to ensure a low visual impact of the buildings themselves, as well as minimum blockage of view paths over the surrounding landscape of the National Park (e.g. Innes et al., 1976). In addition, the engineering works carried out on the Black Birch fan in the 1960s and 1980s, while reducing the likelihood of the stream overtopping the levees in minor flood events, actually increased the likelihood of overtopping and flooding during large rainfall events. A high-level risk has been transferred into an unknown point in the future (chapter 2). Until today the initial levees have been strengthened and raised, therefore increasing the storage volume and reducing the likelihood of overtopping. However, the build-up of material within the modified narrowed channel, and extra material from the formerly stable Sebastopol slope, still enhances the likelihood of overtopping in case of a large magnitude event.

The uncertainties attached to structural measures favour a false sense of security (chapter 2). In addition, the impact of a large earthquake triggering landslides, including rock fall and slides, and a multiplicative effect of earthquake and rainfall on sediment delivery is not factored into the design of engineering works. In terms of the Kitchener fan, a *laissez-fair* attitude prevails in the geotechnical reports cited, based on the assumption that the levees in place are sufficient since no major event has occurred in past and therefore is unlikely to occur in the future (e.g. DOC, 1996). Likewise, detailed hazard assessment of possible debris flows, rock fall or flood events in relation to Tavern creek are not available. Tavern creek is located between Glencoe and Black Birch stream; Skermer et al. (2002) concluded that Tavern dyke, which has been built on the Glencoe fan, would not only shield the lower Glencoe fan area from debris flows coming out of Glencoe, but also out of the Tavern catchment. The type of processes and their frequency-magnitude relationship are not discussed in the geotechnical reports cited for this research. Findlay (1994) and McSaveney et al. (1995) stated that rock fall or rock avalanche material is lying underneath the alluvial material of Glencoe fan. It is feasible to consider the possibility of a large rock fall or slide breaking out of the Sealy Range face immediately above the village, or higher up, triggered by earthquake or rainfall. Again, this is not discussed in the geotechnical reports sighted.

The village is also an example of costs arising from damage to the engineering measures themselves. Both, structural and non-structural measures are associated with substantial levels of uncertainty regarding the frequency and magnitude of geophysical processes occurring. These uncertainties are clearly stated in the geotechnical reports, and cautionary voices have been raised throughout the last 25 years. Frequency-magnitude figures on which the existing measures are based are listed at the end of chapter 10. Magnitudes of sediment delivery are uncertain since a detailed quantification of sediment storage in the catchments has not been undertaken so far. In addition, the history of recorded rainfall and earthquake events is short.

Furthermore, climate change related alternation of the frequency and magnitude of rainstorms were not considered when designing the structural measures in the 1980s and 1990s.

Despite the history of hazards that manifested in the past, and the known uncertainties on which structural measures are designed, capacities for accommodating overnight visitors have been increased steadily. For example, a sequence of historical photographs shows several extensions of the Hermitage and storeys added during the last 40 years. The current capacity of the Hermitage alone is 212 rooms⁵. In 2003, the 'Old Mountaineer Café' opened on the Glencoe fan, and the same owners planned a NZ\$ 2.5 m health spa to be built in the village (The Press, 16.6.2004). The proposed site for the spa is above Glencoe Lodge on the Glencoe fan, and this application is currently on hold. Further applications lodged with DOC are motels behind Glencoe Lodge, as well as opposite the Youth Hostel on Black Birch fan (Ray Bellringer, personal communication, 26.5.2008).

⁵ <http://www.mount-cook.com/>; accessed 26.5.2008

10. Landslide hazard analysis: methodology and results

10.1 Landsliding in the Western Hutt Hills

Stereoscope analysis of aerial photos from 1941 to 2005 (13 sets) allowed identification and measurement of landslides that occurred in the study area. These include failures on modified and unmodified slopes. Within this analysis, 'new' landslides are defined as those that are located on previously undisturbed terrain, whereas 'reactivated' features are those that have been initiated previously and are detected in subsequent aerial photos. The points of landslide origin as well as the 'affected area', i.e. the whole landslide area rather than only the scar, were digitised within a GIS (Geographical Information System) environment. In this study 'landslide density' represents the number of landslides per ha of survey area, an approach applied for instance by Reid and Page (2002) in the Waipaoa catchment of the Eastern North Island, New Zealand. Both, 'landslide density' and the total 'affected area' can be used to express the magnitude of the landslide event. A 'landslide event' defines a short (1-2 days) period in which the landslides detected on the aerial photo potentially occurred. The damage ratio ('affected area' / survey area) is calculated to represent the proportion of the land surface affected by landsliding and therefore reflects the damage done to the land. Proportional damage as expressed by a 'damage ratio' is a parameter used in other hazard studies, such as earthquakes (Dowrick, 1991, 1993; Nagato and Kawase, 2004) or floods (Kreibich et al., 2005). Since new and reactivated landslides can be damaging, both are included in the analysis. Table 10.1 lists all landslides, new and reactivated, for each year of photo coverage.

Table 10.1: Results of aerial photo analysis and digitization showing the total number of landslides per year of record, 'landslide density', 'affected area' (whole slope surface are affected by the process), damage ratio reflecting the proportion of 'affected area' of the overall study area, and the median landslide size for each year.

Date	Scale	No. of landsl.	'Landsl. density' (no./ha)	'Affect. area'(m ²)	Damage ratio ('affect. area'/ survey area)	Median landsl. size (m ²)
17.2.1941	1: 16,000	62	0.022	9,800	0.0003	95
19.9.1958	1: 44,000	79	0.028	20,700	0.0007	168
6.12.1961	1: 18,000	128	0.045	28,000	0.0010	117
28.9.1969	1: 16,000	132	0.048	35,000	0.0012	151
21.1.1974	1: 40,000	62	0.022	30,300	0.0011	329
3.2.1977	1: 12,000	792	0.281	333,000	0.0118	231
6.10.1980	1: 25,000	194	0.07	67,400	0.0024	194
14.11.1985	1: 20,000	124	0.044	28,000	0.0010	165
1988	1: 20,000	85	0.030	23,700	0.0008	161
22.2.1991	1: 54,000	70	0.026	46,600	0.0017	454
9.12.1996	1: 30,000	43	0.015	18,800	0.0007	297
4.12.2000 & 14.1.2001	1: 25,000	36	0.013	8,000	0.0003	176
19.2.2005	1: 25,000	21	0.007	5,500	0.0002	188

Within the whole time period of analysis, one event dominates: the peak in 'landslide density' and 'affected area' recorded on the 1977 photo, which is between four and five orders of magnitude larger than previous events (figure 10.1).

Figure 10.1: Magnitudes of landslides as expressed by (a) 'landslide density' (no./ha), and (b) 'affected area' (thousands of m²); see also Hufschmidt and Crozier, 2008

Prior to 1977 'affected area' increased with each recorded year, with a small drop in 1974. Similarly, 'landslide density' increased, with a much more pronounced drop in 1974. The difference can be explained by checking the median failure size for 1974 (table 10.1), which is relatively large. In 1980, the density was still high compared to the first period (1941 – 1974), but then decreased continually to the minimum of 21 landslides in 2005. 'Area affected' follows this trend, with one exception in 1991, which again can be explained by a large median landslide size.

Potential error sources from this aerial photo analysis are basically linked to temporal and spatial considerations: the rate of revegetation of the area affected by landslides, and the precision of analysis due to spatial and temporal aerial photo resolution as discussed in the following.

The stereoscopic analysis revealed rapid natural revegetation within bush and on pasture, hence landslide scars can be completely covered within less than three years or even faster. Reid and Page (2002) reported of a span of revegetation of about two years for the east coast of the North Island (Waipaoa catchment, near Gisborne). As Crozier et al. (1980) observed, when potentially enhanced by sowing, regrowth of pasture in the adjacent Wairarapa Region (east of Wellington) can be completed within one year. The revegetation rate has several implications. Firstly, landslides might not be detected in the subsequent aerial photo, particularly when on pasture (20% - 30% of the area over time). However, in bush and forested areas (50% - 60% coverage over time), the height of the vegetation occupying a landslide site would be much lower than the surrounding vegetation, thus revealing the presence of a former landslide. Such inferred landslides were only identified three times throughout the analysis period. Secondly, the chances of classifying a landslide as reactivated while in fact it is a previous landslide where revegetation is not yet completed, is very low. This is because the regrowth rate is higher than the common lapse of three to four years between aerial photo runs. Therefore the risk of double counting landslides is very low. Thirdly, a slip with a fresh appearance is likely to have occurred close to the date of the photo from which it was detected.

As reactivation can only be detected by a fresh signal of an exposed surface, there is a chance that an observed exposure is not the result of re-occurring landsliding, but of vegetation removal by rain or running water. However, in this case, some material translocation would be involved, even when this secondary process is different from the original landslide movement. Field validation was generally not possible for historical landslides due to the start date of the study in mid 2004. To reduce error, stereoscopic analysis did not consider landslides to be reactivated if less than 25% of the previous landslide area was exposed thus ensuring a mass movement rather than just vegetation disturbance.

As table 10.1 illustrates, spatial resolution of the aerial photos alters, ranging from 1:12,000 to 1:50,000. The smaller the scale of the photo, the higher is the probability that small landslides are overlooked. This difference in precision and the potential error are reduced significantly by using a magnification of 10 to 15 for stereoscopic analysis of smaller scale aerial photos. The temporal resolution of the records is reasonably good, with one wider gap between 1941 and 1958 and a smaller between 1961 and 1969 (table 10.1).

10.2 Landslide hazard in the Western Hutt Hills

In this study, either 'landslide density' or 'affected area' is possible surrogates for the magnitude of a landslide event. How often landslide events of a certain magnitude occur within the total period of analysis, i.e. 64 years, accounts for the frequency of this event within this analysis (table 10.2). Annual probability is calculated by dividing the number of events by the overall

period of analysis, and probability in 100 years is calculated by multiplying the annual probability by 100. Other data illustrating landslide occurrence between two photos is only sparsely available, and therefore it is assumed that landslides identified on each photo set are related to the same triggering rainfall. Although this involves some uncertainty, where geological settings or other factors of instability such as regolith depths are similar, landslides tend to occur in groups (Selby, 1985). Historical records, such as newspaper articles and a landslide catalogue (GeoNet) analysed within this study (as will be documented in more detail later) demonstrate that at least higher magnitude rainfall events do trigger failures simultaneously.

Table 10.2: Landslide hazard expressed as annual probability and probability in 100 years, with 'affected area' (m²) as a surrogate for landslide magnitude

Magnitude by 'affected area' (m²)	No. of events	Return period within 64 yrs	Annual probability	probability (100 yrs)
0-10,000	3	21.3	0.05	5
11,000-24,000	3	21.3	0.05	5
25,000-30,000	2	32	0.03	3
31,000-40,000	2	32	0.03	3
41,000-50,000	1	64	0.02	2
51,000-70,000	1	64	0.02	2
71,000-315,000	1	64	0.02	2

From a methodological perspective, it is interesting to compare the usage of 'landslide density' and 'affected area' to express the magnitude of hazard. In 1974 and 1991, the values for 'affected area' exceeded those for the density of landslides, while this situation is reversed in 1961 (figure 10.1), which would result in a slightly different classification of recurrence intervals for specific magnitudes. This further indicates the occurrence of several larger and smaller slides, respectively as shown by median failure size (table 10.1). Generally, small slides can result in extensive damage to properties and infrastructures, which in total can be far higher than the damage of large but rare failures (Selby, 1985). However, large landslides individually have a higher damage potential. The areal photographs used in this study show both small and larger landslides starting close to houses and infrastructure, the latter illustrated by the Kelson failure as one of the larger failures (chapter 9, figure 9.5). Nevertheless, to account for the possible differences in sizes, 'affected area' per event is used as a measure of magnitude rather than 'landslide density'. The classification of 'affected area' follows the natural breaks in the data, which results in a slightly uneven distinction between the classes.

The overall period of records available to a researcher can be a source of error. The framework of cyclic, graded and steady time, established by Schumm and Lichty (1965), has various implications for landslide hazard. One general, though crucial, point is that, depending on the time scale chosen, the observer can perceive different system states. While for example during a relatively short period of time no variation of the system is detected, a longer period may reveal that this 'steady state' is part of a general system change. This change, with further increased time span, might appear to be part of a repetitive variation within the system, which

itself can follow a trend (Chorley and Kennedy, 1971). As for any hazard study, the above applies for this analysis. Especially when no high-magnitude event is recorded, chances are that the records do not capture the full spectrum of system behaviour. Considering this aspect for the Western Hutt Hills, the records capture a landslide event of a very high magnitude (1977, figure 10.1) which has a return period greater than 100 years (Tomlinson and Dyke, 1977; Crozier and Aggett, 2000), as well as medium and small magnitudes, therefore some measure of the natural range has been captured.

10.2.1 Changing landslide hazard?

Plotting annual probabilities of landslides for the years with landslide record shows that probabilities are temporally clustered (figure 10.2). Comparing hazard as the integral of the frequency-magnitude relationship on the one hand (table 10.2), and the temporal pattern of landslide records, which feed this relationship (figure 10.1), on the other hand, suggests that landsliding pattern and therefore hazard changes in time.

Figure 10.2: Annual probability (%) of landsliding according to landslide magnitudes ('affected area' in m^2); years are 'date of rainfall')

The frequency of specific landslide events is often derived by establishing a link with rainfall events of a specific characteristic or magnitude (Corominas et al., 2005). With a long enough rainfall record, occurrence intervals for rainfall events could be calculated and hence potential landslide magnitudes projected, as for instance applied by Reid and Page (2002) (chapter 4). If this relationship were valid for the study area, then a decrease in landslide-triggering rainfall after 1977 would be an explanation for the decline of landsliding as shown by the data in this study.

In order to test the relation between landslide magnitude and rainfall magnitude, first the 'Antecedent Soil Water Status model' developed by Crozier and Eyles (1980) and further

refined for the conditions of the Wellington Region by Glade (2000), is applied to the data set. Antecedent soil water status (SWS) for a given day is based on a deficit or surplus of soil water, which is allowed to develop during ten previous days. Deficit and surplus are based on daily rainfall and potential evapotranspiration, which depletes or fills up the soil moisture storage. According to the model, landslides can only occur when the soil water status is in a condition of excess precipitation, i.e. positive pore water pressure. Glade (2000) developed maximum thresholds of soil water status and daily rainfall which define a probability of landslides occurring in the Wellington region (table 10.3). The thresholds do not imply the magnitude of landsliding.

Table 10.3: Maximum probability thresholds of landslide triggering rainfall after Glade (2000)

Probability (%)	Soil Water Status (mm)	Daily Rainfall (mm)
< 25	12.5	10
> 25	25	55
> 50	40	85
> 75	50	115
100	55	140

To run the 'Antecedent Soil Water Status' (ASWS) model, daily rainfall and potential evapotranspiration ('Priestly-Taylor' as in Rosenberg et al., 1983: 252) for the period of 1937 to 2005 are obtained from the National Climate Database (NIWA – National Institute for Water and Atmospheric Research) for several climate stations in the Western Hutt Hills and Kelburn, which is the principal meteorological station in Wellington. In total, nine years of missing daily rainfall values for the Western Hutt Hills are imputed with a regression based on the Kelburn rainfall with $R^2 = 0.8$ for the period of 1937 to 1967, and $R^2 = 0.76$ for the period 1969 to 1995. Potential evapotranspiration is available for Kelburn only (1961-2005), but due to the high similarity of topographic conditions these data can be justifiably applied to the Western Hutt Hills. For several years pre-1941 and pre-1958, potential evapotranspiration is calculated as the mean monthly value, based on the record 1961-2005.

The ASWS model is run and according to the thresholds shown in table 10.3, days meeting the criteria are extracted from a database created with the software MS 'Access'. Although high soil water status is usually referred to a high susceptibility to landsliding, the records are also searched for days with negative soil water status but high rainfalls, as under these conditions landslides can occur as well. In order to assign a rainfall event to a landslide magnitude, the rainfall event with the highest probability of triggering landslides and closest to the date of the aerial photo is identified (table 10. 4).

Cellular rainfall, which is confined to a limited area, is difficult to measure and therefore cannot be included in the analysis. In this study, rainfall events are assigned which have the highest *probability* to trigger landslides, hence there is some uncertainty in linking the magnitude of rainfall with the magnitude of the landslide event.

To back up the data as much as possible, a literature and newspaper search for reports on landsliding in combination with rainfall events is carried out. The search includes national and local newspapers. A database is generated (with MS 'Access') which classifies the articles according to the date, the newspaper, the wider and specific locations named in the article, information on the size of reported landslides and damage caused. In total, 153 articles starting in January 1930 until August 2006 are entered into the database, which are associated with landslides as well as floods in the Western Hutt Hills and the wider Wellington region.

The following landslide events can be backed up by the literature and newspaper review: 27/12/1939 (Crozier and Aggett, 2000), 26/4/1966 (The Hutt News, 27.4.1966), 20 & 21/12/1976 (Crozier and Aggett, 2000) and numerous newspaper articles (e.g. Evening Post, 21.12.1976; The Hutt News, 26.1.1977) and 15/02/2004 (GeoNet¹). During major storms and landslide events in Wellington City, for example 1974 and 1998, not nearly as much damage was reported for the study area. In other cases severe rainfall in the study area is reported but no reference to landsliding is made, e.g. on the 17/06/1957 (The Hutt News, 19.6.1957). Although landslides have been recorded for 15/2/2004 within the GeoNet database, no references could be found in newspapers. It seems that while major landslide events are covered by the media, smaller events that cause little damage or landslides occurring in the uninhabited hillsides are not well represented. In other cases, landslides have been reported which cannot be associated with rainfall exceeding the thresholds applied in this study. Hence literature and newspaper reports covering the occurrence of landslide-triggering rainfall events can only serve as a back-up with limitations.

Table 10.4: Rainfall events with a chance of more than 25% to trigger landslides, of more than 50% (*), and with a chance of more than 75% (**)

Date of photo	Date of rainfall	Soil water status (SWS, in mm)	Rainfall (mm)	Critical water content (CWC, in mm)	'Landsl. density' (no./ha)
17/2/1941	27/12/1939*	55	105.7	160.7	0.022
19/9/1958	17/06/1957	26	79.1	105.1	0.028
6/12/1961	<i>Conditions to trigger landslides not matched</i>				0.045
28/9/1969	26/4/1966**	108.9	117.8	226.7	0.048
21/1/1974	<i>Conditions to trigger landslides not matched</i>				0.022
3/2/1977	20/12/1976*	51.4	107.0	158.4	0.281
	21/12/1976**	51.4	132.5	183.9	
6/10/1980	20/04/1978*	92.9	97.2	190.1	0.07
14/11/1985	10/12/1983	39.2	104.6	143.8	0.044
1988	14/10/1987	52.9	61.8	114.7	0.03
22/2/1991	10/03/1990	-14.3	56.2	41.9	0.026
9/12/1996	19/11/1995	43.3	81.1	124.4	0.015
14/1/2001	30/10/1999	63.4	66.2	129.6	0.013
19/2/2005	15/02/2004	32	105.8	137.8	0.007

¹ <http://www.geonet.org.nz/landslidecat.html>, accessed 8/8/2006

The study considers only landslides triggered by rainfall. Since located in high proximity to the Wellington fault and several other faults in the region, landslides in the study area could potentially have been induced by earthquakes. However, based on historical records, the threshold for minor landslides in the Wellington Region is likely to be at MM6 (Modified Mercalli Intensity Scale), for small to medium slope failures at MM8 on steep slopes, and for larger and widespread failures at MM9-10 (Hancox et al., 1994). During the study period several earthquakes occurred (some of MM6), but even if these produced landslides they would be only minor (Hancox et al., 1997) and thus unlikely to distort the rainfall-induced landsliding.

Several rainfall events with a probability of 50% or more of triggering landslides are shown in table 10.4: 27/12/1939, 26/4/1966, 20/ and 21/12/1976, and 20/4/1978. Taking into account the threshold for potentially triggering rainfall, the dates 10/12/1983 and 19/11/1995 almost reached the criteria for a 50% probability. In addition, rainfall-records for 2004 show a high magnitude event, which occurred in a situation of relatively small precipitation excess (SWS). Therefore a change in the climatic conditions favouring a decrease of landslide magnitude is not observed.

Figure 10.3 illustrates the extent of the landslide event of December 1976. It is noted that the Vista Grove site in Kelson, which failed in August 2006 (chapter 9, figure 9.5), did not fail.

Figure 10.3: After the 1976 December storm. Note the enlargement showing the site of the Kelson failure at Vista Grove on the 7.8.2006, as marked by a dashed line.

'Critical Water Content' (CWC) is the sum of the antecedent soil water status and rainfall on the day (Crozier, 1997; 1999). 'Critical Water Content', as the magnitude of rainfall, is examined against the landslide magnitude (density) assigned (figure 10.4). The correlation is very weak, with $R^2 = 0.15$ including and $R^2 = 0.26$ excluding the rainstorm in 1976. As discussed above, the

rainfall with the highest probability to trigger the landslide event is used to establish the correlation. Hence the correlation would be even weaker had a lower probability been applied. The relation is also tested for 'affected area', which depicts a very similar pattern as 'landslide density'.

Figure 10.4: Critical water content (CWC) and landslide magnitude (landslide density) for landslide events 1939 – 2005 (years are 'date of the rainfall')

The years 1957, 1978, 1983 and 1987 follow a trend of increasing landslide magnitude with increasing critical water content, as indicated by the line sketched in figure 10.4. In 1966, a high magnitude of landsliding is related to both very high rainfall and soil water status. The relatively low magnitude of 'landslide density' in 1974 (though slightly higher in terms of 'area affected'), can be related to the fact that no threshold larger than 25% was crossed in the years before the aerial photo was taken, and no combination of negative soil water status and high rainfall could be detected in the records. This is why 1974 does not show in figure 10.4. Newspaper articles frequently referred to several unusual dry years in the early 1970s (e.g. The Hutt News, 1970). The event in 1976, which triggered by far the most landslides, occurred after two days of very high rainfall and therefore critical water content, which explains the extreme magnitude of failure.

However, in many cases 'Critical Water Content' and magnitude of landslides do not correlate. In the years previous to the photo of 1961, the conditions required to potentially trigger landslides with a chance of >25% were not matched, but 'landslide density' is relatively high (0.045, table 10.4). This indicates that a small rainfall event triggered a relatively high number of failures. Since no CWC could be assigned according to the threshold values of SWS and daily rainfall, there is no record in figure 10.4. The event of the 20th of April 1978 triggered more landslides than the event of 1966, although the critical water content was less than in 1966. Again, 1983 is characterised by lower critical water content than 1966 and 1939, but has a

similar and higher magnitude of landsliding, respectively. The rainfall event of the 10th of March 1990 with a negative soil water status initiated a comparatively high number of landslides. The years 1995, 1999 and 2004 show smaller and decreasing magnitudes of landslides though CWC rises, as indicated by a line in figure 10.4.

Within this study, the degree of reactivation of landslides was analysed for the period of 1958 to 2005, because due to the lack of pre-1941 photos all landslides detected in 1941 are assumed to be new. Generally, no landslide was detected continuously throughout the whole time of analysis. Only two landslides, initiated in 1976, were reactivated in all subsequent years of record until 2001. For the whole period of analysis, four phases of different reactivation status can be distinguished. Firstly, between 1957 and 1976, 85-95% of all landslides were new. In other words, only 5-15% of all landslides constituted reactivation of existing slides (figure 10.5).

Figure 10.5: The proportion of new landslides and reactivated landslides (%) (years are 'date of rainfall')

In contrast, between 1978 and 1987 the majority of landslides were reactivated (65-80%). Interestingly, during this time, the percentage of new landslides rose, while the percentage of reactivated slides declined gradually. The third phase is commenced by a turning point in 1990: as the gradual trends continued, the number of new landslides triggered exceeded those being reactivated. This development continued during the fourth phase until 1999, when numbers of reactivated landslides rose and again exceeded the number of new landslides. Overall, reactivation of landslides is a minor process, with 74% of all landslides being triggered on undisturbed terrain, and 26% reactivated. The extreme event in the record of 1976, when a huge number of new landslides occurred, is unlikely to be solely responsible for this distribution, but it has possibly enhanced it. However, after an extreme event, reactivation exceeds the occurrence of new landslides and the signal remains in the system for at least 30 years.

10.2.2 Discussion and conclusion

The general temporal distribution of 'landslide density' and 'affected area' is characterised by a continuous decline after the extreme rainfall event in December 1976. As is shown within this study, similar climatic conditions do not necessarily trigger similar magnitude of landslides (figure 10.4). In general, there is no linear relationship between critical water content and the magnitude of landslides. Reactivation of previous landslides does not play an important role within the first phase 1957-1976 (figure 10.5). However, this picture is reversed with the beginning of the second phase. In the subsequent years, reactivation was clearly the dominating factor and numbers of reactivated landslides remained high until 2004 compared to the first period. This probably results from the presence of the very high number of newly affected areas after the event in 1976, which increased the potential for reactivation during subsequent years. Interestingly, in 1999 and, in a much more pronounced way, in 2004 the proportion of reactivation rose again, though the overall number of landslides decreased. The heavy rain, though accompanied by a relatively low soil water status, on the 15th of February 2004, appears to have caused the reactivation of previous landslides. This is the same pattern as after the storm in 1976, though on a smaller level of magnitude.

The trend of decreasing landsliding cannot be related to an external trigger such as rainfall. Therefore the question is: Why do landslide magnitudes decline in time? An explanation for changing landsliding other than that of changing patterns of external triggers is the sensitivity status of the system. The sensitivity of a hillslope ranges from 'stable', 'unstable' (marginally stable) to 'actively unstable' (Crozier and Glade, 2005). Generally, these three states represent different situations of balance between shear strength and shear stress. If this margin of stability is wide, only high-magnitude triggering factors, like a massive rainstorm, move the slope into an actively unstable condition and failure occurs. Is the margin of stability narrow, e.g. due soil saturation, an average amount of rainfall can foster a reaction. Internal thresholds are variable in time and shift the system's state along a spectrum of sensitivity. External landslide triggering factors such as rainfall intensity can change with time as well, while factors such as deforestation and reforestation alter the land's susceptibility to triggering factors and therefore landslide occurrence. The interplay of internal and external thresholds and their variability in time increase the complexity of geosystem behaviour in general as discussed in chapter 4. This is a source of non-linearity, because the same magnitude of external trigger, for example twenty years later, does not necessarily initiate the same magnitude of landslides. In this case, hazard changes because of internal system settings. In this context, the reactivation of existing landslides is of interest. Hillslope systems affected by landslides inherit a special complexity, because the process itself alters its initial condition. This can have two contrasting effects: Firstly, the area affected may become more susceptible to failure after a landslide event, and therefore constitutes a permanent source of hazard (Reimer, 1995; Crozier and Glade, 1999). Secondly, by immediate or continual material export, the process cuts off its own supply and diminishes, a condition referred to as 'event resistance', as Crozier and Preston (1998) and Preston (1999) have shown for examples in New Zealand (chapter 4). Hence, the process itself,

in one way or the other, alters the internal threshold of landsliding and hence the hazard potential.

It is likely that the rainstorm in 1976 changed the overall system settings, in terms of available material, thus altering the internal resistance towards failure. After 1976, many of the potential landslide source areas, the 'colluvium-filled bedrock depressions' at the head of gullies, have been emptied during that event as well as subsequently during the following years by reactivation. This enhances the overall resistance of the terrain to failure and proportionally the reactivation of existing scars becomes more important. About six years after the storm of 1976, landslide numbers decrease and potential landslide-triggering rainfalls fail to produce magnitudes matching those before the extreme event.

As illustrated in figure 10.3, two gullies adjacent to the failure at Vista Grove, Kelson, failed in 1976. However, they did not react during the rainstorm in August 2006 which triggered the gully failure at Vista Grove. This is a specific example that sites, once failed, can become more resistant until enough material is available again to be moved down the slope.

It is concluded that in the Western Hutt Hills, landslide hazard evolves through time. This is based on an overall decline of landslide magnitude for the second part of the records which cannot be related to the rainfall pattern. In addition, the decline is accompanied by a higher degree of landslide reactivation and evidence of a weak relation between climatic conditions and magnitudes of landslides.

Recognising a changing geomorphological system, and therefore a changing hazard, prompts the question of the reliability of hazard estimates expressed in terms of annual probabilities based on frequency-magnitude relations such as those in table 10.2 established for the Western Hutt Hills. Employing solely a stochastically derived frequency-magnitude relation, a common approach in hazard and risk analysis and assessment in general, would therefore potentially obscure a trend of diminishing or increasing hazard in time. Frequency-magnitude relationships as an integral of the overall landslide pattern in time are a common way to calculate hazard. However, possible changes of this pattern within the integral are usually not analysed. Natural risk analysis and assessment would benefit from addressing evolving rather than static geosystems as demonstrated in this study.

10.3 Hazard in Te Arai and Aoraki

Limited availability of information required for a landslide hazard analysis similar to the Western Hutt Hills prohibits a similar approach for Te Arai and Aoraki. Landslide hazard is therefore based on information retrieved from the literature. Tables 10.5 and 10.6 list the results of the literature review, and table 10.7 includes the design parameters on which the levees in Aoraki are based.

This information will enter the risk calculation as presented in chapter 12. Information on changing landslide hazard, however, is not available for this research.

Table 10.5: Magnitude and frequency of landslides for Te Arai, based on frequency and magnitude of landslide-triggering rainfall events associated with a specific landslide magnitude (Reid and Page, 2002).

Location	Magnitude (no./km ²)	Frequency	Probability (100 yrs)	Annual probability	Author
Te Arai	20	60 in 100 yrs	60%	0.6	Reid and Page, 2002
	100	20 in 100 yrs	20%	0.2	
	250	5 in 100 yrs	5%	0.05	

Table 10.6: Magnitude and frequency of debris flows for Glencoe and Black Birch catchments (Aoraki), based on recorded events. No information is available for Kitchener or Tavern catchments.

Location	Magnitude (m ³)	Frequency	Probability (100 yrs)	Annual probability	Author
Glencoe	< 70,000	< 1 in 50 yrs	< 2%	0.02	Skemer et al., 2002
	70,000 - 150,000	Between 1 in 50 and 1 in 200 yrs	Between 2% and 0.5%	Between 0.02 and 0.005	Skemer et al., 2002
	< 150,000	> 1 in 200 yrs	> 0.5%	> 0.005	Skemer et al., 2002
Black Birch	70,000	1 in 25 years	4%	0.04	McSaveney and Whitehouse, 1988

Table 10.7: Design parameters for debris flow mitigation structures in Aoraki

Location	Magnitude (m ³)	Frequency	Probability (100 yrs)	Annual probability	Author
Black Birch	100,000	1 in 50 years	2%	0.02	McSaveney et al., 1995; CRC, 1998; Hurley, 2003
Glencoe	100,000	1 in 200 years	0.5%	0.005	Skemer et al., 2002

11. Vulnerability and resilience analysis: methodology

Currently there is no standardised procedure for analysing vulnerability (Birkmann and Wisner, 2006; Villagran, 2006), as already observed by Bohle et al. (1994) more than ten years ago. Accordingly, Morgenstern (1997) noted the lack of theory and methodology of vulnerability analysis in the field of landslide risk research. He pointed out that this lack is especially notable compared to the body of theory and methodology available for landslide hazard analysis. Similarly, based on the resilience literature reviewed within this thesis (chapter 6), it is evident that methodological standards for measuring resilience are not available at present. Interestingly, in the field of sustainable development a standardised methodology is lacking as well, although the need was clearly identified by Agenda 21 declared in Rio de Janeiro in 1992. Some relate this gap to the multi-dimensional and context-specific nature of sustainability (Moldan and Dahl, 2007). Likewise, vulnerability and resilience are multi-dimensional concepts. In addition, the majority of methods in the field of vulnerability are explicitly designed to suit a certain combination of hazard and elements at risk (Hollenstein, 2005), hence are context-specific to some extent.

Measuring vulnerability and resilience in some way or the other is one of the foci of risk reduction. The 'Hyogo Framework for Action 2005-2015: Building the resilience of nations and communities to disasters (HFA)', an outcome of the World Conference on Disaster Reduction (WCDR) in Kobe 2005 held under the auspice of the UN/ISDR, prioritised the need to *'identify, assess and monitor disaster risks'* (United Nations, 2005: 12). As one of the key activities for implementing this goal, the declaration emphasised the development of indicator systems of disaster risk and vulnerability for multiple scales. The usefulness of such indicators for decision-makers is highlighted, as well as the value of standardised methodologies of risk assessment and monitoring. The 'Expert Working Group on Measuring Vulnerability' (EWG), formed after Kobe, aims at implementing the Hyogo Framework by providing a forum for discussion on how to measure vulnerability. Situated within the context of human security and sustainable human development, the EWG identified a series of challenges in finding suitable methodologies for vulnerability analysis, and reinforced the Hyogo Framework by stating that *'for effective preparedness strategies and sustainable recovery the development of tools to measure vulnerability is a prerequisite'* (Birkmann and Wisner, 2006: 5).

It appears that the problems confronted when aiming to quantify vulnerability are articulated more clearly than those related to resilience. This might reflect the longer research history of the vulnerability field (chapter 2). However, challenges in measuring and standardising resilience must equally emerge. In particular against the background of growing interest in resilience studies a discussion of methodological issues about how to measure resilience is necessary. A synthesising approach to both, as developed in chapter 7, therefore favours not only a conceptually but also methodologically comparable basis.

One objective of this thesis is to quantify the temporal and spatial variability of vulnerability and resilience. The approach chosen is to develop indices reflecting both concepts and, by establishing a temporal sequence of these indices, to compare their development through time. This chapter summarises the methodology of index construction and discusses the opportunities, rules and problems related to such a procedure. Successively, the structure, data and methodology of the vulnerability and resilience indices developed and applied in this thesis are presented.

11.1 General issues and scale

Analysing vulnerability and resilience can be done qualitatively, semi-quantitatively or quantitatively. Either way, the construct is expressed as a condition. In the overall context of risk assessment, qualitative descriptions are often used as a first assessment to identify different vulnerability aspects, or when numerical data is not available (AS/NZ, 2004). Wisner (2006) for instance discussed and exemplified the advantages of participatory approaches which are qualitative self-assessments. Semi-quantitative methods assign values to qualitative ranks in order to introduce a more expanded scale. These values are however not 'real' values and usually expressed on an ordinal scale which bears limited mathematical possibilities. Villagran (2006a) described such an analysis where structural characteristics of buildings (e.g. material of the roof and walls) are associated with classes of low, medium and high vulnerability. These are assigned values of one, three and five, respectively, and combined into one figure. Thirdly, quantitative analysis relies on numerical values based on metric variables on an interval/ratio scale allowing for mathematical operations. Differences between variables can be quantified as true numeric magnitudes. Metric variables can be used as indicators and aggregated into an index. There is no general preference for either of those three types, and as a general rule the approach best suited to meet the defined goal guides which of the three is used (AS/NZ, 2004).

During the second meeting of the 'Expert Working Group on Measuring Vulnerability' (EWG) in 2005, a range of general tension points amongst the participants emerged, mirroring different ways of conceptualising and hence measuring vulnerability (Birkmann and Wisner, 2006). Amongst these, the need to understand vulnerability in all its multi-dimensionality on the one hand (often done qualitatively), and the need for relatively simple tools of analysis on the other hand (often done quantitatively), can be conflicting. This dilemma had been earlier observed by Davidson (1997) who reviewed earthquake risk assessment models developed from the two camps of social sciences and engineering. Clear and readily available vulnerability indicators are often what hazard and disaster managers seek - before, during or after an emergency. Indicators are communication tools which aim at condensing often complex information in a way that allows fast comprehension and application. Consequently indicators, which can be aggregated to an index, simplify reality and the degree of simplification depends on the target audiences (Karlsson et al., 2007; Moldan and Dahl, 2007; Stanners et al., 2007). Such indicators and indices approaches are usually unable to represent all underlying causes of

explanation. This aspect is underlined by Wisner (2003a) who stated that causes and indicators of vulnerability are different. For example, a community's socio-economic profile relates to a certain level of vulnerability, but does not explain why the profile exists in the first place. He concluded that both, indicators and explanatory approaches have their place depending on the purpose of the vulnerability analysis. This would equally apply for resilience analysis. Ideally, indices are closely linked to a conceptual understanding of vulnerability and resilience.

The methodology applied in this thesis follows a quantitative approach based on a set of variables which are transferred into indicators and aggregated to one index for vulnerability and resilience each. Examples of such an approach are given by Briguglio (1995), Davidson (1997), Davidson and Shah (1998), Cutter et al. (2000), Davidson and Lambert (2001), Cutter et al. (2003), Boruff et al. (2005), Cardona (2005, 2006), Bollin and Hidajat (2006), and Plate (2006). The variables included are embedded within the explanatory models of vulnerability and resilience (chapter 7). These models emphasise the role that framing conditions play in people's access to resources, hence the role of different cultural contexts as well as hazard types. The combination of these models and the summary of the various ways in which certain variables relate to vulnerability and resilience (chapter 8) enhances the explanatory power of this approach. The approach followed here is therefore not strictly a taxonomic ('laundry list', chapter 8), but a situational approach as differentiated by Wisner (2004).

Vulnerability and resilience are not only multi-dimensional and partly context-specific constructs, but scale-dependent, which further complicates standardised approaches. Scales range from households, communities, states, to national or global societies. Examples from many practitioners gathered at the second meeting of the EWG illustrate this spectrum. Accordingly, Schneiderbauer and Ehrlich (2006) listed scale-dependent vulnerability indicators. Data availability is also an aspect which differs with scale (Birkmann and Wisner, 2006). Recognising issues of scale is important for another reason: as Wisner (1993) pointed out, a fallacy is lurking when efforts to reduce vulnerability on the national scale are understood to automatically lessen vulnerability on the household scale. Hence, issues of scale in terms of 'up-scaling' and 'down-scaling' apply just as for many other scale-relevant phenomena, and resilience alike.

11.1.1 Why the community scale?

A community can be defined as a group of people who have something in common: a locality and / or a specific interest. Within a community defined by its locality, different interest groups can form different communities. This 'mosaic' of communities (Marsh and Buckle, 2001) is an aspect included in this thesis as will be discussed later. The term 'community' also implies some sense of belonging and commitment. 'Building' a community involves the agent of time: a sense of belonging usually needs some time to develop (Marsh and Buckle, 2001).

Studies addressing the vulnerability and especially the resilience of communities towards landslides are practically non-existent. Typically, in landslide risk analysis vulnerability is

expressed as an individual's probability of loss of life or injury, the potential damage to the built environment and infrastructure, which can be linearly aggregated onto the regional or national scale (chapter 4). Some examples of vulnerability analysis within the applied sciences are described and discussed in chapter 5. The landslide risk assessment carried out for the Geoscience Australia 'Cities Project' with respect to urban communities in Cairns is another example (Michael-Leiba et al., 2003; Michael-Leiba et al., 2005). These studies aggregate data of smallest census unit and apply them for the next larger statistical area which is delineated as the community. While such an approach is valid in some respect, indicators specific to the community scale need to be included to actually represent the community rather than generate an integral of lower statistical units: the sum is more than its parts. The 'infrastructure index' included in this thesis accounts for such community-scale indicators. Moreover, the 'community network' and 'critical facilities' indices represent aspects of community vulnerability and resilience (section 11.4.4). It is also observed that, irrespective of hazard type, statistical boundaries do not necessarily represent communities. Therefore a careful consideration and delineation of community boundaries is necessary.

Apart from the lack of research with respect to landslide risk studies, another argument for the community scale is that a single landslide can disrupt the supply of water, gas and electricity for the whole community. A road blocked by a landslide can restrict access in and out of the community, and therefore affect the supply of medical care, food and other supplies. In addition, natural hazard and disaster management in general benefits from shifting towards the community level. It is increasingly acknowledged that community involvement in management plays a central role in mitigation, preparedness, awareness and response to landslide risk, as well as ideally within the policy-making processes (Allouche and Bowman, 2006; Anderson and Holcombe, 2006; Chen et al., 2006). Awareness training targets the whole community and entails beneficial effects for the participants, as illustrated for earthquake, flood and landslide hazard in a community in Turkey (Karanci et al., 2005). Such community-based programs are likely to have positive spin-offs for social network development. Another motivation for community-based research is to counterbalance common 'top down' management approaches, which tend to neglect community initiatives to reduce risk (Sanderson, 1997; Fordham, 2003). Such approaches are increasingly replaced with participatory projects where local community members are involved and their perspectives and capabilities are valued. This is also seen as generally increasing the success of these projects (Allen, 2003). Although this thesis does not follow a participatory approach, its value is recognised. By focussing on the community scale a link to potential future participatory approaches is ensured.

In conclusion, landslide risk studies appear to be decoupled from increasing efforts of risk researchers to address community vulnerability and resilience. These increasing efforts are reflected by numerous websites and publications such as the UN/ISDR¹ and UN/ISDR's

¹ http://www.unisdr.org/eng/about_isdr/isdr-mission-objectives-eng.htm, accessed 23.1.2008

Platform for Promotion of Early Warning (PPEW)², and the New Zealand Ministry of Civil Defence and Emergency Management³. Allen (2003) observed a surge of community-based approaches within natural hazards and risk research over the last ten years. Also Granger (2003a) identified the community level as an area still underrepresented in the field of natural hazards and disasters generally, and this certainly applies for landslide risk in particular.

Within the context of this thesis social vulnerability and resilience materialise not so much in terms of loss of life, although one case has been reported (The Dominion, 21.12.1976), but rather by overall adverse effect on the livelihood and well-being of community members.

11.2 Indicators and indices

Indicators and indices can be used not only as tools for discovering and monitoring spatio-temporal changes, but also as benchmarks enabling the evaluation of, for example, the success of measures, as threshold values, as policy targets and communication tools (Birkmann, 2005; Villagran, 2006a; Karlsson et al., 2007).

What exactly are indicators and indices? *'An indicator is an easily accessible, comparable, repeatable item of information property judged to "indicate" or point to more complex state of affairs'* (Wisner, 2003a: 13). Indicators summarise the essential characteristics of a system (Saisana and Tarantola, 2002; Moldan and Dahl, 2007) and in this function are measurable variables (Davidson and Shah, 1998; Gall, 2007). Indicators can be qualitative (nominal), semi-quantitative (ordinal) or quantitative (ratio) (Gallopín, 1997), but quantitative indicators are most common (Moldan and Dahl, 2007).

A composite indicator is also referred to as an index (Saisana and Tarantola, 2002; Nardo et al., 2005a) and can be defined as *'a weighted combination of two or more indicators'* which aims to *'summarize the status in some area of concern'* (Rossi and Gilmartin, 1980: 18). As Davidson (1997) argued, indices enable measuring multi-dimensional concepts by combining a variety of information and translating it into a simple and ideally user-friendly format. She developed the Earthquake Disaster Risk Index (EDRI) (Davidson, 1997; Davidson and Shah, 1998), designed to compare the risk related to earthquakes between cities. Also on the global scale many examples exist for such composite indicators such as the United Nations' 'Human Development Index' (HDI) or the United Nations' 'Disaster Risk Index' (DRI).

The strength of an index lies in its synthesis of complex data within one figure, which allows non-specialists such as the general public or government agencies to access information which otherwise would be difficult to obtain and to comprehend. In addition, indices facilitate the

² http://www.ewc3.org/upload/downloads/Early_warning_complete2.pdf, accessed 23.1.2008

³ http://www.civildefence.govt.nz/memwebsite.nsf/wpg_URL/For-the-CDEM-Sector-Publications-CDEM-Act-2002?OpenDocument, accessed 30.1.2008

uncovering of trends (Davidson, 1997; Saisana and Tarantola, 2002; Nardo et al., 2005a), which is of special interest for this thesis.

However, an index masks the variability of individual indicators, as well as their interrelations, if these are not revealed as well. In addition, methodological index validity is a crucial issue since indices are increasingly used as communication and policy making tools in fields such as economy, society and environment (Nardo et al., 2005a). Throughout the process of index development a range of decisions have to be made. Generally, indices are similar to mathematical models and no standards exist. Consequently, some of the choices during the process of index-building are subjective. These choices are guided by the proposed outcome of the procedure and ideally by best practice (Saisana and Tarantola, 2002, Nardo et al., 2005a). If indices are not developed carefully or are difficult to interpret they are misleading. This, in turn, affects the quality of the decisions made based on these indices. In order to ensure high index validity, choices need to be transparent and their results need to be tested by statistical procedures (Saisana and Tarantola, 2002; Nardo et al., 2005a).

Despite the problems of 'measuring' constructs such as vulnerability and resilience, and the challenges encountered when designing an index, such an approach is very useful in the context of this thesis. This is because constructing a sequence of vulnerability and resilience indices enables the:

1. detection of possible changes in time,
2. quantification of the magnitude of these changes,
3. detection and quantification not only of variations of the final index, but of all individual indicators feeding into the index.

The results of such an analysis can be easily communicated. In addition, when data and methodology are made transparent, vulnerability and resilience indices can be reproduced, evaluated and interpreted by a range of interested parties, not only the researcher.

11.3 Index construction

In the following, a series of steps involved in designing an index as a composite of indicators are summarised, briefly discussed and applied within the context of this thesis:

1. Definition of goals
2. Index structure
3. Indicators: selection, quality, cost & availability, and comprehensiveness
4. Character of frequency distributions: normality, outliers
5. Character of relationships: testing for indicator correlation
6. Imputation
7. Normalisation
8. Weighting
9. Aggregation

10. Validation

11. Sensitivity analysis (SA)

Uncertainty analysis (UA) should be applied throughout the process to assist with decisions made, for instance which imputation, normalisation and aggregation method is used.

11.3.1 Definition of goals

Before starting to construct an index, its purpose and intended audience should be clarified (Benson, 2004; Birkmann, 2006a; Birkmann and Wisner, 2006 referring to Bohle's contribution to the discussion about measuring vulnerability; Queste and Lauwe, 2006; Wisner, 2006; Gall, 2007). Purpose and intended audience will influence decisions made throughout the process.

11.3.2 Index structure

The more indicators and sub-indices enter an index (while reflecting more aspects of the condition to be measured), the more sources of error are introduced. With increasing complexity the index progressively sacrifices simplicity and clarity, which aggravates its comprehension for users (Pelling, 2006; Gall, 2007).

11.3.3 Indicators

Selection: Indicator selection is one of the biggest challenges of indicator and index development. Often the choice of indicators is guided by what seems relevant or simply is available (Karlsson et al., 2007). Hence the choice of indicators, as well as their total number, is ultimately subjective and contestable (Davidson, 1997; Downing, 2004; Villagran, 2006; Gall, 2007). A set of variables typically associated with social vulnerability is described by a range of authors (chapter 8). There is, however, no standard as such with respect to the compilation of such a variable set which can be used as indicators. As mentioned in the beginning of this chapter, this lack of standards is probably a result of the context-specific nature of vulnerability, as well as its multi-dimensionality and scale-dependency, which equally applies for resilience. As noted previously, under these circumstances the best approach towards developing the indices is to ensure their incorporation into an explanatory, conceptual model. This is because the model will help to analyse and structure information, hence guide the selection of indicators and deliver a justification for their selection (Downing, 2004; Nardo et al., 2005a; Gall, 2007; Stanners et al., 2007).

Indicators should be meaningful in order to appropriately represent the construct they aim to express (Rossi and Gilmartin, 1980; Davidson, 1997; Birkmann, 2006a; Bauler et al., 2007; Gall, 2007). For example with respect to vulnerability, indicators should not be too general as they become too vague to be traced or too far removed from their relation to vulnerability, for example 'poverty' or 'criminal activities' (Wisner, 2003a). Also Davidson (1997) identified a problem in a too vague definition of indicators, since they can be ambiguous. Also proxy or substitute indicators divert from the variable they aim to measure which introduces some uncertainty (Bauler et al., 2007). For example, the industrial profile of a country could be used

as in indicator of greenhouse gas emission, but this would not reflect measures taken to reduce emissions (Gallopín, 1997). In contrast, a direct indicator for household income is the yearly household earning.

Davidson (1997) recommended defining indicators as precisely as possible, identifying their main contribution towards the overall indicator, and on the grounds of existing knowledge, finding the best compromise between the number of indicators and the presentation of the concept to be measured.

Quality: The quality of underlying data used for indicators influences the internal validity of the overall index. Indicators tend to be quantitative hence the level of measurement error needs to be known and made transparent (Rossi and Gilmartin, 1980; Moldan and Dahl, 2007). Common issues especially in relation to census data are that the composition of the population changes, the timing of the measurement itself, and monetary values change (Rossi and Gilmartin, 1980). Data gaps introduce a level of uncertainty, as do imputation techniques applied for filling in these gaps (Bauler et al., 2007).

Cost and availability: Ideally, indicators should be cost effective and easily accessible so as to promote their applicability and reproducibility (Bauler et al., 2007; Moldan and Dahl, 2007). When the goal is to construct time sequences, an aspect which prevents indicators from being included is time-inconsistency with respect to spatio-temporal comparability (Rossi and Gilmartin, 1980; Villagran, 2006 after Briguglio, 2003).

Census data can be prone to a lack of comparability. Since every country envisages a reflection of its society, usually the most efficient set of questions is chosen to gain the best picture possible. Because societies change, new variables are added and former variables are changed or even dismissed. Additionally, quality issues arise: if questions are poorly constructed, answers will not match quality requirements, therefore questions are changed in order to gain better results. Moreover, statistical boundaries can change since communities grow or shrink and measurement units have to be adjusted. Generally, every national census has to perform a balancing act between preserving consistency of data to gain comparable data series, and to adjust the census to get the best reflection as possible (Morrison 1985, 1991).

Comprehensiveness: Indicators should be easily understood by the target audience, for instance the public and decision-makers, not just the specialist. Therefore, one aspect that should be considered is to choose intuitive, descriptive and accessible indicators (Rossi and Gilmartin, 1980; Villagran, 2006 after Briguglio, 2003; Bauler et al., 2007). As stated previously, indicators and indices are not only analysis but also communication tools, and especially in the field of risk, effective communication between science and risk management and the public is important.

11.3.4 Character of frequency distributions: normality, outliers

Many statistical tests, such as the Pearson product moment correlation coefficient (r), assume that variables are normally distributed in the population. Assuming the distribution is normal, the area under the (symmetric) normal curve represents the percentage, or proportion, of data falling within a specific range. For example, 95% of the data falls between two standard deviations above or below the mean when the distribution is normal. Skewness and kurtosis can be used to characterise the shape of a distribution (Corty, 2007).

Skewness is also an indication for outliers in the data set. Outliers are data points separated from the remainder of other data points in a distribution (Corty, 2007). Outliers can be produced by sampling or measurement errors (Nardo et al., 2005b). However, they can also represent extreme values which are actual observations. Consequently, it is difficult to decide whether a value is the result of measurement errors or observed and real (Corty, 2007).

If data points are imputed, the distribution of the data used for estimating missing data should be tested for outliers. This is because outliers influence single imputation techniques: they distort the arithmetic mean and correlation coefficients which influences imputation based on the mean and regression, respectively (Nardo et al., 2005b, Corty, 2007). After imputation the data should be again tested for outliers. This is because outliers can also influence normalisation techniques, such as 'minimum-maximum observed' and z-scores (Nardo et al., 2005b).

11.3.5 Imputation

Nardo et al. (2005b) described a range of options for dealing with missing data. Firstly, as a rule of thumb, if less than five percent of the total data set is missing, these cases can be omitted ('case deletion').

Secondly, Nardo et al. (2005b) listed a single imputation technique which replaces the missing value by the arithmetic mean (mode, median) of the recorded value. Linear regression analysis is another form of single imputation. Are two variables strongly correlated, the missing values of the dependant variable can be estimated based on the independent variable.

As observed within this thesis (11.4.6), a correlation depicting a steep regression line can lead to over- or underestimation of missing values. Also, it might be difficult to decide which threshold of the correlation coefficient should be used to decide whether a regression technique is feasible.

No ideal measure of the uncertainty inherent in the imputation technique exists for single imputations. A measure of variance is one possibility. However as Nardo et al. (2005b) concluded, the variance of data sets completed by single imputation tends to underestimate the true variance because the imputed value is biased towards the value distribution of the data set.

Thirdly, multiple imputation techniques, such as Markov Chain Monte Carlo, use a random process of estimating a missing value multiple times. As a result a set of estimated values, with the total size depending on the number of imputations, is created. One single descriptor of the set of estimations (e.g. arithmetic mean) can be used as the final value, with a measure of variance of the estimated values as a good documentation of uncertainty (Nardo et al, 2005b). Multiple imputation is best applied for large data sets. In fact, this technique requires a sufficiently large sample size (Schafer, 1997).

11.3.6 Character of relationships: multivariate analysis

After a complete data set is compiled, it should be tested whether relationships exist between the variables which will feed into the index. Multivariate analysis enables exploring these relationships, and a possible method to start with is the test based on the Pearson product moment correlation coefficient 'r' (Rowntree, 2004; Corty, 2007). This enhances a general understanding of the statistical significance of these connections.

Furthermore, multivariate analysis can be used to explore the conceptual structure of the index. Factor analysis is a method applied in this context which is based on the correlation between variables. The most common variant of factor analysis is using principal components. Principal component analysis (PCA) extracts underlying dimensions of the variables by identifying the components which capture most of the information inherent in the data set (Nardo et al., 2005a). These components can be treated as new variables which are statistically independent (Rogerson, 2006). For example, social vulnerability and hazard can be regarded as underlying dimensions or components of risk. Variables associated with vulnerability will be more correlated amongst themselves than with variables representing hazard. Those variables strongly related to a component can then be grouped together to form a (sub-)index which is part of the final index (Hardy and Bryman, 2004).

PCA explores whether a large number of variables share a smaller number of factors or components which account for their interrelations (Miller, 1991, Nardo et al, 2005a). Because PCA replaces a potentially large set of interrelated variables by a smaller number of new, independent variables (the components), PCA is a powerful tool for data reduction. This is not only appealing for enhanced transparency, but also because large data sets can be difficult to manage and to map. Visualising results by using only three components instead of twenty variables is much easier (Rogerson, 2006). Especially for the non-specialist end user, a condensed and more transparent overview will enhance understanding and interpretation, therefore applicability of the results of the index exercise.

