Chapter 7
The Use of Geo-information in Eco-DRR: From Mapping to Decision Support

Bart Krol, Luc Boerboom, Joan Looijen, and Cees van Westen

Abstract Ecosystem services can play an important role as measures for disaster risk reduction. At the same time it is important to find out where and how ecosystem-based disaster risk reduction really can make a difference. If we want to find out what will be the effect of alternative risk reduction measures, how ecosystem services can play a role in this context, and how they compare with other types of interventions, then there is a clear role for geo-information. Geographical information, such as obtained from spatial-temporal simulation modelling and spatial multi-criteria evaluation, is used for analyzing and monitoring what could be the effect of alternative development scenarios on the exposure to natural hazards, or of different combinations of engineered, ecosystem-based and other non-structural risk reduction measures. This helps to set management priorities and propose actions for risk reduction and risk-informed spatial planning. With the help of a spatial decision support system, the effect of risk reduction alternatives and their effect on risk reduction – now and in the future – can be analyzed and compared. This can support the selection of 'best' alternatives. The recently developed RiskChanges is presented, which is a web-based, open-source spatial decision support tool for the analysis of changing risk to natural hazards. It is envisaged that the use of the RiskChanges will support the provision of relevant geo-information about risk and changes in risk, and thus provides input for structured risk reduction-, disaster response-, and spatial development-planning.

Keywords GIS • Planning • Spatial Decision Support System (SDSS) • Simulation modelling • Uncertainty

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7.1 Introduction

Ecosystem services can play an important role as measures for disaster risk reduction. At the same time it is important to find out where and how ecosystem-based disaster risk reduction (Eco-DRR) really can make a difference. For example, insight is needed about what will be the risk-reducing effect of ecological interventions, and how ecosystem services compare with other risk reduction alternatives. This requires access to geo-information and structural development of capacity to both generate and use this geo-information.

Geo-information helps planners and decision makers to be informed about which areas are exposed to hazards, where this exposure increases and where greater risk may develop, or where the occurrence of multiple-hazards will further increase vulnerability of local communities and corresponding disaster risk. Altan et al. (2010) provide a useful demonstration of the possibilities of using geo-information technology in disaster risk management, targeted at decision-makers and disaster management practitioners. Using geo-information (e.g. spatial-temporal simulation models), it is possible to analyze and monitor what could be the effect of alternative development scenarios on the exposure to natural hazards (see for example Sliuzas et al. 2013a). With the help of geo-information, different combinations of engineered, ecosystem-based and other non-structural risk reduction measures can be compared. This helps risk managers to set management priorities and propose actions for risk reduction. Especially in areas where land is scarce, it is important to have adequate spatial and temporal information available, to support the analysis of costs and benefits of ecosystem services as measures for disaster risk reduction.

The parties (stakeholders) involved in planning, design and decision-making in disaster risk reduction typically have different views and priorities (Peters Guarin et al. 2012). Modelers and planners, for example, may have different perspectives on the uncertainty of hazards and risk and judge risk reduction alternatives and trade-offs differently. An effective Decision Support System (DSS) facilitates collaborative decision-making by different groups of stakeholders, dealing with the different perspectives they may have. An example is the Planning Kit DSS that was developed to support the design process of the ‘Room for the River programme’ in The Netherlands (Kors 2004; de Bruijn 2007). A Spatial Decision Support System (SDSS), in addition, facilitates the use of geographical data and models that use these data; it also includes models for the structuring of spatial decision making processes and methods for decision support, such as spatial multi-criteria evaluation (see for example Sugumaran and Degroote 2010).

In this chapter, we present the use of geo-information in Eco-DRR to analyze how and where ecosystem functions can be beneficial for risk reduction and how these may change over time; to find out what are the trade-offs of different ecosystem services; to carry out risk assessments and to share risk information with stakeholders; to compare the risk reduction effect of different intervention alternatives using simulation modelling; and to facilitate collaborative decision-making. This chapter also introduces RiskChanges: a web-based SDSS for the analysis of changing risk to natural hazards. Its aim is to support the evaluation of the effect of different risk reduction alternatives (involving both structural and non-structural, including ecosystem-based measures) on reducing disaster risk, both now and in the future (see also Whelchel et al., Chap. 6; Bayani and Barthélemy, Chap. 10).