Correlation between variables is also referred to as multicollinearity (Lewis-Beck et al., 2004). While multicollinearity is a necessity for PCA, it is a disadvantage for causal models such as multiple regression. Multiple linear regression assumes that the explanatory variables are independent. If this is not the case, the variance or standard error increases, which widens the

confidence interval (Nardo et al., 2005a). However, confidence intervals are preferably narrow in order to enable a precise significance testing (Corty, 2007). Hence multiple regression with high levels of multicollinearity is not very meaningful.

In the context of indices it can be argued that multicollinearity would introduce artificial weighting of the phenomenon represented by the two (or more) correlated variables (Rossi and Gilmartin, 1980; Pelling, 2006). This is because each of the two collinear variables carries a certain weight, and the unique phenomenon that these two variables represent would receive the sum of the two weights in the index. By excluding one of the two variables or assigning less weight to correlated indicators, this effect of double-counting can be accounted for (Nardo et al, 2005a). Eliminating indicators based on multivariate analysis is therefore not only a method for reducing the number of indicators, but also for reducing artificial weighting.

Excluding variables or decreasing weights based on multicollinearity is not without danger. When excluding variables or manipulating weights it is assumed that each of the variables does not capture more than the shared unique phenomenon (Nardo et al., 2005a). However, variables frequently represent more than one phenomenon that is important to reflect the concept to be measured. As illustrated in chapter 8, several variables combine different aspects and represent access to more than one resource. Under these circumstances, excluding or devaluing collinear variables can potentially undermine the conceptual basis of the index. As Nardo et al. (2005a: 55) concluded, weights should ideally express the contribution of a variable towards the index. Therefore they recommended that *'double counting should not only be determined by statistical analysis but also by the analysis of the indicator itself vis à vis the rest of the indicators and the phenomenon they all aim to picture'*.

Furthermore, multiple regression, which can be used as a method for variable reduction, is adversely affected by multicollinearity as outlined above. Hence the method for reducing collinear variables itself is restrained by the very phenomenon it aims to eliminate.

11.3.7 Normalisation

Commonly indicators display different data scales, ranging from nominal, ordinal, to interval or ratio scales. When the aim is to design a quantitative index, they are likely to display different units, e.g. dollar values and as percentages. Due to different units, minimum and maximum magnitudes and degrees of dispersion differ. This compromises comparability and mathematical aggregation. Hence before aggregating indicators they need to display the same zero point (Davidson, 1997; Nardo et al., 2005b; Bauler et al., 2007). This is achieved by statistical 'scaling' or 'normalisation' techniques, such as 'maximum observed', 'minimum-maximum observed', or 'z-scores'.

Z-score standardisation is a normalisation technique which transforms every indicator value into a unitless number. This is achieved by subtracting the mean of the distribution (μ) from each data point of the distribution (x), divided by the standard deviation (σ) of the distribution (after Nardo et al., 2005b: 60):

$$x_{scaled} = \frac{x - \mu}{\sigma} \quad (\text{equation 11.1})$$

Thus z-scores measure how far away a score is from the mean, and the unit is standard deviations (Hardy and Bryman, 2004; Rowntree, 2004; Corty, 2007). A value of '+3' for variable A is higher than a value of '+1' for variable B, and the difference between A and B is two standard deviations. Therefore, there is no question which value performs better, and how much better.

Values rescaled by 'min-max observed' are calculated by subtracting the minimum value (min) of a population from the data point (x), divided by the difference of the maximum (max) and minimum values (after Nardo et al., 2005b: 61):

$$x_{scaled} = \frac{x - \min}{\max - \min} \quad (\text{equation 11.2})$$

While 'min-max observed' is a technique very sensitive towards outliers, z-scores are more robust when outliers are present, although the mean and standard deviation used for calculating z-scores will be influenced by outliers to some extent (Saisana and Tarantola, 2002; Nardo et al., 2005b). However, compared to the minimum and maximum values the mean is more stable since it relies on the entire distribution.

Z-scores, just as min-max scaled values, are sample-specific, meaning that the mean, the standard deviation and therefore the calculated values are dependent on the sample used. Excluding one data point, or including another data point, produces different results. Therefore, z-scores, just as min-max scaled values, do not produce *absolute* but *relative* values, which, however, are standardised and hence comparable amongst themselves (Davidson, 1997).

Davidson (1997) and Nardo et al. (2005b) discuss a number of other normalisation techniques for different purposes and scales. Of these, however, none is suitable for this research.

11.3.8 Weighting

Not all indicators are necessarily equally important within an index, which introduces the need for weighting procedures. Weights greatly influence the index value and resulting ranks, which is why weighting procedures must be made transparent (Nardo et al., 2005b). Weighting can be undertaken using statistical methods such as Principal Component Analysis (PCA) and regression with least squares minimization (R^2) as the weight. Non-statistical or participatory methods are expert-based approaches such as budget allocation or analytical hierarchy process (AHP). Equal weighting (EW) is a method which expresses that indicators are believed to be equally important for the construct to be measured. Equal weighting is suitable when indicators are highly correlated, but represent different phenomenon of the concept to be measured.

Generally, while statistical approaches ensure a comparatively high level of objectivity, participatory methods display a much higher level of subjectivity. This is because the importance of each variable, or its weight, towards the overall analysis is likely to be judged differently amongst those who are asked to define a weight (Nardo et al., 2005b).

The issue of artificial weights as a result of multicollinearity has been discussed previously. In addition, inherent or implied weights incur from the number of indicators that are combined into a (sub-)index. Similarly, the number of sub-indices influences their individual contribution towards the final index score. If the index structure consists of several sub-indices, for example if five indicators are aggregated into one sub-index, their relative contribution towards the final score will be smaller than compared to three indicators aggregated into a sub-index. This is sometimes referred to as 'hidden weighting' (Hak, 2007). If the inherent or hidden weighting differs with the intended weighting, this can be accounted for by modifying weights accordingly. Another aspect to consider is that although the individual weight of an indicator is inherently influenced by how many other indicators are combined into a sub-index, the weight of the sub-index is influenced by the number of its indicators. If weights are assigned equally, the sub-index with the higher number of indicators will have a greater weight (Nardo et al., 2005b). Aggregation techniques can account for this effect as shown in section 11.4.11.

It is important to realise that every index represents a weighting of the indicators, even if this is not clearly stated. Therefore, transparency of weights is important in reducing uncertainty related to the index scores.

The following section illustrates how weighting can be influenced by the aggregation method chosen.

11.3.9 Aggregation

Just as choices regarding normalisation and weighting techniques should match the goal of the index construction, aggregation methods differ with respect to their suitability for the goal pursued (Davidson, 1997).

Two different categories of aggregation techniques are available: linear and geometric (multiplicative) aggregation, which are compensatory methods, and non-compensatory methods such as 'multi-criteria'.

Linear combination of weighted indicators standardised to the same measurement unit is one possible aggregation method. The arithmetic mean of the indicators should be used when indicators are intended to be equally weighted. In comparison, the geometric mean is the product of equally weighted indicators. This method appeals when combining strictly positive indicators on different measurement scales. Linear aggregation and geometric aggregation are feasible only when no synergies among indicators exist. The combination of two or more indicators cannot reflect an amplifying effect which entails a higher score compared to the sum or product of the individual indicators (Nardo et al., 2005b). For example, a combination of chemical substances in water or air can have a more severe impact on plant growth than each

substance individually (Dietz and van der Straaten, 1992, in Nardo et al., 2005a). Linear and geometric aggregation cannot represent such effects and assume preferential independence of all indicators.

In addition and as mentioned before, linear aggregation of a certain number of indicators and/or indices implies a hidden weight which might not be intended (Nardo et al., 2005a). Perhaps more importantly, linear aggregation entails a full compensation of indicators: poor indicator performance is compensated by a sufficiently good performance of another indicator. Weights therefore do not represent the intended importance of the indicator, but become substitution rates (Esty et al, 2005). Geometric (multiplicative) aggregation implies partial compensability, since compensability is lower when indicator and/or (sub-)index values are low (Nardo et al., 2005a).

A judgement is necessary whether to allow for compensation between indicators and sub-indices. If very different dimensions are included, each is equally legitimate and linear or multiplicative techniques are not feasible. In contrast, when good performances are allowed to compensate for poor performances, then linear and multiplicative aggregation techniques are applicable (Nardo et al., 2005a).

Since compensability is lower when indicator values are low, the geometric mean produces lower scores for communities which perform poorly on most indicators but well on few. In benchmarking exercises, these communities would prefer a linear aggregation based on the arithmetic mean (Nardo et al., 2005a). Final index scores can therefore be manipulated by the aggregation technique, depending on the desired outcome.

In contrast, when indicator values change in time, for example when a community increases its score compared to a formerly low indicator, the geometric mean produces greater changes for low scoring indicators (Nardo et al., 2005a). Therefore, while the geometric mean reduces indicator compensation, it rewards improvements of initially low indicators relative to already high scoring indicators. While this might be desirable for some indices, it distorts the actual magnitude of temporal change of the indicator.

The 'multi-criteria' non-compensation technique avoids the disadvantages of linear and geometric aggregation. Multi-criteria aggregation ensures that weights reflect the conceptual importance they should be represented in the final index score. In addition, this technique is preferential when the index represents a combination of very different dimensions which should not be allowed to compensate each other, for instance environmental and economic components. In addition, a multi-criteria method does not assume independence (Nardo et al., 2005a).

The multi-criteria approach (MCA) is a pair-wise comparison of all areas (communities, countries etc.) included in the analysis. For all indicators the performance for one area is evaluated against the performance of all other areas, for each pair separately. Each indicator value is listed for each area in the impact matrix. Based on the impact matrix it can be checked

which area performed best compared to all other areas, for each indicator. Subsequently, each area is assigned a new value which also takes into account the weight of the indicator. Say community A scores highest in four out of eight indicators compared to community B, it will receive a value of $4 \times 1/8 = 0.5$, as will community B. If community A scores highest in three out of eight indicators compared to community C, it will receive $3 \times 1/8 = 0.375$, while community C receives $5 \times 1/8 = 0.625$. In this way, every community is compared with each other and an outranking matrix is produced which lists all pair-wise rank values. As a final aggregation step, several algorithms are available. One option is to base the final ranking on the maximum total of the pair-wise ranking which is calculated as the sum for each pair-wise rank (Nardo et al., 2005a).

While multi-criteria circumnavigates the problems associated with linear and geometric aggregation, the final aggregation is based on ranks, meaning an ordinal value. Hence magnitudes of differences between communities cannot be reflected. For instance, it is only recorded that community A performs better than community B, but not by how much. The difference between their indicator values can be very large or very small – however that information is lost in the process (Nardo et al., 2005b). Although the multi-criteria method relies on interval/ratio values, the final outcome is ordinal. Therefore, the advantage and incentive to use interval/ratio data, mainly the ability to depict the magnitudes of differences, is traded for an index score which masks absolute differences. The loss of information starts with the first level of aggregation and has to consequently follow through the whole structure of the index.

11.3.10 Uncertainty analysis (UA) and sensitivity analysis (SA)

All of the above described steps involve judgements which affect the outcome of the index. Uncertainty analysis (UA) and sensitivity analysis (SA) assist in estimating index robustness and the transparency of its computation. While UA targets uncertainty which can trickle through the whole index structure, SA aims at revealing the extent to which individual sources of uncertainty affect the output variance (Nardo et al., 2005b). For example, when weights are determined by budget allocation and AHP, indicator values can be recalculated with a large number of random sets of weights (like a Monte Carlo simulation) and compared to the results obtained from the two original weighting procedures, which is a form of uncertainty analysis (Saisana and Tarantola, 2002). Uncertainty analysis can also encompass the estimate of data error, different normalisation techniques, and different aggregation methods (Nardo et al., 2005b).

Continuing the above example, sensitivity analysis can investigate to what extent the index varies in relation to the variation of a specific weight, i.e. how sensitive the index is towards changes in one or several weights. Hence the larger the sensitivity towards one or several weights, the more influential and important are these weights. Such analysis does therefore not only supply information about the most important weighting factor, but also creates transparency of the overall index (Saisana and Tarantola, 2002).

11.3.11 Validation

'The association of an abstract theoretical concept with its empirical manifestation is at the heart of validity. Validity is generally defined as the extent to which any measuring instrument measures what it is intended to measure' (Lewis-Beck et al., 1171). This not to be confused with internal index validity owned to the technical soundness and transparency of the methodology, which has surfaced frequently so far and can be accounted for. The citation above pinpoints a general problem encountered when aiming at constructing vulnerability and resilience indices: Do they actually measure what they intend to measure? Indices can be validated by testing how well they predict the outcome of an external measure. For example, an index capturing the factors related to a higher risk of asthma can be validated with reported cases of asthma. The problem encountered in the vulnerability field is that no external measure of social vulnerability exist (Davidson, 1997; Gall, 2007), which equally applies for resilience.

Indices of vulnerability and resilience can be constructed in two ways:

1. *'backward-looking', 'outcome-driven', 'deductive':*

A proxy such as mortality is correlated with indicators and/or indices as applied by Adger et al. (2004) in the case of vulnerability to climate-related hazards, and the United Nation's 'Disaster Risk Index' (DRI) (UNDP, 2004a). Regression analysis with mortality as the dependent variable reveals the quality of index performance. However, as stated by the UNDP (2004a), mortality is only one aspect of how vulnerability manifests, and it is not only related to vulnerability. Other proxies such as damage expressed in dollar values face similar problems. In addition, as summarised by Pelling (2006), Gall (2007) and Benson (2004), data on mortality and monetary costs is usually insufficient. Costs relate to physical damage, however the potential impact goes far beyond and indirect costs and long-term costs are usually not included. What is more, loss of human life cannot be quantified without value judgement. In addition, at least on a global scale, smaller events just below the 'disaster threshold' are not reported (Benson, 2004).

2. *'forward-looking', 'predictive', 'inductive':*

As Benson (2004) and Cannon et al. (2001) emphasised, vulnerability is a forward-looking concept which expresses the potential to experience adverse effects, which concurs with the definition of social vulnerability in this thesis. Likewise, resilience can be interpreted as the potential to remain functioning and recover from this harm. Hence both conditions cannot be measured by relying on data solely derived from past events: past experiences are not necessarily related to future loss and damage. Benson (2004) further underlined that vulnerability is a dynamic condition because its compartments are in constant flux – an aspect underlined within this thesis. Hence in addition to the validation limitations imposed by a lack of feasible proxies with respect to backward-looking approaches, forward-looking approaches per se prevent validation.

As observed by Birkmann (2006a) and exemplified by chapter 8, forward-looking approaches still have to rely on empirical studies and experience made in the past, with case studies investigating why damages and loss of life occurred. While validation with the help of proxies derived from past disasters is problematic, general causations between several variables and high levels of adverse effects are feasible. Indices developed on this base reflect the precautionary approach with respect to managing various factors that theoretically influence risk.

11.4 Constructing indices of vulnerability and resilience

11.4.1 Definition of goals

The goals are:

1. to detect spatio-temporal changes of vulnerability and resilience and their components,
2. to quantify the magnitude of change (if change is detected),
3. to reveal the potential interplay between multiple dimensions influencing vulnerability and resilience.

It is emphasised that the aim is not to measure vulnerability and resilience *absolutely*, but *relatively* to each other and for a specific spatio-temporal and cultural context.

11.4.2 Index structure

The flow-path of the methodology for analysing vulnerability and resilience, based on the models developed in chapter 7, is illustrated in figure 11.1. Vulnerability and resilience are approached from two directions: firstly the community profile represented by the 'socio-economic' and 'infrastructure' indices. Depending on access to resources, these two indices define adaptive capacity which influences adaptive activities before, during and after an event.

Two other indices combine aspects which additionally influence vulnerability and resilience: the 'needs' index is associated with vulnerability and includes two aspects affecting physical and emotional well-being, 'fragility & mobility' and 'critical services'. The former accounts for individual characteristics for instance related to certain age groups. The latter represents the availability and functioning of services within the community which are critical for the well-being of the community.

In comparison, the index 'self-sufficiency' is associated with resilience. Community-based sufficiency is reflected by the 'community network index', while individual self-sufficiency is expressed by the index 'self-reliance'.

The three sub-indices, 'adaptive capacity', 'needs' and 'self-sufficiency' combine individual characteristics of community members (aggregated for the whole community) as well as aspects which apply on the community scale only. None of these indices is hazard-specific.

Figure 11.1: Flow-path of vulnerability and resilience analysis

As discussed in chapter 7, the implementation of adaptive activities is related to the willingness to adapt, which in turn is influenced by risk perception and individual attitudes towards risk. Risk perception and individual attitudes towards risk are not measured and analysed within this thesis. It is hypothesised that a high level of adaptive capacity favours the implementation of adaptive activities, while a low level of adaptive capacity discourages the implementation of adaptive activities.

A proxy of risk perception frequently used is the adoption of insurance cover as identified by Gall (2007). Information about insurance cover, either recent or especially in the past, is not available or accessible for this thesis. According to John Lucas, manager of the Insurance Council of New Zealand affiliated with the Earthquake Commission (EQC), an informed estimate based on his New Zealand wide experience is that currently, on average, about 90% of New Zealanders hold insurance for their houses, and about 70% purchase cover for house content (personal communication). John Lucas judged this average to be a reasonable estimate for the Western Hutt Hills. This is an indication of risk perception and implementation of a particular adaptive activity. Whether the nationwide average of insurance cover applies for Aoraki and Te Arai is less certain.

As pointed out in chapter 8, insurance cover is a relatively crude proxy for risk perception since affordability can prevent purchase of cover, even though risk awareness is high. Supplementary information about the level of preparedness and other adaptive activities, especially past activities, is not available for the study areas.

As discussed in chapter 8, the existence, style and quality of risk management ideally positively influences adaptive activities. In addition, risk management is interlinked with government policies in numerous ways. An index measuring risk management performance therefore requires a deeper understanding of social and political processes. Cardona (2005) calculated a 'Risk management index' for evaluating the performance of risk management in several countries in the Caribbean and in Latin America. This is an interesting field which, however, cannot be explored in sufficient depth in this thesis. Measuring the quality or effectiveness of risk management in retrospective would require information which cannot be compiled within the frame of this work.

Nevertheless, one element of risk management included in the analysis is the supply of services during the immediate onset and after an emergency ('critical services index'). Critical facilities such as police, fire service and public as well as private medical services can prevent or lessen negative impacts on a community and its members. The police are responsible for public safety and can assist in search and rescue operations, as well as distributing relief, transporting people to medical facilities and providing first aid. Fire services can prevent or lessen the outbreak of fires threatening homes and lives, undertake search and rescue operations, and cooperate with medical facilities to provide needed transport and first aid. Medical facilities not only provide medical expertise but also medication and equipment for treating injuries. In addition, all three critical facilities provide some degree of shelter.

The index structure outlined above infers a three-level hierarchy, as illustrated in figure 11.2. While six sub-indices constitute the first level, three sub-indices comprise the second level. Of these, two sub-indices contribute to one index for vulnerability and resilience each. Overall, sixteen different indicators contribute to the first level of indices. By comparison Gall (2007) reviewed a range of global indices which display one to up to seven sub-indices, and four up to 33 indicators. The index structure developed in this work is a compromise between reflecting the constructs of vulnerability and resilience on the one side, and transparency and simplicity on the other side.

Figure 11.2: Hierarchy of indices

11.4.3 Data quality, availability, cost, ambiguity

All socio-economic variables, which will enter the index structures as indicators, are derived from data generated by the New Zealand census which is supplied by Statistics New Zealand (SNZ). Hence the **quality** of the variables supplied is generally very good. However, as with every census questionnaire, some answers given might not be correct, either because of misunderstanding the question or deliberately giving false information.

As required by the Statistics Act 1975, in order to ensure confidentiality Statistics New Zealand follows a scheme of randomly rounding each count (including sub-totals and totals) to the base of three, for each census year. With every data set supplied by SNZ, it is stated that zero counts and counts which are already multiples of three are not changed, while other counts, including totals, are rounded to one of the nearest multiples of three. For example, a count of four could be recorded either as six or three. Statistics New Zealand judges the effect of this rounding on the accuracy of census statistics as insignificant. However, it should be noted that as a consequence, percentages derived from very small population totals are more sensitive to changes compared to percentages derived from large population totals. Furthermore, totals of different tables do not match: for instance the total derived by summing up all values for each age class differs from the total derived from summing up males and females.

The New Zealand census differentiates between 'de facto' and 'de jure' populations. The term 'de facto' contains all people present on the census night, and therefore includes visitors, both from within New Zealand and overseas, and excludes New Zealanders temporarily overseas⁴. The term 'de jure' describes the usually resident population which excludes visitors from overseas and New Zealanders temporarily overseas. Residents who are not present at their usual residence on the census night are included¹. Official statistics are based on the 'de facto' population until 1996 and on the 'de jure' population afterwards⁵. However, since 1981 the actual census data is based on the 'de jure' population, while 'de facto' data is available on

⁴ <http://www2.stats.govt.nz/domino/external/omni/omni.nsf/wwwglsry?openview&count=500>, accessed 10.5.2008

⁵ <http://www.stats.govt.nz/products-and-services/Articles/pop-est-changes-Mar99.htm>, accessed 29.6.2005

special request (Morrison, 1991). The base population used in this research for all years is the 'de jure' or 'usually resident' population.

In addition, extraneous errors in the form of comparable dollar values is avoided by calculating and applying constant dollar values where necessary.

A second confidentiality rule applies for data aggregated on the meshblock (MB) level only, which is the smallest geographic unit for which data is released. For meshblocks with a population size under forty and less than twenty households, no personal or household income is published⁶. Rural areas with a small population and household size are potentially affected by this rule. As a result, imputation might be necessary, as will be addressed later in this section. This confidentiality rule is not applied for the next larger geographic unit, the area unit (AU) where population sizes are sufficiently large to ensure confidentiality.

The initial aim for this research was to track the evolution of risk from the 1960s until recently, covering a period of about fifty years. However, this was restricted by the **availability** of data. This time period would have captured the socio-economic profile of communities before the drastic changes in virtually all sectors of society initiated by the Labour government in the 1980s (chapter 9). However, enquiries revealed that before 1981, only data published in census year books is available to the public. These census statistics are not published in a format suitable for use in this research. Without suitable meshblock information data cannot be aggregated in a way that enables comparability in time.

From 1981 onwards, meshblock (MB) data is available for this research. Area unit (AU) boundary changes are circumnavigated by aggregating meshblock data according to AU boundaries for all years where necessary. In the Western Hutt Hills (WHH), the communities 'Normandale' and 'Maungaraki' are rebuilt in this way for 1981 and 1986, while for 1991 to 2006, AU-level data is used. The rebuilding is necessary since the AU 'Maungaraki-Normandale' was split into two AUs with the 1991 census, namely 'Maungaraki' and 'Normandale'. A similar split occurred for the 2006 census, when the AU 'Belmont' was divided into 'Belmont' and 'Tirohanga'. Because of the division these two communities are recreated for the census years 1981, 1986, 1991, 1996 and 2001 according to the 2006 AU boundary. Hence these 'rebuilt' communities are aggregated (summed) meshblock data for the years before a split occurred, and on AU-level data for the years after the split. In Te Arai, two communities, Waerengaokuri and Waingake, are a combination of meshblocks for all years. All other communities are represented by AU-level data.

As stated in section 11.1.1, statistical boundaries do not always reflect community boundaries. For the communities included in this research, however, the census boundaries generally reflect

⁶ <http://www3.stats.govt.nz/meshblock/2006/2006-Census-Meshblock-Dataset-Guide.PDF>, accessed 1.5.2008

community boundaries. In cases where census boundaries divert from community boundaries, the communities are 'rebuilt' as described above.

Meshblock boundaries did not change within community boundaries in the period between 1981 and 2006, which ensures their comparability in time. Apart from the described changes of AU boundaries, a small change occurred for the Korokoro and Maungaraki communities. Part of the Korokoro community was assigned to the Maungaraki community. Since this area was uninhabited at the time, the comparability of census data is not affected. The temporal comparison of meshblock and area unit boundaries is based on NZMS 92, NZMS 144A, and the census databases held by the School of Geography, Environment and Earth Sciences.

Comparability in time is not only potentially affected by changes of spatial boundaries, but also by the nature of the questionnaire itself. In earlier years, the New Zealand census focussed on the best possible representation rather than on data consistency. This philosophy changed with the 1991 census (Morrison 1985, 1991). Therefore, the variables used in this study are checked against possible changes of the categories of each variable.

The only change detected concerns the variable 'industry', because for the years 1981 and 1986 the category 'hunting' was included. In addition, the question aimed at people employed 'full-time' as opposed to 'gainfully employed' in 1991-2006. These changes, however, do not influence the comparability of this variable to any considerable extent.

Because census statistics pre-1991 are archived, they come at a greater **cost** compared to post-1991 statistics. Due to limited funds for this research, part of the required variable set was purchased from SNZ, while some variables were imputed (section 'imputation'). Thankfully, SNZ granted a discount of 50% on the purchased data, supporting greatly this research.

In summary, for some communities and years confidentiality issues at the meshblock level as well as cost-restricted availability of variables affects data quality, since imputation methods have to be used for gap-filling. Data quality is maximised by using the most appropriate imputation methodology where necessary, as discussed in section 11.3.5. When evaluating the complete data set, it appears that data quality overall is satisfactory and does not limit the validity of the indices calculated.

One aspect which needs to be considered when settling on a set of variables is the potential internal **ambiguous** character of variables (Cannon, 2000; Buckle et al., 2000). For example, the elderly can be skilled and resourceful and at the same time quite susceptible to physical and mental harm.

Ambiguity of variables in relation to their effect on access to resources is evaluated based on the information compiled in chapter 8. The adaptation for the New Zealand context is based on own judgements which are essentially subjective but believed to be reasonable. New Zealand's high Human Development Index (HDI) rating for 2005, rank 19 out of 177 countries⁷, and the

⁷ <http://hdrstats.undp.org/indicators/1.html>, accessed 31.1.08

good performances in several fields contributing towards the overall high HDI index⁸ support these judgements. The New Zealand HDI ranking has been generally high and constantly increased throughout the period 1980-2005.

The evaluation of ambiguity is summarised in appendix C, table C.1. As a result of the exercise, it is concluded that within a New Zealand context many variables homogeneously account for either positive or negative access to resources. However, the variable 'age' is ambiguous. While children and the elderly are less likely to receive and understand information relevant for their protection than people of working-age, the elderly are more likely to have local knowledge and might have experienced a similar situation before. At the same time, the young are more likely to have access to social networks within their domestic sphere, mainly through their immediate care giving parents and siblings as compared to the elderly (chapter 8).

Ambiguity within the socio-economic index is avoided by placing the age groups 'below 5' and '65+' into the 'fragility & mobility index' only. This is also justified because the reasoning for a comparatively higher or lower level of adaptive capacity is linked to other variables, namely economic status, household structure and family type. Individual census data which would reveal these relationships are not available at the moment. Correlation analysis on the community scale, however, can indicate whether such interrelations are likely to exist (section 11.4.7).

In addition to age, household structure can be ambiguous. Compared to single households, members of family households and people in flatting situations are less isolated at their home and can benefit from mutual support given within their domestic networks. At the same time, single households perform differently to family households especially with respect to care giving and financial responsibilities. Single households are emotionally and financially less burdened compared to households with a higher ratio of care takers to dependants. Within this thesis, the ambiguous nature of the household structure is accounted for by differentiating between household structure and family type.

With respect to the variable 'ethnicity', settling on the consequences for access to resources turned out to be difficult. The four most common groups of New Zealanders are those with European ancestry ('Pakeha'), Maori, Asian and Pacific Islanders. As can be seen in table 11.1, this pattern has changed recently.

Table 11.1: Proportions of ethnic groups in New Zealand, based on the 2001 and 2006 census, in percent.

Year	European	Maori	Pacific Peoples	Asian	Other
2001	71.0	13.0	5.7	5.9	0.6
2006	67.6	14.6	6.9	9.2	11.2

As discussed later a differentiation in terms of familiarity, language skills and social networks based on ethnicity seems, in practice, very simplistic. In the context of this study two other variables appear to be more appropriate and relevant for the indices developed: the number of

⁸ http://hdrstats.undp.org/countries/data_sheets/cty_ds_NZL.html, accessed 31.1.2008

years since arrival in New Zealand, which can be linked with language skills and familiarity with land and culture, as well as the number of years lived at the current residence with respect to familiarity of local surroundings.

11.4.4 The final set of variables

This section presents all variables entering the indices as indicators. Most variables represent the least (vulnerability) or most favourable (resilience) aspect of that particular variable. For instance, 'household structure' only includes single households, 'gender' only females, and 'years at residence' only those residing between zero and four years at their residence.

For each of these variables its other classes also carry information with respect to vulnerability and resilience. For instance, '5 to 9 years at residence' implies more familiarity with local surroundings compared to '0 to 4 years at residence', and this is likely to increase even more for the class '10 to 14 years at residence'. Within an index structure a different weighting scheme could account for these differences, with a higher weight for the '0 to 4 years' class, and sequentially smaller weights for all other classes. Within this research, however, such a procedure is not applied because of difficulties associated with the weighting and aggregation process of indicators. Since weighting influences index scores considerably, uncertainties and subjectivity should be reduced as much as possible (section 11.3.8). By focussing on the most or least favourable variable class each indicator carries the maximum level of meaning for the index it is assigned to.

Adaptive capacity index

Socio-economic variables aggregated into a **socio-economic index** are:

- household income
- single household
- 1 parent family
- birthplace overseas
- 0-4 years at usual residence
- industry (agriculture, fishery, farming)
- visitors from overseas

Not all of the possible socio-economic variables listed and discussed in chapter 8 are included in this research. The perspective pursued for this thesis is to approach vulnerability and resilience broadly. This includes a review of conceptual models (chapters 5, 6), a synthesis (chapter 7), as well as a discussion of a number of variables which contribute towards vulnerability and resilience (chapter 8). The approach taken here is an increased focus and selective narrowing as the research progresses to its final point. Among the benefits of this approach is not only a deeper comprehension of vulnerability and resilience, but also a broad foundation of knowledge on which future work can be based.

For some of the variables listed above details on how the data enters the indices are given in the following.

Household income

Since not all household income classes are included as variables, a threshold value that defines which level of income should enter the indices has to be established. Stephens et al. (1995) developed a measure of poverty in New Zealand. Households with an after-tax (disposable) income of 60% or less of the median household income are defined as poor. This threshold is now the standard applied by the OECD (OECD, 2005). While the New Zealand Household Economic Survey (HES) is based on disposable income, the census data lists the before-tax income only. Therefore, instead of the disposable household income, the pre-tax household income has to be used in this research.

Obtaining the median pre-tax household income for the period 1981-2006 appeared to be difficult. Statistics New Zealand would only release the data against an additional cost. Fortunately, Mowbray (2001:15) published pre-tax and after-tax median household incomes for the years 1982, 1988, 1993 and 1998 based on HES. Her study covers all years within that period of 1982 to 1998. The Ministry of Social Development, which administered the study at the time, did not provide median household income for the census years needed for this research. Therefore, for the census years 1981, 1986, 1991 and 1996, the pre-tax median household income for the years published (1982, 1988, 1993, 1998) is used. Mowbray (2001) published the median household incomes in 1998 dollars, which are transformed into the actual dollar values for the specific year using the consumer price index (CPI, March quarters). Values for the years 2001 and 2006 are taken from the census.

Salmond et al. (2007) calculated an index of deprivation ('NZDep'), which combines several dimensions of deprivation, each represented by one or more variables taken from the New Zealand census⁹. The recent index (2006) is an updated version of the indices calculated for the census years 1991 to 2001. The dimension 'income' utilised the poverty threshold developed by Stephens et al. (2005) as described previously.

Including such an already existing index into this work is generally possible. However, for a number of reasons this would not benefit the indices developed here. Most importantly, the time-consistency of the deprivation index is not ensured due to changes of the variables (Salmond et al., 2007). Secondly, meshblock data is converted into 'small areas' of at least 100 people, which introduces the problem of spatial comparability. Another aspect is that the dimension 'support' is included in the NZDep by the variable 'single parent' (Salmond et al., 2007), which is in conflict with the conceptual design of this work (this chapter, chapters 5, 7). Generally, the choice of variables entering the NZDep strongly leans conceptually towards deprivation, not towards adaptive capacity, vulnerability and/or resilience. Including the NZDep index in the indices developed in this thesis would reduce their meaningfulness as well as the conceptual and methodological transparency.

⁹ The dimensions of deprivation are: income, owned home, support, employment, qualifications, living space, communication and transport.

1 parent

A two-parent family with two children has a similar parent-to-child (dependant) ratio as a one-parent family with one child. The New Zealand census data does not reveal the number of children per family, meaning that the exact ratio is unknown. For example, it cannot be revealed whether a two-parent or one-parent family has one, two or three children. Since a two-parent family with two or more children has a more favourable dependent ratio compared to a one-parent family with two or more children, only one-parent families are included in the analysis.

Industry

This variable represents community members working within the forestry, agriculture or fishery industry. Working in this industry implies that the livelihood depends, at least to some degree, on the environment as a resource. This indicator therefore captures the extent to which community members are likely affected by adverse effects on environmental resources. The adverse effects can be caused by landslides, as well as floods, tsunami or storms.

Visitors

This variable reflects the number of overseas visitors present in a community. Based on chapter 8, it is assumed that in terms of adaptive capacity, overseas visitors are disadvantaged compared to visitors from within in New Zealand.

Information on seasonal workers, which includes transients present in the community, is generated by the Household Labour Force Survey¹⁰. Community specific data is, however, not produced. The census does not include a variable which specifically captures transient workers who therefore cannot be included in this research.

As mentioned above a number of variables originally discussed in chapter 8 are not included in the final selection of indicators. These are:

- *Education:* A refinement of the census data on education levels is hampered by changes of the education categories included in the census during the period of analysis. Additionally, based on the description of this variable in chapter 8, it appears that the most relevant aspect is that of illiteracy or having no or only very poor education compared with literacy and a basic or higher education. In New Zealand, children are required by law to attend a school until the age of 16 (primary and intermediate levels). A further school stage until the age of 19 is optional but common, until potential tertiary education begins (Statistics New Zealand, 2006; Te Ara – The Encyclopaedia of New Zealand¹¹). Therefore, it can be assumed that the majority of New Zealanders, including immigrant children, relies on at least a basic level of education. This is reflected by the high adult literacy rate which is currently at 99%, according to several sources (Statistics New Zealand does not collect

¹⁰ <http://www.stats.govt.nz/products-and-services/info-releases/hlfs-info-releases.htm>, accessed 6.3.2008

¹¹ <http://www.teara.govt.nz/NewZealandInBrief/Society/6/en>, accessed 30.1.2008

literacy data) ('The world factbook'¹², The Human Development Index¹³, New Zealand Guidebook¹⁴). The situation is not as clear for adult immigrants. However, in the financial year 2004/2005, 61% of all approved immigration applications fell under the skilled/business stream which includes for example the 'Skilled Migrant Category', hence education levels of these immigrants must range between basic and very high. For instance good knowledge of the English language is a prerequisite for successful application under that category (Statistics New Zealand, 2006: 108). In comparison, 10% of the granted applications fell under the international/humanitarian stream for refugees who are not obliged to meet the strict criteria of the skilled/business stream (Statistics New Zealand, 2006: 110).

- *Ethnicity*: One aspect encountered is that the question regarding ethnicity differs between censuses before 1991, between 1991, 1996, 1996 and 2001 (Statistics New Zealand, 2006). Also in 2006, the categories differ slightly. This affects time-consistency and therefore decreases the usefulness of ethnicity data for the socio-economic index. In addition, aspects such as familiarity with language and culture, social networks or discrimination (chapter 8) are difficult to relate to the variable 'ethnicity'. The census category 'European' ('Pakeha') includes New Zealanders who have lived in the country for generations as well as new immigrants. The ethnic group 'Asian' equally aggregates deeply-rooted Asian-New Zealand families and new immigrants. The same applies for the group 'Pacific peoples'. Strictly speaking, only the group 'Maori' can be assumed to display familiarity with language and culture. However, Maori culture is quite different from New Zealanders with European ancestry and Asians and therefore (in combination with potential issues of mutual discrimination) general assumptions with respect to the relation of ethnicity and access to resources cannot be made. As stated previously, two variables are more appropriate for this analysis: firstly the *number of years since arrival* in New Zealand which can be linked with familiarity of language and culture. Secondly, the *number of years lived at the current residence* with respect to familiarity of local surroundings.
- The *disabled, ill and homeless*: the New Zealand census of population does not provide data suitable for this research.
- With respect to the *cohesion of the social network of the community*, time-consistent data on, for example, religious adherence, such as membership in churches, or volunteerism, such as the number of volunteers in social activities, could not be acquired. With respect to civil defence volunteers, reliable information for at least one study area (Western Hutt Hills) and covering the study period was not available or accessible, apart from the general statement that volunteer numbers have declined. In addition the Ministry of Civil Defence

¹² <https://www.cia.gov/library/publications/the-world-factbook/geos/nz.html#People>, accessed 31.1.2008

¹³ http://hdrstats.undp.org/countries/data_sheets/cty_ds_NZL.html, accessed 31.1.2008

¹⁴ <http://209.85.173.104/search?q=cache:yOtxEnyHYKIJ:www.nz.com/new-zealand/guide-book/facts.aspx+NZ+literacy+rate&hl=en&ct=clnk&cd=1&gl=nz>, accessed 31.1.2008

and Emergency Management (CDEM), as a response to that decline, has changed its volunteer structure. This has consequences for the functions of civil defence centres in the Western Hutt communities (personal communication Angie Rodgers, senior advisor of the Hutt City Council Civil Defence and Emergency Management Unit).

Variables combined into the **infrastructure index** are:

- road connectivity
- access points
- roading

The variables reflecting the index 'infrastructure' apply in particular for landslide hazard, but are essentially hazard independent. The first variable, *road connectivity* within the community, accounts for the mobility of people and material. A high connectivity implies that alternative routes can be taken once one or several roads are impassable. The second variable, *access*, represents the opportunity to move people and goods into or out of the community. Road connectivity within and access into the community is also described as 'redundancy' (chapter 8). The information required for calculating road length (km) and road nodes (for road connectivity), and the number of access points per census year are derived from aerial photography and digitised using the Geographical Information System (GIS) ArcMap.

'*Roading*' expresses the susceptibility of roads and bridges to be damaged. Bridges are present in Aoraki and Te Arai. The susceptibility to damage is represented by the age of roads and bridges. Based on the dates of the aerial photographs as well as the dates of supplementary maps, the road length (km) for three age groups is calculated using a geographical information system. The supplementary maps are editions of the NZMS 1, NZMS 260 and NZMS 180 series, starting in the 1940s. The classification boundaries of the age groups are determined by the aerial photography and maps available and are defined as 10-25 years, 32 to 45 years, and 51 to 65 years. Information from the earliest year available (Western Hutt Hills 1941; Te Arai: Waingake 1945, Waerengaokuri 1949, Manutuke 1941; Aoraki 1945) is used to validate the length of roading assigned to the oldest age group.

With new telecommunication technologies being developed within the last 25 years, access to information is likely to have increased considerably, at least in some of the communities. Census data does provide some information on people's access to information, mainly the telephone, TV, radio and fax. Access to at least the first three can be assumed to be part of the standard of living in New Zealand, for the whole time period covered in this work. The interesting element is the rise in the use of internet and mobile phones. The New Zealand census lists access to internet since 2001, and access to mobile phones since 2006. A comparison with earlier years, when the use of internet and mobile phones had already surged, is therefore not possible; hence this aspect is not included in this research.

'Needs index'

Variables entering the **'fragility and mobility index'** are:

- below 5 years of age
- 65 + years of age
- females

Apart from these three variables the type of building material and style, as well as the condition of the dwelling structure, influences the degree of people's injuries if they are located inside a building at the time of a natural hazard occurring (chapter 8). In the context of this study, timber constructions can be assumed to be more susceptible to landslides than brick or concrete buildings. However, other factors such as the number of windows facing the hillside, and the location on the hill with respect to the distance to the source of landslides, affect damage levels. The location on the hill can also be viewed at in terms of houses above which could potentially block landslide material (less damage) or potentially slide onto a building below (more damage). Such detailed analysis, however, is not possible within this study. What is more, census statistics on the material of outer walls is not available in a way that allows for temporal comparison. Besides, strengthening and protective structures such as retention walls change the damage potential, hence the simple information 'brick/concrete' and 'timber' is only meaningful with respect to information of such protective structures. Generating a dataset, accomplished by mapping of protective structures, is not feasible within this thesis: firstly because of time constraints, and secondly because information regarding the 1980s, 1990s and 2001 cannot be generated retrospectively.

Landslide magnitude and timing both influence damage potential (chapter 4). In this study, landslide magnitude and time of day are considered to relate to a worst-case scenario, this means a large magnitude landslide event at night.

The second index, **'critical services'** is comprised of two variables:

- 'critical facilities'
- 'critical infrastructure'

'Critical facilities' is based on the number of hospitals, medical practitioners and other facilities, as well as police and fires stations within the community. As mentioned before these account for a particular aspect of risk management and influence the potential to be adversely affected, for example when not being rescued in a life threatening situation. Information for this indicator for each census year is established by research (current and old phone books, contacting facilities, internet research) and reconnaissance trips into the areas. The number of critical facilities is aggregated as equally weighted sums (the mean) into one number.

'Critical infrastructure' represents the robustness of the reticulation network of critical infrastructure such as water, electricity, gas and sewage. Although a catalogue of critical infrastructure for the Western Hutt Hills was compiled and vulnerability to earthquakes

qualitatively assessed at the beginning of the 1990s by the Centre of Advance Engineering (CAE, 1991), information about landslide-specific *robustness* is patchy. Furthermore, such information is neither available for the whole time period nor for all study sites covered in this thesis. Likewise, reliable information about interdependencies between and within infrastructure networks suitable to be included into this thesis cannot be retrieved from the CAE publication. Other factors which influence infrastructure performance are the resourcefulness, this means the availability of equipment and materials for repair, and the system down-time, meaning the time required for restoring functions (O'Rourke, 2007 referring to Bruneau et al., 2003). According to the Civil Defence and Emergency Act 2002 (MCDEM, 2002, Annex D), 'Lifelines Groups' are required to assess the vulnerability to lifelines. However, contacting the speaker of the Wellington Lifelines Group in May 2007 it appears that no detailed vulnerability analysis of critical infrastructure for the study area is at hand. The study undertaken by the CAE (1991) is the most recent and detailed information available. Also the plan of the 'Wellington Region Emergency Management Group' (2005) affiliated with the 'Lifelines Group', does not contain the required information.

Therefore, 'critical infrastructure' (water, electricity, gas and sewage), is linked to the age of infrastructure only (chapter 8). The age of the roading network serves as a surrogate for the age of reticulation systems. It is assumed that reticulation structures such as pipes and cables were installed when roads were originally built. It is further assumed that if new subdivisions are constructed, the new roads are aligned with critical infrastructure supplying the subdivision. Such an approach was, for example, applied by Granger (2003a). For the Western Hutt Hills, this assumption is checked using the Hutt City Property Enquiry System¹⁵. This internet based database maps water, sewage and storm water pipes, and reveals that critical infrastructure follow the road network. It is assumed that Aoraki and Te Arai display similar patterns, and that the age of the road network is a satisfactory surrogate for critical infrastructure.

Robustness of critical infrastructure is expressed as the length of the reticulation networks between at least 51 and 65 years old. Hence values for robustness for each year and community match the values for road robustness as included in the 'infrastructure' index.

'Self-sufficiency index'

Based on the explanations given in chapter 8 with respect to social networks, the '**community network index**' represents the community-based social network. The associated variable 'community facilities' is therefore specific to the community level. Depending on age and interests, different community members more likely will be affiliated with certain community facilities, which is why a range of different facilities is included. For instance, families with children are likely to be included within the social network facilitated by a school, kindergarten or playcentre. The elderly are more likely to be affiliated with a church and/or community centre.

The community facilities included in this research are:

¹⁵ <http://gis.huttcity.govt.nz/pes/presentation/compass/search.asp?>, accessed 11.02.2008

- schools
- kindergartens
- playcentres
- community centres
- churches
- marae

Aggregating the number of facilities into one variable (as the mean, i.e. the equally weighted sum) differentiates firstly between schools, kindergartens, playcentres and community centres, and secondly between churches and marae. While facilities in the first group can only have values between zero and one, facilities in the second group are counted each. For instance, two schools are counted as one school, while two marae are assigned a value of two. This is because the number of schools, kindergartens and playgroups are likely to be a function of population size rather than the strength of social networks. In addition, the closure of one of two schools in a community is likely to result in the social network being shifted to the remaining school which receives the children from the closed school. Hence the node of social network is shifted, not lost. Therefore, counting each school would entail an artificially increased value. In the case of community centres, there is likely to be only one centre which indeed is observed in this study.

The situation is different for facilities of the second group. Churches and marae, as nodes of social networks, do not necessarily reveal such a compensation effect as described for schools. Community members of one church may not attend the service of the remaining church, because religious affiliation is likely to differ. In such a situation, people are likely to attend churches outside of their community (personal communication with Richard Willis, senior lecturer at the School of Geography, Environment and Earth Sciences).

These external churches potentially facilitate social networks between members of the same community (as would schools, kindergartens and playcentres). However, community members will not necessarily attend the same church in neighbouring areas hence they are likely to be dispersed. It is assumed in this research that churches (and schools etc.) within a community maximise the potential for building social networks.

Maori meeting houses (called 'marae') are integrated into the second group of facilities and each one is counted. This is because a marae is a node for a particular social network, the hapu (wider family kinship). All Maori of the community who can trace their genealogy (whakapapa) to the same ancestor are associated with the marae which represents this ancestor. Therefore, each marae represents a specific network, the hapu, which cannot be replaced by a marae associated with a different ancestor. However, linkages between marae are possible when the ancestors are linked through whakapapa. In this case, common ancestry means that one has the right to participate in the affairs of several marae. Therefore, linkages between members of a network are likely to be enhanced when more marae are present. This conclusion is drawn and confirmed after consulting Laurie Te Nahu who is linked through whakapapa with all four

marae in Manutuke. He also kindly explained the above outlined rules of ancestry and marae affiliations.

The number of schools, community centres, marae, kindergartens, playgroups and churches for each census year is established by research (current and old phone books, contacting facilities, internet research) and reconnaissance trips into the areas.

Finally, the index '**self-reliance**' is represented by the variable 'industry'. According to the Ministry of Civil Defence and Emergency Management (MCDEM, 2008) households should be able to sustain their living functions at least up to three days in case of emergency, this means stocking supplies such as food, water or substitutes for running electric light and radios. Farming households are likely to possess supplies and materials (own water tank/pond, generator, tools, animals etc.), which lasts them longer than three days. These households are therefore considered as more self-reliant and independent from outside assistance than households which do not require such equipment for maintaining their livelihood.

In a qualitative case study Gough (2000) concluded that long and medium-term residents of an isolated community (such as Franz Josef Village, West Coast of the New Zealand South Island) tend to be more prepared to sustain at least the first few days after a natural hazard occurred. While isolation is an interesting aspect to consider with respect to the index 'self-reliance', quantifying the degree of self-reliance depending on the degree of isolation proves to be difficult. The variable 'industry' is therefore considered as a feasible indicator of 'self-reliance'.

Within the overall structure of the indices, the variable 'industry', representing people working in the farming, agriculture or fishery sector, is included twice. Placed within the socio-economic index, 'industry' represents the percentage of livelihoods depending on a productive environment. This accounts for what is called environmental vulnerability, which is strongly related to human vulnerability. The same variable is also related to self-reliability (hence resilience), assuming a higher level of independence from resources supplied by the community or state. Including 'industry' twice is therefore not a form of double-weighting, but necessary since this variable represents two very different aspects.

Likewise, it is noted that the variables 'roading' and 'critical infrastructure' yield the same values. This, however, does not imply double-weighting: the former represents roads including bridges, while the latter captures critical infrastructure supplying water, gas and electricity, as well as handling sewage, which is important for the well-being of people within a community. For reasons of simplicity, and because the values for both variables are identical, 'robustness infrastructure' is used in the statistical procedures described shortly.

The variable 'females' appears in the 'fragility & mobility' index only. As discussed in chapter 8, a range of socio-political aspects associated with the variable 'females' are not covered by other

indicators included in the index design. These aspects are: extra care-giving responsibility, domestic violence, cultural behavioural patterns and discrimination in social and work life. These aspects continue in the New Zealand context. For instance, increasing domestic violence has been reported after the 2004 floods in Whakatane (Research update, 2008). It could be argued that 'females' should be included in the socio-economic index, too. However, it is likely that the variable 'females' is related to other variables such as 'household income', or 'single households' which are included in the socio-economic index. As pointed out in the context of the age aspect, individual data revealing such linkages is not available at the moment. Nevertheless, community based correlations can give some indication. Including 'females' only once means that the socio-political aspects summarised above are, combined with physical susceptibility to harm, represented in the 'fragility & mobility index'.

Until the variables enter the index structure and become indicators, they are expressed as raw data as described so far, i.e. counts for census data, the number of access points, road length etc. An overview of all variables and their translation into indicators is given in section 11.4.10 of this chapter.

11.4.5 Testing for normal distribution

For each variable the sample used for testing normality consists of data for all ten communities (of the three sites) and years. Since Te Arai and Aoraki are not represented in 1981 and 1986, the years from which the sample is drawn are 1991 1996, 2001 and 2006. Because of missing data (appendix C, tables C.2 and C.3), sample sizes (N) range between 20 and 39. Imputation of missing data follows in the next section; hence the test for normality uses actual data only.

Testing whether the variable is distributed normally in the population is done in this research by calculating skewness and kurtosis, and bounding them by their 95% confidence intervals. Skewness is a measure of symmetry in a distribution. A normal distribution is perfectly symmetrical, hence displays a skewness value of zero. Positively skewed distributions tail off to the right, while negatively skewed distribution tail off to the left. Kurtosis reflects how peaked or flat the distribution is, with positive values indicating a pronounced peak and negative values indicating a flatter than normal curve (Corty, 2007). A normal distribution has a value of zero for skewness and kurtosis.

One can be 95% confident that the sample comes from a normally distributed population when zero falls within the confidence intervals for both skewness and kurtosis. In this case H_0 , which says that there is no difference between the sample and the normal distribution, is accepted. If both confidence intervals do not capture zero, it is concluded that the sample does not come from a normally distributed population. H_0 is rejected. The logic of confidence intervals is based on the sample being random. If the sample is not random it is less likely that the population is represented by the sample, and assumptions based on the character of the sample are not necessarily valid for the population (Corty, 2007).

Confidence intervals depend on the standard error (or standard deviation) of the sample, which is dependant on the sample size. The standard error increases with decreasing sample size, hence widens the 95% confidence interval. Corty (2007) based on VanBelle (2002) suggested that the application of confidence intervals and interpretation of the results is meaningful with a sample size of twelve or more only.

Table 11.2 lists the results of the test of normality and flags those variables which are likely to be normally distributed in the population by grey colouring. Skewness and kurtosis are computed using the software SPSS. Calculation of 95% confidence intervals for skewness and kurtosis is based on 1.96 standard deviations times the standard error of the sample. For example, with skewness = -0.15 and standard error = 0.37, the lower and upper margins of the confidence intervals are calculated as $95\%CI = -0.15 \pm 1.96(0.37)$. In this example, the 95% confidence interval ranges from -0.88 to 0.59. Zero falls within this range, and if the same is true for kurtosis, it can be assumed that the sample comes from a normally distributed population.

Table 11.2: 95% confidence intervals (using 1.96 standard deviations) for skewness and kurtosis, based on all available counts for the years 1991-2006. N = sample size. Normally distributed variables are coloured in grey.

Variable	Skewness (S) & Kurtosis (K)	Standard error	N	95% CI lower margin	95% CI upper margin
Age: under 5 yrs	S: 0.53	0.37	40	-0.21	1.26
	K: -1.04	0.73	40	-2.47	0.40
Age: 65 +	S: 0.82	0.37	40	0.09	1.55
	K: 0.19	0.73	40	-1.24	1.62
Gender	S: 0.46	0.37	40	-0.27	1.19
	K: -1.08	0.73	40	-2.51	0.36
Household income	S: 0.82	0.43	30	-0.02	1.65
	K: 0.34	0.83	30	-1.29	1.98
0-4 yrs. at residence	S: 0.61	0.51	20	-0.39	1.62
	K: -0.71	0.99	20	-2.65	1.24
Sngl. household	S: 0.62	0.38	39	-0.12	1.36
	K: -0.68	0.74	39	-2.13	0.77
1 parent	S: 0.61	0.38	38	-0.14	1.36
	K: -0.49	0.75	38	-1.96	0.98
Birthplace	S: 0.65	0.37	40	-0.08	1.39
	K: -0.61	0.73	40	-2.04	0.83
Industry	S: 1.61	0.41	32	0.80	2.42
	K: 2.21	0.81	32	0.63	3.80
Visitor	S: 3.00	0.37	40	2.26	3.73
	K: 7.85	0.73	40	6.42	9.29
Road connect.	S: -0.37	0.37	40	-1.10	0.36
	K: -1.02	0.73	40	-2.46	0.42
Access	S: 0.56	0.37	40	-0.17	1.30
	K: -0.88	0.73	40	-2.32	0.56
Robust. Infra.	S: 1.35	0.37	40	0.61	2.08
	K: 0.63	0.73	40	-0.81	2.07
Critic. Facilities	S: 0.98	0.37	40	0.24	1.71
	K: -0.96	0.73	40	-2.40	0.47
Comm. facilities	S: 0.96	0.37	40	0.23	1.69
	K: -0.57	0.73	40	-2.00	0.87

The variable '*visitor*' clearly does not capture zero for both, skewness and kurtosis. This can be explained by the high values for Aoraki while all other observations have low values. Excluding Aoraki results in assuming normality: the confidence intervals are calculated as $95\%CI = 0.26 \pm 1.96(0.39) = -0.51$ to 1.03 for skewness, and $95\%CI = -1.12 \pm 1.96(0.77) = -2.62$ to 0.39 for kurtosis, with a sample size of 36.

The variable '*industry*' displays high values for both, skewness and kurtosis, although not as high as '*visitor*'. Both variables are the only variables where a consultation of boxplots reveals the presence of outliers. The communities of the Te Arai are characterised by comparatively more people counted for this variable. However, excluding Te Arai still infers non-normality ($N = 28$). This is because the community of Belmont has a comparatively high count in 1996. Communities of Te Arai depict maximum values for the variable '*robustness infrastructure*', and excluding them from the analysis results in confidence intervals which capture zero ($N = 28$).

Of those non-normally distributed variables, '*critical facilities*' and '*community facilities*' have the lowest values of skewness and kurtosis, which are all below two. While kurtosis indicates a normal distribution, skewness values result in confidence intervals which do not capture zero, even though the lower boundaries are close to zero. Comparatively high values for Manutuke (Te Arai) and Aoraki explain the skewed sample distribution for '*critical facilities*', while Manutuke and Maungaraki with their comparatively high scores explain the skewed sample distribution of '*community facilities*'. The variables flagged with high to medium levels of skewness and/or kurtosis will reappear in a related context later in this process.

Esty et al. (2005), in their calculation of the 2005 Environmental Sustainability Index, considered transformation of outliers only when skewness exceeds a value of four standard deviations from the mean. As they argued, data transformation changes indicator values and index scores. Removal of extreme values is beneficial when testing for normality or, depending on the method, imputation. Transformation however masks distinct cases, and is not considered in this research.

One aspect hampers the interpretation when testing for normality: the samples are not random. Obtaining a truly random sample is difficult. In this research, the communities are deliberately chosen to represent different regions which are expected to perform differently on different aspects of vulnerability and resilience. Therefore, the samples in this research do not maximise the chance that they are representative of the variable in the population. In fact, they enhance the probability of high levels of skewness and/or kurtosis, by including such different communities as Aoraki and Te Arai. The outliers pointed out above explain the results of the normality test. If the sample would be larger and less non-random, skewness and kurtosis are likely to decrease and the probability that the variables are normally distributed in the population would increase.

Another aspect to consider is that while the Western Hutt Hills consist of six communities, Te Arai encompasses three communities, and Aoraki is represented by only one community. This can affect the frequency distribution. Since communities within the three areas are likely to perform similar for most socio-economic variables, the samples are biased to the Western Hutt Hills with six communities. This is one explanation for frequently pronounced kurtosis. A bias within the sample is therefore likely. To reduce this bias as much as possible the years 1981 and 1986, which are exclusively represented by the Western Hutt Hills, are excluded from normality analysis.

The question of spatial sample representation comes with the question of temporal representation in this research. Changes in time influence the frequency distribution of the sample. For instance, the variable '*years at residence*' is not normally distributed when based on 2006 data, but normally distributed when based on 2001 data. This can be explained by a (drastic) increase of the proportion of counts increasing from 49.5% to 74.3% for Aoraki between 2001 and 2006, while none of the other communities exhibit an increase of similar magnitude. Temporal representation for normality testing is an aspect that can affect all kinds of research.

An argument against analysing normality for each year individually is the considerably smaller sample size, with a maximum of ten (all communities per year). This size is below the recommended size of twelve, meaning that results are more uncertain. In addition, it can be argued that samples spreading across all years capture temporal changes and are therefore overall more representative. What is more, their interpretation is not affected by small sample sizes.

Increasing the sample size by using meshblocks is not feasible for testing normality. This is because the area unit (AU) for Aoraki is same as the meshblock (MB). The value for Aoraki can therefore not be divided into smaller counts for smaller units. Hence one very large count would be combined with many smaller counts, which produces histograms with large values of skewness and in particular kurtosis. Excluding Aoraki would defeat the purpose of this analysis and not produce more insight into the distribution of the variables, in particular 'visitor', as has been discussed above.

High values for particular communities explain the enhanced skewness and/or kurtosis scores. Therefore, it seems likely that at least those variables which, according to the test, are normally distributed in the population, are indeed normally distributed. However in conclusion, due to the non-randomness of the samples no clear statement can be made about whether the variables are distributed normally in their populations. Whether this impedes further analysis is discussed later.

11.4.6 Imputation

Census-related indicators display cases of missing data only. As described previously, two reasons account for missing data: cost- and access- related availability as well as confidentiality at the meshblock level. All cases of missing data are summarised in appendix C (tables C.2 to C.6).

11.4.6.1 Zero values & case deletion

At the meshblock level, the extent and implication of missing data per variable due to confidentiality is analysed. This can be done since the total meshblock count for each variable is supplied by SNZ although values for individual categories of the variable (e.g. 'age 5-9') are suppressed. For all variables and years, 71 meshblock values are suppressed. Of these, 55% have a value of zero since the total count is zero. Since a value of zero is not affected by rounding procedures, cases with total counts of zero are not case deletions.

For cases with a total count larger than zero (45%), the total count allows an estimate about the true value of the missing count. The number of categories per variable reveals between how many categories the total count is distributed. For example, for the variable '*years at residence*' a meshblock displays a total of '9'. The table lists a total of 7 categories (e.g. '0-4 years at residence', '5-9 years at residence' etc.). Since it is unlikely that the total falls into one category only, it can be assumed that the value for the category of interest, in this case '0-4 years at residence', is small.

Totals for meshblocks with suppressed category values are generally small. Therefore, it is concluded that for all communities and years, case deletion (due to confidentiality) has a minimal affect on data accuracy (appendix C).

For Te Arai, where data for Waingake and Waerengaokuri is aggregated based on three and two meshblocks, respectively, data is imputed as will be illustrated in the next section.

11.4.6.2 AU-based, mean and linear regression imputation

For single imputation of missing data, the sample consists of data points for all available years, for each community. For example, imputing a missing count for 1981 for Tirohanga draws on the sample of one data point each for 1986 to 2006, which equals a sample size of five.

Multiple imputation is not applicable in this research due insufficient case numbers dictated by the number of years with complete counts. For some variables, the sample size is one or two, while the maximum sample size is five as described above. Applying multiple imputation, which generally produces reliable results and a proper measure of uncertainty, with few cases would masks the problem of low case numbers.

Where area unit (AU) data is available although meshblock data is missing, imputation is based on the AU-level count. Area unit (AU)-based imputation uses the variable count of the area unit,

and distributes this count among the communities which are included within this area unit. For example, the AU value for Normandale-Maungaraki, which was one AU until 1991, contains information for both, Normandale and Maungaraki for the years 1981 and 1986. The same applies for Belmont and Tirohanga, since in 1981, 1986, 1991, 1996 and 2001 Belmont included Tirohanga.

Two variations of AU-based imputation are developed for this study.

Firstly, between the two communities included in one AU, the AU-count can be distributed according to their population size ('AU-pop'). It is assumed that the larger the population of a community, the larger the proportion of the AU-count. For example, Tirohanga accounts for 30% of the total population of the combined Tirohanga and Belmont AU for which a count is available. Tirohanga would be assigned 30% of the total AU-count of 50 (15), while Belmont would receive 70% of the AU-count (35). This method assumes that counts are distributed evenly, i.e. are not clustered within the area unit.

If such clustering occurs, a second method is used. Based on years for which AU-data is available, the average ratio by which a community accounts for the total AU-count is calculated. For instance, on average Tirohanga holds 40% of the AU count (50) while only containing 30% of the population. Likewise, Belmont holds 60% of the AU count, while containing 70% of the population. In this case, Tirohanga would receive a count of 20, while Belmont would receive a count of 30. This method does not use the actual population count for the missing year as 'AU-pop', but an average ratio of the count distribution ('AU-ratio'), which is based on all years available.

Generally, AU-based imputation is preferred over single imputation techniques such as the mean or regression, since it allows working with observed data of the missing year. Another reason for preferring AU-based imputation is the impaired reliability of mean and regression methods stemming from a general small number of cases.

Both AU-based methods used in this study do not allow for uncertainty measures as meaningful as for example provided by multiple imputation techniques. However, as a standard procedure applied here AU-based methods are tested with existing data sets. As a measure of uncertainty the root mean square error (RMSE) is used (Mather, 1999: 191):

$$RMSE = \frac{\sum (x_{estimated} - x_{observed})^2}{N} \quad (\text{equation 11.3})$$

In this formula, the denominator is the number of data pairs observed. In this research, RMSE values represent the amount by which an estimated count of people differs from an observed count.

Not only the RMSE, but also the RMSE in relation to the magnitude of the observed count is assessed. For instance, a RMSE of six has different implications for a total observed count of

twelve than compared to a total count of 600. In the first example, the magnitude of variance is 50%, while in the second example the magnitude of variance is 1%. This percentage of variance assists in interpreting the imputation results and ensures comparability between different communities and years.

The error estimation for AU-based imputation is done by omitting one year from the set of available years, imputing a value and testing the value with the observed value. This is done for every year, and the average error of all these years is used for determining the best method and to estimate of the level of uncertainty (see also appendix C).

Linear regression and the arithmetic mean method cannot be tested with this method since omitting one data point, for instance 1996, from the data set changes the relationship between the remaining data points, which has different consequences for different data points excluded. What is more, the variance of the distribution tends to underestimate the true variance.

For linear regression imputation, the regression coefficient serves as guidance. R^2 complements the mean method, which is considered when r^2 values are low. In some cases (e.g. 'industry'), a strong regression would result in a noticeable over- or underestimation of the missing count. In these cases, the mean method is preferred. Generally, imputations based on mean and linear regression with high r^2 values can produce over- or underestimates when the distribution is influenced by outliers.

For Aoraki and Te Arai socio-economic, census-based variables are not available for the years 1981 and 1986. Data for these years is not imputed, since the whole socio-economic data set for these two years would consist of imputed values. In particular, imputation could not rely on existing AU-level counts, but would have to rely solely on the mean and linear regression of the sample.

This situation is different for those communities of the Western Hutt Hills with missing data points, mainly for the year 1981 but also 1986. Firstly, not all of the socio-economic data is missing, and secondly imputation can use AU-level based estimates in most cases.

Therefore, the completed data set extends from 1981 to 2006 for the Western Hutt Hills, and from 1991 to 2006 for Aoraki and Te Arai (appendix C).

The details and a discussion of the imputation methods and results are included in appendix C. In summary, the total number of variables in this study (for all communities and years) is 758, of which 468 are census-based variables (62%). Of these census-based variables, 86% (403) are observed values, while 14% (65) are imputed values. Of these 14%, 71% (46) of the imputations are based on the AU-based method which is considered as a sufficiently accurate method.

When missing values are imputed based on the AU-level methods, the method with the lower average RMSE value is chosen and the proportion of observed variance is calculated. The highest percentage of variance is measured for the variable 'household income' (Tirohanga,

2001), 68%. This is an exceptionally high value not measured otherwise. The variable 'industry' displays relatively high variances for some communities (17% and up to 34%), while also yielding a very good imputation result for other communities. The variable 'visitor' displays lower variances, alternating between 16% and 26.8%. In comparison, the variance for the variable 'females' ranges between 0.4 and 1.5% only. Overall, low count values entail relatively higher variances, which needs to be considered in the case of 'industry' and 'visitor'.

In cases of imputation based on linear regression and the mean (29%, or 19 of all imputed values), r^2 values range between 0.75 and 0.99, which implies sufficient feasibility for applying this method. In cases where r^2 values range between 0.38 and 0.58 the mean is preferred, as is in cases where a steep regression line would lead to a likely over- or underestimation of the missing count.

Estimates based on the mean and linear regression can be biased towards the high or low end of the value range and over- or underestimate the missing count. Both methods are therefore sensitive to the presence of outliers. Normality testing (section 11.4.5) revealed that in particular the variable 'visitor' and, to a lesser extent, the variable 'industry' is influenced by outliers which can distort imputation for missing data points. For both variables imputation is necessary, while the other three variables with enhanced skewness are complete.

Whether the imputation results are robust is analysed by calculating the skewness of the non-imputed and the imputed sample (appendix C). The results show that skewness for both distributions, before and after imputation, is very low throughout the samples. The majority of imputed distributions display lesser skewness compared to non-imputed distributions. These results suggest that the imputation method itself does not produce abnormally high or low values.

Of the complete data set, including non-census based variables, 8.6% (65) are imputed. Overall, the uncertainties attached to the imputed values are low and are not considered to adversely affect the overall quality of the data. This applies in particular for the majority of the imputed data (71%).

The variable '*years at residence*' is special case, where missing years are not filled in by imputation. Instead, based on the available years (2006, 2001, 1986) a calculation backward in time is undertaken for 1996, 1991 and 1981, for all communities. This is possible because the classification of this variable is consistent in time as described in the following.

All available years are structured by the classes '0 years', '1-4 years' (summed to '0-4 years' for this study), '5-9 years', '10-14 years', '15-29 years', and '30 years or more'. Hence people who ticked the '5-9 years' class in 2006 have lived at their current address zero to four years in 2001 (zero years in 2001, 2000-1997: one to four years). Likewise, people who ticked the '10-14 years' class in 2006 have lived at their current address zero to four years in 1996, and so on.

A proportion of people will have moved away or died between two census years. This 'loss' can be calculated by subtracting the count '5-9 years' of the 2006 census from the count '0-4 years' of the 2001 census. Those who ticked the '5-9 years' class in 2006 represent the 'retention', the people who have not moved away since 2001. By subtracting the retention from those who ticked the '0-4 years' class in the 2001 census, the 'loss' of residents is calculated.

Next, a loss rate for 2001 is calculated as the percentage of people who left, based on the loss figure and the population size of 2001. Assuming that the loss rate is similar to the next earlier five year period (between 2001 and 1996), this rate is used to estimate the number of people 'lost' for 1996 (using the population count of 1996). Finally, from the 2001 census, it is known how many people have stayed at their residence: these are the ones who ticked the '5-9 years' class in 2001. Summing loss and retention figures enables an estimate for those residing zero to four years at their usual address in 1996. Likewise, establishing the missing value for 1991 is possible by deriving the retention figures from those who ticked '10-14 years' in 2001. Combined with the loss rate established, the total number of those residing zero to four years in 1991 is estimated. The same procedure is repeated for 1981 based on 1986 data.

This method is feasible and works with real, observed data. A level of uncertainty is introduced because it is assumed that loss rates for five year intervals are similar. This uncertainty cannot be quantified. However, it is feasible to assume that differences are not of a magnitude which would lead to a large distortion of indicator values.

As mentioned before, AU-based methods are not prone to producing outliers. If, however, the recorded AU value were exceptionally high it would translate into the imputed value. Investigating the temporal distribution for each variable for all communities individually reveals that the extent of variations differs. They depict gradual or sudden increases or decreases of different magnitudes, or variations which do not seem to follow a particular pattern. Values which could be defined as outliers are not present.

11.4.7 Character of relationships: multivariate analysis

Multivariate analysis is undertaken to explore the relationships between variables, to statistically examine the conceptual structure of the indices, and to statistically derive weights for every indicator. The method adopted here is a principal component analysis (PCA).

PCA is carried out using a data set containing all cases (communities) for all years (1981 to 2006) per variable, yielding 52 cases. PCA relies on the Pearson product moment correlation coefficient as the first step to examine whether correlations between the variables exist. PCA can only be successful if sufficient correlations exist.

Pearson r correlation coefficient

The Pearson correlation test is based on five assumptions which should be met in order to proceed with the analysis (Corty, 2007: 192-199):

1. The sample is random. Pearson r is robust to violations of this assumption, meaning that the test still produces meaningful results although the sample is not random. The

interpretation of the results should acknowledge that the results stem from a non-random sample.

As pointed out previously, the sample used in this research is neither spatially nor temporally random. However, since Pearson r is robust for non-random samples, the assumption is not violated. The interpretation of the results is not affected, since the goal of the index exercise is to compare three different areas in terms of their relative vulnerability and resilience. The results are indicative for suburban and rural communities, as well as those strongly influenced by tourism. An uncommented, direct transfer of the results for all communities of these types is not envisaged.

2. All variables are of the interval/ratio type. Pearson r is not robust to violations of this assumption. This assumption is met in this research.
3. Each variable is normally distributed in the population. If the sample size is large enough, this assumption does not have to be fulfilled.

As discussed previously, normality testing is affected by the samples not being random, which is linked to the presence of outliers and their effect on normality testing in some cases. Hence no clear statement is possible whether the variables are normally distributed in their populations. The sample size used in this research ($N = 52$) exceeds the conservative threshold of 50. Less conservative thresholds vary between a minimum of 25 and 35 (Corty, 2007). Therefore, the assumption is not violated.

4. The relationships between variables are linear. Pearson r is not robust to violations of this assumption. Consequently, relationships which exist but are not linear are not captured by this correlation test. Testing for linearity is based on evaluating scatter plots for all variable combinations. If a well-defined curve can be seen in the scatter plot Pearson r should not be calculated.

Scatter plots for all variable pairs which enter the analysis are investigated for signs of non-linearity. It is concluded that the linearity assumption is not violated.

5. The variables show homoscedasticity. With a large enough sample size (the conservative threshold is again 50) Pearson r is robust to violations of this assumption. The opposite, heteroscedasticity, implies that the values of variable X increase or decrease as the values of variable Y increases or decreases. In contrast, Pearson r assumes that a variable is spread evenly along the values of the other value. Again, scatter plots can be used for detecting signs of heteroscedasticity.

Eyeballing the scatter plots shows that the variable pairs 'visitors' and 'industry' display signs of a heteroscedastic pattern. This visual evaluation, however, is also influenced by the scale of the axes plotted. Outliers in the scatter plot, namely for 'industry' and 'visitors', increase the scale, which means that those data points closer to each other are condensed and appear to be wrapped around a certain value for one variable. However, heteroscedasticity diminishes when excluding Aoraki and less so when excluding Te Arai, respectively. In addition, 'robustness of infrastructure' depicts a heteroscedastic pattern which vanishes when excluding Te Arai. Finally, the variables 'critical facilities' and

'community facilities' show some heteroscedastic tendencies, which are subdued when specific communities are excluded. With a sample size of 52, it is decided to proceed with Pearson r .

Normality testing carried out earlier excludes imputed values, while testing for heteroscedasticity includes imputed values. Since no variables other than those flagged by the normality testing show signs of heteroscedasticity, it is further confirmed that the imputation process does not produce outliers.

A sufficiently large sample size in order to fulfil the Pearson r assumptions is an important aspect for ensuring validity of the results in this research.

Another aspect to consider is the ratio of cases to variables. Ideally, the number of cases exceeds the number of variables by far - otherwise correlations are likely to be amplified. This is why for instance regression coefficients are usually adjusted downwards to accommodate the case-variable ratio (Rogerson, 2006). Nardo et al. (2005b: 40) observed that no agreement exists regarding which ratio suffices meaningful correlations in the context of PCA. Suggested case-variable ratios are 5:1 and 3:1. In this research, with a number of 52 cases and 15 variables, the ratio is 3.5:1. Therefore the case-to-variable rule is satisfied.

Before proceeding with the correlation analysis, it is also considered whether including the 1981 and 1986 data for the Western Hutt Hills (WHH) has an effect on the outcome. As mentioned in the context of normality testing, this would have potentially biased the frequency distributions towards the WHH, in particular in terms of kurtosis. Scatter plots are examined to see whether WHH data points are indeed scattered or located close to each other. Overwhelmingly, WHH data points are grouped as clouds with only a low degree of scatter, no matter whether a correlation is likely to be established or not. This is not unexpected since communities in the WHH in particular display a similar socio-economic profile, while other variables display a greater degree of variability.

When comparing WHH data points with the complete data set, it is ensured that abscissa and ordinate have similar scales for both plots. As noted above, the eyeballing of scatter is ultimately influenced by the scales of both axes, with decreasing scatter when scales are increased. It is concluded that increasing the number of WHH data points by including the years 1981 and 1986 increases the number of points within these clouds, which has no considerable effect on the relationship of two variables. A Pearson correlation matrix excluding 1981 and 1986 WHH matches the results of a correlation matrix including these two years very closely. This supports the conclusion and the decision to keep these two years within the data set and to continue with a sample size of 52. This yields the benefit of not violating Pearson r assumptions. The low degree of scatter also suggests that the uneven amount of communities, six for WHH, three for Te Arai and one for Aoraki, does not influence the results considerably.

Furthermore, before proceeding with the analysis it is checked whether correlation coefficients should be calculated for each year separately. Considering that variables can change in time, it could be tested whether correlations change accordingly. Calculating Pearson r per year for 1991 to 2006 with all communities shows that correlations are very similar, in fact slightly stronger for the socio-economic variables compared to using all years. All other variables depict generally lower values for Pearson r , or the significance of the correlations drops. Since neither the low sample size (ten cases per year) nor the low case-variable ratio favours the Pearson test, these correlations are indicative at the most.

By using meshblock (MB) rather than area unit (AU) data (each community is presented on the AU level), the number of cases could be boosted to ensure Pearson r assumptions are met. In order to test this approach, three variables, 'single household', '1 parent' and 'visitor', are compiled on the meshblock level and entered into the correlation analysis. The results are listed as following:

- 'single h.hold' and '1 parent': $r(316) = 0.35$ $p < 0.01$
- 'single h.hold' and 'visitor': $r(316) = 0.52$ $p < 0.01$
- '1 parent' and 'visitor': $r(316) = -0.62$ $p > 0.05$

Compared with correlation results based on AU data (listed shortly, table 11.3), these correlations differ. Rogerson (2006) described the effect that scale can have on the results of correlation analysis. Generally, correlation coefficients tend to rise as the level of spatial aggregation increases. In other words, correlations tend to be weaker when analysing many small units, such as meshblocks, compared to analysing few larger units, such as area units. Consequently correlations, in particular with respect to their significance, can be scale-dependent.

With only three examples the increase of correlation from MB to AU level cannot be confirmed – however, these three examples already show that correlation results cannot be transferred between spatial scales without introducing a considerable degree of uncertainty. Since the scale of this research is defined as the community level represented by AU level data (except Waingake and Waerengaokuri which are aggregated meshblocks), a transfer between the MB and AU level (to increase the case number for Pearson r) is not considered.

In summary, indication using AU level data per year illustrates that some correlations are likely to vary between different years. Insufficient sample sizes however preclude a reliable analysis. Results obtained from the MB level cannot be transferred to the AU level without introducing uncertainty. Therefore, using all years on an AU level to calculate Pearson r is preferred.

Table 11.3 illustrates the type, strength and width of confidence intervals of correlations between variables calculated using Pearson r in SPSS, for all communities and years ($N = 52$). The significance level is at 95% (two-tailed).

Table 11.3: Confidence intervals for Pearson r, 95% significance level (*), 1981-2006, all communities

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		Below 5 yrs	65+, yrs	females	hhold \$	sngl hhold.	1parent	birthpl.	0-4 yrs res.	industry	visitor	rd connect	access	robust infra.	comm. fac.	crit. fac.
Below 5 yrs	Pearson r	1	.640(*)	.934(*)	.856(*)	.711(*)	.788(*)	.879(*)	.944(*)	-.289(*)	-.261	.694(*)	.248	-.501(*)	.508(*)	-.005
	Low. bound		.42	.83	.71	.51	.61	.74	.85	-.56	-.54	.49	-.03	-.74	.26	-.29
	Upp. bound		.86	1.0	1.0	.91	.96	1.0	1.0	-.02	.01	.89	.52	-.25	.75	.28
65+ yrs	Pearson r	1		.827*)	.824(*)	.930(*)	.881(*)	.863(*)	.792(*)	-.236	-.237	.669(*)	.406(*)	-.389(*)	.575(*)	.076
	Low. bound			.67	.66	.83	.75	.72	.62	-.52	-.51	.46	.15	-.65	.34	-.21
	Upp. bound			.99	.98	1.0	1.0	1.0	.97	.04	.04	.88	.66	-.12	.81	.36
females	Pearson r			1	.923(*)	.857(*)	.881(*)	.979(*)	.988(*)	-.372(*)	-.254	.777(*)	.310(*)	-.556(*)	.561(*)	.029
	Low. bound				.82	.71	.75	.92	.94	-.64	-.53	.60	.04	-.79	.33	-.25
	Upp. bound				1.0	1.0	1.0	1.0	1.0	-0.11	.02	.96	.58	-.32	.80	.31
hhold \$	Pearson r				1	.853(*)	.867(*)	.912(*)	.929(*)	-.248	-.238	.726(*)	.320(*)	-.506(*)	.641(*)	.100
	Low. bound					.71	.73	.80	.82	-.52	-.51	.53	0.05	-.75	.42	-.18
	Upp. bound					1.0	1.0	1.0	1.0	0.3	0.38	.92	.59	-.26	.86	.38
sngl hhold	Pearson r					1	.912(*)	.906(*)	.836(*)	-.351(*)	-.103	.713(*)	.192	-.478(*)	.536(*)	.071
	Low. bound						.80	.78	.68	-.62	-.39	.51	-.09	-.72	.30	-.21
	Upp. bound						1.0	1.0	.99	-0.08	.18	.91	.47	-.23	.78	.35
1parent	Pearson r						1	.882(*)	.854(*)	-.108	-.272	.603(*)	.358(*)	-.365(*)	.697(*)	.102
	Low. bound							.75	.71	-.39	-.55	.38	.09	-.63	.49	-.18
	Upp. bound							1.0	1.0	.18	.002	.83	.62	-.10	.90	.38
birthpl.	Pearson r							1	.971(*)	-.455(*)	-.200	.804(*)	.215	-.587(*)	.510(*)	.001
	Low. bound								.90	-.71	-.48	.64	-.06	-.82	.26	-.28
	Upp. bound								1.0	-.20	.08	.97	.49	-.36	.75	.28
0-4 yrs res.	Pearson Correlation								1	-.402(*)	-.222	.787(*)	.234	-.576(*)	.536(*)	.023
	Low. bound									-.66	-.50	.61	-.04	-.80	.30	-.26
	Upp. bound									-.14	.06	.96	.51	-.34	.78	.31
industry	Pearson r									1	-.207	-.700(*)	.447(*)	.737(*)	.389(*)	.374(*)
	Low. bound										-.48	-.90	.19	.55	.13	.11

visitor	Upp. bound									.07	-.50	.70	.93	.65	.64
	Pearson r									1	-.003	-.398(*)	-.235	-.138	.507(*)
rd	Low. bound										-.29	-.66	-.51	-.42	.26
	Upp. bound										.28	-.14	.04	.14	.75
connect	Pearson r										1	.059	-.854(*)	.213	-.088
	Low. bound											-.22	-1.0	-.06	-.37
access	Upp. bound											.34	-.71	.50	.19
	Pearson r											1	.111	.475(*)	.158
robust	Low. bound												-.17	.22	-.12
	Upp. bound												.39	.73	.44
infra	Pearson r												1	-.078	.008
	Low. bound													-.36	-.027
comm. fac.,	Upp. bound													.21	.29
	Pearson r													1	.638(*)
crit. fac.	Low. bound														.42
	Upp. bound														.86
	Pearson r														1
	Low. bound														
	Upp. bound														

The matrix shows an overall high degree of significant correlations between most variables, in particular between socio-economic variables and to a lesser extent between socio-economic and other variables. The latter, like 'road connectivity', 'access' or 'community facilities' show a range of significant correlations between each other.

In most cases, the correlation is not only significant at the 95%, but also the 99% level. This means that if H_0 were true, which states that there is no correlation in the population, one would observe these correlations only were rarely, less than 1% of the time. The observed Pearson r values fall into the rare zone, H_0 is rejected and with a high level of certainty, it can be assumed that a correlation in the population exists in the population. High levels of confidence therefore shield against making the type I error, which says that H_0 is rejected although it is true.

It is, however, advisable to investigate the width of the confidence interval for every correlation. Confidence intervals should be narrow to be precise (Rowntree, 2004; Corty, 2007). SPSS does not deliver confidence intervals with Pearson r . A way of displaying the confidence intervals is to convert all counts into z -scores and regress every variable pair in SPSS. The regression coefficient is identical to Pearson r , and so are the confidence intervals for Pearson r ¹⁶.

This method is tested and approved in this research. Investigating the confidence intervals (table 11.3) shows that generally:

- Confidence intervals for the 99% level are very narrow, supporting the assumption that it is very certain that the correlation exists in the population. For example, $r(50) = 0.98$ $p < 0.01$ is associated with a confidence interval ranging from 0.94 to 1.0 (0-4 yrs at residence and females).
- Confidence intervals for the 95% level, and below, tend to be wider. The width increases with a decrease of r , approaching zero with low r values. For example, for the variable pair 'access' and 'h.hold income': $r(50) = 0.32$ $p < 0.05$, the confidence interval ranges from 0.05 to 0.59.

In the case of wide confidence intervals, in particular when just not covering zero like in the example above, the real relationship might be as low as $\rho = 0.051$ or $\rho = 0.58$. Therefore, although the relationship is statistically significant at the 95% level, the assumption that H_0 is not true is imprecise.

Two options narrow a confidence interval: a larger sample size for the same significance level, or a reduced significance level while retaining the same sample size (Corty, 2007). While the first option is not possible, and using meshblocks for the area unit scale of the analysis is not considered, lowering the significance level is possible. However, lowering the significance level from 99% to 98% does not lead to new interpretations, and therefore the 95% significant level and confidence intervals are considered as sufficient to evaluate the results. In order to emphasise the most meaningful correlations, grey shading (table 11. 3) shows those intervals with bounds at or higher than ± 0.55 .

¹⁶ <http://www2.chass.ncsu.edu/garson/PA765/correl.htm#2rs>, accessed 6.5.2008

These results quantify the relationships between vulnerability and resilience variables mapped in chapter 8. While these relationships are not explored further in this thesis, the results resurface in the concluding part of chapter 13.

Besides sample size and significance level, what other reasons can explain the wide confidence intervals observed for many variable pairs?

Multicollinearity tends to increase the standard error of the sample, which widens the confidence interval of a particular significance level (Lewis-Beck et al., 2004). The data set is tested for multicollinearity using tolerance and its countermeasure, the variance-inflation factor (VIF), produced for multiple regression analysis in SPSS. As a rule of thumb, tolerance levels close to zero or at least below 0.2¹⁷ and VIF values above four or five (Nardo et al., 2005b: 41, Rogerson, 2006: 204) indicate multicollinearity between variables.

In SPSS, regressions are calculated for each standardised variable as the dependent and all other variables as the independent variables. The results show that high multicollinearity is present within the data set. This is expected from inspecting the correlation matrix (table 11.3). Only the variables 'visitors' and 'access', do not show high levels of multicollinearity

While multicollinearity is present for nearly all variables, wide confidence intervals for Pearson r are only observed for lower correlations. Multicollinearity is therefore unlikely to explain the wide confidence intervals. Nevertheless, multicollinearity has important implications for PCA, the weighting of variables and the feasibility of multiple regression as will resurface later.

As mentioned earlier, wide confidence intervals can limit the interpretation of significant linear correlations. However, large Pearson r values are related to narrow confidence intervals. Are there other explanations for the high Pearson r observed in table 11.3, apart from rejecting H_0 confidently?

Highly significant correlations can be observed when variables are not independent (Rowntree, 2004; Rogerson, 2006; Corty, 2007). This form of autocorrelation can result from using percentages as input variables for multivariate analysis. Percentages imply that when variable X and Y are based on the same total, a change in variable X must produce a change in variable Y . However, the values used in the correlation analysis are counts. Nevertheless, maximum values for each socio-economic variable are bounded by the total number of people living in one community. For example, variables can only have a maximum number of 210 in the Aoraki of 2006. Variations below that maximum number, however, are independent. In this research, only the variables 'below 5' and '65+' are potentially not independent, because they are shares of the same variable total. Therefore, Pearson r is calculated with the variable 'age' as the equally weighted sum of 'below 5' and '65+'. The new correlation matrix reveals correlations with 'age' and other variables are slightly higher compared to correlations with 'below 5' and '65+'

¹⁷<http://209.85.173.104/search?q=cache:aCjeFLtwaiGJ:www2.chass.ncsu.edu/garson/PA765/regressa.htm>
accessed 6.5.2008

individually. Significance levels do not alter. Hence potential autocorrelation is no explanation for high Pearson r values, other than rejecting H_0 .

As described above, those variables influenced by outliers are associated with low Pearson r values, hence outliers do not distort the medium to strong correlations. Furthermore, it has been concluded earlier that the imputation techniques do not produce outliers. To possibly confirm this conclusion, Pearson r is correlated firstly without the year 1981 and secondly without the year 1986. These are the years where imputed values are mostly present in the data set. With a sample size close to 50 ($N = 46$ for both years), and a case to variable ratio of 3 for both years, in both cases correlations are nearly identical compared to 1981-2006 correlations. It is therefore confirmed that imputed values do not produce outliers.

Investigating scatter plots and revisiting the temporal trends for all variables and communities reveals that if there is a change in time, it is very linear. Calculating Pearson r is based on all years, hence when including all these data points, linear relationships are likely to be revealed more easily. A likely explanation for the in parts very high correlations, in particular amongst the socio-economic variables, is that linear trends in time occur which is then reflected by linear correlations.

Plotting time series for each variable and including all communities confirms this explanation. Variables with matching patterns are highly correlated, while correlations are weak when patterns do not match well.

The question of linearity for well correlated variables ignites the question of non-linearity for overall poorly correlated variables. These are 'visitor' and 'critical facilities'. Although the linearity assumption is checked before proceeding with Pearson r , the variables are correlated using a non-parametric test, Spearman rho, to see whether any difference is observed. The results are summarised as following.

For the variable 'visitor', Spearman correlations are the opposite of Pearson correlations, meaning that a high value of Pearson r is matched by a low value of Spearman rho. In comparison, Pearson correlations for the variable 'critical facilities' are confirmed by the Spearman test. In addition, correlations alter for the variable 'industry' and to a lesser degree for the variable 'robustness infrastructure' when calculated with Spearman rho. These alterations involve either the confirmation of significant Pearson r values, or reversing Pearson r . The effect of calculating Spearman is not as clear as compared to the variable 'visitor'. For all other variables, Pearson r and Spearman rho correlations match.

While the investigation of scatter plots does not reveal clear indications for non-linearity, some relationships may be non-linear, and therefore not revealed by Pearson r . This is mainly the case for the variable 'visitor'. The variable 'critical facilities' does not perform better using

Spearman rho, therefore a non-linear relationship is unlikely. Interestingly, the variable 'industry', and to a lesser extent 'robustness infrastructure', possibly show signs of non-linearity because in some cases they perform better using the Spearman rho test. Non-linear tendencies are less likely compared to 'visitor'. Some indication of heteroscedasticity is associated with these variables. Pearson r is robust to heteroscedasticity with a sufficient sample size. However, high levels of heteroscedasticity could transpire into Pearson r correlations. Recalling the results of normality testing, with descending order the frequency distributions of the variables 'visitor', 'industry' and 'robustness infrastructure' are characterised by pronounced levels of skewness and/or kurtosis, which can be explained by the presence of exceptionally high values. These values form clusters rather than single outliers. Excluding Aoraki from the correlation matrix reveals strong linear relationships between 'visitor' and most other variables. Excluding Te Arai from the correlation matrix changes some correlations for 'industry', but the effect is less evident. In case of 'robustness infrastructure' most formerly significant correlations are not significant anymore. This suggests that the Te Arai cluster mainly influences this relationship. In conclusion, clustered high values for a few communities, as well as possibly non-linear and heteroscedastic tendencies explain low Pearson r values to some extent, apart from accepting H_0 .

In summary, while low significance intervals at the 95% level can be compromised by wide confidence intervals, confidence intervals shrink with increasing Pearson r and especially at the 99% level. Meaningful correlations are identified which would enable a deeper analysis of the relationships between socio-economic variables. Possible explanations for high correlations other than confidently rejecting H_0 are investigated. However, it appears that rejecting H_0 is indeed feasible, in particular as linear trends in time favour linear correlations.

11.4.7.1 Proceeding with PCA?

Based on the observations and explanations described so far, it must be asked whether the characteristics of the data set impede proceeding with a principal component analysis (PCA).

Firstly, the considerations related to the strength and confidence intervals of Pearson r correlations apply for the interpretation of these relationships. If such relationships were to be analysed with more detail, their meaningfulness must be judged carefully.

However, PCA is not an inferential statistical method (Nardo et al., 2005b). PCA is used to reveal correlations and latent dimensions within a data set, therefore is not based on distributional assumptions, and significance levels are not required. Consequently, if the variable is not distributed normally in the population, PCA is not affected.

Secondly, an assumption for a successful PCA is that the variables are collinear. PCA extracts as many components as variables, and when no correlations exist between the variables, as many components would be needed to represent the data set (Hardy and Bryman, 2004). For

instance, a data set with fifteen variables would be represented by fifteen components. The whole idea of data reduction would be defeated.

The Bartlett's test of sphericity is designed to evaluate whether the correlations between the variables is sufficient for producing meaningful results. The H_0 states that the variables in the correlation matrix are not collinear (Nardo et al., 2005b). SPSS provides a Bartlett's test, and the result shows that H_0 can be rejected at the 99% level in this research. Considering previous results, this result is expected.

While multicollinearity is a precondition for PCA, strong multicollinearity can impede a successful application of PCA (Nardo et al., 2005b). This is because a clear differentiation of principal components might not be possible. The Kaiser-Meyer-Olkin (KMO) statistic compares all observed correlations for all variables with partial correlation coefficients between variable pairs. Partial correlations should not be very high in order to reveal components clearly, and as a rule of thumb, KMO values (they range from zero to one) should exceed at least 0.6 but better 0.8 in order to proceed with PCA (Nardo et al., 2005b: 41). SPSS provides the KMO statistic, and the value retained for this analysis is 0.83. Multicollinearity therefore does not compromise the results of a principal component analysis.

Finally, the remaining assumptions which should not be violated in order to calculate principal components have been checked and discussed previously, because they are mostly related to Pearson r . These are: case to variable ratio, the effect of outliers, interval/ratio data and linearity (Nardo et al., 2005b).

11.4.8 Principal Component Analysis

After the correlation matrix is computed, the PCA process continues by extracting the components which represent the latent dimensions in the data set. The aim is to capture most of the variability: the first principal component will account for most of the variability, the second principal component for the second most variability and so on. Graphically, the first component represents the axis in a multi-dimensional space (consisting of the variables entered) along which most of the variables fall, the second component represents the axis along which fewer variables fall and so on. Components are linear aggregations of the original variables. Their axes are at right angles to each other, which illustrates that the new variables, the components, are independent of each other (Hardy and Bryman, 2004).

Each component has an *eigenvalue* which expresses the degree to which the variables are correlated with the component. The eigenvalue therefore represents the proportion of variability in the variables captured by the component (Lewis-Beck et al., 2004). Eigenvalues successively decrease with the number of components extracted.

In comparison, the correlation between a variable and a principal component is called *loading*. Loadings are correlation coefficients. SPSS lists loadings in the component and rotated component matrix. Every component derives its meaning from those variables with the highest loadings for that particular component (Hardy and Bryman, 2004). In other words, the component has something in common with all of the variables most highly associated with

the component. Therefore it is assumed that the component measures this shared dimension (Lewis-Beck et al., 2004). Examples of latent dimensions are job satisfaction, anxiety, air quality, as well as self-reliance or physical susceptibility to harm.

The axes of the principal components can be rotated which increases the distinction between the components. Rotation enhances the loading of each variable on the component it correlates mostly with. At the same time, rotation decreases the loading of each variable with all other components. Orthogonal rotation keeps the component axes at right angles to each other. Because the components are not correlated with each other, none of them captures redundant information (Hardy and Bryman, 2004). The most common rotation used is the 'varimax' method, which is the procedure applied in this thesis.

The rotated component matrix lists the rotated loadings for each variable on each of the components. The squared sum of all rotated loadings over all components is the squared multiple correlation of the variable with all the components. This is also called *communality* (Lewis-Beck et al., 2004). A communality represents the extent to which a variable is correlated with all components, which together explain the variation of all variables. Communalities can therefore be used as weights for the indicator representing the variable in the index (Esty et al., 2005)

The number of components extracted depends on the number of variables entered into the analysis. Since the idea is to reduce data, two criteria are applied to define the number of principal components retained. The first criterion is that the eigenvalue should be larger than one (Hardy and Bryman, 2004; Lewis-Beck et al., 2004, Nardo et al., 2005b). Components with eigenvalues below one will only explain a very small amount of the total variance and are hence omitted. Nothing is gained by keeping this component. The second criterion is the *scree test* which ideally confirms the eigenvalue threshold. A scree plot depicts the eigenvalues of each component. By analogy the geomorphological term 'scree' is used to differentiate the slope, which is made up by the components retained, and the scree meaning the base of the slope, which is made up by the component discarded. The components forming the scree are the 'rubble' and are regarded as small error components. The number of components retained is determined by the value at which the slope kinks into the scree. It is not always easy to determine the number of components to be retained based on the scree plot alone (Hardy and Bryman, 2004). Therefore a combination of eigenvalue and scree plot is the best approach to be followed.

11.4.8.1 PCA: results

As table 11.4 demonstrates, of the fifteen components extracted, the first four components display eigenvalues of more than one (after a varimax rotation).

Table 11.4: Total Variance explained after a varimax rotation

Component	Initial Eigenvalues			Rotation Sums of Squared Loadings		
	Total	% of Variance	Cumulative %	Total	% of Variance	Cumulative %
1	8.699	57.995	57.995	7.815	52.097	52.097
2	2.686	17.909	75.904	2.665	17.766	69.863
3	1.700	11.330	87.234	1.764	11.760	81.623
4	.627	4.183	91.417	1.469	9.794	91.417
5	.534	3.562	94.980			
6	.279	1.860	96.840			
7	.162	1.082	97.921			
8	.106	.707	98.628			
9	.077	.514	99.142			
10	.040	.264	99.406			
11	.033	.220	99.626			
12	.026	.175	99.801			
13	.016	.108	99.909			
14	.009	.058	99.967			
15	.005	.033	100.000			

The fourth component yields an eigenvalue of 0.63 before the components are rotated. Investigating the scree plot (figure 11.3) reveals that a fourth component can be designated as a principal component. The slope of the plot is interpreted to include the third component: it initially still accounts for 11.3% of the variance and its eigenvalue is above one (1.7). The foot of the slope is therefore marked by the fourth component where the slope bends into the scree.

Figure 11.3: Scree plot of the rotated eigenvalues. The components are listed along the abscissa

Including the fourth component and rotating the axes decreases the initial eigenvalues of the first two, and increases the eigenvalue of the third and fourth component, and the latter now exceeds the threshold of one (table 11.4). All four components together explain 91.4% of the variance in the data set. While the first component accounts for 52.1% of the variance, the second component explains 17.8%, and the third and fourth component still explain 11.8% and

9.8% of the variance, respectively. Including the fourth component is also justified because when calculating PCA with five components, this fifth component explains only 3.5% of the variance, and no variable is associated with it.

Variable loadings for each component are listed in table 11.5. Clearly, the socio-economic variables are highly correlated with the first component, with loadings ranging between 0.85 and 0.95. Two socio-economic variables are not highly correlated with the first component: 'industry' and 'visitors'. The former loads heavily on the second component, together with 'robustness infrastructure'. 'Robustness infrastructure' displays highest values in the rural area, the Te Arai communities, and so do values for 'industry', except for Belmont in the WHH (1996). In addition, the variable 'road connectivity' loads highly on the second component, although less pronounced. Compared to 'industry' and 'robustness infrastructure' the relationship is positive. 'Road connectivity' is highest in the suburban Western Hutt Hills. The second component therefore seems to carve out a difference between the rural and the suburban communities.

The variable 'critical facilities' is strongly correlated with the third component as is the variable 'visitor', although to a lesser degree. 'Critical facilities' yields highest values in Manutuke and Aoraki, while the variable 'visitor' scores highest in Aoraki. Especially because of the link between 'critical facilities' and 'visitor', the tourism dimension associated with Aoraki is likely to be represented by this component.

Table 11.5: Variable loadings for rotated components (a). Variable associations with a component are indicated by grey shading

Variable	Component			
	1	2	3	4
below 5 yrs of age	.848	.246	-.081	.126
65+ yrs of age	.873	.133	.004	.181
females	.926	.290	-.049	.146
h.hold income	.919	.199	.030	.163
single h.hold	.921	.181	.052	-.051
1parent	.954	.002	.029	.130
birthplace	.932	.320	-.050	.033
0-4 yrs at residence	.919	.309	-.042	.082
industry	-.193	-.820	.226	.431
visitor	-.286	.336	.740	-.376
road connect.	.625	.735	-.037	.041
access	.231	-.138	-.004	.932
robust. infra	-.356	-.875	-.123	.025
comm. facilities	.679	-.308	.490	.355
crit. facilities	.094	-.169	.944	.148

Extraction Method: Principal Component Analysis. Rotation Method: Varimax with Kaiser Normalization.

a Rotation converged in 6 iterations.

Finally, the variable 'access' loads strongly on the fourth component only. The dimension associated with this variable, access into and exit out of a community is indeed a unique aspect mainly related to topography.

The variable 'community facilities' displays correlations on the low to medium level with all four components. It is mostly affiliated with the first component, the socio-economic dimension. The more even spread between the four components indicates that this variable cannot be easily singled out to represent one specific dimension. This indicates that 'community facilities' is a relevant aspect for several dimensions, in particular the 'socio-economic' dimension.

Table 11.6 summarises the communalities for each variable. Communalities before and after rotation are identical. Clearly, all variables show very high communalities, hence are strongly associated with at least one of the four components. In addition, communalities are very similar. It should be noted that the variable 'community facilities' receives a high overall loading, although it is not associated as strongly with one specific component as most other variables but spread more evenly.

The principal component analysis unveils several latent dimensions in the data set:

- Principal component 1: socio-economic
- Principal component 2: rural – suburban
- Principal component 3: tourism
- Principal component 4: access into and exit out of the community.

Table 11.6: Communalities

Variable	Extraction	Variable	Extraction
below 5 yrs of age	.802	industry	.945
65+ yrs of age	.813	visitor	.884
females	.965	road connect.	.934
h.hold income	.911	access	.941
single h.hold	.887	robust. Infra.	.908
1parent	.927	comm. facilities	.921
birthplace	.975	crit. facilities	.950
0-4 yrs at residence	.948		

Components 1 and 4 reflect phenomena generally common to all study areas, while components 2 and 3 reflect phenomena which are specific for the communities included in the analysis. As pointed out before, the samples used in this research reflect the conceptually anticipated differences between these communities. If PCA would not have depicted these underlying dimensions, in particular components 2 and 3, the justification for using these communities would be weakened. The implications for the structure and weights within the indices are, however, more important.

11.4.8.2 Index structure

Overall, it is concluded that none of the sub-indices are redundant, since a set of variables is associated with each of them. This is demonstrated in the following.

The conceptual grouping of socio-economic variables is confirmed because they are strongly associated with component 1.

Amongst these, both variables reflecting 'age' show lower loadings compared to all others. Their location in the socio-economic index is justified by the PCA results. However, a grouping into a different sub-index, 'fragility and mobility', is encouraged.

The variable 'females' is conceptually and statistically associated with the socio-economic dimension. For reasons discussed earlier, it was decided to place this variable in the 'fragility and mobility index'. With such a high loading on the first component, however, it is considered to place this variable into the socio-economic index instead. Although this variable is related to many other socio-economic variables, it represents specific socio-political dimensions which are not reflected otherwise. Therefore the 'fragility' aspect is subdued but still attached to the variable 'female', now placed in the socio-economic index.

Considering the justification for designing a specific 'fragility and mobility index', the aspect of age could be combined with illness and disability if such data were available, and tested with a PCA.

The second component suggests a grouping of 'industry', 'robust infrastructure' and 'road connectivity', which could be labelled 'rural-suburban index'. However, the goal of the index exercise is not to design a 'rural-suburban' or 'tourism' index, but to unveil differences with respect to vulnerability and resilience. The different characteristics of the three community clusters are well represented by their variable values, which will transpire into the indices of vulnerability and resilience. The original 'infrastructure index' is therefore not changed, and 'industry' is kept in the socio-economic index. Conceptually, the variable 'industry' represents also the aspect of self-reliance, which can also be understood to be associated with rural communities.

The third component suggests a grouping of 'visitor' and 'critical facilities', which could represent the tourism dimension. For the same reasons stated above, this is not considered. The variable 'visitor' is placed within the socio-economic index. 'Critical facilities', together with 'critical infrastructure', represents the 'critical services' index. As pointed out earlier, 'roading' and 'critical infrastructure' are derived from the same source (robustness infrastructure), meaning they are identical. Autocorrelation was avoided by including this variable once ('robustness infrastructure'). 'Robustness critical infrastructure' is conceptually joined with 'critical services'.

Statistically the fourth component, representing 'access' into and exit out of communities, could be treated as an sub-index of its own. However conceptually, this variable is associated in particular with road connectivity and robustness of roads and bridges in the context of facilitating adaptive capacity.

Finally, the variable 'community facilities' cannot be associated clearly with only one of the four components, which justifies its single position in the 'community network index'.

The results of the PCA are compared with results obtained when using different data sets. Firstly, principal components are extracted per year, using all communities for that year ($N = 10$). For the years 1991, 1996, 2001 and 2006 the effect on the number of components, their eigenvalues, variable loadings and communalities are negligible. Due to the small case number, the explanatory power of this observation is, however, limited. Nevertheless, there is some indication that although correlations may change in time, this would not affect index structure and weights for a particular year. A similar situation is detected when excluding the Western Hutt Hills data for 1981 and 1986 ($N = 40$).

Principal components are also analysed in terms of the effect of outliers. As an example, Aoraki (with high counts for the variable 'visitor') is excluded from the data set ($N = 48$, case to variable ratio 3.2). The results suggest three instead of four components, and the variable 'visitor' loads highly on the first component (0.89). In addition, the communality for 'visitor' is lower (0.71 compared to 0.88). The influence on loadings and therefore communalities for all other variables is negligible. Similar effects are observed when excluding Te Arai, where the variables 'industry' and 'robustness infrastructure' have high values compared to other communities ($N = 40$, case to variable ratio: 2.7). The communality for 'industry', however, drops from 0.95 to 0.40.

Excluding a community associated with high scores for the particular variable entails that a specific dimension is not represented, such as the dimension of 'tourism'. Not including cases with high values would defeat the purpose of this research, which is to relatively compare communities with specific characteristics in terms of their vulnerability and resilience.

An important aspect to consider is the high multicollinearity between most variables. As discussed previously, collinear variables can lead to double counting of the shared phenomenon represented, which can introduce a form of artificial weighting.

Excluding a variable from a collinear pair, or from the whole set of collinear variables, could be approached statistically by multiple regression. However, because multicollinearity values are high, multiple regression would not produce meaningful results in this research. Alternatively, deciding on a case by case basis on which variable of a collinear pair should be excluded is a difficult and arbitrary process.

Most importantly, when recapitulating chapter 8, it is observed that all variables represent more than one phenomenon. For example, a variable can be associated with access to different resources, or account for a specific aspect not covered by any other variable. Excluding variables would therefore not only introduce a considerable degree of subjectivity, but also reduce the explanatory power of the vulnerability and resilience indices as discussed in chapter 8.

The initial structuring of the indices considers multicollinearity to some extent. In case of the variables associated with age, it was decided to place them into the 'fragility and mobility index', because fragility and mobility are the phenomena they represent most distinctly, while being

simultaneously related to other socio-economic aspects. Including the two variables twice would have increased their overall influence within the index structure. Although they are related to other variables they are not excluded from the analysis.

Principal component analysis aids the decisions on which variable to place into which group. Designing the index structure is not an easy process. Although a strong conceptual backup is a valuable guidance, decisions made carry some degree of subjectivity: despite a similar conceptual framework different researchers are likely to make different decisions in some cases. It is therefore beneficial to supply some statistical background. In addition, when the results of a PCA and the conceptual index design do not match, the researcher is forced to re-consider the justification for the initial grouping. If this still results in keeping the original groups, the conceptual structure is consolidated as well.

11.4.9 Weighting

A result of the principal component analysis is that the highest loadings are very similar for all variables (table 11.5). This implies that variables are equally important within their components. Furthermore, table 11.6 depicts that communalities are very similar, meaning that all variables are strongly correlated with at least one of the four components. Table 11.7 demonstrates this result of the PCA more clearly, where a weight is attached to the communalities. Weights are the communality values rescaled to a total of one. Rescaling is done by firstly summing up all loadings (total of 13.71), and secondly dividing each loading by the total. In addition, equal weights are listed as one share of the total number of variables (fifteen). It is illustrated that the statistical procedure of deriving weights yields very similar results compared to an equal weights approach.

Table 11.7: Communalities and rescaled weights, PCA

Variable	Extraction	Weight	Equal weight
below 5 yrs of age	.802	.06	.07
65+ yrs of age	.813	.06	.07
females	.965	.07	.07
h.hold income	.911	.07	.07
single h.hold	.887	.06	.07
1parent	.927	.07	.07
birthplace	.975	.07	.07
0-4 yrs at residence	.948	.07	.07
industry	.945	.07	.07
visitor	.884	.06	.07
road connect.	.934	.07	.07
access	.941	.07	.07
robust. infra	.908	.07	.07
comm. facilities	.921	.07	.07
crit. facilities	.950	.07	.07
TOTAL	13.71	1	1

Equal weights are often favoured when evidence for differentiated weights is scarce, disagreement on the importance of variables is high (Nardo et al., 2005b), or an equal weighting scheme is suggested conceptually. In this research, statistical evidence clearly justifies an equal weight approach.