7.2 Geo-information and Ecosystem Services

Depending on their biophysical properties, ecosystems have the potential to supply services. Healthy and well-managed ecosystems help communities to cope with the impacts of more frequent and extreme hazard events and therefore adapt to climate change (Renaud et al. 2013). Ecosystem services that aim to reduce disaster risk are mainly regulating services. All over the world, particularly ecosystems' regulating services are declining, often due to an increase in the use of provisioning ecosystem services, to produce more food, fuel and other products (Millennium Ecosystem Assessment 2005). Increase in agricultural production systems, for example, often comes at the cost of biodiversity and/or other regulating services (for instance those that help control erosion). This causes an imbalance in available ecosystem services that will only increase human exposure to extreme events.

Both the supply and demand for ecosystem services are spatially explicit and may differ from place to place. The production of ecosystem services, for example, is often expressed as a function of land use, climate and environmental variation (Maes et al. 2011). The analysis of ecosystem services and their benefits for different users involves their valuation to reflect human attitudes and preferences. For the assessment of trade-offs between different ecosystem services, proper spatial indicators are required for ecosystem functions and services (Crossman et al. 2013; de Groot et al. 2010). Such an assessment requires the development of geographical information in maps and models: to quantify the benefits received from ecosystem services, to estimate where they are produced, to quantify changes in ecosystems and the services they (can) provide over time, and also to describe the production of ecosystem services as a function of land use, climate and environmental variation. For example, to reduce the risk of flooding, proxies to estimate water retention capacities are calculated as a function of vegetation cover and soil type. A model-based approach of mapping ecosystem services will result in a better exploration of risk reducing scenarios and policy alternatives. Different value maps of ecosystem services can be produced and combined using weighted overlaying techniques, depending on the priorities of the planners and stakeholders involved.

7.2.1 Example from the Netherlands

A good and by now well-known example is the national Room for the River programme in the Netherlands (see at: www.ruimtevoorderivier.nl). This integrated flood risk management programme represents a governmental response to coping with higher water levels in the Dutch rivers without simply raising and strengthening river dikes. An approach of 'working with nature' (see also Meyer 2009; De Vriend and Van Konigsveld 2012) instead of fighting against it has resulted in 34 different flood risk reduction projects spread over the Netherlands, most of which have been finalized in 2015. Two of these projects are introduced in Box 7.1 and Box 7.2. Selected ecosystem-based flood risk reducing measures, such as the restoration of floodplains and wetlands, have a double function in many of these projects: they also enhance the re-establishment of natural values (e.g. the presence of given plant- and animal-species, scenic beauty) and promote the development of recreational activities.

A relevant decision support tool in the Room for the River programme is the Box of Blocks software. This is a combined hydraulic model and scenario planning tool that calculates the hydraulic effects of combinations of structural (e.g. river channel widening) and non-structural (e.g. wetland development) measures for flood risk reduction and thus supports the design and selection of measures (Schut et al. 2010; Dutch Ministry of Water Management, Transport and Public Works 2013). This Box of Blocks tool includes 600 different measures with potential for water level reduction. It was made available to the stakeholders involved in the different projects, who have used it to evaluate and visualize the effectiveness and interdependencies of their proposed measures to reduce water levels. This tool also displays the costs of each measure and the effects on agriculture production and natural values, amongst others. It has also facilitated the dialogue and cooperation between policymakers from different regions, by demonstrating the interdependencies of river management at the national level (Schut et al. 2010).

Box 7.1 River Dike Re-location and Construction of a Flood By-pass at Nijmegen, The Netherlands

Source: www.ruimtevoordewaal.nl; www.infranea.eu

Room for the Waal River at Nijmegen is one of the projects in the Dutch Room for the River programme. Its aim is to protect the city of Nijmegen and its surroundings from future floods and at the same time increase the spatial quality of the urban environment in the project area. The Waal River forms a bottleneck for water discharge in a sharp river bend near Nijmegen. This has recently resulted in high water levels, and caused severe flooding in 1993 and 1995. To protect the inhabitants of the city against floodwater, an existing dike is re-located 350 m inland. In addition, an ancillary river channel is constructed in the river's flood plain, also including the construction of three

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Box 7.1 (continued)
bridges and a new quay. This will create an island in the Waal River and a unique urban river park with many additional possibilities for recreation, cultural activities, and re-establishing of natural values.

For the planning, coordination and modelling of this project a so-called Building Information Modelling (BIM) system is used. This BIM provides three-dimensional (3D) representations of the physical and functional aspects of the planned infrastructural designs considered in the project. These are combined with ecological and water management information available in a Geographical Information System (GIS). In this way, the possible effect of proposed interventions can be modelled and potential conflicts – between design components but also between stakeholder interests – can be identified and discussed. This approach of geographical information sharing and collaborative decision-making supports the different parties involved in designing and managing this complex project (Fig. 7.1).