11.4.9.1 Survey on weighting vulnerability and resilience variables

As part of this research, a survey on weighting vulnerability and resilience variables as part of an exemplified index was undertaken. Questionnaires were distributed at the 2007 meeting of the Association of American Geographers in San Francisco, and a digital version was distributed through various research networks. The target audience consisted of risk researchers and practitioners from various disciplines. The questionnaire and details of the results are included in appendix D. After the survey was distributed, ongoing conceptual work meant that the initial structure of the indices was modified. Hence the index structure used for the survey does not match the final index structure and set of variables included in this research, and a direct comparison is not possible.

However, some interesting observations are made. First of all, the level of agreement on which weight should be assigned for a specific variable is generally high. Secondly, this result is matched by an overall low number of outliers; the maximum number of participants strongly disagreeing is observed for the variable 'education' (in total three, for vulnerability). Thirdly, *within* most sub-indices an equal weighting scheme emerges. Finally, all but two variables display a uni-modal distribution in their sample, meaning that one specific weight was most popular among participants.

11.4.10 Variables become indicators

Indicators are derived from the complete set of variables, usually as percentages of community totals and ratios. Percentages and ratios ensure the comparability of communities in space and time. With respect to indicator comprehensiveness, all indicators are straight-forward and intuitively accessible to various audiences. Tables 11.8 to 11.10 summarise the variables and indicators which enter the three sub-indices 'adaptive capacity', 'needs' and 'self-sufficiency'.

While road connectivity is expressed as the ratio of intersections to total road length (km), access is calculated as the ratio of access points to population size. This ratio implies increased pressure on each access point with increasing population size. Not only in case of evacuation but also with respect to the amount of search and rescue, tools and relief needed, pressure varies with population size. The smaller the ratio, the less favourable are the implications for access to resources, and vice versa. For this indicator, the population size is the sum of the usually resident population and overseas visitors to account for maximum pressure.

Table 11.8: 'Adaptive capacity' index; community totals are the usually resident populations or households, and usually resident population and overseas visitors

Variable	Indicator	Indices	Index
household income	% of hholds at 60% and below of median household income	Socio-Economic	Adaptive capacity
females	% females		
single household	% of single households		
1 parent	% of 1 parent households		
birthplace	% overseas born		
0-4 years at residence	% 0-4 years at current residence		
industry	% farming/forestry industry		
visitors	% visitors from overseas		
road connectivity	ratio intersection nodes/total length of roads	Infra-structure	
access points into community	Ratio access points/total population		
robustness (roads & bridges)	% min. 51-65 yrs of total road length		

Similar to 'access', the ratio of critical facilities to community population size is calculated (table 11.9), because depending on the size of the population the pressure on each facility varies. For instance, a total value of three critical facilities in a small community is more favourable than in a large community where potentially more people are in need of medical, fire and police services. For this indicator, the population size is the sum of the usually resident population and overseas visitors to account for the maximum number of people or pressure on critical facilities.

Table 11.9: 'Needs' index; community totals are the usually resident populations, and the usually resident populations and overseas visitors for critical facilities

Variable	Indicator	Indices	Index
elderly	% 65 years of age and older	Fragility & mobility	Needs
very young	% below 5 years of age		
critical facilities (hospitals, medical practitioners, police, fire stations)	ratio as number per population	Critical services	
robustness infrastr. (water, electricity, gas, sewage)	% min. 51-65 yrs of total network		

Calculating a ratio for 'community facilities' (like for 'critical facilities') is not feasible in the context of community facilities, because due to a compensation effect, the size of the population is not relevant in the context of community networks (table 11.10).

Table 11.10: 'Self-sufficiency' index; the usually resident population is the total

Variable	Indicator	Indices	Index
community facilities (schools, kindergartens, playcentres, churches, community centres, marae)	total number of comm. facilities	Community network	Self-sufficiency
industry	% farming/fisher/forestry industry	Self-reliance	

11.4.11 Normalisation

The indicator set is transformed into z-scores. For each variable, this is done by combining all communities per year into one sample. The mean and standard deviation of the sample are used to transform each value into a z-score. Sample size varies between ten for the period of 1991 to 2006, and six for the period of 1981 to 2006 where only data for the Western Hutt Hills are available.

The arithmetic mean of the sample is the benchmark used for calculating z-scores. Therefore, when comparing indicators through time the same base year mean and standard deviation should be used (Davidson, 1997; Hardy and Bryman, 2004; Nardo et al., 2005b). For each indicator, all cases, this means communities, per year are used as the distribution. For each indicator the mean and standard deviation of the 2006 distribution are used for calculating z-scores for all other years. Therefore in this research, z-scores are not only sample-specific according to the communities included, but also sample-specific according to the years included. For instance, running an analysis from 1981 till 2001 would use z-scores referenced to the year 2001, which has a different mean and standard deviation than 2006. The methodology is not in conflict with the aim of this research, which is to express vulnerability, resilience and risk in relative, not in absolute terms.

Z-scores are preferred over the 'minimum-maximum' method because they are more robust towards outliers. As tested, for example for the variable 'access', distributions calculated via the 'min-max observed' technique display greater skewness than distributions calculated by z-scores.

Before z-scores are entered into to the index structure (figure 11.4), they are reversed where necessary.

Figure 11.4: Structure of indices, with indication of reversed indicator/index scores

For example, a high score for the indicator 'community facilities' concurs with an increase of the 'self-sufficiency' index. Likewise, an increase of this index matches an increase of the 'resilience index'. In contrast, a high value for the variable 'visitor' does not compile with a higher value in the 'adaptive capacity index'. It is assumed that visitors decrease adaptive capacity, and the z-score for visitor is reversed. Again, high values of adaptive capacity are associated with low values of vulnerability, hence the score for 'adaptive capacity' is reversed (but not altered when calculating the resilience index).

Z-scores are reversed by subtracting the observed value from the mean (rather than the other way around), and dividing the result by the standard deviation as described by Esty et al. (2005).

11.4.11.1 Testing the effects of outliers

Outliers can influence the mean and the standard deviation used for calculating z-scores, which can influence the magnitudes of all z-score in the sample.

Since the mean and standard deviation of 2006 distributions are used to calculate z-scores for all other years, the mean and standard deviation of these other years do not influence normalisation results. Therefore, the 2006 distributions are the focal point for investigating the effect of outliers on the normalisation technique.

The effects of outliers on normalisation results are analysed by calculating the skewness of the sample. The sample consists of all cases (communities) per year (table 11.11). Z-scores exactly represent the frequency distribution of the raw data. Likewise, the frequency distribution of z-scores (1981-2001) referenced to a specific year (2006) is identical to the frequency distribution of z-scores calculated with the mean and standard deviation of each year (1981-2001). Z-scores referenced to the year 2006 are used in the analysis of outliers.

Two indicators exhibit skewness values greater than two (table 11.11). The frequency distribution of the indicator 'single households' is characterised by an outstanding maximum value, 2.6, for Aoraki (before normalisation: 42.9%), and a skewness of 2.07. In addition, the indicator 'visitor' displays a maximum z-score of 2.8 and a skewness of 3.13 standard deviations from the mean for Aoraki (63%).

In these cases, outliers can exert a disproportional influence on the mean and standard deviation of the distribution, and therefore the final z-scores. Excluding outliers would result in:

- '*single households*': very similar pattern of z-scores with overall higher magnitudes into positive and negative directions,
- '*visitors*': values are more differentiated amongst the remaining communities (WHH and Te Arai), with overall higher magnitudes into positive and negative directions.

Outliers, meaning communities with values distant from those of other communities, are not omitted. Transforming or excluding them from the analysis is not considered, because this would defeat the purpose of comparing communities on the basis of vulnerability and resilience. This decision is further justified because firstly only a few cases of outliers are identified (for all years, table 11.11) and the degree of skewness is overall not very high (except one variable, below a value of three). The effect of outliers on the normalisation results is therefore not considered as distorting the results of the index procedure.

Table 11.11: Minimum, maximum and skewness for each variable, z-scores, referenced to 2006

indicator	Western Hutt Hills, Te Arai, Aoraki												Western Hutt Hills					
	2006			2001			1996			1991			1986			1981		
	Min	Max	Skew	Min	Max	Skew	Min	Max	Skew	Min	Max	Skew	Min	Max	Skew	Min	Max	Skew
young (below 5)	-2.02	1.25	-0.68	-1.97	2.34	-0.44	-0.72	1.43	0.19	-2.28	3.02	-0.81	-0.82	2.08	0.71	-0.55	3.89	1.39
Elderly (65+)	-2.41	1.13	-1.60	-1.33	0.96	-0.19	-2.24	0.82	-0.19	-2.52	0.67	-0.52	-2.31	-0.81	-2.85	-0.79	-0.79	0.03
females	-2.0	1.3	-0.73	-9.7	7.0	-1.88	-7.7	1.9	-1.48	-11.7	2.6	-2.17	-4.2	-0.2	-0.69	-2.5	1.2	-0.38
household \$	-1.5	1.4	0.44	-1.6	3.6	0.34	-1.0	3.1	0.89	-1.4	2.8	0.70	-0.5	1.7	0.37	-0.4	2.1	0.56
single household	-1.2	2.6	2.07	-2.2	3.1	1.46	-1.3	3.2	2.70	-1.2	4.2	2.83	-1.3	-0.3	1.26	-1.7	-0.4	0.966
1 parent	-1.8	2.0	0.22	-0.8	2.8	1.82	-1.8	3.3	2.04	-1.8	1.9	0.97	-0.7	0.0	0.87	-0.8	0.0	1.04
birthplace	-1.7	1.6	-0.43	-2.0	0.6	-0.98	-2.1	0.4	-0.80	-1.6	0.1	-1.11	-0.4	0.0	0.04	-0.4	0.0	-0.38
yrs at resid.	-1.1	2.4	1.51	-1.4	0.70	-1.12	-1.0	0.2	-0.43	-1.9	0.2	-0.66	-1.2	0.3	0.66	-0.3	1.2	0.79
Industry	-0.6	1.7	1.28	-0.6	2.9	1.58	-0.6	2.8	1.65	-0.6	2.4	1.34	-0.6	-0.5	2.44	-0.6	-0.6	-
Visitors	-0.4	2.8	3.13	-0.4	2.4	3.14	-0.4	2.5	3.14	-0.4	1.9	3.14	-0.3	-0.3	-	-0.3	-0.3	-
Robustness infra.	-1.4	1.3	-0.48	-1.4	1.3	-0.09	-1.4	1.3	-0.19	-1.4	1.3	-0.25	-1.4	-1.4	-	-1.4	-1.4	-
Road connectivity	-1.4	1.8	0.02	-1.4	1.1	-0.65	-1.4	1.2	-0.59	-1.4	0.8	-0.67	0.2	0.7	0.05	0.2	0.9	0.00
Access	-0.7	1.7	1.25	-0.7	2.3	1.42	-0.7	1.9	1.48	-0.7	2.2	1.41	-0.7	-0.1	0.99	-0.7	-0.3	-0.41
Critic. facilities	-0.5	2.1	1.80	-0.5	1.7	1.76	-0.5	1.4	1.68	-0.5	2.70	2.03	-0.5	-0.1	2.44	-0.5	-0.3	2.44
Community facilities	-1.3	1.6	0.80	-0.8	1.6	1.04	-0.8	1.6	1.05	-0.8	1.6	1.29	-0.8	1.60	1.70	-0.8	0.7	1.43

11.4.12 Aggregation

Choosing the aggregation method is dependent on the goals pursued, the normalisation technique and the way weights are treated within the index.

The latter aspect refers to the problem of full or partial compensability when linear or geometric methods are chosen, respectively. In combination with these methods, weights do not necessarily represent the importance which is conceptually, statistically or otherwise determined for each indicator. The multi-criteria approach avoids the problem of compensability (section 11.3.9). This approach, however, operates on the ordinal scale where the magnitude of differences between (sub-)index scores are eliminated. The second goal identified for this research is to reveal the magnitude of change between indicators, sub-indices and final index scores in space and time. For example, the degree of change can offer risk managers not only an evaluation of risk reduction measures, but also refines the comparison between communities in the sense that priorities for risk reduction measures can be identified. The question is therefore not only which community performs better, and when, but also *how much* better. A multi-criteria approach is therefore not feasible within this research.

This leaves the choice between a linear and a geometric method. Geometric aggregation with the geometric mean reduces the level of compensation, which is generally favourable. However, as discussed in section 11.3.9, the geometric mean rewards improvement of initially low scoring indicators and therefore distorts the comparability in time, and with other indicators. The first goal listed at the beginning of this chapter refers to identifying the spatio-temporal change of indicators and (sub-) indices. Using geometric aggregation is therefore not favoured. In addition, geometric aggregation relies on strictly positive values, which contradicts with using z-scores. For reasons identified in section 11.3.7 and in section 11.4.10, z-scoring is the preferred normalisation technique in this research.

The benefit a geometric aggregation yields in comparison to a linear approach is a lesser degree of compensability. As previously stated, compensability is mainly an issue when the score of one indicator is so high that it offsets a low score in one or several other indicators. Whether this is the case within this research cannot be answered as yet, and is discussed in relation with the results of the index calculations.

Preferential independence, which hampers the application of linear (and geometric) aggregation, is considered and not found to be present in this research. Given the limitations of the multi-criteria and geometric approach within the context of this thesis, linear aggregation is a feasible alternative. The aggregation is carried out using equal weights.

As pointed out in section 11.3.8, the index structure implies an internal weight depending on how indicators and sub-indices are aggregated. Each indicator receives an internal weight depending on the total number of indicators in every sub-index. An indicator may be worth a third when combined with two more indicators into one group, or worth a seventh when

combined with six more indicators. This applies for linear aggregation with the mean, but generally for all aggregation methods.

Indicator aggregation by calculating the mean of indicator scores avoids artificially high totals for the sub-index, as produced by a simple, unweighted sum: for instance, when seven indicators are aggregated compared to when only three indicators are aggregated. However, the hidden weights for each indicator are still present. Table 11.2 illustrates the effect of hidden weights in the index structure developed in this research.

The rescaled weights derived by principal component analysis (table 11.7) require a minor adjustment: because two of the fifteen variables appear twice ('industry' and 'robustness infrastructure'), the total number of variables is seventeen. Table 11.12 lists PCA derived weights rescaled to one for seventeen variables, and weights for an equally weighted approach. As can be seen the difference between the two is even smaller than pointed out previously. In addition, the internal or 'hidden' weights, depending on the number of indicators per sub-index, are listed.

Table 11.12: Weights derived from PCA and equal weights, rescaled to one, and adjusted for seventeen indicators, and internal weights depending on the index structure

	Weight PCA	Equal weight	Internal weight	Sub -indices
below 5 yrs of age	0.05	0.06	0.5	fragility & mobility
65+ yrs of age	0.05	0.06	0.5	
robust critical infrastr.	0.06	0.06	0.5	critical services
crit. facilities	0.06	0.06	0.5	
females	0.06	0.06	0.14	socio- economic
h.hold income	0.06	0.06	0.14	
single h.hold	0.06	0.06	0.14	
1parent	0.06	0.06	0.14	
birthplace	0.06	0.06	0.14	
0-4 yrs residence	0.06	0.06	0.14	
industry	0.06	0.06	0.14	
visitor	0.06	0.06	0.14	
road connect.	0.06	0.06	0.33	infra- structure
access	0.06	0.06	0.33	
robust. roads and bridges	0.06	0.06	0.33	
comm. facilities	0.06	0.06	1	community network
industry	0.06	0.06	1	self-reliance
TOTAL	1	1	6.14	

The conflict between internal weights and the statistically or otherwise derived equal or unequal weights with respect to individual indicators is not easily resolved.

The comparison of sub-indices on the first level of hierarchy is ensured when individual indicators are aggregated as the arithmetic mean. In this thesis, the six sub-indices are calculated as the average of their associated indicators, which are therefore equally weighted

within their sub-index, although (internal) weights for indicators differ. This methodological choice is based on the following considerations:

1. One finding of the PCA is that similar communalities imply equal importance of indicators. However, the importance is not distributed equally between all components, as demonstrated by the loadings (except 'community facilities'). 'Critical facilities', for example is loaded highly on the third component, but its loading for all other components is low. While 'critical facilities' is very important for the dimension it represents, it is less important for the socio-economic dimension. The key to understanding the weighting suggested by PCA is therefore the equal weighting *within the dimension* which is represented by a sub-index.
2. A way of avoiding differences in internal weights is to discard the sub-indices and aggregate all indicators directly into one index. However, sub-indices are valuable tools within the overall index since they allow summarising and analysing sub-totals apart from individual indicator scores on the one hand and the final index score on the other hand. They are therefore not easily discarded.
3. Weights equally distributed between all seventeen indicators independent of the index structure, as listed in table 11.12, are sensitive to the total number of indicators. Adding or removing one or several indicators within one sub-index would therefore not only change the weight of all indicators within this subgroup, but the weight of all indicators in all other groups. As surfaced throughout this chapter, many decisions throughout the indexation process influence the final result, and the overall number of indicators is one aspect. Aggregating indicators with the average method into each sub-index ensures that changes are contained within the sub-index. Robustness towards variations within the index structure is aimed for in this research. This is because prospective work is likely to involve a repeated application of the indices, for example for other areas and or points in time. Comparability in time should be ensured to the maximum extent possible, for instance with respect to z-scoring. The backbone of the indices, their structure, weighting and aggregation, should therefore be as robust as possible.

In relation to the first consideration, it is noted that the grouping of indicators in this research only partly adheres with the structure suggested by principal component analysis. According to the goals of this research, these suggestions are not always followed. Nevertheless, indicators placed into another sub-index or dimension still carry their loading – the dimension they represent is simply included into another dimension which is favoured in relation to the overall goal.

The second hierarchy of aggregation, where the six indices are aggregated into three pairs of two indices, is also performed by using the average method. Each of the six indices is therefore equally weighted, and the internal weights for the whole index structure are equal as well.

Finally, the vulnerability index is calculated by averaging the 'needs' and 'adaptive capacity' indices, which therefore both receive equal weights. The procedure is repeated for the resilience index, for which the 'adaptive capacity index' is combined with the 'self-sufficiency' index, both receiving equal weights. The vulnerability and resilience index are therefore equally weighted and comparable.

In summary, the different number of indicators entering the first hierarchy of indices reveals a conflict between the internal weights depending on the index structure and the intended weighting scheme. The aggregation method ensures that indicators are equally weighted within their sub-indices, and that the resulting sub-indices on the first level of hierarchy are comparable. From the second hierarchy level onwards the conflict disappears, because an equal number of indices are aggregated on each level.

The structure of the indices is built as a relational database in the software MS 'Access'. The following chapter presents and discusses the results of the vulnerability and resilience indices.

12. Vulnerability and resilience analysis: results

Both the vulnerability and the resilience index produce several sets of results reflecting the hierarchical structure of both indices. The details of these results are listed in appendix E, where for each community and year the following data is given:

- percentages and z-scores for each indicator,
- z-scores for the six indices on the first level of aggregation,
- z-scores for the three indices on the second level of aggregation and the final 'vulnerability' and 'resilience' indices.

This chapter firstly presents the results for the 'vulnerability' and 'resilience' indices, as well as for their sub-indices 'needs', 'adaptive capacity' and 'self-sufficiency'. Secondly, the outcomes of sensitivity testing are presented and evaluated. Thirdly, the results of the vulnerability and resilience analysis are discussed with respect to differences in time and space, and in terms of the driving factors of these differences. In addition, methodological aspects are discussed. The chapter finishes with a summary and conclusion.

12.1 Results

The presentation of the results is guided by the following questions:

1. Which communities display the minimum and maximum values per index, during the whole period of analysis?
2. Based on a period of fifteen years (the census years 1991 to 2006), how are communities ranked (on average) for each index? To what degree do these ranks differ?
3. How are communities ranked for the vulnerability and resilience indices, per census year?
4. How have the indices 'vulnerability' and 'resilience' evolved through time for the three groups Western Hutt Hills (WHH), Te Arai and Aoraki?
5. How and to what degree do index scores vary in time for each community?

While the first two questions aim to detect differences in space, questions three, four and five focus on differences in time for both the 'vulnerability' and the 'resilience' index.

Question 1: Which communities display the minimum and maximum values per index, during the whole period of analysis?

Table 12.1 lists minimum and maximum z-scores for each index and for the whole period of analysis. Z-scores, meaning the value of the index, range from negative values to positive values. For example, a minimum value for the index 'self-sufficiency' shows that a community is the least self-sufficient community. In turn, a maximum value for the index 'vulnerability' means that a community is the most vulnerable community.

Aoraki features three times with the lowest scores recorded for the indices 'needs', 'vulnerability' and 'resilience'. Tirohanga holds the minimum value for 'self-sufficiency' for each of the census

years between 1981 and 2006, while Waerengaokuri displays the lowest score for 'adaptive capacity' in 2001.

In terms of maximum values, Waerengaokuri appears twice with maximum values for the indices 'needs' and 'vulnerability'. Manutuke scores highest with respect to 'self-sufficiency', as does Tirohanga for 'adaptive capacity'. Finally, the maximum value for the 'resilience' index features for Maungaraki.

Table 12.1: Minimum and maximum index values (z-scores). Absolute minimum and maximum values are shaded in grey

Index	Min	Community	Max	Community
'needs'	-2.1	Aoraki (1991)	1.05	Waerengaokuri (2006)
'self-sufficiency'	-0.69	Tirohanga (1981 - 2006)	1.33	Manutuke (2001)
'adaptive cap.'	-0.63	Waerengaokuri (2001)	0.70	Tirohanga (1986)
'vulnerability'	-1.25	Aoraki (1991)	0.67	Waerengaokuri (2001)
'resilience'	-0.46	Aoraki (2006)	0.54	Maungaraki (1986)

As will be seen in the following section, these observations indicate the ranking of communities based on average index scores.

Question 2: Based on a period of fifteen years (the census years 1991 to 2006), how are communities ranked (on average) for each index? To what degree do these ranks differ?

This ranking considers not only one point in time, but a longer period. In order to allow the comparison between all communities only the period of 1991 to 2006 is considered. This is because data for Te Arai and Aoraki is not available for 1981 and 1986. For each index, the performance of communities is ranked based on the arithmetic mean of the index scores for 1991, 1996, 2001 and 2006 (tables 12.2 and 12.3).

Table 12.2: Ranking for the indices 'needs', 'self-sufficiency' and 'adaptive capacity', based on the mean for the period 1991-2006. Light grey shading demarcates Te Arai communities, and dark grey shading highlights Aoraki

Needs			Self-sufficiency			Ad. capacity		
Rank	Community	Mean	Rank	Community	Mean	Rank	Community	Mean
1	Waereng.	0.71	1	Manutuke	1.22	1	Maungaraki	0.34
2	Waingake	0.56	2	Waereng.	0.67	2	Tirohanga	0.22
3	Manutuke	0.51	3	Waingake	0.60	3	Kelson	0.21
4	Korokoro	0.40	4	Maungaraki	0.52	4	Normandale	0.12
5	Tirohanga	0.24	5	Kelson	-0.13	5	Aoraki	0.05
6	Belmont	0.13	6	Belmont	-0.43	6	Belmont	0.03
7	Normandale	0.07	7	Korokoro	-0.44	7	Korokoro	-0.08
8	Kelson	-0.22	7	Normandale	-0.44	8	Waingake	-0.12
9	Maungaraki	-0.32	8	Aoraki	-0.55	8	Waereng.	-0.12
10	Aoraki	-1.60	9	Tirohanga	-0.70	9	Manutuke	-0.39

Two communities stand out since they are each ranked first for two out of five indices: Manutuke and Maungaraki. Manutuke yields an, with respect to risk, unfavourable 'vulnerability' score which is 1.3 units higher than the lowest score. However, Manutuke performs best with respect to 'self-sufficiency', with a difference of 2 units to the lowest score.

Table 12.3: Ranking for the indices 'vulnerability' and 'resilience' based on the mean for the period 1991-2006. Light grey shading demarcates Te Arai communities, and dark grey shading highlights Aoraki

Vulnerability			Resilience		
Rank	Community	Mean	Rank	Community	Mean
1	Manutuke	0.45	1	Maungaraki	0.43
2	Waereng.	0.42	2	Manutuke	0.42
3	Waingake	0.34	3	Waereng.	0.28
4	Korokoro	0.24	4	Waingake	0.25
5	Belmont	0.05	5	Kelson	0.10
6	Tirohanga	-0.1	6	Normandale	-0.16
7	Kelson	-0.22	7	Belmont	-0.20
8	Normandale	-0.26	8	Tirohanga	-0.24
9	Maungaraki	-0.33	9	Aoraki	-0.25
10	Aoraki	-0.83	9	Korokoro	-0.25

Maungaraki ranks first for the index 'adaptive capacity', scoring ca. 0.7 units above the lowest score. Moreover, Maungaraki tops the rank of the 'resilience' index equally by ca. 0.7 units above the bottom ranked community. Finally, Waerengaokuri is, on average, ranked unfavourably first for the index 'needs' with a distance of 2.3 units to the lowest ranked community.

When examining the bottom ranks for each index it shows that Aoraki features three times: for the index 'needs' and for the index 'vulnerability'. In addition, Aoraki shares its unfavourable, low grading with Korokoro for the index 'resilience'. Tirohanga scores lowest for the index 'self-sufficiency', while Manutuke is bottom of the list for 'adaptive capacity'.

Overall, it is observed that the communities of Te Arai (shaded in light grey in tables 12.2 and 12.3) occupy the highest or lowest ranks very consistently. All three communities rank highest for 'self-sufficiency', 'needs', and 'vulnerability'. In addition, Te Arai communities are only topped by Maungaraki with respect to 'resilience', and in this case the difference between Manutuke and Maungaraki is only 0.01 units. What is more, communities in Te Arai rank, on average, consistently lowest for the index 'adaptive capacity'. Apart from 'adaptive capacity' where Aoraki is ranked close to the average (0.05), Aoraki is the reciprocal of Te Arai. Hence the Western Hutt Hills are almost consistently sandwiched between Te Arai and Aoraki – except for 'adaptive capacity' where four out of six communities of the WHH occupy the first ranks.

As stated in chapter 11, one goal of this research is not only to detect differences in conditions of vulnerability and resilience, but also the magnitude of difference. Therefore, not only the ranking but also the degree of difference between ranks is of interest to this research.

Magnitudes of change between ranks for the average scores of the indices 'needs', 'self-sufficiency', 'adaptive capacity', 'vulnerability' and 'resilience' are illustrated in figures 12.1 to 12.5. Waerengaokuri is clearly placed unfavourably at the top of the rank of the index 'needs', followed by Waingake and Manutuke with a distance of 0.15 units and 0.2 units, respectively (figure 12.1). The communities in the WHH follow with a regular spacing between them. The exception is Kelson, which drops by almost 0.3 units compared to Normandale. The most

distinct difference is observed between Maungaraki and Aoraki: 1.3 units divide Aoraki from Maungaraki, which is the community ranked second lowest.

Figure 12.1: Ranking for the index 'needs' based on the mean index score for the period 1991-2006 (in z-scores)

With respect to the index 'self-sufficiency' (figure 12.2) Manutuke exceeds the second highest rank by 0.55 units, which is a clear advantage. Waerengaokuri and Waingake are ranked comparatively similarly (0.67 and 0.60). Maungaraki follows closely, but then a large drop in units (0.65) demarcates the difference to Kelson and all other communities of the WHH. While Belmont, Korokoro and Normandale are almost even, index scores decrease further and reach the minimum level at -0.70 (Tirohanga).

Figure 12.2: Ranking for the index 'self-sufficiency' based on the mean index score for the period 1991-2006 (in z-scores)

Compared to the first two indices, differences between ranks for the index 'adaptive capacity' are less distinct, and minimum and maximum scores overall are lower (figure 12.3). Maungaraki leads the ranking by 0.12 units, followed by Tirohanga and Kelson which display very similar values. Subsequently, index scores drop steadily, but with little difference, between ranks. While Waingake and Waerengaokuri are not much different from Korokoro (0.04 units), Manutuke drops by almost 0.3 units and clearly occupies the lowest and least advantageous rank with respect to adaptive capacity.

Figure 12.3: Ranking for the index 'adaptive capacity' based on the mean index score for the period 1991-2006 (in z-scores).

When looking closely at the average scores for the index 'vulnerability' it shows that Te Arai communities clearly lead the ranking (figure 12.4). This is a disadvantageous situation with respect to risk. Korokoro is ranked closer to Te Arai than to the WHH: the community differs by ca. 0.2 units to Belmont, but only 0.1 units to Waingake. The remaining communities of the WHH are equally spaced, by about 0.1 units, along the decreasing ranks. As with the index 'needs' Aoraki clearly differs from all other communities, by 0.5 units. The overall range of index scores, however, is smaller, which is also observed for the index 'resilience'. This can be attributed to the method of aggregation, which uses the arithmetic mean of two sub-indices to calculate the final score.

Figure 12.4: Ranking for the index 'vulnerability' based on the mean index score for the period 1991-2006 (in z-scores)

With respect to the index 'resilience' (figure 12.5), Maungaraki and Manutuke compete for the highest rank, while Waerengaokuri drops obviously (by 0.14 units) to third place, closely followed by Waingake. Kelson is ranked closer to Maungaraki/Te Arai at 0.15 units below Waingake but is 0.26 units above Normandale. Subsequently, the differences in ranks are consistently small and Aoraki and Korokoro share the lowest and least desirable rank for 'resilience'.

Figure 12.5: Ranking for the index 'resilience' based on the mean index score for the period 1991-2006 (in z-scores).

Question 3: How are communities ranked for the vulnerability and resilience indices, per census year?

While question two aims to show average rankings for the two final indices and their sub-indices, the development of the ranking in time is the focal point of this question. While rankings for all indices in time are listed in appendix E, within this chapter only 'vulnerability' and 'resilience' indices rankings are included.

Tables 12.4 and 12.5 list the ranking results as a sequence for the census years 1981 and 1986, and then again for the census years starting in 1991 to 2006. It is observed that the temporal variability of ranks between Te Arai, WHH and Aoraki for both vulnerability and resilience indices is very low. In particular, with respect to vulnerability Te Arai almost consistently ranks highest, while Aoraki is always at the bottom of the rank. This means that the average index scores presented previously do not mask great temporal variations between the three groups. Ranks for the index 'resilience' vary to a greater extent, which concurs with the slightly less coherent difference between average values of the three groups. However, the overall picture is clear: Te Arai and Maungaraki compete for the highest scores, while Aoraki occupies below average and bottom ranks, interchanging with WHH communities.

The relative steady performance in ranking of the three groups in time, however, does not necessarily imply steady index scores as presented in the context of questions four and five.

Table 12.4: Temporal change of ranking for the index 'vulnerability', 1981-2006

1981			1986			1991			1996			2001			2006		
<i>R.</i>	<i>Comm.</i>	<i>Vuln.</i>	<i>R.</i>	<i>Comm.</i>	<i>Vuln.</i>	<i>R.</i>	<i>Comm.</i>	<i>Vuln.</i>	<i>R.</i>	<i>Comm.</i>	<i>Vuln.</i>	<i>R.</i>	<i>Comm.</i>	<i>Vuln.</i>	<i>R.</i>	<i>Comm.</i>	<i>Vuln.</i>
1	Kelson	-0.13	1	Kelson	-0.35	1	Manutuke	0.64	1	Manutuke	0.36	1	Waeren.	0.67	1	Waeren.	0.55
2	Korokoro	-0.38	2	Belmont	-0.44	2	Waeren.	0.45	2	Korokoro	0.35	2	Waingake	0.54	2	Manutuke	0.37
3	Belmont	-0.41	3	Korokoro	-0.49	3	Waingake	0.37	3	Waingake	0.19	3	Manutuke	0.42	3	Waingake	0.25
4	Maung.	-0.44	4	Norm.	-0.52	4	Korokoro	0.20	4	Belmont	0.02	4	Korokoro	0.29	4	Korokoro	0.11
5	Norm.	-0.49	5	Maung.	-0.69	5	Belmont	0.10	5	Waereng.	0.01	5	Belmont	0.06	5	Belmont	0.02
6	Tirohanga	-0.76	6	Tirohanga	-0.81	6	Tirohanga	0.05	6	Norm.	-0.03	6	Norm.	0.01	6	Norm.	-0.03
						7	Norm.	-0.06	7	Tirohanga	-0.15	7	Tirohanga	-0.05	7	Kelson	-0.09
						8	Kelson	-0.26	8	Kelson	-0.34	8	Kelson	-0.18	8	Tirohanga	-0.24
						9	Maung.	-0.47	9	Maung.	-0.34	9	Maung.	-0.27	8	Maung.	-0.24
						10	Aoraki	-1.25	10	Aoraki	-0.72	10	Aoraki	-0.64	9	Aoraki	-0.69

Table 12.5: Temporal change of ranking for the index 'resilience', 1981-2006

1981			1986			1991			1996			2001			2006		
<i>R.</i>	<i>Comm.</i>	<i>Res.</i>	<i>R.</i>	<i>Comm.</i>	<i>Res.</i>	<i>R.</i>	<i>Comm.</i>	<i>Res.</i>	<i>R.</i>	<i>Comm.</i>	<i>Res.</i>	<i>R.</i>	<i>Comm.</i>	<i>Res.</i>	<i>R.</i>	<i>Comm.</i>	<i>Res.</i>
1	Norm.	0.23	1	Maung.	0.54	1	Waereng.	0.48	1	Waereng.	0.52	1	Manutuke	0.43	1	Maung.	0.45
2	Tirohanga	0.05	2	Kelson	0.11	1	Maung.	0.48	2	Maung.	0.44	2	Maung.	0.36	2	Manutuke	0.43
3	Maung.	0.02	3	Belmont	0.08	2	Manutuke	0.41	3	Manutuke	0.41	3	Waingake	0.31	3	Waereng.	0.22
4	Kelson	-0.04	4	Norm.	0.06	3	Waingake	0.31	4	Waingake	0.29	4	Kelson	0.09	4	Waingake	0.08
5	Belmont	-0.12	5	Tirohanga	0.00	4	Kelson	0.07	5	Kelson	0.16	5	Waereng.	-0.12	5	Kelson	0.07
6	Korokoro	-0.13	6	Korokoro	-0.04	5	Norm.	-0.12	6	Norm.	-0.15	6	Aoraki	-0.15	6	Norm.	-0.13
						6	Aoraki	-0.14	7	Belmont	-0.18	7	Belmont	-0.23	7	Tirohanga	-0.19
						7	Belmont	-0.20	8	Tirohanga	-0.26	7	Norm.	-0.23	7	Belmont	-0.19
						8	Korokoro	-0.21	9	Aoraki	-0.27	8	Tirohanga	-0.27	8	Korokoro	-0.26
						9	Tirohanga	-0.23	9	Korokoro	-0.27	9	Korokoro	-0.28	9	Aoraki	-0.46

Question 4: How have the indices 'vulnerability' and 'resilience' evolved through time for the three groups Western Hutt Hills (WHH), Te Arai and Aoraki?

Communities are grouped according to the three locations Te Arai, WHH and Aoraki. For each group (except Aoraki) average scores based on all community scores per group are calculated to depict the development of the indices 'needs', 'self-sufficiency', 'adaptive capacity', 'vulnerability' and 'resilience'. While the first three indices are included in appendix E, the latter two are presented within this chapter (figures 12.6, 12.7).

The results match the differences in ranks, and the magnitude of difference between ranks, for the three locations as already noticed in the context of questions two and three. However, changes in time are noticed with respect to their type and magnitude. While these two aspects are explored in more detail when attending question five, general trends can be observed.

During the census years 1991 and 2006 the 'vulnerability' score increases for Aoraki, meaning that it evolves into a less favourable direction with respect to risk. In comparison, for the WHH the score fluctuates slightly just below average (figure 12.6). In contrast, scores tend to vary more for Te Arai and do not seem to follow a distinct increase or decrease. When including the results for the years 1981 and 1986 a pronounced increase is observed for the WHH.

Figure 12.6: Index 'vulnerability' for the three groups Western Hutt Hills, Te Arai and Aoraki

In comparison, a pronounced and undesirable drop without recovery is recorded for Te Arai with respect to the index 'resilience' between 1996 and 2001. In addition, values fluctuate more for the WHH: even when discarding the 1980s (which witnessed a distinct increase in 1986 after scoring average (0.00) in 1981), values tend to vary more when compared to vulnerability. Nevertheless, they are still below average and comparable with scores for the index 'vulnerability'. The evolution for Aoraki, which experiences a pronounced decline in 2006 for the index 'resilience', is less consistent compared to the index 'vulnerability'. Parallel to the

disadvantage which is associated with an increase of the index 'vulnerability', Aoraki witnesses an equally unfavourable drop of scores for the index 'resilience'.

Figure 12.7: Index 'resilience' for the three groups Western Hutt Hills, Te Arai and Aoraki

Question 5: How and to what degree do index scores vary in time for each community?

The type of index evolution is of interest here, meaning whether indices increase or decrease gradually or abruptly¹, are constant, or fluctuate.

A profile sheet for each community communicates the trends of index scores, the average ranking (based on the census 1991 to 2006), and the ranking per year for the indices 'vulnerability' and 'resilience'. These profile sheets offer an instant overview for each community and a comparison between them (appendix F). The results are summarised and discussed in section 12.3.

In addition, the communities are ranked based on the number of indices with magnitudes of change of 0.5 units or more, at least for one point in time. Considering that the minimum and maximum values observed are -2.1 and 1.33 (question 1), a change of 0.5 units is a reasonable indicator for sudden change.

Since data for the years 1981 and 1986 is available for the WHH communities, but not for Te Arai and Aoraki two sets of rankings are generated. The first ranking is done for the WHH (1981-2006) on the one hand, and Te Arai and Aoraki (1991-2006) on the other hand. The second ranking includes all communities, for the period of 1991 to 2006.

¹ A change is considered to be abrupt when the index score changes by 0.5 or more units for two consecutive years.

Table 12.6: Ranking of communities based on the number of indices changed by 0.5 units or more, 1981-2006 for WHH and 1991-2006 for Te Arai and Aoraki

Community	No. change of 0.5 units or more	Rank	Community	No. change of 0.5 units or more	Rank
Tirohanga	3	1	Waerengaokuri	5	1
Belmont	3	1	Aoraki	3	2
Korokoro	2	2	Waingake	2	3
Normandale	2	2	Manutuke	0	4
Maungaraki	1	3			
Kelson	1	3			

Table 12.7: Ranking of communities based on the number of indices changed by 0.5 units or more, 1991-2006

Community	No. change of 0.5 units or more	Rank
Waerengaokuri	5	1
Aoraki	3	2
Waingake	2	3
Normandale	0	4
Tirohanga	0	4
Belmont	0	4
Kelson	0	4
Korokoro	0	4
Maungaraki	0	4
Manutuke	0	4

The first ranking reveals that within the WHH, Tirohanga and Belmont display the greatest temporal variability of index scores, followed by Korokoro and Normandale. Maungaraki and Kelson are the least variable communities with only one index changing with a magnitude of 0.5 or more.

Comparing Te Arai and Aoraki, the difference between each rank is more pronounced. Waerengaokuri is ranked first with all indices changing abruptly in time. Aoraki is rated the second most variable community, closely followed by Waingake. Manutuke does not show any great changes at all.

The combined ranking for the period 1991 to 2006 shows that the ranking of Te Arai and Aoraki does not change, meaning that Waerengaokuri is obviously ranked first, followed by Aoraki and Waingake, while Manutuke is still placed amongst the lowest ranks. Manutuke is now joined by the communities of the WHH in this respect. By excluding the 1980s, none of these would display an index which changes abruptly in time.

Different periods of analysis result in different outcomes or 'perceptions' of trends in data depending on the time window considered (chapter 4). Possible explanations for the distinct difference for some of the WHH communities between 1981 and 1990s are discussed in section 12.4.

12.2 Sensitivity analysis

Sensitivity analysis aims to measure the reliability of the index results (chapter 11); this is done by changing input parameters and comparing these changes with the original index scores.

In this research, three critical points are identified which potentially entail different index results:

1. The presence of considerably high or low indicator values for some communities compared to all other communities.
2. A different sample of communities.
3. Data uncertainty stemming from the rounding procedure of census data introduced by Statistics New Zealand, for communities with small population sizes.

For each critical point sensitivity analysis is carried out by recalculating the z-scores for all indicators based on the alternated data set. Subsequently, the indices 'vulnerability' and 'resilience' are recalculated. The differences between original and recalculated results is measured, plotted and discussed. While the results for the 'vulnerability' and 'resilience' indices are presented in this chapter, appendix G includes the results for the indices 'needs', 'self-sufficiency' and 'adaptive capacity'.

During the original normalisation procedure, index scores for the census years 1981 to 2001 are referenced to the year 2006 by using the mean and standard deviation of the year 2006 for all subsequent years (chapter 11). Therefore, the SA focuses on the results obtained for the year 2006.

The first two critical issues identified can be combined into one analysis step, since in this research, specific communities are associated with very high or low values for specific indicators (e.g. Aoraki and 'visitors').

12.2.1 Critical points 1 and 2: presence of very high or low indicator values and a different sample

As discussed in chapter 11, results of normality testing reveal the presence of pronounced values (in descending order) for the indicators 'visitor', 'industry', 'robustness infrastructure' ('critical infrastructure' and 'roading'), 'critical facilities' and 'community facilities'. In order to test the sensitivity of index scores with respect to these indicators, three communities are excluded from the sample one at a time. Furthermore, these communities are associated with positive or negative peak values for other indicators. In addition, a community without pronounced values is excluded from the data set.

- Aoraki: to account for 'visitor', 'critical facilities'; in addition peak values in 'yrs at residence', 'birthplace', 'single household', 'below five years of age', '65 years of age and more'
- Manutuke: to account for 'industry', 'robustness infrastructure', 'critical facilities', 'community facilities'; in addition peak values are recorded for 'birthplace', '1 parent' and '\$ household'
- Maungaraki: to account for peak value in 'robustness infrastructure'; in addition peaks for 'community facilities', 'connectivity' and 'below five years of age'
- Normandale: a community without pronounced values in the indicator set

Figures 12.8 and 12.9 display the results of the sensitivity analysis when Aoraki is excluded from the sample.

Figure 12.8: Sensitivity of the 'vulnerability' index; sample without Aoraki, 2006

The analysis shows that for all communities a decrease of vulnerability scores is recorded (figure 12.8). Index scores for Waingake, Waerengaokuri, Manutuke and Kelson decrease by magnitudes of 0.09, 0.04, 0.12 and 0.12, respectively. The difference for Korokoro is 0.02 units which is less than compared to Maungaraki (0.05). The other three communities display scores about 0.1 units below their original scores.

Evaluating the effects of such changes on the community *ranking* is difficult. If the difference between original ranks is very small, a change of rank is likely even though the absolute change between original and recalculated scores is small. Hence differences in ranks do not necessarily match the differences of index scores. Therefore, when testing for sensitivity only the degree to which original and recalculated values vary is a meaningful measure and the focus of the following analysis.

In comparison to the index 'vulnerability', variations of scores for the index 'resilience' are overall smaller, with a maximum difference between original and recalculated value of 0.13 (Korokoro), followed by Maungaraki (0.09), Belmont and Kelson (both 0.05) (figure 12.9).

Figure 12.9: Sensitivity of the 'resilience' index; sample without Aoraki, 2006

In comparison to Aoraki, excluding Manutuke from the sample for calculating the index 'vulnerability', yields smaller changes between original and recalculated values (figure 12.10). Of these, the largest magnitude of change is recorded for Waingake (0.07 units), closely followed by Waerengaokuri (0.06 units), Korokoro (0.05 units) and Belmont (0.05 units).

Figure 12.10: Sensitivity of the 'vulnerability' index; sample without Manutuke, 2006. Note that the original score for Manutuke is plotted twice.

Excluding Manutuke, however, affects the outcomes of the 'resilience' score, with Waingake and Waerengaokuri displaying hardly any change (figure 12.11). For all other communities,

index scores are slightly raised with Maungaraki climbing by 1.3 units, Kelson by 0.08 units and Aoraki by 0.06 units.

Figure 12.11: Sensitivity of the 'resilience' index; sample without Manutuke, 2006. Note that the original score for Manutuke is plotted twice

Excluding Maungaraki from the sample of communities reveals that hardly any change between original and recalculated scores for the index 'vulnerability' is detected for Waingake and Waerengaokuri (figure 12.12). All other communities vary between only 0.01 units (Manutuke) and 0.06 units (Kelson).

Figure 12.12: Sensitivity of the 'vulnerability' index; sample without Maungaraki, 2006. Note that the original score for Maungaraki is plotted twice

With respect to the index 'resilience', the variation is comparatively larger (figure 12.13).

Figure 12.13: Sensitivity of the 'resilience' index; sample without Maungaraki, 2006. Note that the original score for Maungaraki is plotted twice

The minimum degree of change is recorded for Waerengaokuri (0.02 units), while the maximum degree of change is recorded for Kelson (0.11 units), closely followed by Manutuke (0.09 units). The majority of the remaining communities display variations of about 0.05 units.

Finally, sensitivity is tested when the sample does not include Normandale, a community without noticeable peaks in indicator values.

With respect to the index 'vulnerability', the difference between original and recalculated values ranges between 0.00 units (Kelson) and 0.03 units (Manutuke, Aoraki) (figure 12.14).

Figure 12.14: Sensitivity of the 'vulnerability' index; sample without Normandale, 2006. Note that the original score for Normandale is plotted twice

Similar results are obtained when testing the sensitivity of the index 'resilience'. The difference between original and recalculated values for Tirohanga and Belmont is 0.00 units, while all other communities vary up to 0.04 units (Maungaraki) (figure 12.15).

Figure 12.15: Sensitivity of the 'resilience' index; sample without Normandale, 2006. Note that the original score for Normandale is plotted twice

In summary, when Aoraki is excluded from the sample, the degree of variability is the greatest, particularly for the index 'vulnerability'. The smallest effect is recorded when the sample excludes Normandale for both indices. All tests show that changes are homogeneous, meaning that all communities either increase or decrease compared to the original values. Furthermore,

differences in final index scores tend to be more subdued than differences in the sub-indices 'needs', 'self-sufficiency' and 'adaptive capacity' (appendix G). In addition, there is hardly any difference between the variation of the results for the index 'vulnerability' and the index 'resilience'.

It is concluded that the magnitude of variation is low: only a few cases exceed a change of 0.1 units. With respect to the presence of very high or low values, and a different sample, both indices are robust.

12.2.2 Critical point 3: data uncertainty due to rounding procedure

The third critical point examined is the possible effect which the random rounding procedure (implemented by Statistics New Zealand, SNZ) can exert on index scores. In particular, communities with small population sizes are potentially affected, since when compared to larger communities, small changes in counts result in higher changes in percentages which are then transformed into z-scores.

The communities potentially sensitive to the rounding procedure (in descending order) are Waerengaokuri (pop: 96, 2006), Waingake (pop: 144, 2006), and Aoraki (pop: 210, 2006). The next largest community, Manutuke (pop: 600, 2006) is considered to be immune to changes introduced by rounding, as are the WHH communities ranging from a population of 1200 in 2006 (Tirohanga) to 3552 in 2006 (Maungaraki).

It is noted that indicator values for Waingake and Waerengaokuri are based on three and two meshblocks, respectively. Hence the rounding error amplifies because every meshblock is affected by the rounding. In comparison, most other communities are based on one single value (one area unit). Where meshblocks are aggregated in order to ensure consistent community boundaries (in the WHH), population sizes are sufficiently high to prevent considerable effects on the variable count.

Non-census based variables, interpolated variables and variables with a count of zero are excluded from the sensitivity analysis. The set of indicators examined consists of 'below 5 years', '65+ years', 'yrs at residence', 'birthplace', 'gender' and 'single household'. For these, counts are raised to the next higher level of three. For example, when the recorded count is 7, the z-score is recalculated based on a count of nine.

In order to detect the maximum impact on indices scores, all five indicators are rounded up when re-calculating the indices for Waingake, Waerengaokuri and Aoraki. Rounding values to the lower base of three would not alter the extent of change, only the direction of change and is therefore not included.

However, since the rounding procedure implemented by SNZ is random, all indicators could indeed be raised by three, or decreased by three, or some might be raised while others are lower. While it is not feasible to test every possible combination, one test presented here is based on rounding up three indicators and rounding down two indicators. This is tested for the smallest community only (Waerengaokuri).

Details for the sub-indices 'needs', self-sufficiency' and 'adaptive capacity' are illustrated in appendix G.

12.2.2.1 Rounding up only

Sensitivity testing for Waerengaokuri, which is the smallest community in terms of population, reveals a jump by 0.52 units for Waerengaokuri itself with respect to the index 'vulnerability' (figure 12.16). The variability for all other communities is comparable with magnitudes observed previously, although Manutuke and Aoraki experience a drop of 0.16 and 0.13 units, respectively.

Figure 12.16: Sensitivity of the 'vulnerability' index; rounding procedure Waerengaokuri, 2006

In comparison, Waerengaokuri drops by only 0.23 units when sensitivity is tested for the index 'resilience', while all other values are almost identical (figure 12.17).

Figure 12.17: Sensitivity of the 'resilience' index; rounding procedure Waerengaokuri, 2006

For Waingake, the effect on the vulnerability score is similar (increase by 0.62 units) to the effect on Waerengaokuri, although the population is about 50% larger (figure 12.18). This is because three rather than two meshblocks are combined to create the values for Waingake, and each meshblock is subject to the rounding procedure. It is therefore not only the population size but also the number of meshblocks aggregated which influences the index score for small communities. Changes for all other communities are at magnitudes between 0.04 and 0.11 units.

Figure 12.18: Sensitivity of the 'vulnerability' index; rounding procedure Waingake, 2006

In case of the index 'resilience', the effect for communities other than Waingake is very small, while Waingake itself drops by 0.2 units (figure 12.19).

Figure 12.19: Sensitivity of the 'resilience' index; rounding procedure Waingake, 2006

Sensitivity testing for Aoraki, with a population size almost double the size of Waingake, shows that the 'vulnerability' index score increases by 0.11 units, while all other communities are very similar (figure 12.20). The magnitude of change for Aoraki compared to Waerengaokuri and Waingake is relatively small.

Figure 12.20: Sensitivity of the 'vulnerability' index; rounding procedure Aoraki, 2006

In case of the index 'resilience' the rounding effect is even more subdued, with Aoraki dropping by only 0.03 units and all other values being almost identical (figure 12.21)

Figure 12.21: Sensitivity of the 'resilience' index; rounding procedure Aoraki, 2006

12.2.2.2 Rounding up and down, Waerengaokuri

A scenario with some indicators being raised and some being lowered to the next base of three is examined for Waerengaokuri.

The effect on the Waerengaokuri score (increase of 0.30 units) for 'vulnerability' is smaller (nearly 50%) compared to the first scenario when all indicators are rounded up (figure 12.22). Overall, variability for other communities is smaller, apart for Manutuke and Aoraki which (again, figure 12.16) vary the most by about 0.14 and 0.15 units, respectively.

Figure 12.22: Sensitivity of the 'vulnerability' index; rounding procedure (up and down) Waerengaokuri, 2006

By comparison, test results for the 'resilience' index reveal that original and recalculated values for all communities are almost identical (figure 12.23).

In summary, with a community population of 96 and two meshblocks, or a community population of 144 and three meshblocks, the effects of random ranking on the outcomes of the index 'vulnerability' are considerable. Values for the index 'resilience' are affected as well, although far less when compared to values for the index 'vulnerability'. The scenario with a combination of values being rounded up and down shows that the effect for the index 'vulnerability' is smaller but still considerable, while the index 'resilience' is hardly affected.

Figure 12.23: Sensitivity of the 'resilience' index; rounding procedure (up and down) Waerengaokuri, 2006

Both 'vulnerability' and 'resilience' indices include 'adaptive capacity', which is a sub-index partly based on census data. In comparison, the index 'needs' consists entirely of two census-based indicators ('below 5 years of age', '65 + years of age'), while 'self-sufficiency' includes only one census-based indicator ('industry'). Although the indicator 'industry' is not part of the set tested for sensitivity to rounding, the results concur with the general observation that the index 'vulnerability' is overall more sensitive to rounding effects than the index 'resilience'. This is because the former contains more census-based indicators.

The uncertainty introduced by the random rounding procedure decreases with population size and is negligible at a population of 210 (Aoraki).

In conclusion, the random rounding procedure implemented by Statistics New Zealand causes considerable uncertainty when modelling a 'worst-case' scenario (all indicators are rounded up). This scenario may or may not be the case – the user of census data cannot know which

procedure was applied. The effect of rounding is reduced considerably when values are rounded up and down, which implies that differences are compensated.

The testing reveals that ideally the type of vulnerability and resilience analysis developed in this thesis should favour communities with at least 200 people. In addition, the fewer the number of meshblocks that are aggregated for areas with a low population, the lesser the effect on the results.

In this research, the uncertainty introduced by the rounding affects two of the ten communities, in particular with respect to outcomes of the 'vulnerability' index. This uncertainty is a problem related to the type of input data, not the indices themselves, and can therefore not be resolved. Indeed, the methodology for index construction applied in this research is not sensitive to this problem: overall, the effects of data uncertainty within both indices are very contained and do not spread amongst the communities of the sample.

12.3 Discussion

The discussion synthesises the sequence of questions posed in section 12.1. The focus of the discussion is to reveal the driving factors behind both the 'vulnerability' and 'resilience' index scores. Firstly, spatial differences (between the three locations as well as within these groups) are examined. Secondly, differences in time are analysed for the census years 1981 to 2006 (WHH) and 1991 to 2006 (Te Arai, Aoraki). The discussion draws on the performance of individual indicators which enter the 'vulnerability' and 'resilience' indices according to the index structure described in chapter 11. In addition, methodological issues are discussed at the end of this section.

12.3.1 Spatial analysis: the 'vulnerability' index

The three locations Te Arai, WHH and Aoraki clearly perform differently with respect to the indices 'vulnerability' and 'resilience'. In the following, comparisons between communities are based on average percentages for indicators which are calculated on the base of yearly percentages for the census years 1991 to 2006.

In case of the index 'vulnerability' all communities of the **Te Arai** are, on average, ranked highest, meaning least favourable with respect to risk. This is because they are all ranked lowest for 'adaptive capacity' and all rank highest for the index 'needs'.

With respect to the index '**needs**', Waerengaokuri and Manutuke have, on average, the highest percentage of children under five years of age (9.7% and 10.4%, respectively). In comparison, the portion of children of this age group is lower in Waingake (7.8%), however similar to Tirohanga and Belmont. In addition, the proportion of elderly (65 years of age and older) in Manutuke and Waingake is amongst the highest of all communities (7.9% and 7.8%, respectively). In Waerengaokuri this figure is at 6%, which is still amongst the highest figures

compared to the WHH and Aoraki. In addition, Te Arai communities contain the highest share of critical infrastructure aged at least 51 to 65 years. Moreover, neither Waingake nor Waerengaokuri have critical facilities such as medical facilities, a police station or a fire station. Manutuke is better placed in this respect, with a police and fire station present since 1991. In combination, these factors explain the high scores for the index 'needs'.

When examining the '**adaptive capacity**' index more closely, one indicator which stands out amongst those aggregated into the 'socio-economic' sub-index is 'household income'. On average, in Waingake and Manutuke 21% of households are at or below the poverty threshold, closely followed by Waerengaokuri (18%). In addition, the most prominent difference is observed for the indicator 'industry' because almost 30% of residents in Waingake and Waerengaokuri are working in the farming, forestry or fishing sector, while this number drops by 50% for Manutuke (15%). In comparison, the share of people working in this sector in Aoraki and WHH varies between 0.1% and 0.5%. While proportions of single households in Waerengaokuri and Manutuke are comparable with WHH or Aoraki, Waingake has, on average, the second highest portion of single households (20%). Comparatively many one-parent households are present in Waingake (9.8%) and in particular Manutuke (20%) – the highest figures on average for all communities. As with critical infrastructure, Te Arai has the highest share of aged roading. In addition, road connectivity is much lower compared to all other communities. All these factors decrease scores for the index 'adaptive capacity'.

The percentage of females within the Te Arai communities is only slightly lower than compared to the WHH. Compared to the two other locations, the percentage of residents born overseas is very low, ranging between 4.7% (Waingake) to 8.5% (Waerengaokuri). Of the Te Arai communities, Waingake and Manutuke are characterised by low proportions of people living at their residence for four years or less; Manutuke displays the lowest average degree of all communities (36%). No visitors from overseas are recorded for Waingake and Waerengaokuri, while the number is only slightly higher for Manutuke (0.4%). With respect to the pressure on access points, the Te Arai communities are in a much better situation than all other communities. In particular, Waingake and Waerengaokuri display the most favourable ratio of access points to population size, while the average score drops by more than 50% for Manutuke, and rapidly for all other communities. These factors prevent an even lower score for the index 'adaptive capacity'.

On average, **Aoraki** clearly scores lowest for the index 'vulnerability' which matches the very low score for the index 'needs'. This good performance for the 'vulnerability index' is not affected by an only middle-range score for 'adaptive capacity'.

In Aoraki, only few community members are, on average, below five years or above 65 years of age (3.4% and 2.8%), which favours low scores for the index '**needs**'. The portion of aged critical infrastructure is amongst the lowest of all communities. Aoraki is the community with the second largest number (after Maungaraki) of critical facilities (medical and fire station).

On average, 19.7% of the households in Aoraki are below the poverty line, which influences the index '**adaptive capacity**' adversely – this score is comparable with Te Arai. Most strikingly, about half of all residents in Aoraki live alone; this proportion is more than double compared to Korokoro (20.5%), which is (on average) the community with the second highest proportion of single households.

Aoraki is a community which shows one of the highest shares (22%) of residents born overseas. The average score for another indicator, 0-4 years at residence, is relatively high: 57.3% of residents live four or less years in the village, compared to 52% in Tirohanga and only 36.9% in Manutuke. One indicator displays outstanding scores: 55% of people present in Aoraki are visitors, which is by far the largest amount recorded (Te Arai: about zero, WHH: between 0.6% and 1.4% on average). Finally, the ratio of access points for the population present is amongst the least favourable.

With respect to scores for the index 'adaptive capacity', the lowest overall percentage (2.3%) of one-parent households works in favour of Aoraki. On average, Aoraki displays the lowest percentage of females (40.7%). In addition, only 0.3% of community members work in the farming, fishing or forestry industry. The degree of aged roading is amongst the lowest of all communities, while road connectivity is less than average. In Aoraki, the less favourable scores of some indicators are balanced by a good performance of other indicators. This combination results in a score for the index 'adaptive capacity' which is just above average.

For all indices other than 'adaptive capacity' the communities of the **Western Hutt Hills** tend to be placed between Te Arai and Aoraki. When comparing average scores for the index 'needs' and 'vulnerability' it appears that the sequence of communities is very similar (question 1). Interestingly, Korokoro's scores are the least favourable for the indices 'needs' and 'adaptive capacity'. In contrast, Maungaraki scores, on average, lowest (meaning most favourably) for the index 'needs' and performs best (among all communities) for the index 'adaptive capacity'. Therefore, Korokoro is in a far less desirable situation with respect to risk than Maungaraki. Maungaraki is rewarded with a low vulnerability score.

When looking more closely at the components of the index '**needs**' it is observed that on average Korokoro contains the highest proportion of elderly (8.4%) compared not only to other communities of the WHH but also to Te Arai and Aoraki. In addition, Korokoro is the only community within the WHH, and overall, where the percentage of people aged 65 and more exceeds the percentage of children below five years of age (6.4%). After Kelson (9.4%), Normandale is characterised by a medium value for children under five years (7.2%), and a medium value for the elderly (5.6%). The balance between children under five and the elderly is almost even in Maungaraki, and generally both age indicators rate amongst the lowest scores observed in the WHH.

Korokoro by far exceeds all other communities of the WHH in terms of the portion of aged critical infrastructure (76%). Aerial photo analysis revealed that Korokoro is one or perhaps even the oldest suburb in the WHH. In contrast, Maungaraki was built rapidly in the early 1960s which means that with a cut-off year of 2005, critical infrastructure has not reached the most susceptible age group yet. Consequently, Maungaraki scores lowest for this indicator (0%). Likewise Kelson, which scores second lowest with respect to the index 'needs' for the WHH, has the second lowest average proportion of aged critical infrastructure (11.6%). In contrast, Normandale has the second highest share of aged critical infrastructure (58.4%). Belmont follows closely with 53.6%, and in Tirohanga this value is comparatively low (36.1%). While no critical facilities have been present during the period of analysis in Korokoro or Normandale, one medical facility existed in Kelson in 1991. Maungaraki does not show the constancy of critical facilities present as Aoraki and Manutuke, but performs best compared to all other communities (including Te Arai and Aoraki) with at least one, in some years even two, medical facilities located within the community.

Examining the components of the index '**adaptive capacity**', Tirohanga clearly shows the lowest average percentage of households at or below the poverty level (6.8%); Normandale follows (8.4%), then Belmont (9.1%), Kelson (9.4%), Maungaraki (10.8%) and Korokoro (11.8%). Differences between the percentages of females are negligible between the communities of the WHH, which on average make up about 50% of the population. Korokoro clearly tops all other communities of the WHH in terms of single person households (20.5%, next lowest: Maungaraki: 15.3%), which places it on the same level as Waingake. Kelson and Normandale closely follow Maungaraki, and Belmont shows a distinct lower proportion of one-person households compared to all other communities of the sample (9.1%). With respect to single parent households, differences between the six communities are very small, with Tirohanga displaying the lowest share of 5.3% compared to Maungaraki at the top end with 8.2%. Likewise, differences in the indicator 'birthplace' for WHH are very small and are generally around the 20% level next to Aoraki. In addition, the variation of people resident for four years or less is homogenous, ranging between 47% (Korokoro) and 52% (Tirohanga). However, Normandale stands out with only 43% of its residents, on average, living at their usual address for four years or less. Again, differences with respect to the indicator 'industry' are small, ranging between 0% (Tirohanga) to 0.5% (Belmont). Finally, no considerable variation is observed for the portion of overseas visitors, with only Korokoro overtopping the other communities with a share of 2.3%.

The differences in the proportion of aged critical infrastructure translate into the index 'roading', and mirrors the history of suburban development in the WHH. Road connectivity is overall similar, with Maungaraki scoring best for this indicator with a value of 3.8 nodes per kilometre which is the highest value overall. The ratio of access points to community members is very

homogenous amongst the communities of the WHH, with only Normandale performing slightly better than the rest. The lowest values are calculated for Kelson.

12.3.2 Spatial analysis: the 'resilience' index

The differences between the three locations presented and discussed so far also manifest for the indices 'self-sufficiency' and 'resilience'. Te Arai communities top the scores for the first index although they are closely followed by Maungaraki; a distinct distance to all other communities is recorded for the next lower-scoring community (Kelson). Tirohanga, on average, scores lowest and is placed clearly below Aoraki. Maungaraki only just leads the scores for the index 'resilience', followed by the block of Te Arai communities, then the WHH and Aoraki which shares its bottom position with Korokoro (question 1).

While the results for the index 'adaptive capacity', which is considered as an element of resilience in this research, are discussed above, the focus here is to examine the situation for the index 'self-sufficiency'.

Two communities score obviously highest for the index '**self-sufficiency**': Maungaraki and Manutuke (**Te Arai**). During the whole period of analysis, four marae are present in Manutuke, which are among the oldest in the country (Ria, 1986). No other marae are present in the sample of communities. In addition, one church offers its services, and one school is active. In comparison, Waingake and Waerengaokuri offer a school only.

The comparatively high percentage of community members working in the farming, forestry or fishery industry (both 30% in Waingake and Waerengaokuri and 15% for Manutuke) – a disadvantage in terms of adaptive capacity and vulnerability – is turned into an advantage with respect to the 'self-sufficiency' and 'resilience' indices.

Aoraki is a community where a school and, more recently, a community centre are present. Comparatively, the score for the index 'community facilities' is, however, low. Likewise, the low value for the indicator 'industry' is, within the context of self-reliance, a disadvantage.

Maungaraki leads the 'self-sufficiency' scores within the **WHH**, and the rank of the index 'resilience'. Korokoro, which displays the least favourable (highest) scores for both the index 'needs' and 'vulnerability', is (besides Aoraki) overall ranked the least resilient community.

As mentioned above, Maungaraki is (next to Manutuke) the community with the largest number of community facilities. A school, a community centre, a kindergarten, a playgroup and two churches are operating since 1986. Kelson is ranked second for this indicator within the WHH communities and is, together with Maungaraki and Aoraki, amongst the three communities with a community centre in addition to a school. Korokoro, Normandale and Belmont are positioned only slighted better than Tirohanga, where only a school is present.

As with Aoraki, the comparatively low proportion of people working in the farming, forestry or fishing sector entails consistently low scores for the sub-index 'self-reliance'.

Figure 12.24 summarises not only the differences discussed above but also the magnitude of difference between the three locations for the five index scores. The plotted values are the averages of the means, for each census year between 1991 and 2006, for each community per location.

Both 'vulnerability' and 'resilience' scores drop along the Te Arai-Aoraki gradient. The index 'vulnerability' decreases by 0.50 units between Te Arai and WHH, and another 0.72 units between WHH and Aoraki. The total magnitude of change is therefore 1.2 units, which (on the scale the data is recorded) is a considerable difference.

Maximum values for the index 'vulnerability' are coupled with maximum values for the index 'resilience' for the communities of the Te Arai. Again, scores for 'resilience' drop along the gradient – however to a much smaller extent compared to 'vulnerability'. The WHH are placed 0.33 units below Te Arai, and Aoraki is located 0.24 units below the WHH. The maximum magnitude of difference is therefore 0.57 units.

Scores for the indices 'vulnerability' and 'resilience' for Te Arai and WHH are far closer than compared to Aoraki. For the latter, the score for 'resilience' is more than three times higher than the score for 'vulnerability'.

Figure 12.24: Index scores averaged for all years and communities within each group (except Aoraki), 1991-2006. When calculating the index 'vulnerability', values for the sub-index 'adaptive capacity' are reversed. This is because low values for 'adaptive capacity' are associated with high values in 'vulnerability'.

On average, the communities of Te Arai display clearly high values for the index 'self-sufficiency', while the distance in scores for the index 'adaptive capacity' is not as distinct. This explains why the Te Arai is ranked, on average, above the WHH and Aoraki for the index 'resilience'.

It should be noted that since Aoraki is only one community, a poor performance cannot be compensated by a very good performance of another community when calculating mean scores, as is the case for some of the communities in Te Arai and WHH. However, as discussed above, Aoraki features some of the most distinct high or low indicator values, decreasing the scores for the indices 'vulnerability' and 'resilience' alike. In addition, communities with a similar set-up as Aoraki can be expected to share some of its characteristics, for instance with respect to the socio-economic profile. This, in turn, would emphasise Aoraki's performance compared to Te Arai and WHH.

12.3.3 Spatial analysis: the ratio of 'vulnerability' to 'resilience' (VR-ratio)

The vulnerability and resilience analysis not only enables the identification of differences between the three locations (and within these) for both conditions, and the driving factors behind these differences. What is more, the relation of vulnerability and resilience can be examined. As surfaced in the presentation and discussion of the analysis results so far, several combinations of vulnerability and resilience levels are observed.

When comparing the three locations² a pattern emerges which can be expressed as the ratio between index scores for 'vulnerability' and 'resilience' (VR-ratio). While values above one indicate that vulnerability exceeds resilience, values below one show that resilience exceeds vulnerability. Values of one imply that both are equal (figure 12.25).

Since negative values would skew the interpretation of the ratio of vulnerability to resilience, all values are shifted up by a value of 1.3. This ensures positive values for all calculations. The value of 1.3 is derived by identifying the lowest overall value for vulnerability and resilience, for each community and year (Aoraki, -1.25, 1991). This value is used in further comparisons between the mean of each community, as well as in the analysis of yearly values for each community. To ensure consistency, the same value is used for the following analysis.

As demonstrated in figure 12.25, the ratio for Te Arai exceeds one, which suggests that Te Arai is the least favourable location with respect to risk. The ratio for WHH is below one, indicating a more favourable condition. However, the ratio is only just below one (0.93), which indicates that the benefit is only small. Indeed, the communities of the WHH are, on average, closely placed below Te Arai. Aoraki is in a considerably better situation compared to Te Arai and WHH: the ratio of vulnerability to resilience is about half of the ratio for Te Arai and WHH.

²As previously, the comparison is based on the mean values (1991-2006) for each community, from which again a mean score for all communities per location is computed.

Figure 12.25: Ratio of vulnerability to resilience

When dissolving the mean values for the three groups, a more differentiated pattern emerges (figure 12.26). Clearly, Korokoro is the community with the least favourable ratio of vulnerability to resilience, followed by Belmont and Tirohanga. It is only now that the communities of the Te Arai appear at very similar values just above one. Manutuke displays the most favourable ratio of the Te Arai. Normandale follows closely, while Kelson is obviously better placed, and so is again Maungaraki. Maungaraki and Aoraki have a very similar VR-ratio, which brings them into the best situation with respect to risk.

Figure 12.26: Ratio of vulnerability to resilience, based on the average values for the years 1991-2006, for all communities

12.3.4 Temporal analysis: the 'vulnerability' index

A variation of different types and magnitudes of change is observed with respect to the indices 'needs', 'self-sufficiency', 'adaptive capacity' and the final indices 'vulnerability' and 'resilience'. The changes and the factors causing these changes are discussed in this section.

Two aspects need to be considered with respect to the analysis of temporal variations. Firstly, observations depend strongly on the length of the time period. As discussed in chapter 4, the perception of the observer is influenced by the time record available. Hence the types and magnitudes of change presented and discussed in this research are relative: if it were possible to extend the period of analysis into the 1970 or even further, a different pattern may be observed.

Secondly, temporal variations of census-based indicator values, which are percentages converted into z-scores, can occur due to a change of the indicator itself, the socio-economic composition of the community, or both. For example, a decrease of the percentage of children below the age of five may be caused by people of different age groups moving into the community. Likewise, a proportional increase of the elderly may be caused by young and middle aged people moving out of the community. Interpretations of varying percentages are therefore accompanied with a level of uncertainty when aiming to understand what causes the observed changes. In this research, this uncertainty cannot be erased. Increases or decreases in the percentage of a specific indicator are therefore interpreted as changes of the indicator itself, such as 'single household', rather than of other changes in the composition of the population. As will be discussed later in this section, several distinct, linear trends are noticed for a range of communities. Since it is unlikely that the composition of all communities changed simultaneously in the same way, focussing on the indicator itself as the cause of the change is justified.

Magnitudes and types of index development vary amongst the communities of **Te Arai**. While for Waingake some fluctuation is registered for the index '**needs**', the index score drops abruptly in 1996 for Waerengaokuri (and increases abruptly afterwards), while Manutuke witnesses a gradual, not very pronounced decline which comes to a halt in 2006 (appendix F). Since values for both the indicator 'critical facilities' and 'critical infrastructure' are very constant in time for all three communities, the change in scores for the index 'needs' is mainly driven by the age-related indicators. Indeed, both the portion of children under five years of age as well of the elderly is very steady during the period 1991 to 2006 for Waingake. A drop in the number of children under five years of age is recorded for Manutuke (from 13% to 9%), while the number of elderly is steady, with a slight increase in 2006 (from 7.5% to 9%). A distinct 'valley' shape (appendix F), with a lowest value of 3.3% in 1996, is recorded for the share of the elderly in Waerengaokuri. This development is matched by the proportion of children under five, which reaches its minimum (6.7%) in 1996, jumps to 11.5% in 2001 and falls again slightly to 9.4% in 2006.

When comparing the magnitude of change between not only Te Arai communities, but also all other communities, the population size needs to be considered. As concluded previously, communities with a small population size are more sensitive towards rounding uncertainty.

Likewise, temporal changes of census data (population size or counts), even if only small, provoke a larger effect on the proportion, for instance of children under five years, compared to larger communities.

The implication of such changes are still meaningful, in the sense that raising for instance the number of elderly by 20 will influence a small community more than a larger community. Absolute percentages and hence index scores can therefore still be evaluated. However, comparing magnitudes of temporal change between relatively small and large communities is difficult. The ranking presented in section 12.1 (question 5), showing the variability of index scores in time, illustrates this effect: Waerengaokuri, the smallest community, is ranked first with all five indices showing abrupt changes in time.

Generally, small population sizes can hamper spatial analysis as observed by Finnis (2006). She assessed groups at risk to volcanic hazard in Taranaki, New Zealand, by combining hazard, demographic (census) data and socio-cognitive data obtained by surveys. In particular when aiming to address a regional context, for example for devising a public education strategy, she encountered the problem of lacking representability in cases of a small population size per spatial unit.

Manutuke stands out as one of the least variable communities, not only in comparison with Waingake and Waerengaokuri. Values for '**adaptive capacity**' alternate only little; a peak in 1991 for the index 'needs' (highest proportion of children under five years) and the second lowest value for 'adaptive capacity' produce a maximum value for the index 'vulnerability' in 1991. Subsequently, index scores stabilise.

For Manutuke no clear trend but a slightly fluctuating development is characteristic for the indicators 'household income', 'females', 'one-parent household', 'birthplace', 'industry' and 'visitors'. A gradual increase in the share of people resident for four years or less is recorded between 1991 (31%) and 2006 (39%). The portion of single households drops between 1991 and 1996 from 12.9% to 9.2%, but only to increase steadily in the following census years and reaching almost 20% in 2006.

Indicators associated with infrastructure are almost constant in time, in particular 'roading' and 'road connectivity'.

As discussed above, evaluating magnitudes of change is a difficult task for small communities such as Waerengaokuri and Waingake. Values for 'household income', 'gender', 'single household', 'one-parent household', 'birthplace', '0-4 years at residence' and 'industry' oscillate around a certain value for both communities. It may be misleading, however, to consider these two small communities as frequently changing.

For both communities, a steady indicator is 'visitors' which displays values of zero for all years. As with Manutuke, the indicators 'roading', 'road connectivity' and 'access' are constant in time as well.

The period of analysis for the **WHH** expands into the 1980s. Magnitudes of change are not directly comparable with Te Arai and Aoraki when based on a different period of time as pointed out previously. However, when aiming to reveal trends in the data the additional information contained in the years 1981 and 1986 is included in the discussion of temporal changes in the WHH.

During this time Belmont, Tirohanga, Normandale and Korokoro experienced abrupt changes, both for the indices 'needs' and 'vulnerability'. The development of Belmont and Tirohanga is very similar, not only for these two but for all indices. Belmont and in particular Tirohanga display pronounced negative values for the index '**needs**' in 1981 and 1986. This can be explained by the lack of aged critical infrastructure at these points in time – a phenomenon which is observed not only for Belmont and Tirohanga but for all communities of the WHH. With time, this proportion increases for all communities other than Maungaraki. Changes are, however, only relatively small after 1986. As discussed previously, Maungaraki as the 'youngest' suburb has not reached the critical age (for infrastructure) as yet, and is therefore in a favourable situation with respect to the indices 'needs' and 'vulnerability'.

The indicator 'critical facilities' is a constant for Tirohanga and Belmont since neither medical facilities, a police station or a fire station are operating during the period of analysis. As with 'critical infrastructure' this is a widespread phenomenon of the WHH communities. As mentioned previously, Maungaraki is an exception because it provides medical facilities for its residents, with a maximum of two facilities in 1986, 1991 and 1996. One of these closed between 1996 and 2001. In Kelson, one medical facility was located in 1991.

Changes in population size can affect this indicator since it expresses the ratio of critical facilities to community members. Variations of population size for the three locations are presented shortly. Nevertheless, if no critical facilities are present, the value will be zero.

The two age-related indicators therefore noticeably influence the development of the scores for the index 'needs'. The proportion of children under five years of age has gradually dropped, but only slightly, over time in Belmont (1981: 8.8%, 2006: 7.4%). Values for Tirohanga fluctuate more, but apart from a peak in 1991 (10.2%) are stable between 6% and 8%. Of the other four communities, Kelson displays a clear gradual decline of the portion of children under five years of age between 1981 (14.6%) until 1996 (8.7%), which stabilised on this level for the following years. An overall drop is also recorded for Normandale, however to a smaller extent (from 8.3% in 1981 to 6.3% in 2006). Values for Maungaraki fluctuate around a value of 6% and 8%, respectively.

Interestingly, while Kelson experiences a continuous and considerable decline in children less than five years of age, its proportion of people with 65 years of age and more increased gradually and pronounced from 1.1% in 1981 to 5.6% in 2006. Likewise, Maungaraki and

Normandale show an emphasised and gradual increase of the proportion of people in this age group, with values of 2.7% and 2.8% in 1981, and values of 7.3% and 7.1% in 2006, respectively. This trend is not, or only slightly (Normandale), counterbalanced by a decline in children under the age of five. Moreover, also Tirohanga experiences a pronounced increase with values rising from 0.5% to 6.8%. As mentioned previously, the proportion of elderly in Korokoro has always been the highest, and the increase is comparatively small (by about 3%). Only Belmont shows very little increase of the elderly (by about 2%)

For the period 1981-2006 only Tirohanga and Belmont display abrupt changes with respect to the index '**adaptive capacity**'. A similar, though not as pronounced, drop in index scores after 1986 is observed for Normandale and Korokoro. Generally, however, all communities of the WHH experience their maximum values for 'adaptive capacity' in the 1980s.

This is because the communities of the WHH show a distinct and steady increase of values (meaning an unfavourable evolution) from 1981 until 2006 for most of the socio-economic indicators associated with the index 'adaptive capacity', in particular the indicators 'single household', 'one-parent household' and 'birthplace'. The largest increase is recorded for Kelson where the value for the indicator 'single household' steadily rises almost threefold from 6.4% in 1981 to 17.4% in 2006. Values for Maungaraki double during this period, and the magnitude of increase varies between 5% and 8% for all other communities. In case of the indicator 'one-parent household' proportions double for Belmont, Kelson and Maungaraki. Tirohanga, Korokoro and Normandale fluctuate more, and the trend of increase is less pronounced. Increases for the indicator 'birthplace' are clearly gradual and are overall on a magnitude of about 5%. The indicators '0-4 years at residence' and 'visitor' also show an overall increase in time, however on a smaller magnitude. Variation for all communities with respect to the indicators 'industry' and 'females' is negligible.

Tirohanga and Belmont both experience the highest proportion of households at or below the poverty threshold in 1981 and 1986. While the proportion of these households drops from 18.9% in 1981 to 7% in 1991 for Tirohanga, the decline for Belmont is slightly less (from 14.9% in 1981 to 7.8% in 1991). A comparable magnitude of change between 1981 and 1991 is recorded for Korokoro, where the portion of households at or below poverty threshold decreases from 20% to 11.2% and stabilises at this level. Normandale also experiences its maximum amount of low income households in the 1980s, although the distance to the 1990s is not that obvious (drop of ca. 4%). The portion is stable around 10% for Kelson and Maungaraki. The dominance of indicator scores increasing gradually in time, with minimum values in the 1980s, therefore counteracts the pronounced peak values for the indicator 'household income' for some communities during the 1980s.

In addition, the absence of aged critical infrastructure in the 1980s is matched with the absence of aged roading networks which emphasises the high values of the index 'adaptive capacity' in the 1980s. Changes in the indicator 'road connectivity' are negligible for Korokoro, Belmont and

Normandale. Tirohanga witnesses a small increase of connectivity. Maungaraki stands out amongst all communities: with the second largest value of all in 1981, connectivity increased constantly to a value of 4.6 nodes per kilometre - a score about double as high compared to all other communities. In contrast, road connectivity in Kelson decreases in time, from the highest value in 1981 (3.3) to 2.5 in 2006 which is below most other communities. Scores for the indicator 'access' hardly change for Kelson, Maungaraki, Korokoro or Normandale. Tirohanga displays the overall highest and most favourable ratio of access points to population during the 1980s and in 1991, which decreases however afterwards. This is linked to a distinct increase of the population size as will be illustrated shortly. Likewise the values decrease for Belmont which is after Normandale the community with the third highest values for this indicator. The lowest scores are recorded for Kelson.

Aoraki experiences an abrupt change with respect to the index '**needs**': after the overall minimal value of -1.68 the score rises to -1.33 in 1996, continues to rise, but only to plummet between 2001 and 2006. The indicator 'critical facilities' follows a similar type of change, which is mostly due to the development of population rather than a change in the number of critical facilities (which is constant). The indicator 'critical infrastructure' hardly changes in time. The two age-related indicators support the observed pattern of the index 'needs'. Both 'below five years of age' and '65 years and more' are rather constant in time but display a peak in 1996 and 2001, respectively, which explains the increase of the index 'needs' for these two years.

The index '**adaptive capacity**' decreases steadily and considerably in time. This can be partly explained by a steady increase of the proportion of households at or below the poverty threshold (1991: 19.2%, 2001: 26.1%), although the proportion drops to 9.5% in 2006. A drastic increase is recorded for the indicator 'females', where figures rise from 35.3% in 1991 to 50% in 2006. In addition, the proportion of one-parent households rises from 0% to 4.8% in 2006. Another pronounced increase is the development of the indicator 'birthplace', where the share of residents born overseas doubles from 17.6% in 1991 to 34.3% in 2006. Moreover, after a steady level at about 50% between 1991 and 2001 the proportion of people residing four or less years in the community increases to 74.3%. Finally, visitor numbers rise steadily from 44.4% in 1991 to 63.2% in 2006. A counteracting development is observed for the indicator 'single household', where the proportion drops from 57.7% in 1991 to 42.9% in 2006. It appears that only the indicator 'industry' is rather constant.

Similar to values for the indicator 'critical infrastructure' values for the indicator 'roading' hardly change in time. Likewise, the indicator 'road connectivity' shows little variation. The indicator 'access' varies slightly due to changes in the population size, not because of a change of access points into the community. Therefore, the scores for the index 'adaptive capacity' are mainly driven by the socio-economic indicators.

12.3.5 Temporal analysis: the 'resilience' index

The focus of this section is the index '**self-sufficiency**'. Again, compared to other communities of **Te Arai** and overall, Manutuke displays only little variation for this index and, in combination

with 'adaptive capacity', shows constant values for the index 'resilience'. This can be explained by neither an increase nor decrease in the number of community facilities over time (one school, four marae, one church). In addition, values for the indicator 'industry' vary only to a small extent. The interpretation of temporal changes for Waingake and Waerengaokuri needs to be treated with caution; for both communities, values for the indicator 'industry' vary considerably. For example, the score for Waingake rises from 24.5% in 1996 to 37.2% in 2001, only to drop to the 1996-level in 2006. In Waerengaokuri, the 1990s vary comparatively little, but values drop between 1996 and 2001 from 36.7% to 23.1%. Again, this value hardly changes in 2006. For Waingake one factor which definitely contributes to a decrease of values for the indices 'self-sufficiency' and 'resilience' is the closure of the school in 2001. This leaves Waingake without a community facility. In comparison, the school in Waerengaokuri is still operating in 2006. As in Waingake, no other facilities are present during the time of analysis.

In the **Western Hutt Hills**, some communities show only little variation of scores for the index 'self-sufficiency'. One stabilising factor is that for all communities, changes of the indicator 'industry' are minor. Differences do, however, occur with respect to the indicator 'community facilities'. In Maungaraki, a community centre opened in 1986, and a second church. Overall, Maungaraki is and has always been best equipped with community facilities, which explains its constant (high) level of the index 'self-sufficiency'. Kelson witnessed a continuous growth of community facilities, starting with a school and playgroup in 1981, a community centre in 1986 and a church in 1996. In Belmont two schools are operating continuously, and a playgroup. In Korokoro and Normandale one school and a kindergarten or playgroup, respectively, have been and are still present. Finally Tirohanga never had any community facilities other than a school.

Scores for the index 'self-sufficiency' for **Aoraki** increased stepwise between 1996 and 2001. Again, this is not so much the result of the indicator 'industry', but the indicator 'community facilities'. A school has been and is still operating continuously during the period of analysis, and in 2001 a community centre was added. However no other facilities are present.

12.3.6 Trends in population size

While changes of individual indicators in time are discussed so far, the type and magnitude of the variation in community population is of interest in this research. Figures 12.27 and 12.28 plot the development of population figures for the WHH during the period 1981 to 2006, and for Te Arai and Aoraki for the period 1991 to 2006.

Some distinct differences emerge between the communities, not only in absolute population size, but also in the development of population in time. In the WHH, Korokoro, Maungaraki and Normandale are relatively stable with respect to their population sizes, while Tirohanga, Belmont and Kelson experience an increase of population size.

Figure 12.27: Population (absolute numbers) for the Western Hutt Hills³

In Te Arai, only Waerengaokuri shows a rise in population figures, while Waingake is relatively stable. In contrast, Manutuke as well as Aoraki loose community members.

Figure 12.28: Population (absolute numbers) for Te Arai and Aoraki⁴

The magnitude of these changes is captured when comparing the percentage of change for each community. Table 12.8 depicts changes between 1981 and 2006 as well as between 1991 and 2006 for the WHH, in addition to changes between five year intervals. For Te Arai and Aoraki, changes between 1991 and 2006, and five year intervals, are listed. Depending on the

³ Lines are added to improve the readability of the graphics and are not intended to demarcate interpolation between measured values.

start and end date of the comparison, percentages of change differ, which (again) is obvious when including the 1980s for the WHH.

Table 12.8: Change of population (in percentages)

	% change 1981- 2006	% change 1991- 2006	% change 1981- 1986	% change 1986- 1991	% change 1991- 1996	% change 1996- 2001	% change 2001- 2006
Korokoro	3.4	11.5	1.2	-8.4	8.1	-0.7	3.9
Maungaraki	-0.2	5.6	-4.0	-1.6	1.3	-2.2	6.6
Normandale	1.6	3.7	3.8	-5.6	1.0	-1.2	3.9
Tirohanga	80.2	70.2	4.1	1.7	21.3	19.6	17.3
Belmont	36.7	25.3	9.3	-0.1	9.5	4.1	9.9
Kelson	18.3	2.8	14.2	0.7	1.8	-1.2	2.2
Waingake		-2.0			8.2	-18.9	11.6
Waereng.		18.5			11.1	-13.3	23.1
Manutuke		-11.1			18.7	-20.2	-6.1
Aoraki		-17.6			29.4	-8.2	-30.7

After an initial growth, the second half of the 1980s in the WHH is dominated by population losses in the Western Hutt Hills. Where an increase is recorded, it is not very pronounced. With the beginning of the 1990s, this trend comes to a halt in all communities of the WHH, plus Te Arai and Aoraki, grow. Subsequently, numbers for the second half to the 1990s decline again for most communities, although to a smaller extent than previously. It is, however, during this period that the communities of the Te Arai show their greatest decline. While almost all communities can recover between 2001 and 2006 and noticeably grow again, Manutuke and in particular Aoraki decline further.

The data illustrates clearly that Tirohanga and Belmont are the two communities which witness a considerable increase of population. In particular Tirohanga has grown extensively: the population increases by 70% between 1991 and 2006. Tirohanga therefore by far exceeds any other rate of population growth. Belmont and Kelson encounter a substantial growth between 1981 and 1986 (9.3% and 14.2%, respectively). Hence Kelson's growth rate jumps up to 18.3% for the period of 1981 to 2006.

Belmont and Tirohanga are the two communities with the highest number of indices showing abrupt changes during 1981 and 2006. These indices are 'needs', 'adaptive capacity' and hence 'vulnerability', which concurs with the dynamic pattern observed within the socio-economic domain.

Temporal changes for Waerengaokuri and Waingake need to be interpreted with care, since they are comparatively more sensitive to the rounding procedure applied by Statistics New Zealand (SNZ). However, generally Waerengaokuri appears to gain in population size, while Waingake is more stable and seems to even suffer a slight loss during the period of 1991 to 2006. In contrast, the development for Manutuke is clear: after a strong increase between 1991 and

1996 by 18.7%, numbers fell almost by the same amount (20%) in the following interval, and the decline diminished to about 6% between 2001 and 2006. A similar pattern is observed for Aoraki, where an initial increase between 1991 and 1996 is more than compensated in the following years. Between 2001 and 2006, population numbers fell by 30.7%.

12.3.7 Temporal analysis: the ratio of 'vulnerability' to 'resilience' (VR-ratio)

Not only the temporal variation of vulnerability and resilience each, but also the change of their relation is of interest in this research. Table 12.9 (and figure 12.29) lists the ratio of vulnerability to resilience for each point in time for all communities. Index scores are increased by 1.3 units to avoid negative figures.

Aoraki and Maungaraki stand out because they consistently show the most favourable, meaning lowest, ratio of vulnerability to resilience. For both, however, the ratio increases in time. While this development is gradual for Maungaraki, the values climb drastically for Aoraki: the ratio increases by 0.68 units between 1991 and 2006, compared to 0.14 units for Maungaraki. Already in 1996 and more clearly in 2001, Aoraki has overtaken Maungaraki.

Shaded in dark grey are those communities where the ratio of vulnerability to resilience increases between 1991 and 2006, although not as steadily and to a smaller extent (Waingake, Waerengaokuri, Kelson, Normandale, Belmont). A drop of the ratio is registered for Manutuke (by 0.17 units). In addition, the VR-ratio tends to decline for Tirohanga, however this is less clear since the value varies to a greater extent. However, the absolute change is the second largest (0.30 units). For Korokoro the evolution of the VR-ratio describes a curve where after a substantial increase for 1996 and 2001, the ratio drops to a value similar to 1991.

Table 12.9: The ratio of vulnerability to resilience, between 1981 and 2006, for all communities

	1981	1986	1991	1996	2001	2006
Waingake			1.04	0.94	1.15	1.13
Waerengaokuri			0.98	0.72	1.67	1.22
Manutuke			1.14	0.97	1.00	0.97
Kelson	0.93	0.67	0.76	0.66	0.81	0.88
Korokoro	0.78	0.64	1.39	1.60	1.56	1.36
Maungaraki	0.56	0.33	0.47	0.55	0.62	0.61
Normandale	0.61	0.58	1.05	1.11	1.22	1.09
Tirohanga	0.46	0.38	1.26	1.11	1.22	0.96
Belmont	0.66	0.63	1.27	1.18	1.27	1.19
Aoraki			0.04	0.56	0.58	0.73

When considering the 1980s for the WHH, a very distinct increase of VR-the ratio is registered between 1986 and 1991. The only exceptions are Maungaraki and Kelson, for which the 1981 value is just below or even above the 2006 value, respectively.

Figure 12.29: The ratio of vulnerability to resilience (since no values are available for Te Arai and Aoraki in the 1980s, their value is set to zero)⁴.

12.4 Methodological considerations

Firstly, one methodological aspect is the *appropriateness of the indicators* chosen to represent a specific dimension. The dimension of self-reliance is represented by one indicator only ('industry'). It is, however, feasible to assume that for Aoraki, a remote community encountering harsh conditions on a regular basis, self-reliance is higher than assumed. This means that self-reliance is not only attributed to being equipped with tools and resources needed to sustain a livelihood, but to being located in a remote area where resources and assistance from outside are not readily available. This may also be relevant for Waingake and Waerengaokuri. As mentioned in chapter 11 this is an interesting aspect, but difficult to quantify and justify on an empirical basis. Further work in particular with respect to the self-reliance of remote communities is needed to refine this dimension.

In addition, the indicator 'industry' as supplied by Statistics New Zealand does not differentiate between farming and forestry. The implications for vulnerability and resilience (livelihood depending on productive environment, self-reliance) are mainly associated with the farming sector, however they do apply to forestry and fishery as well to some extent. A shift from farming to forestry means that the number of employees in the forestry sector is likely to increase compared to those working in the farming sector. Consequently, the implications associated with the indicator 'industry' for both vulnerability and resilience may not relate as

⁴ Lines are added to improve the readability of the graphics and are not intended to demarcate interpolation between measured values. For 1981 and 1986 no values are calculated for Waingake, Waerengaokuri, Manutuke and Aoraki, which are set to zero for displaying purposes only.

much to these two conditions (livelihood, self-reliance) as the indicator suggests. However, as discussed in chapter 9, shifts from farming to forestry occurred before the 1990s, and the land use has been stable since with a dominance of farming. The shift from farming to horticulture in Manutuke does not affect the meaningfulness of the indicator, since the base of livelihood is equally based on the productivity of the land, and implications for self-reliance are not likely to change considerably.

The indicators 'critical infrastructure' and 'roading' are based on the assumption that with an age of at least 51 to 65 years, these structures are more susceptible to harm than younger structures. Maintenance will modify this linear assumption. Information which would reflect this aspect are not available for this research, hence the values for these indicators are interpreted as maximum values.

The community network is represented by the number of community facilities. This is a feasible approach; however, research in the form of interviews would be an enhancement when aiming to capture the strength of community networks. Such a procedure could not be included in this research, although methodologically it would be easy to include within the index structure. This is a prospect for future work, and may for example research the importance of pubs or sport clubs as nodes in the community network.

Due to limitations of available data, the pre-tax income is used when determining the cut-off point between households below and above the poverty threshold. This may increase the proportion of households included in this category, since the cut-off point is higher than compared to a post-tax income. Values are therefore interpreted as slightly overestimated than underestimated. Since the same cut-off point is used for all communities their comparison is not affected.

Secondly, as a result of the index structure and the aggregation method (chapter 11), *compensability* between sub-indices and between indicators is allowed for. Compensability implies that a very good performance in one sub-index or indicator can off-set the poor performance in another sub-index or indicator when these are aggregated. It is not possible to discuss every path of compensation within the index structure; however, an overview is given in the following.

At the third level of hierarchy, where the sub-indices 'needs', 'adaptive capacity' and 'self-sufficiency' are combined, compensation is conceptually feasible. For example, a community with comparatively high self-sufficiency can compensate for a low condition of adaptive capacity. This is because a relatively high self-reliance and/or a strong community network can abate the disadvantages stemming from a lack of adaptive activities before, during or after a crisis. Similarly, a low self-sufficiency may not influence resilience as much when adaptive

capacity is high. With respect to the condition of vulnerability, comparatively high adaptive capacity can reduce the disadvantages a community is likely to encounter when critical services are lacking, or a relatively high proportion of community members is susceptible to be harmed (index 'needs'). Moreover, a low score of the index 'needs' is an advantage when adaptive capacity is low with respect to the condition of vulnerability.

At the second level of hierarchy, three pairs of two indices are combined. Compensation between the first pair, 'fragility & mobility' and 'critical services', is feasible: a favourable ratio of critical facilities to community members means that especially fragile and immobile people are likely to receive medical help or other assistance. The indicator 'critical facilities' aggregates medical services, police and fire services into one value, which again implies compensability. This is feasible to some extent, since, for example, the task of first aid can be covered by all three services.

For the second pair of indices, 'socio-economic' and 'infrastructure', compensation is feasible as well. With respect to the socio-economic dimension, access to resources may well be possible, which may, however, be handicapped depending on the condition of infrastructure (in particular during and after a crisis). In turn, a good infrastructure condition may assist when socio-economic conditions are not favourable.

The third pair of indices, 'community network' and 'self-reliance', can also compensate each other. For example, high levels of self-reliance imply that community networks need not be strained, which is beneficial when these are weak. Likewise, strong community networks can abate low self-reliance.

The indicator 'community facilities' is a combination of several community facilities, which are associated with different social networks. Schools, kindergartens and playcentres foster relations in particular between families. Churches, community centres and marae reach a variety of demographic groups. Within these two circles, compensation of community facilities is therefore feasible. Since the two circles can overlap, compensation between them is, to some extent, possible as well.

At the first level of hierarchy, compensability between indicators is allowed for to some extent, since conceptually they all contribute to the dimension they represent. However, compensability between for instance the indicator 'below five years of age' and '65 years of age and more' is, strictly speaking, not correct. A small share of children under five reduces the condition of vulnerability, however does not decrease the susceptibility of the elderly to be harmed. A low proportion of one-parent households does not abate the unfamiliarity of surroundings of those who just moved into the area or are visiting from overseas. Hence a good or poor performance for some of these socio-economic indicators can positively or negatively influence the indices 'adaptive capacity' and 'needs', but not the individual dimension which is associated with another indicator. With respect to the indicators which relate to the index 'infrastructure', some

compensability is likely, for instance high road connectivity means that failed bridges or road segments may be circumnavigated.

In summary, the effect of compensability is conceptually feasible for the majority of sub-index and indicator pairs, however not necessarily applicable in particular for the socio-economic dimension of adaptive capacity.

It should, however, be considered that the effect of compensation is mainly relevant when one indicator is sufficiently high to off-set at least one other, low-scoring indicator. Within this research, this effect is possible in Aoraki, since the indicator 'visitor' scores exceptionally high especially in the more recent years. Likewise, Aoraki displays very pronounced values for the two age-related indicators, for 'single household', '0-4 years at residence', 'household income' and 'females'. Some of these contribute to a decrease of adaptive capacity and therefore tend to aggravate rather than compensate each other. In fact, the aggravation effect is reduced by the aggregation method applied (arithmetic mean).

With respect to Te Arai, high values are reached for the indicator 'household income'. This indicator is therefore likely to compensate some of the other socio-economic indicators with respect to adaptive capacity. In the WHH, the two indicators 'roading' and 'critical infrastructure' (both based on their age) tend to dominate the scores for the indices 'needs' and 'adaptive capacity' for 1981 and 1986. However, these two indicators score not as highly compared to the ones listed for Aoraki and Te Arai.

The possible effect of compensation, in addition to the general approach of combining indicators into one index score, highlights the importance of ensuring a high transparency of the index structure and methods applied throughout the process. In addition, results for all sub-indices and the individual indicators should be made accessible.

Thirdly, another methodological aspect to consider when interpreting index scores is the difference of *internal weights*, introduced by the structure of the indices. While the final indices and their sub-indices are not affected as concluded in chapter 11, indicators are affected. The aggregation method ensures that within each sub-index, each indicator receives an equal weight which as suggested by the outcomes of the principal component analysis.

However, because of the index structure, the socio-economic indicators in particular receive a smaller weight compared to all other indicators. Consequently, each indicator influences the final index score to a smaller degree. For example, exceptionally high values for some of the socio-economic indicators in Aoraki do not influence the overall index result as much as they would when placed into another sub-index. In comparison, the two indicators 'below five years of age' and '65 years of age and more' receive an internal weight of 0.5, hence influence the index 'vulnerability' comparatively more. If they were to be placed within the socio-economic sub-index, their weight and influence would be smaller.

With the current indices structure, the comparatively very low proportion of children under five years of age and people aged 65 or more reduces the index 'fragility and mobility' in Aoraki, hence the index 'needs' and therefore the index 'vulnerability'. Likewise, high scores for the age-related indicators in Te Arai and Korokoro, which receive a comparatively high internal weight, pronounce the high scores for the index 'needs'. In addition, high values for the indicators 'critical infrastructure' and 'roading', which have relatively high internal weights, tend to emphasise an increase of the 'vulnerability' score for Te Arai. In contrast, Maungaraki scores lowest for these indicators, which underlines its tendency towards a low level of vulnerability. Hence when exceptionally high or low indicator values receive a relatively high internal weight, they emphasise the result of the associated sub-index for the particular community. Consequently, the magnitude of difference compared to other communities is enhanced.

As illustrated in section 12.1, on average the magnitudes of difference between the community rankings are most pronounced for the indices 'needs' and 'self-sufficiency', and less so for the index 'adaptive capacity'. The latter consists of a higher number of indicators which firstly receive a smaller internal weight, and secondly are allowed to compensate each other. Variations between communities are therefore less pronounced for this index.

Since all communities receive the same internal weights for the same indicators and sub-indices, their comparison is sound and the analysis reliable. However, it is noted that the index structure can enhance the magnitude of difference between communities when high scoring indicators are associated with comparatively larger internal weights.

This may or may not be desired, and can be counteracted by modifying the internal weights. Generally, modification of weights is an option when, depending on the context and aim of vulnerability and resilience analysis, one or several indicators are considered to be more important than others. Within this research, a modification of weights is not undertaken. The results are interpreted and evaluated in context of the specific index structure and methodology, and their consistency ensures a spatially and temporally comparative vulnerability and resilience analysis.

Generally, a disadvantage of indices is that they can be designed to produce or enhance a desired outcome. This is exemplified by different internal weights and placing of specific indicators within the index structure. While such forms of manipulation are not aimed for in this research, indices introduce the possibility of manipulation and misuse. Therefore, transparency of the index structure and the methodological choices is a 'must-do' for any sort of index construction.

Finally, with respect to *presenting the outcomes* of the index procedure, it is demonstrated in this research that ranking masks the magnitudes of difference between communities. In particular, temporal variation of index scores is not necessarily captured by rankings only, and

can in fact lead to a misinterpretation of the results. This is mainly due to changes in the overall number of ranks if two or more communities score equally, as well as the interdependence of community ranks: a community's score might not increase itself, but because of changes in other communities, its rank changes.

Therefore, displaying actual magnitudes of change in time and space is an advantage of a quantitative approach towards vulnerability and resilience analysis. When transparency and awareness of the index structure and methodology are ensured, the indices not only allow a statement on which community is more vulnerable or resilient than another community, but also on how much more vulnerable and resilient they are.

12.5 Summary and conclusion

12.5.1 Space

The three locations Western Hutt Hills, Te Arai and Aoraki differ clearly with respect to their conditions of vulnerability and resilience. Using the average index scores based on the period 1991 to 2006, as well as index scores for specific years, demonstrates that the Te Arai communities are noticeably more vulnerable than those of the Western Hutt Hills, which in turn are clearly more vulnerable than Aoraki. However, communities of the Te Arai are considerably more resilient than those of the WHH, which are in turn more resilient than Aoraki.

Two communities are exceptions of this observation: Maungaraki and Korokoro. Maungaraki, on average, just overtops Manutuke with respect to resilience due to its higher adaptive capacity, while Korokoro shares the lowest rank, least desirable rank with Aoraki.

Comparing vulnerability and resilience for these three locations reveals that on average, Te Arai has the least favourable (highest) ratio of vulnerability to resilience, closely followed by the WHH communities. In contrast, Aoraki shows the most favourable ratio of vulnerability to resilience. Dissolving the three groups into their individual communities changes this pattern to some extent. It is now Korokoro which has the highest ratio, followed by Belmont and Tirohanga, and only now the communities of the Te Arai follow. Aoraki, however, is still the community with the lowest (most favourable) ratio of vulnerability to resilience.

A range of characteristics render the communities of the **Te Arai** more **vulnerable** than those of the WHH and Aoraki. A comparatively high portion of children below five years of age and of elderly people (especially Manutuke) increases the proportion of those who are more likely to be harmed and in need of assistance. In addition, critical infrastructure is relatively aged, and critical facilities are only present in the most accessible community, Manutuke. The degree to which the livelihood of community members depends on a productive environment is high. In addition, road connectivity (which implies redundancy) is very low. What is more, relatively many households have a very low income, are single households (Waingake) or one-parent households (Manutuke), which aggravates the condition of vulnerability.

Aspects which counteract these characteristics are a comparatively low presence of overseas visitors, of people who just recently moved there, or are born overseas. Moreover, on average the population pressure on access points is comparatively low. However, these aspects cannot counterbalance the dominance of characteristics which produce a relatively high level of vulnerability, which is a result of the high scores for the index 'needs' and low scores for 'adaptive capacity'.

In addition to adaptive capacity, self-sufficiency is considered an element of **resilience** in this research. Self-sufficiency, expressed as a function of the community network and self-reliance, is generally high in Te Arai.

A differentiation between Waerengaokuri and Waingake on the one side and Manutuke on the other side is necessary with respect to community facilities. Manutuke has an exceptionally high density of community facilities, and the presence of four marae is a major contribution to this density. With respect to the indicator 'industry', Te Arai communities by far exceed the scores of the WHH and Aoraki.

Many of the characteristics identified as enhancing the condition of vulnerability are likely to exist in many other rural communities in New Zealand with a farming background. In addition, communities with a strong Maori presence are likely to provide greater possibilities to build networks and to increase their resilience.

In the **Western Hutt Hills** the situation is more differentiated: the six communities vary more extensively with respect to specific indicator values. However, on average the WHH display a moderate condition of **vulnerability**. Korokoro as a suburb with a high degree of elderly, a high degree of aged critical infrastructure, of single households, and households with low income and without medical facilities is the most vulnerable in the WHH. In contrast, Maungaraki is (on average) the least vulnerable community with a relatively low proportion of children below five years of age and people aged 65 and more. In addition, Maungaraki is comparatively better equipped with critical facilities in relation to its population size. What is more, in contrast to all communities included in this research its infrastructure has not reached the critical age yet. Maungaraki has, however, on average the second highest share of low income households, of single households and the highest proportion of single parents.

The communities of the WHH also vary with respect to their **resilience**. While Maungaraki provides the best opportunities for building networks, Tirohanga is only equipped with a school. Community centres are only present in Maungaraki and Kelson. What unifies the communities is their low presence of people working in the farming, forestry or fishing industry which is disadvantage with respect to self-reliance.

The suburban communities of the Western Hutt Hills display a variety of socio-economic and infrastructure-related aspects. Distinct differences are for example the high proportion of the elderly in Korokoro, while Kelson is a community with comparatively more children under five, hence young families. Tirohanga appears to be the most affluent community, and so forth. However, typical for all communities is the low degree of people working in the farming, fishing or forestry sector, a low proportion of visitors from overseas and a high degree of road connectivity. Likewise, relatively high shares of people living in the community for only four years or less, and a relatively high degree of people born overseas is a characteristic of the WHH. Compared to Te Arai, the communities of the WHH are therefore more transient and attract more immigrants. In addition, physical access into the communities is restricted which is, considering their substantial population size, a great disadvantage. Access into the communities is determined by their location perched on top of steeply dissected hills.

In **Aoraki**, the lowest proportion of children under five and of the elderly, a comparatively good equipment with critical facilities in relation to its population size, and a relatively moderate share of aged infrastructure reduce the score for the index 'needs', and therefore lessen the **vulnerability** of this community. However, relatively many households have only a low income or are single households. In addition, the high degree of visitors, of residents born overseas or living in the village for only four years or less decrease adaptive capacity. Nevertheless, the small presence of one-parent households, the extremely low proportion of females between 1991 and 2001, and only few people working in the farming, fishery or forestry sector compensate these factors. Overall, adaptive capacity is at an average level compared to the WHH and Te Arai.

Aoraki's exceptionally low value for both age-related indicators and its good position with respect to 'critical facilities' and 'critical services' produce the lowest score for the index 'needs'. This level is sufficiently low to compensate an only average adaptive capacity, which in turn results in the lowest average and annual (census years) vulnerability overall.

With respect to **resilience**, self-reliance is not very high in the community. This observation, however, is likely to be an underestimation (as discussed previously), since the remoteness of the place may foster self-reliance which is not captured by the indicator 'industry'. A community centre was opened fairly recently and provides opportunities for building social networks. With only the school as a second community facility, the level of community networks is, comparatively, below average.

Aoraki combines a set of characteristics which mirror its special location and function. Not a place for young families or the elderly, the village shows high proportion of single households which may well be associated with young seasonal workers servicing the influx of tourists, especially in the summer. Aoraki also attracts relatively many residents born overseas, which can be associated with the reliable and growing opportunity for seasonal employment. Aoraki is

also a rather transient place, with a comparatively high share of people living in the community for only four years or less. In relation to its small population size and in comparison with the situation in Te Arai and WHH, the village is very well equipped with critical facilities. This is likely to be a function of its remoteness in combination with a high number of visitors.

When comparing the **ratio of vulnerability to resilience (VR-ratio)** for all communities based on their average values (period 1991-2006), the grouping into the three locations Te Arai, WHH and Aoraki breaks up. Korokoro has the least favourable ratio of vulnerability to resilience (1.5), meaning that vulnerability exceeds resilience by about 50%. Due to their relatively high resilience, the Te Arai communities are in a situation where vulnerability is paired with an almost equally high level of resilience. However, the ratio of vulnerability to resilience is most favourable in Maungaraki and Aoraki. For both communities, resilience exceeds vulnerability by about 100%.