Fig. 7.1 3D-impression (downstream view) of the expected results of the Room for the River project at Nijmegen. River bend in Waal river (*left side*) and construction of an ancillary river channel (*right sight*) create a new island for recreation and re-establishing natural values (Image: Room for the Waal Nijmegen, (www.ruimtevoordewaal.nl), used with permission).

Within the boundary conditions for lowering of river water levels and connected flood risk reduction set by the national Room for the River programme, it is left to the regional and local stakeholders in the respective projects to negotiate and decide for a mix of structural and non-structural – including ecosystem-based – flood protection measures. This decentralized approach also holds for the selection of additional tools and techniques to support the design, planning and management of projects.

Box 7.2 Flood By-Pass Development Near the Dutch Town Kampen

Source: www.ruimtevoorderivierijsseldelta.nl

A combination of increased water discharge (rainfall-induced) by the IJssel River and expected sea level rise make the Dutch towns of Kampen and Zwolle and their hinterland increasingly more vulnerable to the effects of flooding. To increase the resilience to climate change and at the same time improve the spatial quality of the area, a new flood channel, the Reeve Deep by-pass, will be constructed in the IJssel river delta. Apart from flood protection measures, there are several other spatial issues to be considered in the development of an integrated flood protection plan, including: attention to nature management (the development of a new wetland area, in particular), interests of the agricultural sector, options for recreation, the development of new housing areas, and the presence of a railway and several highways. For the spatial design of the flood by-pass a Digital Elevation Model (DEM) was used. Both the average and expected extreme water levels are projected on this model. This helps to obtain a better geographical understanding of the delta landscape and the potential wetland areas. Taking into account the hydraulic requirements set by the national Room for the River programme, this has ultimately led to the development of an integrated spatial plan for the IJssel delta (Fig. 7.2).

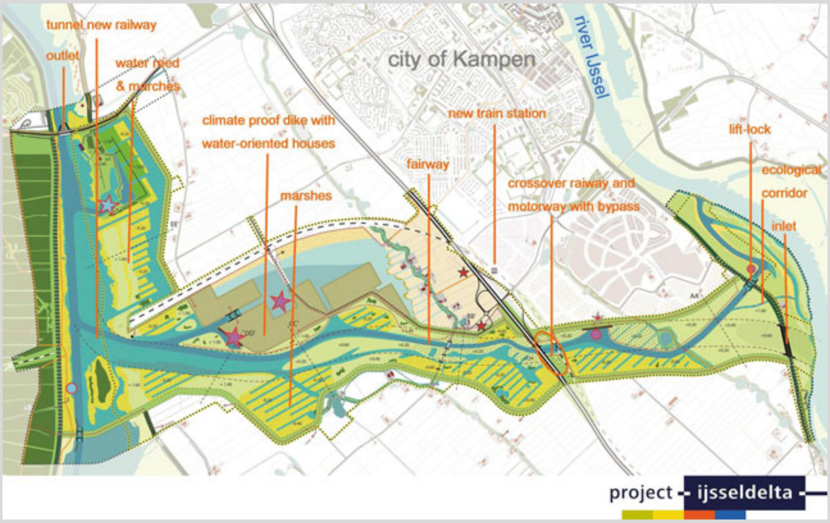

Fig. 7.2 Overview of the spatial development plan for the IJssel delta near Kampen (IJssel river, new flood channel and other water bodies in *blue colours*; wetlands and other vegetation cover in *green colours*) (Image, courtesy of A. Otten, Province of Overijssel)

7.3 Geo-information and Risk Assessment

Disaster risk can be defined as the probability for harmful consequences or losses, in a given area and over a period of time (Birkmann et al. 2013). This makes risk a geographical problem, with both spatial and temporal aspects playing a role. The assessment of risk requires a geographical analysis, because its different components – i.e. the assessment of natural hazards, of elements at risk and their vulnerability – both differ and vary in space and time (van Westen 2010). This dynamic character of the risk concept makes the collection of geographical data – of past and present hazard events, of elements at risk and their vulnerability – and their spatial-temporal analysis often a complex task. This is even more so if multiple hazards are considered, for example hazards sharing the same triggering event or occurring as a cascade of hazard events (van Westen 2013).