12.5.2 Time

The three locations differ with respect to the rate of change of processes influencing vulnerability in particular, but also resilience. While the Te Arai communities are relatively constant during the period of 1991 to 2006, gradual changes are observed for the WHH communities. When including the 1980s many communities of the WHH experience abrupt changes. Processes operate most quickly in Aoraki during the period 1991 to 2006, meaning that Aoraki is the most variable community.

Of the **Te Arai** Waerengaokuri varies obviously in its indicator values, sub-indices and final 'vulnerability' and 'resilience' indices. Its small population size leaves Waerengaokuri more sensitive towards smaller changes. Therefore, it may be misleading to conclude that the socio-economic composition varies greatly in time. A similar argument applies for Waingake, although variations in particular of the sub-indices and final indices are clearly smaller than compared to Waerengaokuri.

Manutuke, a community with a far larger population size, shows only little variation of **vulnerability**. However, a noticeable increase of the proportion of people living for four or less years at their address, of single households, and the elderly (comparatively smaller increase) is registered. Another noticeable process is the decline of the proportion of children under five years of age. However, in comparison to the WHH and Aoraki, Manutuke is the least variable community. This translates into the scores of sub-indices and final levels of vulnerability and resilience, for which no abrupt changes in time are registered.

Typical for all communities of the Te Arai is the consistency with respect to critical facilities, critical infrastructure, roading, road connectivity, access and the proportion of visitors.

With respect to **resilience**, the share of people working in the farming, forestry and fishery industry is stable for Manutuke. Employment in this sector varies more in Waerengaokuri and Waingake. However, as mentioned above this variability may be misleading. As illustrated in

chapter 9, the degree of farming has been constant during the period of analysis. Regardless, a pronounced shift from pasture to horticulture occurred in the Manutuke community. More drastic shifts from farming to forestry probably occurred during the 1980s in the hill country of the Te Arai. Although changes within this industry occurred during the period of analysis, mainly from farming to horticulture, the implications for vulnerability and resilience are not altered, which means that overall, not much change is recorded for Te Arai.

What is more, community facilities hardly vary in Te Arai. However, the school in Waingake was closed in 2001. Considering the tendency towards depopulation in Te Arai, these two processes are likely to be interlinked.

There is some indication that at least Manutuke has become more transient, that the proportion of single households increases in time as the proportion of children below five years of age decreases. However, overall the conditions of vulnerability and resilience in Te Arai over time are relatively stable.

The period of analysis for the **WHH** extends into the 1980s. While direct, numerical comparisons between the three locations are based on the period 1991 to 2006 only, the data for the 1980s are a bonus when aiming to understand the processes in the WHH.

The most pronounced variation for a range of communities is the increase of the index 'needs' after 1986, which translates into an increase of the index '**vulnerability**'. One of the driving processes behind this observation is a considerable increase of aged critical infrastructure and roading between 1986 and 1991. With time, these features reach a critical age which is associated with a higher susceptibility to harm. What is more, a range of processes operate consistently during 1981 and 2006. This leads to a rise in the proportion of specific socio-economic groups. Hence the 1980s are, comparatively, a period with higher adaptive capacity and a lower score for the index 'needs', meaning an overall lower vulnerability than compared to the 1990s and especially until 2006.

It is mainly the proportion of elderly, of single households, of one-parent households, of people born overseas, and to a lesser extent, the proportion of people living for four years or less in the communities which continuously increase over time. Between 1981 and 2006, percentages rise considerably, in some cases twofold or threefold. Even when examining the period between 1991 and 2006 only, the magnitude of change is still higher compared to Te Arai, and is predominately of a magnitude of five percent. Moreover, the increasing population, especially in Tirohanga and Belmont, results in an increasing pressure on access points and critical facilities. It is this aspect which is noted in particular for Tirohanga and Belmont.

The proportion of households at a low income level tends to decrease in time, as does the proportion of children under five for a range of communities. The proportion of people working in the farming, forestry or fishing industry, the proportion of females, and road connectivity are

overall constant in time. However, in Maungaraki road connectivity increases noticeably in time, while it decreases in Kelson. The type of development in Maungaraki tends to fill in free spaces in the already existing residential area, while Kelson is a suburb extending more into formerly unhabited terrain.

With respect to **resilience**, changes are mainly the result of changes in the number of community facilities. However, only Maungaraki and Kelson really gain in this respect, and are the only communities with a community centre.

The WHH are communities where processes gradually operate which increase their vulnerability, for example by an increase of the proportion of elderly which increases the value for the index 'needs'. Nevertheless, it is mainly the drop of adaptive capacity which drives the increase of vulnerability. This also affects resilience, since adaptive capacity is a component of resilience. However, the rather constant situation with respect to community networks and self-reliance subdues these trends with respect to resilience.

The WHH are dormitory suburbs of Wellington and reflect a number of socio-economic changes which are likely to be observed in comparable suburbs. In addition, between 1991 and 2006 all communities experience a gradual increase in population size. Two communities, Tirohanga and Belmont, however, experience a large and fast growth of their population when considering the period between 1981 and 2006 as well as 1991 and 2006. In particular Tirohanga grew phenomenally, with an increase by nearly 20% for several five-year periods.

Compared to Te Arai and WHH, **Aoraki** experiences the most pronounced changes for the period 1991 to 2006, in particular with respect to the socio-economic fabric. This translates into a distinct drop of adaptive capacity in time, which is an unfavourable trend with respect to **vulnerability** and resilience. The processes responsible for these changes are the increase of households at or below poverty level, of the proportion of females, of one-parent households, of residents born overseas, of people living at their address for only four years or less, and the number of visitors from overseas.

Only infrastructure-related aspects, and the indicator 'industry', are constants, while the proportion of single households decreases substantially in time. This decline can, however, not compensate the otherwise growing presence of socio-economic groups which are associated with a lower adaptive capacity. A pronounced increase of the index 'needs' is recorded between 1991 and 2006, which drops again in 2006.

In the context of **resilience**, self-sufficiency is relatively constant in time. However, the relatively small increase of self-sufficiency paired with a considerable drop of adaptive capacity results in a fluctuation of resilience scores, which reach their minimum in 2006.

The greatest surge of population within five years, compared to all other communities, is recorded for Aoraki: the population grew by almost 30% between 1991 and 1996. However, the population dropped again by 30% between 2001 and 2006.

Aoraki is the community where processes, which influence its resilience and especially its vulnerability, are operating most quickly compared to Te Arai and the WHH. Relatively large changes during short periods of time are also recorded for its population size.

When comparing the **ratio of vulnerability to resilience**, Aoraki obviously shows the fastest and most considerable increase between 1991 and 2006. For most of communities of the WHH the ratio increases, but less steadily and to a smaller extent. For Tirohanga, the ratio tends to decline substantially, although not very steadily. Likewise, the ratio of vulnerability to resilience drops for Manutuke more gradually but to a smaller extent. Korokoro does not show a distinct difference in its ratio between 1991 and 2006. When including the 1980s for the WHH, the increase of the ratio is, for most communities, substantial.

On average, Aoraki is the least vulnerable community due to its average adaptive capacity, but the very low score in the index 'needs'. Its ratio of vulnerability to resilience is, on average, the lowest between 1991 and 2006. However, the temporal decomposition of the ratio reveals that Aoraki holds the most favourable ratio in 1991 only. The ratio increases rapidly, meaning that the benefit of a favourable ratio is diminishing fast. As a result, Aoraki overtakes Maungaraki in 1996.

The quick increase of the ratio between vulnerability and resilience for Aoraki supports the conclusion that in Aoraki, socio-economic processes operate faster than compared to the WHH and especially Te Arai.

When analysing vulnerability and resilience only for a certain point in time, the situation in Aoraki may be evaluated as the most favourable, especially when considering the comparatively very low level of vulnerability. However, examining the direction and magnitude of temporal variation reveals that Aoraki's situation is changing quickly, and not to its advantage with respect to risk (figure 12.30). This is particularly because the ratio of vulnerability to resilience is worsening (increasing) steadily and rapidly during the period of analysis.

For all other communities apart from Tirohanga and Manutuke, the ratio of vulnerability to resilience increases in time as well, although not as distinct or fast compared to Aoraki. Only Tirohanga and Manutuke improve their VR-ratio. Processes that influence vulnerability and resilience operate very slowly (or are almost replaced by constants) in Te Arai, but are faster in the WHH. For all communities vulnerability varies more than resilience.

Figure 12.30: The ratio of vulnerability to resilience (VR ratio) and the speed of processes

A decrease of the VR-ratio is registered for Manutuke. However, since processes operate relatively slowly in Manutuke, the beneficial effect of this improvement is subdued. In comparison Tirohanga, for which a considerable drop in the VR-ratio is registered, is in a better position.

Apart from the communities' individual spatio-temporal vulnerability and resilience, the development of the relationship between vulnerability and resilience enables a more differentiated interpretation of the potential to be adversely affected by natural hazards such as landslides. Chapter 13 includes this aspect and presents the final step of this research, the analysis of the evolution of risk.

13. Risk analysis: methodology and results

This chapter firstly discusses the methodology for calculating risk based on the components hazard, elements at risk, vulnerability and resilience. Subsequently, the results of the risk analysis are presented and analysed in the light of spatial and temporal variation at the scales addressed in this investigation. The driving factors behind these differences are identified and discussed. In addition, risk is analysed with respect to changing hazard for the communities of the Western Hutt Hills. The thesis is completed with concluding remarks and perspectives on future research.

13.1 Methodology

Within quantitative risk assessment (QRA), the risk 'equation' $R = H * E * V$ described by Varnes (1984) according to UNDRO (1982) has gained international acceptance, with R = risk, H = hazard, E = elements at risk and V = vulnerability. An example of how such a quantitative approach is applied in the context of landslide risk analysis is given in chapter 4.

Since the concept of natural risk brackets a wide range of dimensions, this 'risk formula' may appear simplistic. However, it combines some of the main components of risk, which are associated with both the geosystem (hazard) and the social system (elements at risk, vulnerability). What is more, this risk equation is versatile in the sense that anything can be an 'element at risk': societies, buildings, economies, individuals, communities and so forth. As Bücking (1994) noted, the usage of such a 'risk formula' is justified when its operationalisation is transparent and the level of adverse effects and probabilities of geophysical process occurrence can be determined precisely. In reality this is difficult to achieve, as has been discussed in this thesis. As Kröger (2004) concluded, some degree of uncertainty will always remain, hence transparency and uncertainty analysis improve subsequent risk evaluation and management.

The conventional 'risk formula', as described above, lacks one important component: resilience. As demonstrated in this research, resilience and vulnerability are interrelated and both influence risk. In addition, the formula is static in the sense that only the initial degree of damage (through the degree of vulnerability) is included, inferred from the immediate impact of a geophysical process.

By including resilience ('Res') the component of time is introduced, as resilience is a condition that has meaning with reference to an undefined period of time following an event impact. Depending on the condition of vulnerability a certain degree of initial damage is encountered. However, already shortly after a natural hazard occurs the adverse effects can be reduced and the spiralling of damage can be prevented or minimised when individuals or communities are resilient. Therefore, the conception of risk shifts from the potential of initial damage to a conception which includes not only the initial but also the adverse effects in the long-term. Measuring these long-term effects is challenging; nevertheless, by including resilience the conceptual basis of risk is open to such approaches.

Two options for including resilience are explored in this research. In both cases resilience is referenced to vulnerability. The theoretical basis for such an approach acknowledges that the ability to 'bounce back' after an impact, while related to capability, must also to some extent be a function of the magnitude of initial impact as represented by vulnerability (chapter 7).

Firstly (approach 'A'), risk can be expressed as:
$$R = H * E * (V + V/Res)$$

As discussed in chapter 12, a ratio of vulnerability to resilience ('VR-ratio') greater than one indicates that vulnerability exceeds resilience, and a ratio of below one indicates that resilience exceeds vulnerability. With respect to risk, the first possibility is less favourable than the second. A VR-ratio equal to one is a neutral value. It is important here to emphasise that the comparison of vulnerability to resilience is done on the basis of indices which produce relative, not absolute, results for the spatial and temporal scales addressed in this research.

This approach aligns with the aim of this research which is to identify relative risk, and how relative risk changes in time. This is because a VR-ratio of below one favours a lower level of risk compared to a ratio of one or above one, with all other factors being constant. Risk will increase in any case, even if the ratio of vulnerability to resilience is near zero. The meaningfulness of the comparison of all communities is, however, guaranteed.

Secondly (approach 'B'), risk can be calculated as:
$$R = H * E * V * V/Res$$

This method produces results which match the aim of this research as well. In contrast to the first approach, this formula results in a reduction of risk when the VR-ratio is below zero and in an increase of risk when the ratio is above zero. Hence the abating effect of resilience on the overall potential degree of damage is acknowledged to a greater extent compared to the first formula: communities with a ratio below one are rewarded with a decrease of risk. Likewise, a ratio of above one amplifies the unfavourable situation where vulnerability is higher than resilience, since risk is (relatively) higher. If vulnerability and resilience are equal, risk is a function of hazard, elements at risk and their vulnerability only.

Before testing both approaches, the vulnerability value is modified in two ways. As described in chapter 12, for certain analysis both vulnerability and resilience negative index values are avoided by shifting all z-scores up by 1.3 units. The shift ensures that no negative values of risk are calculated; conceptually this would be feasible, but the communication of results is easier when positive risk values are generated only.

Secondly, the shifted vulnerability values are rescaled to the value of one. This is done to ensure that the effects of vulnerability on risk are comparable. If some values would be below one and others would be above one, risk would be reduced and increased which would not align with the meaning of the original vulnerability score. Vulnerability values are rescaled by summing up all z-scores for all communities for the year 2006. The value of one is divided by the total, and the resulting factor is multiplied with each z-score to calculate the equivalent score

on a scale of zero to one. In order to ensure comparability in time, the years 1981 to 2001 are referenced to 2006 by using the same multiplication factor as for 2006.

Hazard is expressed as the annual probability of occurrence of a landslide event of a certain magnitude. The risk analysis is based on a 'worst-case' scenario where the whole community would be affected. This scenario implies that exposure is equal within the community.

For the Western Hutt Hills (WHH) and Te Arai, the largest magnitude of a landslide event observed is considered as the 'worst-case' scenario. Based on historic records (e.g. newspaper articles), it can be verified that the whole community was affected during and after these events due to the extensive occurrence of landslides. The landslide analysis for the WHH (chapter 10) reveals that the largest magnitude recorded so far is an event where a total area of 71,000-315,000 m² is affected by landsliding, which translates into a density of 0.07 to 0.28 landslides per hectare (or 28 landslides per km²). This was the December 1976 storm. This event has an annual probability of 0.02 or, in other words, a 2% probability of occurrence in 100 years.

As presented in chapter 10, the largest magnitude of a landslide event recorded in Te Arai (Cyclone Bola in 1988) has a density of 250 landslides per km², and an annual frequency of 0.05 or, in other words, a probability of occurrence of 5% in 100 years (Reid and Page, 2002).

For Aoraki, the 'worst-case' scenario is based on the magnitude for which the protection works are designed. As listed in chapter 10, the Black Birch and Glencoe levees are each designed to withstand a magnitude of debris with a volume of 100,000m³. While for the Black Birch fan this magnitude is estimated to occur with a probability of 2% in 100 years, the same magnitude is estimated to occur with a probability of 0.5% in 100 years for Glencoe.

Since the village is spread across the two fans, the probability for the whole community of a 100,000m³ event occurring is computed as the weighted mean of these two probabilities. The area potentially affected for each fan is calculated with a Geographic Information System (ArcGIS) and expressed as the percentage of the total village area (Glencoe: 57.1% or a weight of 0.57; Black Birch: 42.8% or a weight of 0.43). The weights are used for calculating the average probability, which is 0.01 or, in other words, a 1% chance of this magnitude occurring in 100 years for the whole village.¹

As an '**element at risk**' the population size for each community is entered in the risk calculation. Population size, i.e. the number of people, is used in this analysis as a generic indicator of elements at risk, not with the intention of expressing risk in terms of death or injury. In this research **risk** expresses the probability and extent to which a community is adversely (i.e. badly, 'worst-case') affected, for a specific (census) year.

¹ With the protection works in place, which are designed for a magnitude of 100,000m³, the village would theoretically not be affected if this event were to occur. The magnitude considered in this analysis is therefore a minimum 'worst-case' magnitude, since the protection works would compensate this magnitude. Since no information concerning the frequency of a (slightly) larger magnitude is available, the mean frequency as calculated (0.01) is used.

13.2 Results

The results of the risk analysis for each community and year are illustrated in figure 13.1, based on the first method which adds vulnerability and the VR-ratio before multiplying the outcome with hazard and elements at risk (approach 'A').

Figure 13.1: Changes of risk in time, for the equation $R = H * E * (V + V/Res)$

Figure 13.2 depicts the results of the risk analysis when hazards, elements at risk, vulnerability and the VR-ratio are multiplied ('approach B').

Figure 13.2: Changes of risk in time, for the calculation $R = H * E * V * V/Res$

While the development or pattern of risk in time is similar for most communities, the scales are different, meaning that values based on approach 'B' are smaller. More importantly, some distinct differences between the two approaches emerge:

- Manutuke 1991: Compared to approach 'A', risk increases in comparison to all other communities when applying approach 'B'. This is because the VR-ratio is 1.14 for this year, and approach 'B' amplifies this unfavourable ratio. Consequently, Manutuke is the community with the highest risk for that year.
- Korokoro: With a VR-ratio of clearly above one for the years 1991 to 2006, Korokoro's risk is, compared to other communities, higher when using approach 'B'. Likewise, for 1981 and 1986, risk is lower compared to approach 'A' since the VR-ratio is 0.78 and 0.64, respectively.
- Kelson and Maungaraki: with VR-ratios constantly below zero, risk is comparatively lower for these two communities when using approach 'B'.

The relation of risk for Waerengaokuri, Waingake and Aoraki hardly differs between the two calculations.

In summary, while the difference in risk is not pronounced for most communities, it is for some, especially Korokoro, Maungaraki and Kelson. While Korokoro is punished with a higher risk value compared to other communities due to its high VR-ratio, Kelson and Maungaraki are rewarded with a lower risk value compared to other communities, based on their low VR-ratios. Different risk calculations will yield different results and will affect the ranking of communities. As with the vulnerability and resilience indices, the outcome depends to some extent on the methodological choices made by the analyst.

Approach 'B' has the advantage that if resilience is larger than vulnerability, risk decreases depending on how much more resilience exceeds vulnerability. A change of the VR-ratio to a value below one can be triggered by either a decrease of vulnerability or an increase of resilience. Hence such favourable changes are rewarded by a decrease of risk, or punished if the VR-ratio yields values of above one.

A disadvantage of this approach is that if vulnerability equals resilience (VR-ratio of 1), risk is a function of hazard, elements at risk and vulnerability only, and resilience does not influence risk at all.

Approach 'A' does not reward a VR-ratio below one with a decrease of risk, which is conceptually less consistent than approach 'B'. Approach 'A', however, ensures the comparability of risk according to differences in the VR-ratio. This is because if vulnerability and resilience are equal (VR-ratio of 1), risk is relatively lower compared to a VR-ratio of above one, and relatively higher compared to a VR-ratio of below one. In any case, resilience will influence the relative levels of risk.

In conclusion, Approach 'A' is preferred over approach 'B' because the influence of resilience on risk should be guaranteed with every possible value of the VR-ratio, including a value of 1. This is rated as more important than a conceptually less consistent (though still meaningful) method. The following discussion of the results is therefore based on the risk calculation $R = H * E * (V + V/Res)$.

13.3 Discussion

The discussion is guided by the following questions:

1. Which communities display the minimum and maximum values of risk, during the whole period of analysis?
2. Based on the census years 1991 to 2006, how are communities ranked (on average)? To what degree do these ranks differ?
3. Which risk levels are calculated for each community per census year?
4. What are the driving factors of changes in risk?

Questions 1 and 2: Which communities display the minimum and maximum values of risk, during the whole period of analysis? Based on the census years 1991 to 2006, how are communities ranked (on average)? To what degree do these ranks differ?

The minimum value for risk is calculated for Aoraki with 0.1 in 1991, and the maximum value of risk is calculated as 66.3 for Belmont in 2006.

Mean and median values are listed in table 13.1 and illustrated in figure 13.3. The comparison with the mean and median reveals that risk values are mostly distributed evenly, with only Maungaraki and Belmont showing very little indication of skewness. However, the median for Aoraki is, in comparison to the other communities, noticeably higher than the mean value risk, which indicates that values are skewed towards the lower range.

Table 13.1: Mean and median of risk based on the census years 1991 to 2006

	Rank	Mean	Median
Belmont	1	61.1	60.8
Normandale	2	49.4	49.3
Kelson	3	44.4	44.2
Maungaraki	4	43.5	44.7
Korokoro	5	39.2	39.6
Manutuke	6	39.0	39.7
Tirohanga	7	22.9	22.7
Waingake	8	8.6	8.5
Waerengaokuri	9	5.5	5.5
Aoraki	10	1.4	1.8

The community with the, on average, clearly highest risk value is Belmont (61.1), followed by Normandale (49.4), Kelson (44.4) and, closely after, Maungaraki (43.5) (figure 13.3). Korokoro (39.3) and Manutuke (39.0) are almost similar, while Tirohanga follows with a larger drop of

16.1 units. Likewise, Waingake and Waerengaokuri are clearly lower placed, and so is Aoraki with a value of 1.4, which demarcates a drop of 4.1 units.

The influence of population size (the 'element at risk') on risk is modified by vulnerability and resilience levels. For example, Belmont shows the highest risk (on average), but is neither the largest community nor exposed to the highest hazard. Likewise Normandale, with the second highest average degree of risk, is only the fourth largest community. And Aoraki, with a population larger than Waerengaokuri and Waingake, displays the lowest level of risk.

Figure 13.3: Mean risk based on the census years 1991 to 2006

With respect to the average values of the indices 'vulnerability' and 'resilience', the ten communities are coherently ranked according to their locations. This means that distinct differences between the WHH, Te Arai and Aoraki emerge, which are also very consistent in time (chapter 12).

With risk, this coherent pattern is altered only slightly: Manutuke (Te Arai) is placed solidly between two communities of the WHH, and is almost similar to Korokoro. In addition, Tirohanga clearly differs from all other communities of the WHH and is placed almost exactly between Manutuke and Waingake (the distance to Manutuke is 16.1 units and to Waingake 14.3 units).

In this research risk is associated with a community, which is a unit and therefore comparable with what is also called 'societal risk'. Individual risk for members of each community can be calculated by dividing risk by the population size. This is exemplified based on the average risk listed in table 13.1, and the average population size derived from the census years 1991 to 2006. Individual risk is listed in table 13.2, hence the factor 'population size' is excluded. As demonstrated by the ranking, the two smallest communities show the highest level of mean individual risk. However, difference in hazard, vulnerability and resilience result in a ranking which overrules population sizes; for instance the third smallest community (Aoraki) is at the bottom of the rank, joined by Maungaraki (the largest community).

Table 13.2: Mean individual risk based on the mean risk and the mean population for each community, for the census years 1991 to 2006

	Rank	Individual risk (average)
Waingake	1	0.06
Waerengaokuri	1	0.06
Manutuke	1	0.06
Belmont	2	0.03
Korokoro	2	0.03
Normandale	3	0.02
Tirohanga	3	0.02
Kelson	3	0.02
Maungaraki	4	0.01
Aoraki	4	0.01

Question 3: Which risk levels are calculated for each community per census year?

The ranking of communities based on average scores of risk varies in time for some communities. When examining the risk score per community and census year for the period 1991 to 2006, it is evident that Belmont cements its first rank, with an obvious distance to the next lower ranked community for all years (table 13.3, figures 13.1, 13.4). Likewise, Normandale is consistently the community with the second highest risk, but overtopped by Kelson in 2006. It is only due to the increase of risk in 2001 and 2006 that Kelson holds the third rank. This rank is strongly contested by Maungaraki which shows a steady increase of risk between 1991 and 2006. In 1996, the risk for Korokoro climbs up to a level which is slightly higher compared to Maungaraki, and the subsequent drop in risk ensures its fifth rank. A strong contestant for this rank is Manutuke which starts higher than Korokoro in 1991 and 1996, but shows a larger decline of risk in 2001 and 2006. Tirohanga clearly keeps its rank, and so do Waingake, Waerengaokuri and Aoraki.

Table 13.3: Risk per community and year

	1981	1986	1991	1996	2001	2006
Korokoro	21.2	17.7	34.6	43.1	41.6	37.6
Maungaraki	44.6	25.9	35.6	42.6	46.8	48.9
Normandale	27.8	27.1	46.1	48.9	53.1	49.7
Tirohanga	6.7	5.8	19.2	20.5	26.8	25.0
Belmont	27.5	28.4	56.5	57.4	64.1	66.3
Kelson	45.0	37.7	42.8	38.0	45.7	51.2
Waingake			8.6	8.4	8.3	9.0
Waerengaokuri			4.5	3.7	7.1	6.5
Manutuke			43.4	43.9	36.1	32.8
Aoraki			0.1	2.0	1.9	1.6

A considerable increase of risk is registered for most communities of the WHH between 1981 and 1991, as is observed for the indices 'needs' and 'vulnerability' (chapter 12). This pattern can be explained by an increase of the proportion of critical infrastructure ('needs' index) and roads ('adaptive capacity' index) reaching a certain age (min. 51 to 65 years) in 1991 which is

associated with higher susceptibility to damage than compared to younger infrastructure and roads.

Figure 13.4: The evolution of risk²

When comparing not the absolute but the proportional changes of risk in time the increase of risk between 1986 and 1991 for the WHH is demonstrated clearly (table 13.4). Between 1981 and 2006 risk increases for all communities of the WHH, and Tirohanga and Belmont show the greatest change with a gain of 270.5% and 140.9%, respectively. The population of these two communities grows most extensively during this period compared to all other communities. In addition, vulnerability and the VR-ratio rise between 1986 and 1991 which amplifies the change of risk during 1981 and 2006.

Table 13.4: Change of risk in percent

	% change 1981- 2006	% change 1991- 2006	% change 1981- 1986	% change 1986- 1991	% change 1991- 1996	% change 1996- 2001	% change 2001- 2006
Korokoro	77.7	8.7	-16.1	94.9	24.6	-3.4	-9.7
Maungaraki	9.8	37.3	-41.9	37.6	19.4	10.1	4.5
Normandale	78.9	7.6	-2.4	70.3	6.1	8.4	-6.4
Tirohanga	270.5	30.3	-14.3	231.8	7.0	31.0	-7.0
Belmont	140.9	17.4	3.2	98.8	1.7	11.5	3.5
Kelson	13.8	19.7	-16.3	13.5	-11.3	20.4	12.1
Waingake		4.4			-2.9	-0.5	8.1
Waereng.		44.6			-18.3	92.5	-8.0
Manutuke		-24.4			1.1	-17.8	-9.1
Aoraki		1242.1			1538.1	-4.2	-14.5

² Lines between years are intended to improve the readability of the graph and do not imply interpolation of risk between the data points. For 1981 and 1986 no risk is calculated for Waingake, Waerengaokuri, Manutuke and Aoraki, which is set to zero for displaying purposes only.

When considering the period 1991 to 2006 only, the picture changes noticeably. While risk for all communities in the WHH still increases, it is now Maungaraki which depicts the greatest percentage of increase (37%), followed by Tirohanga (30.3%), while Belmont (17.4) is overtopped by Kelson (19.7%). The increase of risk for Maungaraki does not concur with the only small increase of population (5.6%), but can be associated with a steady increase of vulnerability and the VR-ratio.

During 1991 and 2006 proportional changes in the WHH are exceeded by the increase of risk in Waerengaokuri (44.6%) (**Te Arai**). As discussed in chapter 12, this community displays great variability which is likely to stem from its higher sensitivity to larger magnitudes of change when expressed in percent. In comparison, Waingake shows only a slight (4.4%) increase of risk. Manutuke is the only community where risk between 1991 and 2006 decreases. This decrease is considerable with a drop of 24.4%. The distinct decline is associated with a clear reduction of population size and a drop in the VR-ratio (less distinct than population).

Aoraki is the community which experiences by far the greatest proportional change in risk: 1242.1% between 1991 and 2006. This figure is exceeded by an increase of 1538.1% between 1991 and 1996. Hence most of the change occurred during this period, and risk declines in the two following years. This development is related to a strong increase of population between 1991 and 1996 (29.4%) and a large increase of the VR-ratio.

Question 4: What are the driving factors of changes in risk?

In the following, the evolution of risk for each community is portrayed and discussed with respect to the processes driving risk.

Waingake

Vulnerability, resilience & VR-ratio:

Hazard: 0.05

Element at risk:

Risk:

Risk is almost constant in time for Waingake, since values range between 8.6 and 8.9 units. A slight drop in risk is registered for 2001 despite an increase of vulnerability and the VR-ratio. The driver of this process is a decrease in population by 18.9% (a total of 30 people) between 1996 and 2001.

Waerengaokuri**Vulnerability, resilience & VR-ratio:** **Hazard: 0.05** **Element at risk:** **Risk:**

Waerengaokuri shows more variability of risk than Waingake, with a maximum difference between 1996 and 2001 of 3.4 units. The lowest value of risk in 1996 is related to the distinct drop of vulnerability and a (more subdued) increase of resilience. Because of the second highest number of people living in the community that year, risk, however, does not drop as much as vulnerability and the VR-ratio suggest.

Higher levels of risk in 2001 and 2006 match the maximum values of vulnerability and the VR-ratio registered for those years. In 2001 risk is comparatively higher than in 1996 despite a (small) drop in population by 12 people (13.3%). A decrease of vulnerability and the VR-ratio is compensated to some extent by an increase of population in 2006.

Manutuke

Vulnerability, resilience & VR-ratio:

Hazard: 0.05

Element at risk:

Risk:

Risk for Manutuke drops in 2001 by 7.8 units and drops again in 2006 by 3.2 units. Manutuke is the only community where compared to 1991 the level of risk is lower than in 2006. Manutuke can improve (reduce) its VR-ratio with time compared to 1991, which supports the decrease of risk. The main driver is, however, the decline in population: Between 1996 and 2001, the community loses 162 people (20.2%), while between 2001 and 2006 the magnitude of loss is comparatively small (39 people).

Korokoro

Vulnerability, resilience & VR-ratio:

Hazard: 0.02

Element at risk:

Risk:

The pattern of risk in Korokoro closely follows the evolution of vulnerability and the VR-ratio. For example, despite a drop in population (8.4%) between 1986 and 1991, risk increases by 16 units during this period.

Generally, changes in population are relatively small. Compared to other communities in the WHH, Korokoro is the second smallest community.

Maungaraki

Vulnerability, resilience & VR-ratio:

Hazard: 0.02

Element at risk:

Risk:

As is the case for Korokoro, the evolution of risk follows the pattern of vulnerability and the VR-ratio closely. A drop in population numbers during the 1980s (in total 195 people) emphasises the minimum level of risk registered for 1986. With an only slightly varying population size (which increases and decreases alike), risk continuously climbs from 1986 onwards, matching the development of vulnerability and the VR-ratio. A slight drop of the VR-ratio in 2006 is compensated by the largest increase of population recorded, with a total gain of 219 people.

Normandale**Vulnerability, resilience & VR-ratio:** **Hazard: 0.02** **Element at risk:** **Risk:**

Like in Korokoro and Maungaraki, risk in Normandale follows the pattern of vulnerability and the VR-ratio. Variation in population size is small, with a maximum of -5.6% between 1986 and 1991 (120 people).

Tirohanga

Vulnerability, resilience & VR-ratio:

Hazard: 0.02

Element at risk:

Risk:

Compared to other communities in the WHH, risk in Tirohanga evolves not as similar to the pattern of vulnerability and the VR-ratio. The maximum vulnerability and VR-ratio in 1991 are not matched with a maximum risk value. The process which modifies the pattern of vulnerability and the VR-ratio is the distinct growth in population, which climbs by 70.2% (in total 345 people) between 1991 and 2006. Then, again, the drop of risk in 2006 is caused by a distinct drop of the VR-ratio between 2001 and 2006, which reaches its minimum in 2006 for the period 1991 to 2006 (0.96).

The very low levels of vulnerability and the VR-ratio in 1981 and 1986 dominate the risk level, in particular since the population is rather constant during these years.

Belmont**Vulnerability, resilience & VR-ratio:** **Hazard: 0.02** **Element at risk:** **Risk:**

As in Tirohanga, the evolution of risk in Belmont follows the pattern of vulnerability and the VR-ratio to some extent only. While both vulnerability and the VR-ratio oscillate only slightly between 1991 and 2006, the level of risk increases steadily in time and reaches its maximum in 2006 (by 9 units between 1991 and 2006, by 38 units between 1981 and 2006). This development concurs with the trend in population size. However, the distinct lower vulnerability and VR-ratio during in 1981 and 1986 determines the comparatively low level of risk for these years.

Kelson**Vulnerability, resilience & VR-ratio:** **Hazard: 0.02** **Element at risk:** **Risk:**

Like most other communities of the WHH, risk in Kelson follows the pattern of vulnerability and the VR-ratio. There is no clear trend in risk, since the level of risk tends to fluctuate, in particular for the years 1981 to 1996. Risk increases for two consecutive years (2001 and 2006) and reaches its peak in 2006.

The population in Kelson varies to a small extent only, apart from the rise between 1981 and 1986 which causes an increase of 14.2% (in total 315 people). Despite this increase, risk drops in 1986 due to a substantial drop in both vulnerability and the VR-ratio, which are amongst the lowest calculated during 1981 and 2006.

Aoraki**Vulnerability, resilience & VR-ratio:** **Hazard: 0.01** **Element at risk:** **Risk:**

Risk in Aoraki matches the development of vulnerability and the VR-ratio closely for some years, but not very well for other years. Generally, risk varies only to a small degree, with the largest change recorded between 1991 and 1996 of 1.9 units. For Aoraki, however, this is a drastic rise of 1538.1%. This increase is not matched by the increase of population, which is considerable (29.4% or 75 people) but in itself not able to cause the change of risk. The driving processes behind this increase of risk are the increase of vulnerability and the VR-ratio.

Risk drops slightly after its peak in 1996 which coincides with a peak of population. Despite the almost steady increase of vulnerability and the VR-ratio between 2001 and 2006, risk declines by 0.4 units during this time, which matches the considerable drop in population (30.7% between 2001 and 2006, or 93 people).

13.4 Changing hazard

The analysis of risk as presented and discussed so far assumes that hazard is constant in time. As demonstrated in chapter 10, this is not necessarily the case. In this section, risk is modelled for the Western Hutt Hills with changing landslide hazard. The lack of necessary information for Te Arai and Aoraki prohibits an analysis of changing hazard for these two sites.

For the Western Hutt Hills probabilities of a landslide event occurring with a certain magnitude are associated with each year for the period 1939 to 2004. These annual probabilities are an outcome of the landslide hazard analysis covered in chapter 10. Risk analysis for the WHH so far is based on a 'worst-case' scenario where the whole community is affected and the entire population sizes is used as an 'element at risk'. In the following analysis, an event of a smaller magnitude (which is associated with a higher frequency) is related to a smaller proportion of the community being affected. This proportion is an estimate based on the magnitudes of landslide events observed for the period 1939 to 2004 (table 13.5). Based on this estimate, the 'element at risk' is modified where necessary.

Since census years do not exactly match the years for which landslides are mapped from aerial photography, the probability of the year closest to the census year is used³.

Table 13.5: Parameters for modelling changing landslide hazard

	1981	1986	1991	1996	2001	2006
probability	0.02	0.05	0.02	0.05	0.05	0.05
community affected	100%	20%	100%	20%	20%	20%

Figure 13.5 illustrates the results of the risk analysis when hazard varies in time. Risk levels are not altered for the years 1981 and 1991 since hazard is similar to the original risk calculation (figure 13.1). However, the degree of risk for the years 1986, 1996, 2001 and 2006 is considerably lower compared to the original risk calculation: risk levels decrease by about 50%. Consequently, the original general trend of increasing risk for the WHH communities, in particular between 1986 and 2006, is interrupted by the peak in 1991. Risk levels tend to increase from 1996 onwards, but more subdued.

³ The census year 1981 falls exactly between the years 1978 and 1983 for which aerial photography is available. The probability associated with the year 1978 is applied.

Figure 13.5: The evolution of risk with changing hazard

This calculation of risk based on changing hazard is an example only. It aims to illustrate the effect that a dynamic approach to hazard and risk analysis can exert on the outcomes of such analysis. In this example, risk operates on a lower level due to a tendency of landslide hazard to decrease within the residential areas of the WHH, which in turn can be explained by the reaction of the geomorphological system to a major landslide event (chapter 10).

For two reasons, forward-looking scenarios of risk analysis may have to consider an increase of hazard. Firstly, with time new material can accumulate and re-fill the preferred sources for landslides (the 'colluvium-filled bedrock depressions', CBDs). This process, however, operates much slower than the process of suburbanisation which is still ongoing in the WHH. Construction activities are likely to destabilise some of the still filled CBDs, hence a rainfall event of a smaller magnitude may trigger a comparatively large landslide, or a comparatively larger number of landslides. Only detailed geomorphological mapping can identify to which extent those CBDs still filled with colluvium are present in potential development sites.

13.5 Summary and conclusion

The spatial comparison of average levels of risk (based on the period 1991 to 2006) reveals that the WHH, Te Arai and Aoraki are almost consistently grouped along the highest to the lowest levels of risk (in that order). This pattern is modified when excluding the effect of population size, meaning when calculating individual risk.

13.5.1 Space

Belmont is clearly the community with the highest risk, on average for the period 1991 to 2006 as well as for each of the five-year intervals during this period. Belmont combines an average

level of vulnerability with a very low level of resilience, which results in one of the highest VR-ratios calculated. Simultaneously, Belmont has the fourth lowest population of all ten communities only. Like for all the communities of the WHH, the hazard is, compared to Te Arai and Aoraki, on a medium level.

Normandale is ranked, on average, second on the scale of risk. The average level of vulnerability is comparatively low, and resilience is about average. The relation between the two, however, entails VR-ratios of mostly above one. Normandale has the fourth largest population size.

Kelson and **Maungaraki** display the fourth and second lowest average vulnerability, respectively, while ranked relatively high for resilience (fifth and first). Consequently, Kelson and even more so Maungaraki enjoy some of the lowest VR-ratios, in particular during the period 1991 to 2006. However, Kelson is the second largest and Maungaraki is the largest community with respect to population size, which excludes these two communities from the lower ranks of risk despite their otherwise favourable settings.

Korokoro and **Manutuke** are ranked fourth and first for vulnerability (on average), respectively. While Korokoro is the community with the (apart from Aoraki) lowest resilience, Manutuke has, on average, the second highest degree of resilience only just overtopped by Maungaraki. The different relation between vulnerability and resilience is reflected by the VR-ratio: while Korokoro constantly shows the highest values for all communities (clearly above one), for Manutuke the VR-ratio fluctuates around a level of one most of the time. Although the population in Korokoro is about double the population in Manutuke, both have similar degrees of risk. The clearly higher vulnerability in Manutuke is a driving factor behind this outcome, as well as the higher level of hazard.

Tirohanga is ranked about average for vulnerability, and shows a low level of resilience. The relation of both results in a VR-ratio above one for most of the years between 1991 and 2006. The population size is, compared to all other communities, of a medium size.

Waingake and **Waerengaokuri** display both high levels of vulnerability and resilience, and the VR-ratio varies between values of below and above one, in particular for Waerengaokuri. Although hazard is higher than compared to the WHH, due to their small population sizes these two communities are ranked, on average for the census years 1991 to 2006, the third and second lowest with respect to risk. Eliminating the effect of the population size on risk (individual risk) would increase the ranking of risk for these two communities, as exemplified in the context of questions one and two.

Aoraki clearly displays the lowest level of risk. One factor is the hazard, which is the smallest for all three sites. However, more importantly vulnerability is on average and for all years much lower than for all other communities. With resilience fluctuating between average and low levels, Aoraki holds the lowest VR-ratio for most years. In addition, its population is the third smallest.

The overall ranking of risk between the communities is dominated by the population size. This means that the communities of the Western Hutt Hills are, apart from Tirohanga, placed consistently on the highest ranks of risk. Among these communities, the influence of population size is overruled by the interplay of vulnerability and the relation of vulnerability to resilience. Likewise, Manutuke's rank above Tirohanga which, especially between 1991 and 2006 has a far larger population size, is caused by Manutuke's condition of vulnerability, resilience and hazard. Waerengaokuri and Waingake, which are considerably smaller in population size than Aoraki, have higher levels of risk than Aoraki. The interplay of the components of risk ensures that Aoraki differs distinctly from all other communities.

13.5.2 Time

The abrupt changes of, in particular, vulnerability between 1986 and 1991 translate into the level of risk observed for the communities of the **WHH**. The highest percentages of change in risk are recorded for the interval between 1986 and 1991. Only Maungaraki and Kelson show a less distinct difference between these two years.

While Tirohanga and Belmont encounter the largest percentage of increase in risk for the period 1981 to 2006 (270.5% and 140.9%, respectively), this picture is modified when considering the period 1991 to 2006. It is now Maungaraki which changes the most (37.3%), which is caused by the steady and considerable climb of vulnerability and the ratio of vulnerability to resilience during these years. Tirohanga is the second most variable community of the WHH (30.3%), followed by Kelson (19.7%). Kelson just overtops Belmont; like Maungaraki, Kelson witnesses an increase of vulnerability and the VR-ratio in that period. In comparison, Belmont does not show great variety of the VR-ratio.

These observations are interrupted by peaked changes of risk for some of the five-year intervals. Tirohanga stands out with an increase of risk by 30% between 1996 and 2001, which coincides with a peak increase of population and the VR-ratio. In addition, Korokoro and Maungaraki experience great increases of about 20% between 1991 and 1996.

In the **Te Arai**, Waerengaokuri shows the greatest variability of risk, which however is likely to be emphasised by its small population as discussed in chapter 12. Waingake shows only very little variation of risk between 1991 and 2006 (4.4%) and for five-year intervals.

Manutuke, in contrast, depicts a considerable decline of risk by 24.4% during 1991 and 2006. The peak of decrease occurs during 1996 and 2006 (17.8%), which coincides with a peak decrease of population during that time (20.2%). Manutuke is the only community for which risk decreases between the period 1991 and 2006.

The greatest increase of all, however, is calculated for **Aoraki** where the risk level changes by 1538.1% during five years. In addition, the change of risk between 1991 and 2006 is exceptionally high compared to all other communities (1242.1%).

As concluded in chapter 12 the three locations Te Arai, WHH and Aoraki differ with respect to the rate by which processes operate. The grouping along a gradient from Te Arai to WHH and Aoraki from relatively slow to relatively fast operating processes is demonstrated by the degree to which risk changes for each community (fig 13.6)⁴. In particular, Aoraki's position is cemented: compared to all other communities, the extent of Aoraki's proportional increase of risk for a given period of time suggests that the process of risk operates the fastest of all communities.

An exception of this gradient is Manutuke: due to the fast loss of population especially between 1996 and 2001, but also between 2001 and 2006, Manutuke's decline of risk is comparable with the speed of processes operating in the WHH. Hence, while processes which influence vulnerability and resilience operate relatively slowly (as also illustrated by the rather constant VR-ratio, chapter 12) in Manutuke, depopulation as a process influencing the element at risk operates rather quickly.

Furthermore, Korokoro and Normandale, both communities with only little variation of population in time, are located closer to Te Arai along the gradient of the rate with which risk operates.

Figure 13.6: The level and process rate of risk

The conclusions drawn with respect to vulnerability and resilience match the situation which emerges when analysing risk. While risk levels are relatively high in the WHH, they change only gradually. This means that a reduction or an increase of risk is likely to occur at a medium pace only. Te Arai ranks at the medium to low scale of risk, and fast changes are not expected since risk operates relatively slow except in Manutuke. In contrast, Aoraki, which shows the lowest level of risk faces a rapid increase of risk during the period 1991 and 2006. The implications of approaching risk as a process for risk management are outlined in the final section.

⁴ Note that variability in Waerengaokuri with respect to vulnerability and the VR-ratio is likely related to the higher sensitivity of this community to changes of indicator values.

13.6 Concluding remarks and perspectives

Analysing risk for one point in time only cannot reveal the direction and speed of the process of risk. Approaching risk as a process rather than a static construct provides a more informed base for risk evaluation and management. Such an approach has formed the core of this thesis and has been implemented not only by spatio-temporal treatment of the components affecting risk, but also by incorporating indices of vulnerability and resilience predicated on factors that will control the temporal response to hazard.

In this research, it has been demonstrated how processes operating in society shape the evolution of risk on the time scale analysed. Following the political-economic reconstruction which greatly influenced the country's younger history (chapter 9), socio-economic change is evident in the three locations, in particular the Western Hutt Hills and Aoraki.

The Western Hutt Hills show an increasing influx of immigrants, more transient households, single households and one-parent households, as well as a decline in young children. With an aging population, the proportion of elderly is on the rise. Some of these processes operate in the rural communities of the Te Arai as well, although at a slower pace. Here, shifts in population are more distinct, and while a change of farming to forestry has come to a halt, horticulture has clearly expanded. Aoraki, with its specific character as a hot-spot for tourism, shows distinct differences and the most rapid rates of change in socio-economic fabric.

Furthermore, it has been illustrated in this thesis that the relationships between the socio-economic variables vary in strength and the degree of confidence. Figure 13.7 summarises the results of the multivariate correlation analysis presented in chapter 11. Illustrated is the combination of the correlation coefficient with the width of the confidence interval: the higher the coefficient and the narrower the interval, the stronger and meaningful is the relation.

Such correlations should be interpreted with care. Since the degree of significant correlations between the variables is generally very high, the correlations with exceptionally high coefficients and narrow confidence intervals (highlighted in red) are of most interest in this research. For example, communities with a high proportion of people born overseas tend to have a high proportion of females, which is observed for the WHH and increasingly so for Aoraki. Te Arai, in contrast, with a low proportion of people born overseas is characterised by a relatively smaller proportion of women. A high proportion of people born overseas is strongly associated with a high proportion of people living for only four or less years in the community, which indicates a relationship between transient and immigrant people. These two groups are more likely to be present in WHH and Aoraki than in Te Arai. More examples of such distinct relationships are highlighted in figure 13.7.

These relationships provide insights in the socio-economic fabric of communities. They pinpoint combinations of socio-economic groups which are of special interest to risk managers. It is in particular the combination of most vulnerable groups which amplifies the vulnerability of

communities. In addition, the presence of one specific group, like single households, suggests the presence of another group, such as the elderly. Such relationships are useful when only information on one of the two groups is readily at hand.

Figure 13.7: Correlation coefficients (Pearson) for the Western Hutt Hills, Te Arai and Aoraki, for the census years 1981 to 2006

As exemplified in this thesis, it is not only the socio-economic fabric and the way plus the speed by which the fabric changes, which influences risk. Changes in the geosystem are caused by the interplay of internal and external processes. In particular with respect to landslides, situations of high internal sensitivity coupled with the occurrence of a triggering (external) process like a rainstorm may not only cause a large degree of damage to the social system, but also alter the geosystem in the long-term. Establishing the history of the geosystem, meaning its sensitivity and the rate at which processes operate, enables a more informed evaluation of landslide hazard. The conventional approach of establishing frequency-magnitude relationships for a certain area and period is essentially static, since changes of the frequency and magnitude of processes, such as landslides, during the analysis period are not considered.

Landslide hazard analysis, which must be included in any form of landslide risk management, benefits from a dynamic approach to hazard. Such an approach ideally includes the interplay of processes operating within and outside the geosystem. For many regions in New Zealand (and worldwide), changing frequency-magnitude relationships of external, potentially landslide-triggering processes such as rainfall are to be expected in the context of climate change.

Therefore, forward-looking approaches on risk should include both socio-economic and geophysical processes, as well as their process rates. Socio-economic processes (influenced by the framing conditions or 'culture') are associated with both vulnerability and resilience (figure 13.8), while geophysical processes are associated with hazard (influenced by the framing conditions of 'nature'). As discussed in chapter 3 and exemplified in figure 13.8, the intersection of these processes operating in society and the material world creates a situation of risk for 'elements at risk' such as the population of a community, and their assets or artefacts. As demonstrated in this research, processes at this intersection are for example socio-economic changes as well as suburbanisation, farming, tourism and their implications for vulnerability and resilience. The speed of these processes and associated changes is variable; hence risk evolves at a different pace at different locations.

Figure 13.8: A dynamic model of risk (from chapter 3).

While a theory of risk is as such not available at present, the dynamic model of risk represents an ideal framework for the notion of hazard (from a systems perspective), and for the models of vulnerability and resilience (emphasising the path from framing conditions via access to resources to adaptive activities) developed in this research.

A process-based approach is of special interest for risk management which ideally follows a forward-looking perspective. As has been demonstrated in this thesis, different levels of risk are associated with different process rates. A community can be characterised by a high level of risk, and if processes operate rather slowly, a fast reduction of risk is unlikely. In these cases, risk management can inject skills and resources which aim at an immediate reduction of risk. Against the background of slowly operating processes, such measurements should ensure a long-term, sustainable degree of efficiency. In contrast, a community can enjoy a relatively low level of risk, which, however, is increasing rapidly. This combination results in a high level of uncertainty for risk planning and management. In addition, a false sense of security is generated when only the relatively low level of risk, but not the high process rate of risk, is taken into account.

13.6.1 Perspectives

While three, partly very different, locations are analysed in this research, further studies can concentrate on one of these three locations separately. For example, Aoraki receives a relatively very low level of risk since it is compared with communities which show a much higher vulnerability and population size. It would be interesting to include only similar sorts of communities with a focus on a specific process, such as tourism, in order to analyse how, for example, Aoraki performs compared to communities with a similar set-up. Likewise, the rural communities of the Te Arai could be ranked and analysed as part of a sample which includes rural communities only. In addition, dormitory suburbs of a major city such as the Western Hutt Hills can be analysed with respect to other suburbs with similar characteristics. This may also refine the relationships between the socio-economic variables presented in this research.

Furthermore, a more detailed analysis of the geomorphological system of the Western Hutt Hills, but in particular the Te Arai and Aoraki would deliver more insight into the history of these systems. Such work could include a quantification of sediment sources and sinks, a refinement of the system's sensitivity and hence an estimate whether frequency-magnitude relationships are subject to change.

A process-orientated and forward-looking perspective of risk can involve the modelling of scenarios based on changes in society which influence vulnerability and resilience as well as the interplay of 'nature' and society through land use change. The latter does not only involve changes in the agricultural sector but also processes such as suburban spread into landslide-prone areas and further investment into tourism-related facilities and enterprises. Indication of an intensification of these processes in the form of new subdivisions being built in the Western Hutt Hills is registered during visits undertaken in the context of this research. Likewise, further development of tourism-related facilities is planned for Aoraki, despite its high exposure to potentially very threatening geophysical processes like earthquake, floods and landslides.

Although challenging, modelling risk against the background of processes operating in nature and society would ideally incorporate aspects of non-linearity and complexity, which may be enhanced by different process rates within the geosystem and the social system.

14. Summary

In global terms, disasters are becoming more frequent, causing increasing losses at the community, regional, and national levels. This trend of increasing losses clearly demonstrates that natural risk is dynamic. However, currently there are no established methods of risk analysis that are able to comprehensively capture temporal variations in natural risk.

The aim of this research is to identify these temporal changes of risk, i.e. the evolution of risk, from landsliding for several locations in New Zealand. While risk analysis usually targets a particular point in time, this research analyses the progression of risk through time with reference to several five-year intervals (based on census years) starting in 1981 until 2006. The scale of the analysis is the community level – a scale underrepresented in landslide risk studies in particular.

Within this study, risk is not expressed as an absolute level of loss, such as a dollar value or the number of fatalities. Instead, risk is considered as the probability and extent of adverse effects on a community inferred from landsliding. As such, risk is relative: the aim is to quantify risk for a set of communities at several points in time so that spatio-temporal comparisons can be made for this set.

The concepts and applications developed in this work emphasise that risk is a *process*, rather than a constant. Quantification of risk for several points in time allows the tracing of the risk process and enables rates of change in risk to be established, thus providing additional information for risk management.

The study sites encompass several communities in the Western Hutt Hills (close to Wellington) and in the Gisborne area (Te Arai, east coast of the North Island). While the former location is characterised by suburban sprawl, the latter represents rural communities with a background in pastoral farming, horticulture and forestry. In addition, both locations are compared with an alpine community in the South Island (Mt. Cook/Aoraki Village), which has become a synonym for tourism in New Zealand.

The objectives of the risk analysis are to:

1. establish landslide hazard, i.e. the frequency and magnitude of landsliding for each location,
2. develop an index of social vulnerability per census year and community,
3. develop an index of social resilience per census year and community,
4. combine 1.-3. and, together with exposure ('elements at risk'), determine risk from landsliding for each community through time.

Since a comprehensive theory of natural risk is lacking, a range of approaches towards theorising 'human-nature' relationships are reviewed in order to find a framework for the risk

analysis. These approaches stem from fields such as human ecology, sociology (Luhmann), actor-network theory (Latour) and socio-ecological theory (Boyden, Sieferle, Fischer-Kowalski). As a result of this review, a model of risk is presented which places risk, hazard, elements at risk, vulnerability and resilience within a framework of a 'human-nature' system.

The development of a conceptual and methodological framework for analysing the components of risk has required familiarisation with and an understanding of how scholars from different disciplines have approached the subjects in the past. The development and central topics of the research fields 'science and technology', 'human ecology', 'social sciences', 'applied sciences' and the 'structuralist paradigm' are summarised and discussed. During the history of this wide field of natural hazard and risk research, the concept of vulnerability has gained a key role and has (relatively) recently been joined by the concept of resilience.

Despite the different, and at times opposing, positions of the different research fields related to strategies of risk reduction, some synergies emerge during this review. In particular, the human ecology school and the structuralist paradigm share, in general, positions with respect to the problems of a 'techno-fix' approach, and on the social causation and rooting of hazard and disaster in the daily structures of life.