At the same time geographical data, GIS and remote sensing technology are to date widely applied for the analysis of natural hazards and disaster risk. In the form of GIS-based risk maps, risk related information is supplied in many countries to mandated agencies and authorities. Increasingly, also the general public is informed about risk and changes in risk in their living environment (Basta et al. 2007). An example is the systematic delivery of geographical risk information in The Netherlands using the on-line risk information portal: 'risicokaart' (see at www.risicokaart.nl). A number of relevant examples of the application of geo-information in a disaster risk context are presented elsewhere in this book.

7.3.1 *Qualitative and Quantitative Approaches*

There is an increasing need for quantitative forms of risk assessment that express risk as probability of a given level of loss together with the associated uncertainties (see for example Corominas et al. 2014; Crozier and Glade 2005). Quantitative methods are expected to allow for an objective and reproducible way of risk assessment also in a multi-hazard risk context (Kappes et al. 2012). At the same time, however, quantitative risk assessment methods mostly focus on physical vulnerability aspects, whereas qualitative risk assessment approaches tend to also incorporate other (i.e. economic, social, ecological, institutional, cultural) vulnerability aspects (van Westen 2013).

Qualitative and semi-quantitative approaches to risk assessment are often considered when the availability of (numerical) geographical data is limited. This kind of risk assessment is also considered as an initial screening process to identify natural hazards and risk (van Westen 2013). An international example is the annual World Risk Report (2014) that uses a risk index approach to rank countries worldwide based on their potential disaster risk. In a multi-criteria type of analysis using 28 different indicators influencing risk, a so-called World Risk Index value was computed for each country considered. A national level example applying the risk index approach is the development of a landslide risk index map for Cuba (Castellanos Abella and van Westen 2007). The adopted approach involves the use of multiple spatial indicators as input for a Spatial Multi-Criteria Evaluation (SMCE). In the absence of reliable landslide inventory data, hazard indicator maps are used representing both conditional factors (e.g. slope, geology, land cover) and triggering factors (e.g. earthquakes, rainfall). Geographical data about population distribution, transportation and housing, amongst others are used to represent physical aspects of vulnerability. In fact, Castellanos Abella and Van Westen (2007) label their approach as semi-quantitative because of the use of weighing certain indicators to allow for better representation of the spatial variability present in the available data. The resulting national risk index map of Cuba provides geographical information that supports decision makers in prioritizing resources for further risk assessments at provincial, municipal and local levels.

A risk assessment using SMCE can also be carried out at the sub-national level, for example for a province, district or municipality. As a qualitative approach, SMCE can be labelled as subjective and mainly useful if data are lacking for a more quantitative risk analysis. But it can offer more than just that. Applying SMCE, it is possible to use expert knowledge – from engineers, economists, authorities, local communities, amongst others – and to include ‘soft’ information like perception and preferences in a risk assessment (Alkema and Boerboom 2012). The active involvement of these multiple stakeholders – frequently with initially conflicting views and perceptions – in an SMCE procedure facilitates collaborative decision-making processes (Alkema and Boerboom 2012).

Geographical information about risk and also about expected changes in risk over time can be used to evaluate and compare the expected effects of different strategies for risk reduction. With the help of geographical data, modelling techniques and GIS-software tools, so-called ‘what if’ type of analyses can be carried out and alternative future scenarios can be generated and compared to support decision-making processes (Longley et al. 2005).

7.3.2 Risk Assessment Tools

Two well-known examples of a combined methodology and open-source software tool for quantitative, probabilistic multi-hazard risk assessment are HAZUS-MH and CAPRA. HAZUS-MH (www.fema.gov/hazus) was developed by the Federal Emergency Management Agency in the USA. CAPRA, the Central American Probabilistic Risk Assessment Program (www.ecapra.org) was initiated by the Center for Coordination of Natural Disaster Prevention in Central America (CEPREDENAC), the United Nations International Strategy for Disaster Reduction (UNISDR) and the World Bank.

To support the building of capacity in disaster risk management in national and local governments, The World Bank’s Global Facility for Disaster Reduction and Recovery (GFDRR) has recently reviewed 31 open-source and open-access software packages for the quantitative analysis of natural hazards and risks (GFDRR 2014). Increasingly, free and open-source GIS software tools are also extended with new functionalities that are specifically relevant in a hazard and risk analysis context. An example is the functionality for SMCE in the ILWIS GIS software package (http://52north.org/communities/ilwis/ilwis-open). Another example is the QGIS software package (www.qgis.org) with its INASAFE (http://insafe.org) plugin that is used to generate hazard impact scenarios in support of disaster preparedness and response planning. A new initiative is the development of RiskChanges, a web-based, open-source SDSS for analyzing changing hydro-meteorological risk (van Westen et al. 2014). RiskChanges is described in more detail later in this chapter.