Key definitions and characteristics, the heterogeneous terminology and some explicit explanatory approaches to vulnerability (PAR, Access, Applied Sciences, D. Alexander, Hazards-of-a-place (Cutter), Turner et al., BBC (Bogardi, Birkmann, Cardona), BDW (Bohle, Downing, Watts)) and to resilience (Tobin, Paton, Buckle) are summarised and discussed in this thesis. From the pool of models reviewed, a set of components is extracted which is considered as essential for any model of vulnerability and resilience. Since none of the models reviewed contains the complete set and because conceptual/terminological divergences prevail, new models of vulnerability and resilience are developed for this research.

These models are based on a synthesis of the reviewed research fields and models, and are influenced mainly by three approaches: the human ecology school (adjustment/adaptation), the livelihood/structuralist paradigm and 'socio-ecological' systems research associated with climate change and global environmental change research. The key aspects of the models are that

1. vulnerability and resilience are not reciprocals ('flipsides'), but are instead treated as independent although related concepts;
2. adaptation, although almost exclusively claimed by some resilience researchers, is equally rooted within the history of vulnerability research, in particular in association with the human ecology school, and therefore plays a central role for both concepts;
3. adaptive capacity is the result of access to resources, which is influenced by the socio-economic and infrastructure profile (of a community, a nation), which in turn is shaped by the political, economic, cultural and environmental structures of a society.

The models of vulnerability and resilience serve as templates for the quantitative analysis which is based on indices. A strong conceptual underpinning is even more important since the process of index construction offers manipulation opportunities and requires a range of (partly subjective) decisions, such as the selection of indicators. In order to minimise the degree of subjectivity inherent in any index structure, a firm conceptual grounding is beneficial. Additionally, methodological transparency, uncertainty and sensitivity analysis should accompany the steps of index construction (such as imputation, normalisation, weighting and aggregation) as described in this thesis.

Vulnerability and resilience indices combine data from the New Zealand Census, information extracted from aerial photos and other sources. A set of indicators enters a hierarchical structure of sub-indices, which are aggregated, based on an equal weight approach suggested by the results of a principal component analysis (PCA), to the final indices of vulnerability and resilience. Sensitivity testing suggests that both indices are robust towards variations of input data.

The indices enable not only a ranking of communities, but also a quantification of the magnitudes of change between communities, and the change for each community in time. Furthermore, individual indicators are analysed in order to reveal the driving factors behind observed spatial patterns and trends.

A grouping of the communities according to their location emerges, which is most distinct for the index 'vulnerability': the communities of the Te Arai (on average and per census year) are ranked the most vulnerable, followed by the communities of the Western Hutt Hills (WHH). Aoraki is clearly ranked as the least vulnerable community.

With respect to resilience, the grouping of the three locations is less distinct but still present. Maungaraki (WHH) just overtops the Te Arai, which means that these communities are the most resilient. Communities of the WHH are placed at the middle range of the index, except Korokoro (WHH), which shares the bottom (least resilient) rank with Aoraki.

A ratio of vulnerability to resilience (VR-ratio) is calculated (by dividing vulnerability with resilience) to investigate the relationship of vulnerability to resilience. On average, Te Arai shows the highest value (above 1, meaning least favourable with respect to risk), followed by the WHH and Aoraki which is clearly the community with the lowest (meaning most favourable), VR-ratio.

The temporal analysis shows that while no trend for vulnerability is observed for Te Arai, vulnerability tends to increase for the WHH and in particular for Aoraki. Simultaneously, resilience declines for Te Arai and Aoraki, while no trend is observed for the WHH.

The VR-ratio is consistently lowest (most favourable) for Aoraki and Maungaraki (WHH), although values increase for both communities. In particular Aoraki witnesses a drastic rise,

indicating a sudden change for the worse with respect to the evolution of risk. Generally, VR-ratios increase in time, while only two communities depict a (modest) decline.

Overall, magnitudes of change, meaning process rates, are the greatest for Aoraki, followed by the WHH and Te Arai. It is illustrated that, for example, a community can enjoy a relatively low level of vulnerability, which does, however, increase quickly. Likewise, a community may be highly vulnerable over considerable periods of time.

Because of the excellent data coverage for the WHH, landslide hazard analysis is based on detailed aerial photo interpretation (thirteen sets of aerial photos between 1941 and 2005), while for the Te Arai and Aoraki a literature based approach is applied. The dominant types of landslides (according to the nomenclature of Varnes, 1978) are shallow rock slides, debris flows and slides, earth flows and slides (WHH), earth slips and slumps, shallow earth flows and gully erosion (Te Arai), as well as debris flows and rock falls (Aoraki).

For the WHH a frequency-magnitude relationship is established that enables the calculation of the annual probability of a certain landslide event magnitude (landslide density or affected area) to occur (hazard).

The 'Antecedent Soil Water Status' model (Crozier and Eyles, 1980) is used to investigate whether the 'critical water content' (the sum of antecedent soil water and rainfall on the day) correlates with the observed magnitudes of landslides. The correlation is weak, meaning there is no statistical evidence for a linear relationship between landslide magnitude and critical water content. This non-linearity is explained by the history of the geomorphological system: a major storm (December 1976) had triggered a large landslide event. The storm emptied sediment sources and subsequent rainfall events could consequently no longer trigger the expected equivalent magnitudes of landsliding. It is demonstrated in this research that due to the changed (decreased) sensitivity of the geomorphological system, a frequency-magnitude relationship, which is a common approach in hazard analysis, masks the variability of hazard in time.

Finally, the results of the hazard, vulnerability and resilience analysis are, in combination with the community population as the 'element at risk', merged to quantify landslide risk for each community. The calculation is based on a 'worst-case' scenario, meaning the largest observed magnitude of a landslide event occurring at night.

Two options for calculating risk are presented and discussed. Both methods divert from the conventional methodology, which involves a combination of hazard, elements at risk and vulnerability while excluding resilience.

The results of the risk calculation (based on the preferred approach of $\text{risk} = \text{hazard} \times \text{elements at risk} \times (\text{vulnerability} + \text{vulnerability}/\text{resilience})$) show that, on average and per census year, the Western Hutt Hills are ranked at the top, followed by Te Arai (with the exception of Manutuke), and Aoraki. The grouping of the three locations is distinct, and Aoraki's position at the bottom of

the risk rank is clearly evident. For all communities, except Manutuke (Te Arai), risk increases in time. A considerable decline of population and a decrease of the VR-ratio are the driving processes in Manutuke. Population as the 'element at risk' strongly influences risk, and it is illustrated how risk is modified by the interplay of hazard, vulnerability and resilience.

By far the greatest variability of risk is calculated for Aoraki, followed by the WHH and Te Arai (except Manutuke). The combination of risk level and the rate at which the process of risk operates shows that, for example, Aoraki enjoys the lowest level of risk which is, however, changing (increasing) rapidly. Furthermore, the process of risk operates differently depending on the nature of the suburban, rural or tourism-dominated communities. The effect on risk when temporal changes of hazard are included in the analysis is illustrated for the WHH.

It is demonstrated in this research that analysing risk for a single point in time delivers only half the 'truth'. Analysing risk as a process rather than a static construct enables a more informed basis for assessing, evaluating and treating, hence managing, risk.

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Appendices:

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Appendix A: Terminology

Stream A 'Human Ecology'		Stream B 'Climate Change and Global Environmental Change'		Stream C 'Development and Livelihood'	
Adjustment ≠ adaptation	Authors	Adjustment = adaptation	Authors	Capability	Authors
Adjustment = short-term, immediate, minor changes	Kates 1970; Burton, Kates and White 1978, 1993; Heathcote 1985; Kates 1985; White, Kates and Burton 2001; Kasperson et al. 2005	No differentiation between the two, adaptation can also be a response to short-term, e.g. yearly fluctuations, utilisation of opportunities, reactive and proactive	Smit, 1993; Watson et al., 1996; Smithers and Smith, 1997; Smit et al. 2000; Brooks, 2003; Klein et al., 2003; Smit and Wandel, 2006; IPCC, 2001; Janssen and Ostrom, 2006	Ability to sustain quality of life: ability to cope with stress and shocks and utilise livelihood opportunities, this is reactive (cope) and proactive (dynamically adaptable)	Chambers and Conway, 1992 referring to the works of A. Sen; Anderson and Woodrow 1989, 1998
Adaptation = long-term, substantial changes, slow, can involve culture	Burton, Kates and White 1978, 1993; Heathcote 1985; Kates 1985; Kasperson et al., 2005; Turner et al., 2003	Different degrees of alternations in this context possible, from minor to substantial, but still labelled adaptation	Smit and Wandel, 2006; Risby, 1999		
Adjustments can evolve into adaptations	White, Kates and Burton 2001				
Mitigation can be a form of adjusting/adapting	Smit et al. 2000 for environmental hazards	Mitigation is clearly separated from adaptation	Smit et al., 2000; McCarthy et al., 2001 and IPCC, 2001; IPCC 2007b, c		
Adaptive capacity ≠ coping capacity	Turner et al. 2003; Chambers and Conway, 1992; Gallopin, 2006	Adaptive capacity = coping capacity	Smit et al., 2000; Brooks, 2003; Smit and Wandel, 2006; IPCC, 2001; Adger, 2006; Ford and Smit, 2004	Capability including coping and adapting	Chambers and Conway, 1992
Coping as overall term including adaptation	Burton, Kates and White, 1978, 1993	Adaptive capacity to increase coping range, used as one concept of adapting or coping, coping more or less	Adjustment and adaptation as form of coping Kasperson et al. 2005		

		the same a bit more of 'grappling'			
		Adaptive capacity as part of resilience or even used interchangeably	Turner et al., 2003; Adger, 2006; Folke, 2006; Carpenter et al., 2001; Pelling, 2003; Berkes and Jolly, 2001; Smit and Wandel, 2006; ISDR ¹	Vulnerability: exposure (external) & capacity to cope (internal)	Chambers and Conway, 1992; Watts and Bohle, 1993; Bohle et al., 1994; Bohle, 2001
		Resilience: persist, self-organise, capacity for learning and adapting	Carpenter et al, 2001; Folke, 2006; Adger, 2006	Vulnerability: exposure (external) & capacity to cope (internal) & potentiality (resilience)	Watts and Bohle, 1993; Bohle et al., 1994; Bohle, 2001
Vulnerability: degree to which a system is susceptible to injury or damage	Burton, Kates and White, 1978, 1993; White, Kates and Burton, 2001	Vulnerability: exposure & sensitivity & adaptive capacity/resilience Resilience is on one side of the vulnerability equation	Kasperson et al., 1995a; McCarthy et al., 2001; Folke et al., 2002 ; Brooks, 2003; Adger, 2006; Kasperson et al., 2005; Smit and Wandel, 2006; IPCC, 2007b, c; Turner et al., 2003; Birkmann, 2006	Vulnerability: capacity to cope & to resist and recover (resilience)	Wisner et al., 2004

¹ <http://www.unisdr.org/eng/library/lib-terminology-eng.htm>, accessed 18.8.2008

Appendix B: 'Socio-ecological' systems and panarchy

In the book 'Panarchy', edited by Lance Gunderson and C.S. Holling (2002b), research from the 'Resilience Alliance'¹ and the results of comparative case study analysis are synthesised to form the basis for a theoretical underpinning of changes in coupled social and ecological systems – combined as 'socio-ecological systems'.

The model of an 'adaptive cycle' is devoted to capturing these changing socio-ecological systems. It depicts a system's journey along the four phases of 1. exploitation (r), 2. conservation (K), 3. release (Ω) and 4. reorganisation (α) (Berkes and Folke, 2002; Holling and Gunderson, 2002) (figure B.1).

Figure B.1: The adaptive cycle (Holling and Gunderson, 2002: 34)

The phase of exploitation is dominated by what is labelled in ecology the 'r-strategy'. Initially, the potential (based on already accumulated resources) is low, and so is the connectivity between internal variables controlling the variability of the system. This means much room for innovation but at the same time high uncertainty. As the phase continues, it slowly but eventually evolves into the conservation stage (K). Competition means that the most successful strategies and structures start to establish themselves, and as a result connectivity and potential grow. More connectivity means less innovation, but also less uncertainty and more predictability. At the peak of the K phase, potential is high, connectivity is high and structures are maintained. Net growth slows and the system enters a stage that is seen as persistent and rigid. A shift has occurred from those who adapt to uncertainty (r) to those who control variability (K), which entails a loss of resilience (defined as the ability to maintain functioning while changing, this means adapting to alternating conditions, chapter 6). With low resilience, any trigger of even small magnitude very rapidly switches the peak of the K phase into the release (Ω) phase: established structures collapse, chaos might arise, resources are released, potential plummets, and so does connectivity because of dissolving structures. It should be noted that

¹ An international conglomeration of resilience researchers, <http://www.resalliance.org/1.php>, accessed 9.12.2007

connectivity in figure B.1 is still relatively high which is misleading. Human adaptation can prevent such a sudden shift of state. As Ω develops quickly into reorganisation (α), uncertainty is still high, predictability is low but potential grows (based on those resources left after the Ω phase). During α , connectedness is still relatively low, but resources are reorganised, room for innovations and novelty grows, and so does resilience. Simultaneously due to low connectedness the ability to control variability is limited, potential (resources) can 'leak' and a flip into another system state is most likely. Nevertheless, the α phase is the beginning or 'template' for the next r phase (Holling and Gunderson, 2002). 'Panarchy' refers to the nested structure of time and space scales, based on the Greek god of nature, Pan. Panarchy represents the adaptive and evolutionary character of the adaptive cycle, representing creation and destruction, change and persistence, predictability and unpredictability (Holling, Gunderson and Peterson, 2002). The interconnection of scales is possible especially during the Ω and K phase (figure B.2). During Ω , a 'revolt' on one scale can cascade 'upwards' to a state of low resilience (K) in a larger and slower operation adaptive cycle.

Figure B.2: Panarchy (Holling, Gunderson and Peterson, 2002: 75)

The second connection ('remember' is when from such a larger and slower adaptive cycle resources (high potential) accumulated during the K phase can cascade 'downwards' to assist with the α phase with low potential (Holling, Gunderson and Peterson, 2002).

The adaptive cycle is based on the assumption that collapses and the emerging need of innovation, reorganisation and rebuilding are likely processes, or even non-preventable effects of human utilisations of nature (Carpenter et al., 2002). Under the auspice of the Resilience Alliance, many examples both ecological and social such as economy are drawn upon to underlay the model of the adaptive cycle.

An 'adaptive cycle' operates according to a worldview labelled 'nature evolving' which is characterised by changing framing conditions under which systems operate (Holling, Gunderson and Peterson, 2002). Within this view, resilience (the ability to deal with disturbances while remaining functioning, chapter 6) is not assumed to be static but contracts and expands during the (evolutionary) change of a system along four phases of the cycle as outlined below (Holling and Gunderson, 2002). Holling, Gunderson and Peterson (2002) further underpinned the notions of non-linearity, self-organisation, learning and adaptation within systems that are perceived to be constantly changing. 'Nature evolving' can vary abruptly and is characterised by the unpredictability of ecosystem dynamics as emphasised by Holling (1973). 'Nature evolving' further concurs with Holling's claim of adaptive management which conserves nothing but the ability to change and to keep options open (see also chapter 6).

During an adaptive cycle, resources are accumulated and released in periods of crisis or collapse, which creates opportunities for innovation. Holling, Gunderson and Ludwig (2002) underlined the potential they see in the concept of the adaptive cycle to decipher complex system behaviour at various scales and for various systems. The adaptive cycle reflects the shift between resilient and unstable to less resilient and stable states, hence capturing the interplay between resilience and stability as discussed in chapter 6, while emphasising the role of evolutionary change. The metaphor of the adaptive cycle combines two contrasting elements: growth and stability on the one hand, and change and diversity on the other hand. Therefore it symbolises that fostering only one of the two sides is not feasible in the context of effective sustainable environmental management (Holling and Gunderson, 2002).

While the 'adaptive cycle' includes the chance for novelty and opportunity after collapse when reorganisation takes place in phase four, the notion of evolutionary change implies that change can be irreversible, this means systems do not necessarily return to their original state (chapter 6). A regime shift can be irreversible, reversible or effectively irreversible, i.e. not reversible during time spans which are of interest for humans. Depending on who judges the quality of a new regime, it can be categorised as 'desirable' or 'undesirable'. A system's regime can therefore be desirable for some groups within socio-ecological systems, while it is undesirable for others. In the latter case, a high level of resilience is not favourable since it prevents real transformation. This can be interpreted from an ecological perspective, as well as from a socio-economic or political perspective (Walker et al., 2004).

According to Carpenter et al. (2002) and Holling, Gunderson and Ludwig (2002) the overall goal of authors of the Resilience Alliance is to develop a theoretical base, 'an integrated theory', crossing disciplinary boundaries to understand the changes in 'socio-ecological systems'. Although the model of the adaptive cycle, coupled with panarchy, has been introduced as a 'metaphor' not a theory (Holling and Gunderson, 2002) it resides at the centre of such theory construction. Socio-ecological systems are seen as complex systems that are characterised by interconnections between ecological systems and humans. Against the background of resource

management and sustainability, Berkes and Folke (2002) underlined that social and ecological systems cannot be perceived as separate unities. They criticised the neglect of relations between both, and a preference for discipline-defined isolated system examination. Berkes and Folke (2002: 122) further emphasised that the separation into two different systems is 'artificial and arbitrary' – hence the usage of the term 'socio-ecological system'. This perception is emphasised by Walker et al. (2004) and Walker et al. (2006:1) who stated that '*social-ecological systems [...] are neither humans embedded in an ecological system nor ecosystems embedded in human systems [...], but rather a different thing altogether*'.

The concept of 'adaptive cycle' expanding over various spatial scales, and connected insights into how systems respond to disturbances yield some valuable and interesting ideas, most of them like non-linearity, complexity (though partly understood differently) and irreversible change, have appeared at several points in chapter 3.

However what exactly this '*rather different thing*' according to Walker et al. (2006) actually is, other than two related systems, remains unclear. How the classical dualism, identified as hindering progress (see above) is overcome remains fuzzy. The undercurrent of studies embedded in the Resilience Alliance points towards a conceptualisation of social-ecological systems as mainly ecosystem management systems. Therefore, this cannot be an attempt to theoretically define social systems or 'socio-ecological systems' as claimed (see above), but to focus on processes within and between both which are relevant in resource management. This is what Gallopin (2002) referred to as a 'new contract' based on the 'social contract for science' called for by Lubchenco (1998) against the background of a profoundly changing 21st century. The conceptualisation of an interlinked socio-ecological system, though much better than a partial, non-holistic approach, is, however, nothing new.

This is not to say that ecological and social functionalities included are wrong or not useful. Especially with respect to resilience, ecological ideas such as diversity and redundancy (Holling, 1973) can be combined with social networks and trust (Scheffer et al., 2002; Walker et al., 2006) in order to shape a concept of social resilience which promises to be very useful in reducing risk (chapter 6).

However a theoretical base for both, ecological and social systems alike does not surface to an extent where the social sphere is captured in a more differentiated way. The differences between ecological and social systems are identified and some functions typical for social systems are discussed (Westley et al., 2002). However, what exactly constitutes a system, and whether sociological systems essentially operate like ecological systems are questions not answered. Overall, the direction of explanation runs from a sound ecological base towards social systems as Berkes and Folke (2002: 122) pointed out themselves. Based on ecological research (Holling, 1973), key features of ecosystem behaviour are transferred to social systems and activities such as economic mechanisms and ecosystem management (Berkes and Folke, 2002; Holling and Gunderson, 2002). As Adger (2000), who is a member of the Resilience Alliance, mentioned, transferring ecological insights to social systems should be regarded with

caution. Theorising human-nature interaction is a challenging task especially when aiming to find a basis for the diverse disciplines associated with this topic. It cannot be successfully fulfilled if the direction of explanation runs from insight into ecological processes towards what is called 'social-ecological' systems. This is what Hewitt (1983) criticised as the dominant paradigm of approaching natural hazards and disasters from only the direction of the natural sciences, sparking much controversy at the time and still today. Finally when following the phases of the adaptive cycle, collapse is depicted as a way of opening up new opportunities: a welcomed revitalisation after a potentially long phase of 'rigidity' and stagnation, and necessity for evolution and progress. Applying the concept of the adaptive cycle directly for 'socio-ecological' systems which ultimately includes risk, it becomes almost cynical. Although the human potential to avoid collapse is acknowledged, the extent of human suffering during collapse cannot be expressed by the terminology used.

Appendix C: Vulnerability and resilience analysis - methodology

Table C.1: Access to resources filtered by the community profile: the New Zealand context.

		Social capital (SC)	Finan. capital (FC)	Information		Institutional		
				Gener. relevant (INFg)	Local knowl. (INFik)	Welfare (INSw)	Health (INSh)	Relief (INSr)
Hhold income	High		+				+	equal
	Medium		+ 0.5				+ 0.5	equal
	Low		-				-	equal
Age	65+ yrs	-	-	-	+		reflected by economic status	-
	Below 5 yrs	+	-	-	-		reflected by economic status	-
Gender	Male		equal, but comparatively negative for females	equal		equal	reflected by economic status	equal
	Female			equal		equal	reflected by economic status	equal
Hhold structure	Families, flat sharing	+		+				
	Single	-		-				
Family type: Depend-ants	2:0 (couple only)	+	+					
	2:1 and more	+ 0.5	+ 0.5					
	1:0	+	+					
	1:1 and more	- 0.5	- 0.5					
Education	Illiterate		-	-				-
	Basic/higher		+	+				+
Ethnicity (minority)	Group 1	?	reflected by economic status	?	?	?	reflected by economic status	?
	Group 2	?		?	?	?	s.a.	?
	Group 3	?		?	?	?	s.a.	?
Industry			reflected by economic status					
The disabled		-	-	-			reflected by economic status	-
The ill		negative when chronic	negative when chronic	-			reflected by economic status when chronic	-
The homeless		-	-	-			reflected by economic status	
Transients		-	reflected by economic status	-	-		reflected by economic status	neutral

Note that the resource 'environment' is not listed in table C.1. This is because generally, access is assumed to be not restricted when intended (in one way or the other). Ethnicity, however, is likely to be decisive, which cannot be explored into sufficient depth within this research.

The variables listed on the left of table C.1 constitute the socio-economic profile of a community. Grey fields with pronounced boundaries indicate a relation between the variable on the left and a resource in the header of the table. The nature of this relation is either positive, i.e. access to this resource is likely, or negative, i.e. access to this resource is unlikely. This can be differentiated by a medium value such as 0.5. 'Neutral' means that no clear tendency towards a negative or positive relation to a resource within the New Zealand context is identified. Theoretically, the table can be filled in qualitatively like here, or quantitatively when including the percentage of community members per variable. The table serves as a template for any cultural context and can be applied for multiple hazards. Some variables will be more context-specific than others. The homeless, for instance, are most likely to be economically and socially marginalised, independent of the political and cultural context. Also, different health systems bear different consequences for the affordability, coverage and quality of medical treatment of the elderly. Note that the variable 'ethnicity' is not included here for reasons explained in chapter 11.

Filling in table C.1 reveals that not every variable is related to every resource. Possibly not all relations existing in reality are included here which would fill some of the blank fields. As indicated in chapter 8, in many areas more research is needed while at the same time other areas, such as gender and age, have developed a depth which can only be reflected superficially within this thesis.

Table C.2: Available (✓) and imputed variables per year, Western Hutt Hills

Community	Indicator	1981	1986	1991	1996	'01	'06
Korokoro	Household income	✓	✓	✓	✓	✓	✓
Maungaraki		✓	✓	✓	✓	✓	✓
Normandale		✓	✓	✓	✓	✓	✓
Tirohanga		AU based	AU based	AU based	AU based	✓	✓
Belmont		AU based	AU based	AU based	AU based	✓	✓
Kelson		✓	✓	✓	✓	✓	✓
Korokoro	females	✓	✓	✓	✓	✓	✓
Maungaraki		AU based	AU based	✓	✓	✓	✓
Normandale		AU based	AU based	✓	✓	✓	✓
Tirohanga		AU based	AU based	✓	✓	✓	✓
Belmont		AU based	AU based	✓	✓	✓	✓
Kelson		✓	✓	✓	✓	✓	✓
Korokoro	Age (Under 5 and over 65 years)	✓	✓	✓	✓	✓	✓
Maungaraki		✓	✓	✓	✓	✓	✓
Normandale		✓	✓	✓	✓	✓	✓
Tirohanga		✓	✓	✓	✓	✓	✓
Belmont		✓	✓	✓	✓	✓	✓
Kelson		✓	✓	✓	✓	✓	✓
Korokoro	Single household	✓	✓	✓	✓	✓	✓
Maungaraki		✓	✓	✓	✓	✓	✓
Normandale		✓	✓	✓	✓	✓	✓
Tirohanga		✓	✓	✓	✓	✓	✓
Belmont		✓	✓	✓	✓	✓	✓
Kelson		✓	✓	✓	✓	✓	✓
Korokoro	1 parent with child(ren)	mean	✓	✓	✓	✓	✓
Maungaraki		linear regression	✓	✓	✓	✓	✓
Normandale		mean	✓	✓	✓	✓	✓
Tirohanga		linear regression	✓	✓	✓	✓	✓

Belmont		linear regression	✓	✓	✓	✓	✓
Kelson		linear regression	✓	✓	✓	✓	✓
Korokoro	Birthplace	✓	✓	✓	✓	✓	✓
Maungaraki		AU based	AU based	✓	✓	✓	✓
Normandale		AU based	AU based	✓	✓	✓	✓
Tirohanga		AU based	AU based	✓	✓	✓	✓
Belmont		AU based	AU based	✓	✓	✓	✓
Kelson		✓	✓	✓	✓	✓	✓
Korokoro	0-4 years at residence	calc. from 1986	✓	calc. from 2001	calc. from 2001	✓	✓
Maungaraki		calc. from 1986	✓	calc. from 2001	calc. from 2001	✓	✓
Normandale		calc. from 1986	✓	calc. from 2001	calc. from 2001	✓	✓
Tirohanga		calc. from 1986	✓	calc. from 2001	calc. from 2001	✓	✓
Belmont		calc. from 1986	✓	calc. from 2001	calc. from 2001	✓	✓
Kelson		calc. from 1986	✓	calc. from 2001	calc. from 2001	✓	✓
Korokoro	Industry (farming/fish/forestry)	✓	✓	✓	✓	✓	✓
Maungaraki		AU based	AU based	✓	✓	✓	✓
Normandale		AU based	AU based	✓	✓	✓	✓
Tirohanga		AU based	AU based	AU based	✓	✓	✓
Belmont		AU based	AU based	AU based	✓	✓	✓
Kelson		✓	✓	✓	✓	✓	✓
Korokoro	Visitor	✓	linear regression	✓	✓	✓	✓
Maungaraki		AU based	linear regression	✓	✓	✓	✓
Normandale		AU based	mean	✓	✓	✓	✓
Tirohanga		AU based	mean	✓	✓	✓	✓
Belmont		AU based	mean	✓	✓	✓	✓
Kelson		✓	mean	✓	✓	✓	✓
Korokoro	Road connectivity (ratio intersections/road length)	✓	✓	✓	✓	✓	✓
Maungaraki		✓	✓	✓	✓	✓	✓
Normandale		✓	✓	✓	✓	✓	✓
Tirohanga		✓	✓	✓	✓	✓	✓
Belmont		✓	✓	✓	✓	✓	✓
Kelson		✓	✓	✓	✓	✓	✓
Korokoro	Access points (ratio access points/population size)	✓	✓	✓	✓	✓	✓
Maungaraki		✓	✓	✓	✓	✓	✓
Normandale		✓	✓	✓	✓	✓	✓
Tirohanga		✓	✓	✓	✓	✓	✓
Belmont		✓	✓	✓	✓	✓	✓
Kelson		✓	✓	✓	✓	✓	✓
Korokoro	Robustness infrastructure (age min. 51-65 years)	✓	✓	✓	✓	✓	✓
Maungaraki		✓	✓	✓	✓	✓	✓
Normandale		✓	✓	✓	✓	✓	✓

Tirohanga	critical facilities (hospitals, medical practitioners, police, fire stations)	✓	✓	✓	✓	✓	✓
Belmont		✓	✓	✓	✓	✓	✓
Kelson		✓	✓	✓	✓	✓	✓
Korokoro		✓	✓	✓	✓	✓	✓
Maungaraki		✓	✓	✓	✓	✓	✓
Normandale		✓	✓	✓	✓	✓	✓
Tirohanga		✓	✓	✓	✓	✓	✓
Belmont		✓	✓	✓	✓	✓	✓
Kelson		✓	✓	✓	✓	✓	✓
Korokoro	Community facilities (number of schools, community centres, kindergartens, playgroups, churches, marae)	✓	✓	✓	✓	✓	✓
Maungaraki		✓	✓	✓	✓	✓	✓
Normandale		✓	✓	✓	✓	✓	✓
Tirohanga		✓	✓	✓	✓	✓	✓
Belmont		✓	✓	✓	✓	✓	✓
Kelson		✓	✓	✓	✓	✓	✓

Table C.3: Available (✓) and imputed variable per year, Aoraki and Te Arai

Community		Indicator	1991	1996	2001	2006
Waingake	Te Arai	Household income (less than 60% of median household income, in %)	AU based (100%)	AU based (100%)	✓	AU based (100%)
Waerengaokuri			AU based (50%)	AU based (50%)	✓	AU based (50%)
Manutuke			✓	✓	✓	✓
Aoraki			✓	✓	✓	✓
Waingake	Te Arai	Gender (females, in %)	✓	✓	✓	✓
Waerengaokuri			✓	✓	✓	✓
Manutuke			✓	✓	✓	✓
Aoraki			✓	✓	✓	✓
Waingake	Te Arai	Age (Under 5 and over 65 years, in %)	✓	✓	✓	✓
Waerengaokuri			✓	✓	✓	✓
Manutuke			✓	✓	✓	✓
Aoraki			✓	✓	✓	✓
Waingake	Te Arai	Single household, in %	✓	✓	✓	✓
Waerengaokuri			Mean (50%)	✓	✓	✓
Manutuke			✓	✓	✓	✓
Aoraki			✓	✓	✓	✓
Waingake	Te Arai	1 parent with child(ren), in %	✓	✓	Mean (33%)	✓
Waerengaokuri			Mean (50%)	✓	✓	✓
Manutuke			✓	✓	✓	✓
Aoraki			✓	✓	✓	✓
Waingake	Te Arai	Birthplace (overseas born, in %)	✓	✓	✓	✓
Waerengaokuri			✓	✓	✓	✓
Manutuke			✓	✓	✓	✓
Aoraki			✓	✓	✓	✓
Waingake	Te Arai	years at residence (0-4 years, in %)	calc. from 2001	calc. from 2001	✓	✓
Waerengaokuri			calc. from 2001	calc. from 2001	✓	✓
Manutuke			calc. from 2001	calc. from 2001	✓	✓

Aoraki			calc. from 2001	calc. from 2001	✓	✓
Waingake	Te Arai	Industry (farming/fish/ forestry, in %)	Mean (100%)	✓	✓	AU based (100%)
Waerengaokuri			Mean (100%)	✓	✓	AU based (100%)
Manutuke			mean	✓	✓	✓
Aoraki			mean	✓	✓	✓
Waingake	Te Arai	Visitor (overseas visitors, in %)	✓	✓	✓	✓
Waerengaokuri			✓	✓	✓	✓
Manutuke			✓	✓	✓	✓
Aoraki			✓	✓	✓	✓
Waingake	Te Arai	Road connectivity (ratio intersections/road length)	✓	✓	✓	✓
Waerengaokuri			✓	✓	✓	✓
Manutuke			✓	✓	✓	✓
Aoraki			✓	✓	✓	✓
Waingake	Te Arai	Access points (ratio access points/population size)	✓	✓	✓	✓
Waerengaokuri			✓	✓	✓	✓
Manutuke			✓	✓	✓	✓
Aoraki			✓	✓	✓	✓
Waingake	Te Arai	Robustness infrastructure (age min. 51-65 years, as % of total network length)	✓	✓	✓	✓
Waerengaokuri			✓	✓	✓	✓
Manutuke			✓	✓	✓	✓
Aoraki			✓	✓	✓	✓
Waingake	Te Arai	critical facilities (hospitals, medical practitioners, police, fire stations, ratio to population size)	✓	✓	✓	✓
Waerengaokuri			✓	✓	✓	✓
Manutuke			✓	✓	✓	✓
Aoraki			✓	✓	✓	✓
Waingake	Te Arai	Community facilities (number of schools, community centres, kindergartens, playgroups, churches, marae)	✓	✓	✓	✓
Waerengaokuri			✓	✓	✓	✓
Manutuke			✓	✓	✓	✓
Aoraki			✓	✓	✓	✓

Table C.4: Zero and missing values due to confidentiality for Tirohanga, which contains eight meshblocks in total. Fields shaded in grey are zero values, not case deletions.

Variable	Years	No. of missing count per year	Value of total count per year	No. of classes
Visitors	1991 - 2001	1	0	
Years at residence	1986	1	9	7
Age	1981	1	12	14
	1981	1	24	14
	1986	1	9	14
Household income	1981	2	6	5
	1986	1	0	
	1986	1	6	5
Single household	1981	1	3	6
	1986	3	0	
1-parent	1986	1	3	3

Table C.5: Zero and missing values due to confidentiality for Belmont, which contains 19 meshblocks in total. Fields shaded in grey are zero values, not case deletions.

Variable	Years	No. of missing counts per year	Value of total count per year	No. of classes
Visitors	1991-2001	1	0	
Years at residence	1986	1	9	7
Age	1981	1	12	14
	1981	1	24	14
	1986	1	9	14
Gender	1991-2001	1	0	
Household income	1981	1	0	
	1981	1	9	5
	1986	4	0	
	1986	3	6	5
	2001	2	0	
Single household	1981	2	0	
	1981	4	3	6
	1986	2	6	6
	1986	1	0	
	1991-2001	2	0	
1-parent	1986	1	0	
	1986	2	3	3
	1991-2001	2	0	

Table C.6: Zero and missing values due to confidentiality for Maungaraki, which contains 22 meshblocks in total. Fields shaded in grey are zero values, not case deletions.

Variable	Years	No. of missing counts per year	Value of total count per year	No. of classes
Visitors	1991 – 2001	1	0	
Age	1981	1	24	14
Gender	1991-2001	1	0	
Single household	1981	1	6	6

Table C.7: Zero and missing values due to confidentiality for Normandale, which contains 17 meshblocks in total. Fields shaded in grey are zero values, not case deletions.

Variable	Years	No. of missing counts per year	Value of total count per year	No. of classes
Visitors	1991 – 2001	1	0	
Age	1981	1	27	14
Gender	1991-2001	1	0	
Household income	1981	1	6	5
Single household	1981	1	6	
1-parent	1986	1	0	

Testing of AU-based imputation, and parameters for mean and linear regression methods

The testing of imputation techniques based on RMSE is based on available years, and the year (count) to be tested is excluded from the data set. For instance, AU-level data available for 1991 until 2006 entails that the RMSE for 1991 is calculated by using the estimated and observed counts for 1996-2006, the RMSE for 1996 is calculated by using the estimated and observed counts of 1991, 200-2006, and so on. The procedure simulates the case of a missing data point. Subsequently, the *average RMSE* for all years is calculated. While RMSE calculations usually

include all data pairs at once, the RMSE is calculated for each data pair (i.e. year) for each community individually, and then the average for all years is calculated. This two-step process enables exploring the magnitude of error for each data pair separately. Subsequently, based on the (average) RMSE the proportion of variance from the observed count is calculated for two reference years. This is to account for varying magnitudes of the total count.

RMSE values and the percentage of variance for two reference years are measures of uncertainty. However, this uncertainty relates to the data set used for testing, not for the missing data as such. It is therefore assumed that uncertainty for the tested years is comparable to the uncertainty of the missing years.

Tables C.8 to C.15 list RMSE results (averaged for all available years) for each imputation technique tested, as well as the proportion of variance for the earliest and latest year (i.e. the reference years) available. This variance is listed for the chosen method only, which is also coloured in grey.

Table C.8: Error estimate for 'visitor'

Missing: 1981	RMSE, AU-pop	% variance	RMSE, AU-ratio¹	r², LReg¹
Maungaraki	3.4	1991:19.1	4.5	0.85
		2006: 21.7		
Normandale	3.4	1991:16.4	4.5	0.01
		2006: 16.4		
Tirohanga	2.4	1991: 26.8	4.3	0.57
		2006: 13.4		
Belmont	2.4	1991: 8.1	4.3	0.03
		2006: 7.3		
Missing: 1986	RMSE, AU-pop	RMSE, AU-ratio	mean¹	r², LReg
Maungaraki	no AU data	no AU data		0.85 ¹
Normandale	no AU data	no AU data	✓	0.01 ¹
Tirohanga	no AU data	no AU data	✓	0.57 ¹
Belmont	no AU data	no AU data	✓	0.03 ¹
Kelson	no AU data	no AU data	✓	0.04 ³
Korokoro	no AU data	no AU data		0.78 ³

¹testing based on 1991-2006, ²based on 1991-2006, ³based on 1981, 1991-2006

Imputing missing values for Maungaraki (1981) could be based on a linear regression. However, since the AU-level method uses an actual observed count, the AU-method is preferred. Imputing values for 1986, where no AU-level data is available, varies between using the mean and linear regression in cases where r² values indicate a temporal trend.

Table C.9: Error estimate for 'females', ¹ testing based on 1991-2006

Missing: 1981, 1986	RMSE, AU-pop¹	% variance
Maungaraki	7.9	1991: 0.5 2006: 0.4
Normandale	7.9	1991: 0.8 2006: 0.8
Tirohanga	5.6	1991: 1.5 2006: 1.0
Belmont	5.6	1991: 0.5 2006: 0.4

Since the level of uncertainty for the 'AU-pop' method displays a magnitude of 1.5% to 0.4%, this method is applied. Further testing with 'AU-ratio', 'mean' or 'LReg' would not improve the imputation results considerably. The results of the 'AU-pop' method indicate a very even distribution of females between the communities. In addition, the overall high counts, for instance 1692 females in Maungaraki in 1991, favour an overall very low percentage of variance.

Table C.10: Error estimate for 'birthplace'

Missing: 1981, 1986	RMSE, AU-pop	% variance	RMSE, AU-ratio¹	% variance
Maungaraki	43.2		28.7	'91: 4.3 '06: 3.3
Normandale	43.2		28.7	'91: 7.2 '06: 6.8
Tirohanga	10.6	1991: 2.5 2006: 3.6	24.0	
Belmont	10.6	1991: 7.7 2006: 1.8	24.0	

¹ testing based on 1991-2006

Because the AU-based methods are preferred over mean and linear regression, and the level of uncertainty varies between 1.8% and 7.7%, no further testing of mean and linear regression is undertaken.

For the variable 'household income', imputation for each household income class is necessary. The testing of AU-based imputation is limited, since only two years are available for calculating an average RMSE (table C.11).

Table C.11: Average RMSE for different household income classes (2006 classification), based on 2001 and 2006

AU-ratio	< 20,000	20,001-30,000	30,001-50,000	50,001-70,000	70,001-100,000	100,001 or more
Tirohanga	1.5	6.2	6.2	4.1	3.5	4.6
Belmont	1.5	6.2	6.2	4.1	3.5	4.6
% variance, 2001	< 20,000	20,001-30,000	30,001-50,000	50,001-70,000	70,001-100,000	100,001 or more
Tirohanga	10.3	68.6	14.8	6.8	5.2	2.7
Belmont	3.3	12.9	6.7	2.8	2.1	1.5
AU-pop	< 20,000	20,001-30,000	30,001-50,000	50,001-70,000	70,001-100,000	100,001 or more
Tirohanga	4.7	5.0	6.6	6.0	3.5	21.6
Belmont	4.6	5.1	6.6	5.4	3.5	22.8

The average ratio for 'AU-ratio' is listed in table C.12. The table further lists the population distribution, which would be the bases for assigning the total AU-level count. As can be seen from the table below, Tirohanga is underrepresented in the low income classes, but overrepresented in the high income classes (and vice versa for Belmont). This suggested a clustered distribution for the low and high income classes and therefore favours the AU-ratio approach for imputation. For each missing year, the average ratio per income class is used as the basis for distributing the AU count between Tirohanga and Belmont. Constant dollar values for each 2006 class boundary are calculated to ensure comparability in time.

Table C.12: Average ratio (in %) for 'AU-ratio' and percentage of population for 'AU-pop', for different household income classes (classes based on 2006)

AU-ratio	< 20,000	20,001- 30,000	30,001- 50,000	50,001- 70,000	70,001- 100,000	100,001 or more
Tirohanga	22.5	24.0	26.9	27.4	30.5	36.4
Belmont	77.5	76.0	73.1	72.6	69.5	63.6
AU-pop, 2001	< 20,000	20,001- 30,000	30,001- 50,000	50,001- 70,000	70,001- 100,000	100,001 or more
Tirohanga	29.9	29.9	29.9	29.9	29.9	29.9
Belmont	70.1	70.1	70.1	70.1	70.1	70.1
AU-pop, 2006	< 20,000	20,001- 30,000	30,001- 50,000	50,001- 70,000	70,001- 100,000	100,001 or more
Tirohanga	30.1	30.1	30.1	30.1	30.1	30.1
Belmont	69.1	69.1	69.1	69.1	69.1	69.1

For those missing data points in the Te Arai communities (Waingake and Waerengaokuri), no average ratio can be calculated for the AU-ratio method, since only 2001 provides a complete dataset. The population distribution of each missing year is used instead ('AU-pop'). The total count for each year is derived from the AU 'Tiniroto' which contains both, Waingake and Waerengaokuri. Similarly, population percentages are based on the usually resident population of the AU 'Tiniroto'. Since only a complete set for the year 2001 is available, the RMSE testing procedure cannot be applied.

Linear regression and the mean method are not considered as imputation techniques, since for Belmont and Tirohanga only two years, and for Te Arai only one year is available. AU-based imputation is rated as the most feasible technique.

For imputation of data missing for the variable '1 parent' in 1981, linear regression is used when r^2 values suggest a temporal trend. In cases of a very strong correlation, this technique might entail an over-or underestimation of the missing data point. This is because the slope of the regression line is very steep. In comparison, the mean method is biased towards the mean of the count population. This increases values for 1981 in a way which counteracts the temporal trend inherent in the data series. For instance, a clear tendency of increasing counts in time would not be continued for 1981, but reversed with a value higher than 1986 and even 1991 and then again an increase for 1996-2006. Therefore linear regression is chosen for those years displaying high r^2 values. Low r^2 values justify the usage of mean imputation, since no clear temporal trend is recognised.

Table C.13: Error estimation for '1 parent'

Missing: 1981	RMSE, AU-pop/ratio	mean¹	r^2, LReg¹.
Maungaraki	no AU data		0.99
Normandale	no AU data	✓	0.45

Tirohanga	no AU data		0.75
Belmont	no AU data		0.87
Kelson	no AU data		0.97
Korokoro	no AU data	✓	0.38
Missing: 2001	RMSE, AU-pop/ratio	mean²	r², LReg
Waingake (1MB)	no AU data	✓	0
Missing: 1991	RMSE, AU-pop/ratio	mean³	r², LReg
Waereng. (1MB)	no AU data	✓	0

¹ based on 1986 – 2006, ² based on 1991, 1996, 2006, ³ based on 1996-2006

A similar logic as described above is applied for the variables 'couple with child(ren)' and 'couple without child(ren)'. Missing data for these two variables match those of the variable '1 parent' since they are derived from the same table supplied by SNZ. These two variables must be imputed since they count towards the total number of households – a figure needed not only for '1 parent', but also for single households and household income. The variable 'couple with child(ren)' is imputed (for 1981) via linear regression for Kelson ($r^2 = 0.86$), Maungaraki ($r^2 = 0.78$), Normandale ($r^2 = 0.84$), Tirohanga ($r^2 = 0.90$) and Belmont ($r^2 = 0.88$) based on 1986-2006, while the mean method is used for Korokoro ($r^2 = 0.003$). The variable 'couple without child(ren)' is imputed via regression for Maungaraki ($r^2 = 0.94$), Normandale ($r^2 = 0.90$), Tirohanga ($r^2 = 0.81$), and Belmont (0.97) based on 1986-2006, while Kelson is imputed with the mean of data points 1986-2006 ($r^2 = 0.58$). For 2001 Waingake, 'couple with' and 'couple without child(ren)' are imputed by linear regression (both have $r^2 = 0.75$) based on 1991, 1996 and 2006. For '1 parent', both mean and linear regression produce the same result since data points for all available years are the same ('3'). This situation repeats in the case of Waerengaokuri (1991), where both mean and regression methods produce the same count. The variable 'couple with child(ren)' is imputed by the mean of 1996-2006 ($r^2 = 0.25$), while 'couple without child(ren)' is based on regression ($r^2 = 0.75$).

Linear regressions are strong because gradual and linear temporal trends are evident for these variables. Imputation with linear regression is unlikely to considerably over- or underestimate the missing data points.

Since no temporal trend is revealed for the variable 'single household' for Waerengaokuri ($r^2 = 0$), the mean method is used which in this case produces the same result.

Table C.14: Error estimation for 'single household'

Missing: 1991	RMSE, AU-pop/ratio	Mean¹	r², LReg
Waereng. (1MB)	no AU data	✓	0

¹ based on 1996-2006

Imputation for the variable 'industry' is based on the two AU-level methods and the mean. For the years 1981, 1986 and 1991, linear regression is likely to result into a over- or underestimate of the missing values.

It should be noted that the percentage of variance for the variable industry is more affected by the rounding procedure applied by Statistics New Zealand, since counts are very low for the Western Hutt Hills and Aoraki.

Table C.15: Error estimation for 'industry'

Missing: 1981, 1986	RMSE, AU- pop	RMSE, AU- ratio¹	% variance	r², LReg
Maungaraki	2.4	1.0	1991: 34.0 2006: 17.0	0.6
Normandale	2.4	1.0	1991: 34.0 2006: 17.0	0.4
Tirohanga (and for 1991)	3.8	0.0	1996: 0.0 2006: 0.0	0.75 ²
Belmont (and for 1991)	3.8	0.0	1996: 0.0 2006: 0.0	0.99 ^{2a}
Missing: 1991	RMSE, AU- pop	RMSE, AU- ratio	r², LReg³	Mean³
Aoraki	no AU data	no AU data	0.75	✓ ^{2b}
Missing: 2006	RMSE, AU- pop⁴	% variance	RMSE, AU- ratio⁴	r², LReg/mean
Waingake	9	1996: 23.1 2001: 18.7	12	only 2 counts
Waereng.	6	1996: 17.0 2001: 31.1	13	only 2 counts
Missing: 1991	RMSE, AU- pop	RMSE, AU- ratio	r², LReg⁵	Mean⁵
Waingake	no AU data	no AU data	only 2 counts	✓
Waereng.	no AU data	no AU data	only 2 counts	✓
Manutuke	no AU data	no AU data	only 2 counts	✓
Missing: 2006	RMSE, AU- pop	% variance	RMSE, AU- ratio	r², LReg./Mean
Waingake	9	1996: 19 2001: 31	12	only 2 counts
Waereng.	6	1996: 23 2001: 17	13	only 2 counts

¹testing based on 1991-2006/1996-2006

²LReg would entail an underestimation of the missing value, in this case negative numbers

^{2a, b}LReg would result into a likely overestimation of the missing value

³based on 1996-2006

⁴testing based on 1996, 2001

⁵based on 1996, 2001

Robust imputation?

Whether the imputation results are robust is analysed by calculating the skewness of the non-imputed and the imputed sample. A comparison between both reveals whether the imputation method itself produces very high or low values. Tables C.16 to C.20 list minimum and maximum counts and skewness for those variables where either the mean and/or regression method for imputation is used. Imputations based on the AU level do not produce outliers, unless the AU level itself is an outlier. In this case, however, the outlier is not the result of the imputation technique but an actual recorded value.

Skewness of the non-imputed distribution is highest for Aoraki (1.73 standard deviations from the mean), where observed values for 2006, 2001, and 1996 are zero, zero and three, respectively. Skewness values are lowest for the variable '1 parent' where most communities show a steady increase of recorded counts, hence values close to the mean of the distribution.

Table C.16: 'visitors'

Community	Before imputation			After imputation		
	Min	Max	Skewness	Min	Max	Skewness
Maungaraki	18	27	1.12	12	27	0.31
Normandale	6	21	-0.54	6	21	-0.53
Tirohanga	3	18	-0.48	3	18	-0.39
Belmont	15	33	0.00	15	33	0.00
Kelson	9	30	0.30	9	30	0.27
Korokoro	9	30	1.58	9	30	1.79

Table C.17: 'industry'

Community	Before imputation			After imputation		
	Min	Max	Skewness	Min	Max	Skewness
Aoraki	0	3	1.73	0	3	1.41

For Te Arai, no skewness can be calculated based on two data points.

Table C.18: '1 parent'

Community	Before imputation			After imputation		
	Min	Max	Skewness	Min	Max	Skewness
Maungaraki	63	126	-0.10	47	126	-0.03
Normandale	36	63	0.56	36	63	0.56
Tirohanga	9	21	-0.51	7	21	-0.14
Belmont	36	84	0.00	26	81	0.09
Kelson	54	105	0.49	37	105	0.25
Korokoro	30	42	0.05	30	42	0.11

Table C.19: 'couple with child(ren)'

Community	Before imputation			After imputation		
	Min	Max	Skewness	Min	Max	Skewness
Maungaraki	453	558	-0.20	453	576	-0.25
Normandale	291	354	0.33	291	371	0.06
Tirohanga	123	213	1.15	95	213	0.60
Belmont	339	396	1.04	323	396	0.56
Kelson	393	438	0.6	393	444	0.20
Korokoro	156	174	-0.16	156	174	-0.14

Table C.20: 'couple without child(ren)'

Community	Before imputation			After imputation		
	Min	Max	Skewness	Min	Max	Skewness
Maungaraki	288	450	-0.9	268	450	-0.36
Normandale	183	279	0.57	151	279	0.30
Tirohanga	39	123	-0.85	30	123	-0.28
Belmont	168	270	0.22	145	270	0.12
Kelson	132	270	-0.98	231	270	-0.99
Korokoro	120	171	-1.03	116	171	-0.40

For Te Arai, no skewness can be calculated based on two data points.

Appendix D: Survey on weighting vulnerability and resilience variables

The response of the survey (21 for vulnerability and 14 for resilience) is low. However, some interesting observations are made. The questionnaires are included at the end of this appendix.

VULNERABILITY: Results

The results of the survey are summarised in table D.1. Absolute values for mean, median, minimum and maximum weights are not comparable between different dimensions since the number of variables per dimension is not equal.

Table D.1: Descriptive statistics (mean, median, standard deviation, minimum, maximum, interquartile range (IQR), lower and upper boundaries of IQR, skewness, number of outliers), for weights assigned to vulnerability variables, sample size = 20. Bold borders indicate which variables are grouped into a sub-index.

Dimen.	variable	Mean	Mdn	Std. Dev.	Min	Max	IQR ¹	IQR from		Skew	No. of outl. ²
cultural	perc	0.57	0.6	0.15	0.3	0.8	0.3	0.5	0.7	-0.19	-
	risk_tak	0.42	0.4	0.15	0.2	0.7	0.3	0.3	0.5	0.19	-
economic	\$_ind_hhold	0.43	0.4	0.13	0.2	0.7	0.3	0.3	0.6	0.29	-
	Empl_stat	0.26	0.3	0.11	0.1	0.5	0.1	0.2	0.3	0.30	1
	\$_state	0.31	0.3	0.13	0.1	0.6	0.2	0.2	0.4	0.43	-
demographic	Age	0.28	0.3	0.07	0.2	0.4	0.1	0.2	0.3	0.29	-
	Gender	0.24	0.2	0.10	0.1	0.4	0.1	0.2	0.3	0.24	-
	Marit_stat	0.2	0.2	0.1	0.0	0.4	0.1	0.1	0.2	0.1	-
	Educ	0.28	0.3	0.12	0.1	0.5	0.1	0.2	0.3	0.47	3
infra-struct.	Rd_nw_con	0.35	0.4	0.09	0.2	0.5	0.1	0.3	0.4	-0.69	-
	Sec_supply	0.38	0.33	0.12	0.2	0.7	0.1	0.3	0.4	1.2	2
	Rob_tele	0.27	0.3	0.07	0.1	0.4	0.1	0.2	0.3	-0.55	-
housing	Dwell_mat	0.51	0.5	0.10	0.3	0.7	0.1	0.5	0.6	-0.55	2
	Dwell_con	0.49	0.5	0.10	0.3	0.7	0.1	0.4	0.5	0.55	2

¹ IQR = 0.3: moderate level of agreement, 0.2 = high level, 0.1 = very high level

² in a boxplot, defined as a score between 1.5 and 3 times box lengths away from upper or lower edge of the box; an extreme score is a score greater than 3 box lengths

(<http://academic.udayton.edu/gregelvers/psy216/spss/descript1.htm>, accessed 30.5.2008)

Question 1: What is the level of agreement for each weight?

- Mostly a very high level of agreement: all weights for 'demographic', 'infrastructure' and 'housing' display an IQR of 0.1
- The 'economic' dimension has the highest variation in agreement: 'personal/hhold income': moderate (IQR of 0.3), 'economic status of state': high, 'employment status': very high
- 'Cultural' dimension: 'perception of hazard and risk' and 'individual risk taking' moderate level: IQR of 0.3

Question 2: For which variables do weights differ considerably from all other participants?

- Three participants disagreed considerably from the majority of participants when assigning a weight for 'education' (3, which is the maximum number of 'outliers' observed)
- The same two participants disagreed strongly on the weighting for 'dwelling material' and 'dwelling condition' ('housing dimension'). Two cases of disagreement are also recorded for 'security of supplies' (2)
- One participant disagreed strongly on 'employment status'

Question 3: For which variables per dimension is an equal weighting scheme feasible?

This question needs to be answered for each dimension (sub-index) separately, since the number of variables per dimension differs, and hence their relative weight.

- The dimensions 'housing', 'infrastructure' and 'demographic' receive very homogenous average and median weights for their variables, suggesting that an equal weighting scheme is feasible
- Differences in weights, which are overall not very high, are possibly more feasible for the variables of the 'economic' and 'cultural' dimensions

Question 4: What is the weight mostly assigned to each variable?

The results mostly reflect the findings with respect to the mean and median, however the weights for one variable ('education') display a bimodal distribution in the sample.

Table D.2: Most frequent weights assigned for each variable; it should be noted that the total sample size is 20 only, which means that the frequency expressed as percentage is sensitive to small differences in the data.

Dimen.	variable	Mode	% frequency
cultural	perc	0.5	25
	risk_tak	0.5	25
economic	\$_ind_hhold	0.4	30
	Empl_stat	0.2	35
	\$_state	0.2	30
demographic	Age	0.3	50
	Gender	0.2	30
	Marit_stat	0.2	45
	Educ	0.2; 0.3	30; 30
infrastructure	Rd_nw_con	0.4	50
	Sec_supply	0.3	30
	Rob_tele	0.3	40
housing	Dwell_mat	0.5	45
	Dwell_con	0.5	45

RESILIENCE: Results

The results of the survey are summarised in table D.3. Absolute values for mean, median, minimum and maximum weights are not comparable between different dimensions since the number of variables per dimension is not equal.

Table D.3: Descriptive statistics (mean, median, standard deviation, minimum, maximum, interquartile range (IQR), lower and upper boundaries of IQR, skewness, number of outliers), for weights assigned to resilience variables, sample size = 13. Bold borders indicate which variables are grouped into a sub-index.

Dimen.	variable	Mean	Mdn	Std. Dev.	Min	Max	IQR ¹	IQR from		Skew	No. of outl ² .
social netw.	Visit	0.23	0.2	0.13	0.1	0.4	0.3	0.1	0.4	0.42	-
	Relig_adh	0.26	0.2	0.11	0.1	0.5	0.1	0.2	0.3	0.80	1
	clubs	0.19	0.2	0.06	0.1	0.3	0.1	0.1	0.2	0.19	2
	Com_fac	0.33	0.3	0.16	0.1	0.6	0.2	0.2	0.4	0.47	-
socio-econ.	Age	0.28	0.2	0.13	0.1	0.5	0.2	0.2	0.4	0.65	-
	gender	0.18	0.2	0.09	0.1	0.4	0.2	0.1	0.3	0.82	-
	Marit_stat	0.21	0.2	0.12	0.0	0.4	0.2	0.1	0.3	0.13	-
	Insur	0.34	0.3	0.15	0.1	0.6	0.2	0.2	0.4	0.45	-
built environ.	Com_serv	0.48	0.5	0.07	0.4	0.6	0.1	0.4	0.5	0.26	-
	Pub_serv	0.51	0.5	0.07	0.4	0.6	0.1	0.5	0.6	-0.26	-

¹ IQR = 0.3: moderate level of agreement, 0.2 = high level, 0.1 = very high level

² in a boxplot, defined as a score between 1.5 and 3 times box lengths away from upper or lower edge of the box; an extreme score is a score greater than 3 box lengths

(<http://academic.udayton.edu/gregelvers/psy216/spss/descript1.htm>, accessed 30.5.2008)

Question 1: What is the level of agreement for each weight?

Overall, very high level and high level of agreement are balanced:

- very high: variables of the 'built environment' dimension ('community facilities' and 'public services'), 'religious adherence' and 'clubs' of the 'social network' dimension (IQR 0.1)
- high level: for all variables of the 'socio-economic' dimension and 'community facilities' ('social networks' dimension);
- moderate level of agreement: 'visitors'

Question 2: For which variables do weights differ considerably from all other participants?

- Overall for only one variable two participants disagreed strongly ('clubs').
- One case of disagreement with the majority of participants for weighting 'religious adherence'.

Question 3: For which variables per dimension is an equal weighting scheme feasible?

It appears that all dimensions receive very homogenous average and median weights, suggesting that an equal weight approach would be feasible.

Question 4: What is the weight mostly assigned to each variable?

The results mostly reflect the findings with respect to the mean and median, however the weights for one variable ('insurance') display a bimodal distribution in the sample.

Table D.4: Most frequent weights assigned for each variable; it should be noted that the total sample size is 13 only which means that the frequency expressed as percentage is sensitive to small differences in the data.

Dimen.	variable	Mode	% frequency
social networks	Visit	0.1	25
	Relig_adh	0.2	25
	clubs	0.2	35
	Com_fac	0.3	20
socio-econ.	Age	0.2	25
	gender	0.1	30
	Marit_stat	0.1	15
	Insur	0.2; 0.3	15; 15
built environ.	Com_serv	0.5	30
	Pub_serv	0.5	30

Please return to:

Weighting VULNERABILITY variables

Name:

Affiliation:

Contact (to notify you of the final results):

Please enter your weights for 'dimension' and 'variable' in the grey shaded area.

Dimension	Weight (sum = 1)	Variable	Weight
Environmental		extent to which a livelihood depends on threatened natural resource	1
			sum= 1
Cultural		perception of hazard and risk	
		individual risk taking	
			sum= 1
Political		public policy on risk reduction in place?	1
			sum= 1
Economic		economic status of individual/househ.	
		employment status	
		economic status of state (1)	
			sum= 1
Demographic		age	
		gender	
		marital status (shared responsibilities)	
		education	
			sum= 1
Infrastructures		road network and connectivity	
		security of supply (water, electricity, gas)	
		robustness of telecom. network	
			sum= 1
Housing		dominant dwelling material	
		dwelling condition	
			sum= 1

Comments?:

(1) e.g. tax income, potentially spent on risk reduction efforts such as funding risk education

Please return to:

Weighting RESILIENCE variables

Name:

Affiliation:

Contact (to notify you of the final results):

Please enter your weights for 'dimension' and 'variable' in the grey shaded area.

Dimension	Weight (sum = 1)	Variable	Weight
Social networks		visitors	
		religious adherence	
		clubs (sport, music, other)	
		community centre, other communal facilities	
		sum= 1	
Self-reliance		dependency on external resources (e.g. for food, water, electricity, gas...)	1
		sum= 1	
Socio-economic		age	
		gender	
		marital status (shared responsibilities)	
		insurance cover	
		sum= 1	
Institutional		local institutions of disaster management	1
		sum= 1	
Built environment		community facilities (shelter, relief)	
		public services (hospital, police, fire station, other)	
		sum= 1	

Comments?:

Appendix E: Vulnerability and resilience analysis: results

Raw data and z-scores, for all communities and years

Waingake		1991	1996	2001	2006
below 5 yrs	%	8.2	7.5	9.3	6.3
	z-score	0.64	0.33	1.21	-0.32
65+	%	8.2	7.5	7.0	8.3
	z-score	0.59	0.32	0.06	0.67
crit. infrastr.	%	82.9	82.9	82.9	82.9
	z-score	0.87	0.87	0.87	0.87
crit. facilities	no./pop (aver.)	0.0	0.0	0.0	0.0
	z-score	-0.50	-0.50	-0.50	-0.50
hhold income	%	20.8	18.8	24.6	17.5
	z-score	2.24	1.71	3.19	1.40
females	%	46.9	45.3	51.2	47.9
	z-score	-1.94	-3.32	1.59	-1.12
single hhold	%	18.8	12.5	24.6	21.1
	z-score	-0.10	-0.79	0.54	0.15
1 parent	%	12.5	6.3	9.8	10.5
	z-score	0.92	-0.42	0.35	0.49
birthplace	%	6.1	1.9	2.3	8.3
	z-score	-1.57	-2.05	-2.00	-1.31
0-4 yrs resid	%	36.4	45.3	51.2	39.6
	z-score	-1.38	-0.49	0.08	-1.06
industry	%	29.9	24.5	37.2	25.0
	z-score	2.18	1.68	2.86	1.72
visitor	%	0.0	0.0	0.0	0.0
	z-score	-0.36	-0.36	-0.36	-0.36
roading	%	82.9	82.9	82.9	82.9
	z-score	0.87	0.87	0.87	0.87
road connect	nodes/km	0.1	0.1	0.1	0.1
	z-score	-1.39	-1.39	-1.39	-1.37
access	acc. points/pop.	0.0	0.0	0.0	0.0
	z-score	1.69	1.50	2.04	0.09
comm. fac.	number (aver.)	0.2	0.2	0.2	0.0
	z-score	-0.77	-0.77	-0.77	-1.26

Waerengaokuri		1991	1996	2001	2006
below 5 yrs	%	11.1	6.7	11.5	9.4
	z-score	2.12	-0.11	2.34	1.25
65+	%	7.4	3.3	3.8	9.4
	z-score	0.25	-1.56	-1.33	1.13
crit. infrastr.	%	100.0	100.0	100.0	100.0
	z-score	1.34	1.34	1.34	1.34
crit. facilities	no./pop (aver.)	0.0	0.0	0.0	0.0
	z-score	-0.50	-0.50	-0.50	-0.50
hhold income	%	14.3	15.2	25.0	16.7
	z-score	0.58	0.80	3.30	1.18
females	%	44.4	46.7	57.7	46.9
	z-score	-4.02	-2.17	7.04	-1.99
single hhold	%	17.9	9.1	0.0	16.7

	z-score	-0.20	-1.17	-2.18	-0.33
1 parent	%	3.6	9.1	12.5	0.0
	z-score	-0.99	0.19	0.92	-1.76
birthplace	%	11.1	6.7	3.8	12.5
	z-score	-1.00	-1.51	-1.83	-0.84
0-4 yrs resid	%	49.3	40.8	57.7	56.3
	z-score	-0.10	-0.94	0.73	0.59
industry	%	32.1	36.7	23.1	25.0
	z-score	2.39	2.81	1.54	1.72
visitor	%	0.0	0.0	0.0	0.0
	z-score	-0.36	-0.36	-0.36	-0.36
roading	%	100.0	100.0	100.0	100.0
	z-score	1.34	1.34	1.34	1.34
road connect	nodes/km	0.2	0.2	0.2	0.2
	z-score	-1.32	-1.32	-1.32	-1.32
access	acc. points/pop.	0.0	0.0	0.0	0.0
	z-score	2.22	1.91	2.34	1.74
comm. fac.	number (aver.)	0.2	0.2	0.2	0.2
	z-score	-0.77	-0.77	-0.77	-0.77

Manutuke		1991	1996	2001	2006
below 5 yrs	%	12.9	9.7	9.9	9.0
	z-score	3.02	1.43	1.49	1.06
65+	%	8.0	7.1	7.5	9.0
	z-score	0.52	0.12	0.30	0.96
crit. infrastr.	%	97.5	97.5	97.5	97.5
	z-score	1.27	1.27	1.27	1.27
crit. facilities	no./pop (aver.)	0.0	0.0	0.0	0.0
	z-score	1.43	1.17	1.57	1.71
hhold income	%	22.9	18.4	24.3	17.6
	z-score	2.75	1.63	3.12	1.43
females	%	50.2	46.8	48.8	49.0
	z-score	0.80	-2.04	-0.36	-0.22
single hhold	%	12.9	9.2	14.3	19.1
	z-score	-0.76	-1.16	-0.60	-0.06
1 parent	%	17.1	23.7	21.4	17.6
	z-score	1.91	3.31	2.82	2.02
birthplace	%	6.7	3.4	5.2	5.0
	z-score	-1.51	-1.88	-1.68	-1.70
0-4 yrs resid	%	31.4	40.4	36.6	39.0
	z-score	-1.87	-0.98	-1.35	-1.12
industry	%	16.0	13.1	17.4	1.0
	z-score	0.88	0.61	1.01	0.74
visitor	%	0.9	0.7	0.0	0.0
	z-score	-0.31	-0.32	-0.36	-0.36
roading	%	97.5	97.5	97.5	97.5
	z-score	1.27	1.27	1.27	1.27
road connect	nodes/km	0.4	0.4	0.4	0.4
	z-score	-1.14	-1.14	-1.14	-1.14
access	acc. points/pop.	0.0	0.0	0.0	0.0
	z-score	0.47	0.29	0.56	0.66

comm. fac.	number (aver.)	1.0	1.0	1.0	1.0
	z-score	1.65	1.65	1.65	1.65

Korokoro		1981	1986	1991	1996	2001	2006
below 5 yrs	%	5.8	5.3	6.3	7.5	6.3	5.4
	z-score	-0.55	-0.82	-0.32	0.29	-0.29	-0.76
65+	%	5.1	5.0	8.3	8.7	9.0	7.5
	z-score	-0.72	-0.81	0.67	0.82	0.96	0.29
crit. infrastr.	%	0.0	0.0	79.8	79.8	74.1	70.2
	z-score	-1.42	-1.42	0.78	0.78	0.62	0.52
crit. facilities	no./pop (aver.)	0.0	0.0	0.0	0.0	0.0	0.0
	z-score	-0.50	-0.50	-0.50	-0.50	-0.50	-0.50
hhold income	%	20.2	18.8	11.2	13.1	11.0	11.8
	z-score	2.08	1.71	-0.21	0.28	-0.25	-0.06
females	%	49.0	48.0	49.5	50.4	51.0	49.3
	z-score	-0.19	-1.08	0.18	0.92	1.43	0.03
single hhold	%	15.9	17.4	18.4	20.0	20.2	23.5
	z-score	-0.42	-0.26	-0.14	0.04	0.06	0.43
1 parent	%	8.4	8.3	6.6	6.3	8.0	8.2
	z-score	0.04	0.02	-0.35	-0.42	-0.05	0.00
birthplace	%	19.8	19.8	20.6	16.6	19.9	22.7
	z-score	-0.01	-0.01	0.08	-0.37	0.01	0.32
0-4 yrs resid	%	50.4	37.9	42.8	49.6	46.6	49.1
	z-score	0.01	-1.22	-0.74	-0.07	-0.37	-0.12
industry	%	0.2	0.7	0.5	0.2	0.2	0.0
	z-score	-0.59	-0.54	-0.56	-0.59	-0.59	-0.61
visitor	%	0.7	0.7	0.8	1.2	1.2	2.3
	z-score	-0.32	-0.32	-0.32	-0.30	-0.30	-0.24
roading	%	0.0	0.0	79.8	79.8	74.1	70.2
	z-score	-1.42	-1.42	0.78	0.78	0.62	0.52
road connect	nodes/km	2.8	2.8	2.8	2.8	2.6	4.6
	z-score	0.51	0.51	0.51	0.51	0.37	1.78
access	acc. points/pop.	0.0	0.0	0.0	0.0	0.0	0.0
	z-score	-0.54	-0.54	-0.52	-0.54	-0.54	-0.55
comm. fac.	number (aver.)	0.3	0.3	0.3	0.3	0.3	0.3
	z-score	-0.29	-0.29	-0.29	-0.29	-0.29	-0.29

Maungaraki		1981	1986	1991	1996	2001	2006
below 5 yrs	%	9.0	5.7	7.1	7.5	6.5	7.9
	z-score	1.07	-0.59	0.13	0.30	-0.20	0.49
65+	%	2.7	3.8	5.0	6.3	6.8	7.3
	z-score	-1.84	-1.36	-0.82	-0.22	-0.04	0.19
crit. infrastr.	%	0.0	0.0	0.0	0.0	0.0	0.0
	z-score	-1.42	-1.42	-1.42	-1.42	-1.42	-1.42
crit. facilities	no./pop (aver.)	0.0	0.0	0.0	0.0	0.0	0.0
	z-score	-0.30	-0.07	-0.06	-0.07	-0.28	-0.30
hhold income	%	11.9	9.9	8.4	11.2	12.0	11.4
	z-score	-0.02	-0.54	-0.91	-0.21	0.00	-0.16
females	%	49.2	47.8	50.3	50.7	51.7	50.7
	z-score	-0.09	-1.25	0.88	1.20	2.01	1.18
single hhold	%	8.5	10.4	11.8	13.9	17.9	17.6

	z-score	-1.24	-1.02	-0.88	-0.64	-0.20	-0.23
1 parent	%	4.5	5.8	6.6	7.8	8.9	9.4
	z-score	-0.81	-0.52	-0.34	-0.09	0.15	0.25
birthplace	%	18.2	19.8	19.7	20.8	25.0	24.7
	z-score	-0.19	-0.01	-0.02	0.11	0.59	0.56
0-4 yrs resid	%	54.5	44.5	45.0	50.9	54.9	52.6
	z-score	0.41	-0.57	-0.52	0.06	0.45	0.23
industry	%	0.1	0.1	0.1	0.1	0.1	0.2
	z-score	-0.61	-0.60	-0.60	-0.60	-0.60	-0.60
visitor	%	0.4	0.4	0.5	0.6	0.6	0.8
	z-score	-0.34	-0.34	-0.33	-0.33	-0.33	-0.32
roading	%	0.0	0.0	0.0	0.0	0.0	0.0
	z-score	-1.42	-1.42	-1.42	-1.42	-1.42	-1.42
road connect	nodes/km	3.0	3.1	3.2	3.8	3.7	4.6
	z-score	0.66	0.73	0.80	1.22	1.15	1.78
access	acc. points/pop.	0.0	0.0	0.0	0.0	0.0	0.0
	z-score	-0.66	-0.66	-0.65	-0.66	-0.65	-0.66
comm. fac.	number (aver.)	0.7	1.0	1.0	1.0	1.0	1.0
	z-score	0.68	1.65	1.65	1.65	1.65	1.65

Normandale		1981	1986	1991	1996	2001	2006
below 5 yrs	%	8.3	8.3	8.8	7.5	6.1	6.3
	z-score	0.73	0.72	0.96	0.33	-0.38	-0.28
65+	%	2.8	3.1	3.9	5.2	6.1	7.1
	z-score	-1.81	-1.67	-1.32	-0.74	-0.32	0.10
crit. infrastr.	%	0.0	0.0	60.4	58.9	57.2	57.2
	z-score	-1.42	-1.42	0.25	0.20	0.16	0.16
crit. facilities	no./pop (aver.)	0.0	0.0	0.0	0.0	0.0	0.0
	z-score	-0.50	-0.50	-0.50	-0.50	-0.50	-0.50
hhold income	%	11.9	10.0	6.5	8.8	12.0	9.6
	z-score	-0.02	-0.52	-1.41	-0.80	0.00	-0.62
females	%	49.1	47.7	50.4	50.7	52.6	49.4
	z-score	-0.12	-1.27	0.99	1.17	2.80	0.07
single hhold	%	6.1	8.1	11.6	13.3	15.2	13.9
	z-score	-1.50	-1.28	-0.89	-0.71	-0.50	-0.63
1 parent	%	7.5	6.8	5.2	6.2	8.6	7.2
	z-score	-0.15	-0.31	-0.65	-0.43	0.08	-0.22
birthplace	%	16.1	16.2	19.9	17.4	19.6	20.1
	z-score	-0.42	-0.42	0.00	-0.28	-0.03	0.03
0-4 yrs resid	%	47.7	45.4	39.7	44.5	47.4	44.0
	z-score	-0.26	-0.49	-1.05	-0.58	-0.29	-0.62
industry	%	0.2	0.2	0.1	0.3	0.4	0.3
	z-score	-0.59	-0.59	-0.60	-0.58	-0.57	-0.58
visitor	%	0.4	0.7	1.0	0.3	0.6	1.0
	z-score	-0.34	-0.32	-0.31	-0.34	-0.33	-0.31
roading	%	0.0	0.0	60.4	58.9	57.2	57.2
	z-score	-1.42	-1.42	0.25	0.20	0.16	0.16
road connect	nodes/km	2.9	2.7	2.7	2.7	2.8	2.8
	z-score	0.59	0.44	1.42	1.42	0.51	0.51
access	acc. points/pop.	0.0	0.0	0.0	0.0	0.0	0.0
	z-score	-0.48	-0.43	-0.41	-0.41	-0.65	-0.43

comm. fac.	number (aver.)	0.3	0.3	0.3	0.3	0.3	0.3
	z-score	-0.29	-0.29	-0.29	-0.29	-0.29	-0.29

Tirohanga		1981	1986	1991	1996	2001	2006
below 5 yrs	%	5.9	5.6	10.2	7.7	7.6	5.8
	z-score	-0.52	-0.63	1.67	0.42	0.37	-0.57
65+	%	0.5	2.2	5.5	4.6	6.5	6.8
	z-score	-2.85	-2.08	-0.58	-1.01	-0.17	-0.04
crit. infrastr.	%	0.0	0.0	41.7	36.4	34.3	32.1
	z-score	-1.42	-1.42	-0.27	-0.42	-0.47	-0.54
crit. facilities	no./pop (aver.)	0.0	0.0	0.0	0.0	0.0	0.0
	z-score	-0.50	-0.50	-0.50	-0.50	-0.50	-0.50
hhold income	%	18.9	17.0	7.0	8.1	5.8	6.2
	z-score	1.75	1.28	-1.28	-0.99	-1.57	-1.49
females	%	46.2	44.3	52.3	51.6	52.2	49.0
	z-score	-2.52	-4.15	2.57	1.93	2.45	-0.22
single hhold	%	4.2	7.9	8.4	7.9	10.8	9.2
	z-score	-1.72	-1.30	-1.25	-1.30	-0.98	-1.16
1 parent	%	4.9	4.8	4.8	5.9	5.8	4.6
	z-score	-0.72	-0.74	-0.73	-0.49	-0.51	-0.77
birthplace	%	19.2	18.5	19.6	23.2	22.0	24.3
	z-score	-0.07	-0.16	-0.03	0.38	0.24	0.50
0-4 yrs resid	%	56.6	39.8	47.5	51.7	56.0	52.8
	z-score	0.63	-1.04	-0.28	0.14	0.56	0.24
industry	%	0.0	0.0	0.0	0.0	0.0	0.0
	z-score	-0.61	-0.61	-0.61	-0.61	-0.61	-0.61
visitor	%	1.2	1.6	1.3	0.3	1.4	1.5
	z-score	-0.30	-0.28	-0.29	-0.34	-0.28	-0.28
roading	%	0.0	0.0	41.7	36.4	34.3	32.1
	z-score	-1.42	-1.42	-0.27	-0.42	-0.47	-0.54
road connect	nodes/km	2.3	2.5	2.9	2.8	3.0	2.7
	z-score	0.16	0.30	0.59	0.51	0.66	0.44
access	acc. points/pop.	0.0	0.0	0.0	0.0	0.0	0.0
	z-score	-0.29	-0.13	-0.14	-0.40	-0.48	-0.53
comm. fac.	number (aver.)	0.2	0.2	0.2	0.2	0.2	0.2
	z-score	-0.77	-0.77	-0.77	-0.77	-0.77	-0.77

Belmont		1981	1986	1991	1996	2001	2006
below 5 yrs	%	8.8	8.6	8.5	7.2	8.1	7.4
	z-score	0.95	0.87	0.81	0.17	0.60	0.24
65+	%	4.2	4.4	5.4	6.0	5.4	6.1
	z-score	-1.20	-1.09	-0.63	-0.37	-0.64	-0.34
crit. infrastr.	%	0.0	0.0	60.4	55.9	50.0	48.1
	z-score	-1.42	-1.42	0.25	0.12	-0.04	-0.09
crit. facilities	no./pop (aver.)	0.00	0.00	0.00	0.00	0.00	0.00
	z-score	-0.50	-0.50	-0.50	-0.50	-0.50	-0.50
hhold income	%	14.9	14.9	7.8	10.4	7.8	10.3
	z-score	0.72	0.74	-1.06	-0.40	-1.06	-0.44
females	%	46.2	44.2	51.2	50.4	51.6	49.6
	z-score	-2.54	-4.19	1.66	0.95	1.96	0.32
single hhold	%	11.3	12.5	13.9	14.0	16.4	15.6

	z-score	-0.93	-0.79	-0.64	-0.63	-0.37	-0.46
1 parent	%	4.5	5.6	7.3	7.0	10.0	8.9
	z-score	-0.81	-0.57	-0.19	-0.26	0.37	0.15
birthplace	%	19.2	18.5	20.4	20.7	19.9	23.2
	z-score	-0.07	-0.16	0.06	0.10	0.00	0.39
0-4 yrs resid	%	49.8	45.9	41.9	47.7	48.8	46.8
	z-score	-0.05	-0.44	-0.83	-0.26	-0.15	-0.34
industry	%	0.5	0.4	0.3	0.9	0.4	0.4
	z-score	-0.57	-0.57	-0.58	-0.52	-0.57	-0.58
visitor	%	1.2	1.2	1.4	0.7	0.8	1.3
	z-score	-0.30	-0.30	-0.28	-0.32	-0.32	-0.29
roading	%	0.0	0.0	60.4	55.9	50.0	48.1
	z-score	-1.42	-1.42	0.25	0.12	-0.04	-0.09
road connect	nodes/km	2.70	2.40	2.40	2.80	2.60	2.50
	z-score	0.44	0.23	0.23	0.51	0.37	0.30
access	acc. points/pop.	0.0	0.0	0.0	0.0	0.0	0.0
	z-score	-0.45	-0.48	-0.48	-0.56	-0.57	-0.60
comm. fac.	number (aver.)	0.3	0.3	0.3	0.3	0.3	0.3
	z-score	-0.29	-0.29	-0.29	-0.29	-0.29	-0.29

Kelson		1981	1986	1991	1996	2001	2006
below 5 yrs	%	14.6	11.0	11.3	8.7	8.8	8.7
	z-score	3.89	2.08	2.22	0.90	0.95	0.91
65+	%	1.1	1.7	1.9	2.5	4.1	5.6
	z-score	-2.56	-2.31	-2.21	-1.91	-1.22	-0.55
crit. infrastr.	%	0.0	0.0	15.3	11.5	10.5	9.1
	z-score	-1.42	-1.42	-1.00	-1.10	-1.13	-1.17
crit. facilities	no./pop (aver.)	0.0	0.0	0.0	0.0	0.0	0.0
	z-score	-0.50	-0.50	-0.22	-0.50	-0.50	-0.50
hhold income	%	10.6	10.8	8.4	10.7	8.8	9.7
	z-score	-0.36	-0.30	-0.91	-0.33	-0.81	-0.60
females	%	50.7	49.0	49.8	49.5	50.8	50.9
	z-score	1.18	-0.23	0.47	0.23	1.30	1.33
single hhold	%	6.2	7.6	12.5	11.4	15.4	17.1
	z-score	-1.49	-1.34	-0.80	-0.92	-0.48	-0.28
1 parent	%	4.5	6.5	6.7	8.0	9.8	10.9
	z-score	-0.79	-0.37	-0.32	-0.04	0.34	0.57
birthplace	%	16.1	17.6	19.8	19.9	21.2	23.4
	z-score	-0.43	-0.26	-0.01	0.01	0.15	0.40
0-4 yrs resid	%	62.3	53.1	46.6	47.9	53.3	48.7
	z-score	1.19	0.28	-0.37	-0.23	0.29	-0.16
industry	%	0.3	0.1	0.4	0.3	0.4	0.1
	z-score	-0.59	-0.60	-0.58	-0.58	-0.58	-0.60
visitor	%	0.4	0.7	1.2	0.5	0.9	0.7
	z-score	-0.34	-0.32	-0.30	-0.33	-0.31	-0.32
roading	%	0.0	0.0	15.3	11.5	10.5	9.1
	z-score	-1.42	-1.42	-1.00	-1.10	-1.13	-1.17
road connect	nodes/km	3.3	3.0	3.0	2.7	2.6	2.5
	z-score	0.87	0.66	0.66	0.44	0.37	0.30
access	acc. points/pop.	0.0	0.0	0.0	0.0	0.0	0.0
	z-score	-0.73	-0.74	-0.74	-0.74	-0.74	-0.74

comm. fac.	number (aver.)	0.3	0.5	0.5	0.7	0.7	0.7
	z-score	-0.29	0.19	0.19	0.68	0.68	0.68

Aoraki		1991	1996	2001	2006
below 5 yrs	%	2.4	5.5	3.0	2.9
	z-score	-2.28	-0.72	-1.97	-2.02
65+	%	1.2	1.8	6.9	1.4
	z-score	-2.52	-2.24	0.04	-2.41
crit. infrastr.	%	17.9	17.9	17.9	17.9
	z-score	-0.93	-0.93	-0.93	-0.93
crit. facilities	no./pop (aver.)	0.0	0.0	0.0	0.0
	z-score	2.68	1.44	1.65	2.06
hhold income	%	19.2	24.1	26.1	9.5
	z-score	1.83	3.08	3.57	-0.63
females	%	35.3	40.0	37.6	50.0
	z-score	-11.67	-7.74	-9.72	0.62
single hhold	%	57.7	48.3	47.8	42.9
	z-score	4.21	3.17	3.12	2.57
1 parent	%	0.0	0.0	4.3	4.8
	z-score	-1.76	-1.76	-0.83	-0.74
birthplace	%	17.6	15.5	20.8	34.3
	z-score	-0.25	-0.50	0.11	1.65
0-4 yrs resid	%	52.5	52.7	49.5	74.3
	z-score	0.22	0.24	-0.08	2.37
industry	%	0.4	0.9	0.0	0.0
	z-score	-0.57	-0.53	-0.61	-0.61
visitor	%	44.4	56.2	55.3	63.2
	z-score	1.90	2.49	2.45	2.84
roading	%	17.9	17.9	17.9	17.9
	z-score	-0.93	-0.93	-0.93	-0.93
road connect	nodes/km	1.7	1.9	1.9	1.9
	z-score	-0.26	-0.12	-0.12	-0.12
access	acc. points/pop.	0.0	0.0	0.0	0.0
	z-score	-0.57	-0.67	-0.65	-0.62
comm. fac.	number (aver.)	0.2	0.2	0.3	0.3
	z-score	-0.77	-0.77	-0.29	-0.29

Z-scores for the six indices (first, second and final level)

Waingake

year	frag_mob	crit_serv	soc_eco	infra	com_netw	self_rel
1991	0.62	0.68	0.00	-0.19	-0.77	2.18
1996	0.32	0.68	0.51	-0.25	-0.77	1.68
2001	0.64	0.68	-0.78	-0.07	-0.77	2.86
2006	0.17	0.68	0.01	-0.17	-1.26	1.72

year	needs	self-suff	ad.cap.	res	vuln
1991	0.65	0.70	-0.09	0.31	0.37
1996	0.50	0.45	0.13	0.29	0.19
2001	0.66	1.04	-0.43	0.31	0.54
2006	0.43	0.23	-0.08	0.08	0.25

Waerengaokuri

year	frag_mob	crit_serv	soc_eco	infra	com_netw	self_rel
1991	1.19	0.92	0.46	-0.15	-0.77	2.39
1996	-0.84	0.92	0.29	-0.25	-0.77	2.81
2001	0.50	0.92	-1.15	-0.11	-0.77	1.54
2006	1.19	0.92	0.22	-0.31	-0.77	1.72

year	needs	self-suff	ad.cap.	res	vuln
1991	1.05	0.81	0.16	0.48	0.45
1996	0.04	1.02	0.02	0.52	0.01
2001	0.71	0.38	-0.63	-0.12	0.67
2006	1.05	0.47	-0.04	0.22	0.55

Manutuke

year	frag_mob	crit_serv	soc_eco	infra	com_netw	self_rel
1991	1.77	-0.08	-0.24	-0.65	1.65	0.88
1996	0.78	0.05	0.10	-0.71	1.65	0.61
2001	0.90	-0.15	-0.33	-0.62	1.65	1.01
2006	1.01	-0.22	-0.09	-0.59	1.65	0.74

year	needs	self-suff	ad.cap.	res	vuln
1991	0.84	1.26	-0.44	0.41	0.64
1996	0.41	1.13	-0.30	0.41	0.36
2001	0.37	1.33	-0.47	0.43	0.42
2006	0.40	1.19	-0.34	0.43	0.37

Korokoro

year	frag_mob	crit_serv	soc_eco	infra	com_netw	self_rel
1981	-0.67	-0.46	-0.07	0.47	-0.29	-0.59
1986	-0.82	-0.54	0.21	0.46	-0.29	-0.54
1991	0.17	0.64	0.26	-0.26	-0.29	-0.56
1996	0.56	0.64	0.06	-0.27	-0.29	-0.59
2001	0.33	0.56	0.01	-0.26	-0.29	-0.59
2006	-0.24	0.51	0.03	-0.19	-0.29	-0.61

year	needs	self-suff	ad.cap.	res	vuln
1981	-0.56	-0.44	0.20	-0.12	-0.38
1986	-0.64	-0.42	0.34	-0.04	-0.49
1991	0.41	-0.43	0.00	-0.21	0.20
1996	0.60	-0.44	-0.10	-0.27	0.35
2001	0.45	-0.44	-0.13	-0.28	0.29
2006	0.13	-0.45	-0.08	-0.26	0.11

Maungaraki

year	frag_mob	crit_serv	soc_eco	infra	com_netw	self_rel
1981	-0.39	-0.56	0.36	0.47	0.68	-0.61
1986	-0.98	-0.60	0.61	0.50	1.65	-0.60
1991	-0.35	-0.68	0.34	0.52	1.65	-0.60
1996	0.04	-0.68	0.06	0.66	1.65	-0.60
2001	-0.12	-0.57	-0.26	0.64	1.65	-0.60
2006	0.34	-0.56	-0.11	0.85	1.65	-0.60

year	needs	self-suff	ad.cap.	res	vuln
1981	-0.47	0.04	0.42	0.23	-0.44
1986	-0.83	0.52	0.55	0.54	-0.69
1991	-0.51	0.52	0.43	0.48	-0.47
1996	-0.32	0.52	0.36	0.44	-0.34
2001	-0.35	0.52	0.19	0.36	-0.27
2006	-0.11	0.53	0.37	0.45	-0.24

Normandale

year	frag_mob	crit_serv	soc_eco	infra	com_netw	self_rel
1981	-0.54	-0.46	0.45	0.51	-0.29	-0.59
1986	-0.48	-0.59	0.65	0.48	-0.29	-0.59
1991	-0.18	0.37	0.49	-0.07	-0.29	-0.60
1996	-0.21	0.35	0.32	-0.06	-0.29	-0.58
2001	-0.35	0.33	-0.04	-0.02	-0.29	-0.58
2006	-0.09	0.33	0.36	-0.02	-0.29	-0.58

year	needs	self-suff	ad.cap.	res	vuln
1981	-0.50	-0.44	0.48	0.02	-0.49
1986	-0.47	-0.44	0.56	0.06	-0.52
1991	0.10	-0.44	0.21	-0.12	-0.06
1996	0.07	-0.44	0.13	-0.15	-0.03
2001	-0.01	-0.43	-0.03	-0.23	0.01
2006	0.12	-0.44	0.17	-0.13	-0.03

Tirohanga

year	frag_mob	crit_serv	soc_eco	infra	com_netw	self_rel
1981	-1.68	-0.46	0.45	0.43	-0.77	-0.61
1986	-1.36	-0.61	0.87	0.53	-0.77	-0.61
1991	0.55	0.11	0.24	0.24	-0.77	-0.61
1996	-0.30	0.04	0.16	0.18	-0.77	-0.61
2001	0.10	0.01	0.09	0.22	-0.77	-0.61
2006	-0.30	-0.02	0.47	0.15	-0.77	-0.61

year	needs	self-suff	ad.cap.	res	vuln
1981	-1.07	-0.69	0.44	-0.13	-0.76
1986	-0.91	-0.69	0.70	0.00	-0.81
1991	0.33	-0.69	0.24	-0.23	0.05
1996	-0.13	-0.69	0.17	-0.26	-0.15
2001	0.06	-0.69	0.15	-0.27	-0.05
2006	-0.16	-0.69	0.31	-0.19	-0.24

Belmont

year	frag_mob	crit_serv	soc_eco	infra	com_netw	self_rel
1981	-0.12	-0.46	0.57	0.47	-0.29	-0.57
1986	-0.11	-0.46	0.78	0.39	-0.29	-0.57
1991	0.09	0.37	0.23	-0.16	-0.29	-0.58
1996	-0.10	0.31	0.17	-0.06	-0.29	-0.52
2001	-0.02	0.23	0.02	-0.05	-0.29	-0.57
2006	-0.05	0.20	0.16	-0.07	-0.29	-0.58

year	needs	self-suff	ad.cap.	res	vuln
1981	-0.29	-0.43	0.52	0.05	-0.41
1986	-0.29	-0.43	0.59	0.08	-0.44
1991	0.23	-0.44	0.04	-0.20	0.10
1996	0.11	-0.41	0.06	-0.18	0.02
2001	0.10	-0.43	-0.02	-0.23	0.06
2006	0.08	-0.43	0.04	-0.19	0.02

Kelson

year	frag_mob	crit_serv	soc_eco	infra	com_netw	self_rel
1981	0.66	-0.46	0.20	0.52	-0.29	-0.59
1986	-0.11	-0.60	0.39	0.45	0.19	-0.60
1991	0.01	-0.39	0.35	0.30	0.19	-0.58
1996	-0.50	-0.30	0.28	0.27	0.68	-0.58
2001	-0.13	-0.32	0.01	0.25	0.68	-0.58
2006	0.18	-0.34	-0.04	0.24	0.68	-0.60

year	needs	self-suff	ad.cap.	res	vuln
1981	0.10	-0.44	0.36	-0.04	-0.13
1986	-0.29	-0.20	0.42	0.11	-0.35
1991	-0.19	-0.19	0.33	0.07	-0.26
1996	-0.40	0.05	0.27	0.16	-0.34
2001	-0.23	0.05	0.13	0.09	-0.18
2006	-0.08	0.04	0.10	0.07	-0.09

Aoraki

year	frag_mob	crit_serv	soc_eco	infra	com_netw	self_rel
1991	-2.40	-1.80	0.76	0.03	-0.77	-0.57
1996	-1.48	-1.18	0.19	0.05	-0.77	-0.53
2001	-0.96	-1.29	0.25	0.05	-0.29	-0.61
2006	-2.22	-1.49	-1.01	0.06	-0.29	-0.61

year	needs	self-suff	ad.cap.	res	vuln
1991	-2.10	-0.67	0.40	-0.14	-1.25
1996	-1.33	-0.65	0.12	-0.27	-0.72
2001	-1.13	-0.45	0.15	-0.15	-0.64
2006	-1.86	-0.45	-0.47	-0.46	-0.69

Table E.1: Temporal change of ranking for the index 'needs', 1981-2006

1981			1986			1991			1996			2001			2006		
R.	Comm.	Needs	R.	Comm.	Needs	R.	Waereng.	1.05	R.	Comm.	Needs	R.	Comm.	Needs	R.	Comm.	Needs
1	Kelson	0.10	1	Belmont	-0.29	1	Manutuke	0.84	1	Korokoro	0.60	1	Waereng.	0.71	1	Waereng.	1.05
2	Belmont	-0.29	1	Kelson	-0.29	2	Waingake	0.65	2	Waingake	0.50	2	Waingake	0.66	2	Waingake	0.43
3	Maung.	-0.47	3	Norm.	-0.47	3	Korokoro	0.41	3	Manutuke	0.41	3	Korokoro	0.45	3	Manutuke	0.40
4	Norm.	-0.50	4	Korokoro	-0.64	4	Tirohanga	0.33	4	Belmont	0.11	4	Manutuke	0.37	4	Korokoro	0.13
5	Korokoro	-0.56	5	Maung.	-0.83	5	Belmont	0.23	5	Norm.	0.07	5	Belmont	0.10	5	Norm.	0.12
6	Tirohanga	-1.07	6	Tirohanga	-0.91	6	Norm.	0.10	6	Waereng.	0.04	6	Tirohanga	0.06	6	Belmont	0.08
						7	Kelson	-0.19	7	Tirohanga	-0.13	7	Norm.	-0.01	7	Kelson	-0.08
						8	Maung.	-0.51	8	Maung.	-0.32	8	Kelson	-0.23	8	Maung.	-0.11
						9	Aoraki	-2.10	9	Kelson	-0.40	9	Maung.	-0.35	9	Tirohanga	-0.16
						10			10	Aoraki	-1.33	10	Aoraki	-1.13	10	Aoraki	-1.86

Table E.2: Temporal change of ranking for the index 'self-sufficiency', 1981-2006

1981			1986			1991			1996			2001			2006		
R.	Comm.	Self-suff.	R.	Comm.	Self-suff.	R.	Comm.	Self-suff.	R.	Comm.	Self-suff.	R.	Comm.	Self-suff.	R.	Comm.	Self-suff.
1	Norm.	0.04	1	Maung.	0.52	1	Manutuke	1.26	1	Manutuke	1.13	1	Manutuke	1.33	1	Manutuke	1.19
2	Tirohanga	-0.43	2	Kelson	-0.20	2	Waereng.	0.81	2	Waereng.	1.02	2	Waingake	1.04	2	Maung.	0.53
3	Kelson	-0.44	3	Korokoro	-0.42	3	Waingake	0.70	3	Maung.	0.52	3	Maung.	0.52	3	Waereng.	0.47
3	Belmont	-0.44	4	Belmont	-0.43	4	Maung.	0.52	4	Waingake	0.45	4	Waereng.	0.38	4	Waingake	0.23
3	Maung.	-0.44	5	Norm.	-0.44	5	Kelson	-0.19	5	Kelson	0.05	5	Kelson	0.05	5	Kelson	0.04
4	Korokoro	-0.69	6	Tirohanga	-0.69	6	Korokoro	-0.43	6	Belmont	-0.41	6	Norm.	-0.43	6	Belmont	-0.43
						7	Belmont	-0.44	7	Norm.	-0.44	6	Belmont	-0.43	7	Norm.	-0.44
						7	Norm.	-0.44	7	Korokoro	-0.44	7	Korokoro	-0.44	8	Korokoro	-0.45
						8	Aoraki	-0.67	8	Aoraki	-0.65	8	Aoraki	-0.45	8	Aoraki	-0.45
						9	Tirohanga	-0.69	9	Tirohanga	-0.69	9	Tirohanga	-0.69	9	Tirohanga	-0.69

Table E.3: Temporal change of ranking for the index 'adaptive capacity', 1981-2006

1981			1986			1991			1996			2001			2006		
R.	Comm.	Ad.cap.	R.	Comm.	Ad.cap.	R.	Comm.	Ad.cap.	R.	Comm.	Ad.cap.	R.	Comm.	Ad.cap.	R.	Comm.	Ad.cap.
1	Tirohanga	0.52	1	Tirohanga	0.70	1	Maung.	0.43	1	Maung.	0.36	1	Maung.	0.19	1	Maung.	0.37
2	Maung.	0.48	2	Belmont	0.59	2	Aoraki	0.40	2	Kelson	0.27	2	Tirohanga	0.15	2	Tirohanga	0.31
3	Korokoro	0.44	3	Norm.	0.56	3	Kelson	0.33	3	Tirohanga	0.17	2	Aoraki	0.15	3	Norm.	0.17
4	Norm.	0.42	4	Maung.	0.55	4	Tirohanga	0.24	4	Norm.	0.13	3	Kelson	0.13	4	Kelson	0.10
5	Kelson	0.36	5	Kelson	0.42	5	Norm.	0.21	4	Waingake	0.13	4	Belmont	-0.02	5	Belmont	0.04
6	Belmont	0.20	6	Korokoro	0.34	6	Waereng.	0.16	5	Aoraki	0.12	5	Norm.	-0.03	6	Waereng.	-0.04
						7	Belmont	0.04	6	Belmont	0.06	6	Korokoro	-0.13	7	Korokoro	-0.08
						8	Korokoro	0.00	7	Waereng.	0.02	7	Waingake	-0.43	7	Waingake	-0.08
						9	Waingake	-0.09	8	Korokoro	-0.10	8	Manutuke	-0.47	8	Manutuke	-0.34
						10	Manutuke	-0.44	9	Manutuke	-0.30	9	Waereng.	-0.63	9	Aoraki	-0.47

The evolution of the indices 'needs', 'self-sufficiency' and 'adaptive capacity' for the three groups 'Western Hutt Hills', 'Te Arai' and 'Aoraki'

Figure E.1: Index 'needs' for the three groups Western Hutt Hills, Te Arai and Aoraki

Figure E.2: Index 'self-sufficiency' for the three groups Western Hutt Hills, Te Arai and Aoraki

Figure E.3: Index 'adaptive capacity' for the three groups Western Hutt Hills, Te Arai and Aoraki

Appendix F: Community profiles

A symbol key (table xx) describes the type of index evolution observed for each community. The symbol key serves as an aid for quickly comparing the communities, and does not aim to interpolate specific values between census years.

Table F.1: Symbol key for generalised types of development in time

Type	Symbol
Constant
Abrupt increase/decrease
subdued increase/decrease
Abrupt peak/valley
Subdued peak/valley
Abrupt wave
Subdued wave
Abrupt plateau
Subdued plateau
Abrupt slope
Subdued slope

Six different types of development are observed: constant level, strong or weak increase or decrease, abrupt or subdued peaks or drops ('valley'), abrupt or subdued oscillations ('wave'), abrupt or subdued changes at the end of the time series ('plateau'), and abrupt or subdued changes at the beginning of the time series ('slope').

Waingake

¹ years 1991-2006

Change of indices in time:

- 'needs': fluctuating with a peak in 2001
- 'self-sufficiency': increase by 0.6 units between 1996 and 2001; decrease by 0.8 units between 2001 and 2006
- 'adaptive capacity': decreases by 0.55 units (1996-2001), and reaches the 1991 level in 2006
- 'vulnerability': increase by 0.35 units between 1996 and 2001, drop by 0.3 units afterwards
- 'resilience': constant in time but drop by 0.25 units between 2001 and 2006

RANKS	1991	1996	2001	2006	mean
'Vulnerability'	3	3	2	3	3
'Resilience'	3	4	3	4	4

¹ years 1991-2006

Change of indices in time:

- 'needs': drop of 1.0 units between 1991 and 1996, continuous increase until 2006 score matches 1991 score
- 'self-sufficiency': drop of 0.6 units between 1996 and 2001
- 'adaptive capacity': fairly constant but decrease by 0.65 units between 1996 and 2001, recovering almost to previous level in 2006
- 'vulnerability': variability between 1996 and 2001, increase by 0.66 units
- 'resilience': constant levels for 1991 and 1996, but drop by 0.65 units and comparatively low recovery

RANKS	1991	1996	2001	2006	mean
'Vulnerability'	2	5	1	1	2
'Resilience'	1	1	5	3	3

Manutuke

¹ years 1991-2006

Change of indices in time:

- 'needs': almost linear decrease, in total by 0.43 units
- 'self-sufficiency': constantly very high scores
- 'adaptive capacity': negative scores without much fluctuation
- 'vulnerability': drop by 0.28 units between 1991 and 1996, stabilising on this level
- 'resilience': constant at 0.4 units

RANKS	1991	1996	2001	2006	mean
'Vulnerability'	1	1	3	2	1
'Resilience'	2	3	1	1	2

¹ years 1991-2006

² years 1981-2006

Change of indices in time:

- 'needs': jump from -0.64 units in 1986 to 0.4 and 0.6 units in 1991 and 1996 respectively (maximum increase: 1.2 units); decreasing thereafter
- 'self-sufficiency': constantly about 0.4 units below average
- 'adaptive capacity': drop by 0.3 units between 1986 and 1991, and below average thereafter
- 'vulnerability': jump by 0.7 units between 1986 and 1991, decreasing after 1996
- 'resilience': less fluctuation, decreasing in the 1990s and stagnating at this level

RANKS	1981	1986	1991	1996	2001	2006	mean
'Vulnerability'	2	3	4	2	4	4	4
'Resilience'	6	6	8	9	9	8	9

Maungaraki

¹ years 1991-2006

² years 1981-2006

Change of indices in time:

- 'needs': constantly below average scores, but increasing steadily, largest magnitude of change between 1986 and 2001 (0.7 units)
- 'self-sufficiency': jump from about average to 0.5 units, constant at this level
- 'adaptive capacity': some variation, with a maximum of 0.2 units
- 'vulnerability': below average values, with the lowest score in 1986 and an gradual increase afterwards
- 'resilience': increase from 1981 and almost constant at this level with little fluctuation

RANKS	1981	1986	1991	1996	2001	2006	mean
'Vulnerability'	4	5	9	9	9	8	9
'Resilience'	3	1	1	2	2	1	1

Normandale

¹ years 1991-2006

² years 1981-2006

Change of indices in time:

- 'needs': increase by 0.57 units between 1986 and 1991 and subsequently fluctuating around average scores
- 'self-sufficiency': constant at a level of -0.4
- 'adaptive capacity': drop of well above average level by 0.35 units, decreasing further and recovering in 2006
- 'vulnerability': increase by 0.46 units, stabilising in the 1990s and until 2006 at an slightly below average level
- 'resilience': fluctuating around the average with a maximum of -0.2 units in 2001

RANKS	1981	1986	1991	1996	2001	2006	mean
'Vulnerability'	5	4	7	6	6	6	8
'Resilience'	1	4	5	6	7	6	6

Tirohanga

¹ years 1991-2006

² years 1981-2006

Change of indices in time:

- 'needs': low values in the 1980s, which increase to above average (by 1.24 units between 1986 and 1991); fluctuating in the 1990s around average stabilising on a below average level
- 'self-sufficiency': continuously well below average
- 'adaptive capacity': peak in 1986 and dropping by 0.5 units between 1986 and 1991, slight increase between 2001 and 2006
- 'vulnerability': low values in the 1980s but jump by 0.85 units between 1986 and 1991, retaining below average levels afterwards
- 'resilience': slight increase in the 1980s, stabilising on just below average level

RANKS	1981	1986	1991	1996	2001	2006	mean
'Vulnerability'	6	6	6	7	7	8	6
'Resilience'	2	5	9	8	8	7	8

¹ years 1991-2006

² years 1981-2006

Change of indices in time:

- 'needs': below average values in the 1980s, increase by 0.52 units between 1986 and 1991, little but steady decline afterwards
- 'self-sufficiency': constantly at about -0.4 units
- 'adaptive capacity': highest values in the 1980s and drop by 0.55 units between 1986 and 1991, fluctuating slightly around average thereafter
- 'vulnerability': lowest scores in the 1980s, increase by 0.53 units between 1986 and 1991, fluctuating around average for all later years
- 'resilience': decreasing from scores slightly above average in the 1980s, constantly at about -0.2 units thereafter

RANKS	1981	1986	1991	1996	2001	2006	mean
'Vulnerability'	3	2	5	4	5	5	5
'Resilience'	5	3	7	7	7	7	7

Kelson

¹ years 1991-2006

² years 1981-2006

Change of indices in time:

- 'needs': constantly below average, with scores varying by up to 0.21 units
- 'self-sufficiency': continuous increase during the 1980s and stagnation between 1996 and 2006, total change between 1981 and 2006 of 0.5 units
- 'adaptive capacity': after a peak in the 1980s continuous decline, with a change of 0.3 units
- 'vulnerability': constantly below average, maximum change between 1981 and 1986 by 0.22 units
- 'resilience': just above average, with a small peak in 1996

RANKS	1981	1986	1991	1996	2001	2006	mean
'Vulnerability'	1	1	8	8	8	7	7
'Resilience'	4	2	4	5	4	5	5

¹ years 1991-2006

Change of indices in time:

- 'needs': constantly at well below average, increasing by 0.77 units between 1991 and 1996, dropping by 0.73 units between 2001 and 2006
- 'self-sufficiency': increase by about 0.2 units between the 1990s and 2001 and 2006
- 'adaptive capacity': decrease until dropping to below average at -0.5 in 2006
- 'vulnerability': lowest score in 1991, increase by 0.52 units between 1991 and 1996, stabilising afterwards
- 'resilience': fluctuating below average, dropping by 0.3 units between 2001 and 2006

RANKS	1991	1996	2001	2006	mean
'Vulnerability'	10	10	10	9	10
'Resilience'	6	9	6	9	9

Appendix G: Vulnerability and resilience indices - sensitivity analysis
Excluding Aoraki

Figure G.1: Sensitivity of the ‘needs’ index; sample without Aoraki, 2006

Figure G.2: Sensitivity of the ‘self-sufficiency’ index; sample without Aoraki, 2006

Figure G.3: Sensitivity of 'adaptive capacity' index; sample without Aoraki

Excluding Manutuke

Figure G.4: Sensitivity of 'needs' index; sample without Manutuke

Figure G.5: Sensitivity of 'self-sufficiency' index; sample without Manutuke

Figure G.6: Sensitivity of 'adaptive capacity' index; sample without Manutuke

Excluding Maungaraki

Figure G.7: Sensitivity of 'needs' index; sample without Maungaraki

FigureG.8: Sensitivity of 'self-sufficiency' index; sample without Maungaraki

Figure G.9: Sensitivity of 'adaptive capacity' index; sample without Maungaraki

Excluding Normandale

Figure G.10: Sensitivity of 'needs' index; sample without Normandale

Figure G.11: Sensitivity of 'self-sufficiency' index; sample without Normandale

Figure G.12: Sensitivity of 'adaptive capacity' index; sample without Normandale

Rounding Waerengaokuri

Figure G.13: Sensitivity of 'needs' index; rounding for Waerengaokuri

Figure G.14: Sensitivity of 'self-sufficiency' index; rounding for Waerengaokuri

Figure G.15: Sensitivity of 'adaptive capacity' index; rounding for Waerengaokuri

Rounding Waingake

Figure G.16: Sensitivity of 'needs' index; rounding for Waingake

Figure G.17: Sensitivity of 'self-sufficiency' index; rounding for Waingake

Figure G.18: Sensitivity of 'adaptive capacity' index; rounding for Waingake

Rounding Aoraki

Figure G.19: Sensitivity of 'needs' index; rounding for Aoraki

Figure G.20: Sensitivity of 'self-sufficiency' index; rounding for Aoraki

Figure G.21: Sensitivity of 'adaptive capacity' index; rounding for Aoraki

Rounding up and down, Waerengaokuri

Figure G.22: Sensitivity of 'needs' index; rounding up and down for Waerengaokuri

Figure G.23: Sensitivity of 'self-sufficiency' index; rounding up and down for Waerengaokuri

Figure G.24: Sensitivity of 'adaptive capacity' index; rounding up and down for Waerengaokuri