7.3.3 Spatial-Temporal Simulation Modelling

Predictive modelling is increasingly used for analyzing and monitoring what could be the effect of alternative development scenarios on the exposure to natural hazards, or of different combinations of engineered, ecosystem-based and other non-structural risk reduction measures in space and time. In this manner, possible trends or future situations can be considered, together with alternative policy options and interventions for risk reduction. In Box 7.3 an example of flood simulation modelling in Kampala, Uganda is presented, where the development and application of a scenario-based urbanization and flood modelling approach has created an information environment that facilitates the development of an integrated flood management strategy (Sliuzas et al. 2013a).

Unfortunately, in practice the link between the modelling and prediction of (hazardous) natural processes and corresponding risks on the one hand and their management and governance on the other hand is still rather weak (Greiving et al. 2014). Scientific developments in hazard and risk assessment and the needs and demands of decision-makers and end-users of risk information are still not well connected (van Westen 2013). Additional challenges are posed by the often-existing uncertainty in space and time about the possible roles and effects of urban growth processes, land use trends, climate change, and other future scenarios. A decision support mechanism can bring different stakeholders (representing different disciplines, sectors, etc.) together more easily in the assessment of risk and the search for effective risk management strategies. This interaction between stakeholders is, for example, an integral part of joint planning of flood risk reduction projects in the Room for the River programme in The Netherlands (see for example: Roth and Winnubst 2014).

Box 7.3 Scenario-Based Modelling of Current and Future Flood Risk in Kampala, Uganda

Source: Sliuzas et al. (2013a, b).

Accelerated urban growth and increasing rainfall-induced flood problems have motivated Kampala – the capital city of Uganda – to join UN-HABITAT's Cities and Climate Change Initiative (CCCI). As part of CCCI's Integrated Flood Management Project in Kampala, researchers and students from the University of Twente, Makerere University and a German consultant have analyzed the current and possible future flood risk situation in Lubigi catchment inside Kampala. In this catchment (approx. area $= 28$ km^2) a system of lined channels connects populated hills to a system of central drains in the catchment's main valley – increasingly populated as well – that subsequently drain into a natural wetland system further downstream. Residents and business owners have developed a number of mechanisms to cope with the effect of flooding, but the frequent rainfall-induced floods are a nuisance and also pose a risk with significant costs, both economic as well as health related.

The open-source spatial-temporal modelling environment OpenLISEM (http://blogs.itc.nl/lisem) was used to simulate a 10-year rainstorm event of 1000 mm in a day, considering a series of possible future scenarios, including:

- Maintaining the current situation of unimproved drainage and unregulated urban development, i.e. a scenario of 'no change';
- Physical improvement of the drainage system with structural interventions in the main drain and culverts in secondary channels, i.e. a 'hard engineering' scenario;
- A 'green engineering' scenario involving a number of so called Sustainable Drainage System (SuDS, see also Woods-Ballard et al. 2007) options for improving the functioning of drainage channels, using a mix of widening and deepening of drains, creation of grassed waterways, identification of areas for temporary water storage;
- A 'planning only' scenario consisting of urban development control, including identification of flood hazard zones and restriction of housing.

These scenarios were further refined considering an urban growth projection for 2020, using annual growth rates of 4.2% ('trend') and 6.5% ('high').

Based on the predictive flood modelling using OpenLISEM the 'no change' scenario shows severe flooding (up to 2 m and for more than 24 h) in areas along the primary drainage channel; in large areas flood water stays up to 24 h until the water level decreases to manageable levels. The 'hard engineering' scenario is expected to reduce the extent and duration of flooding but will not eliminate it. Using the modelling results, the researchers

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Box 7.3 (continued)

also observed that improved culverts in the secondary channels reduced local flooding, but at the same time cause water to be delivered more rapidly to areas downstream and thus potentially increase flood problems elsewhere. Given the modelling results, it is expected that the increased water infiltration in the 'green engineering' scenario will also contribute to a reduction of the flood problem. The planning scenario shows the importance of controlling and regulating urban development for dealing with flood problems in the future. The scenario-based flood modelling has also resulted in the identification of a number of areas that face chronic flooding: flooding hot spots where urban development control and dedicated planning measures are especially important.

The results obtained by the research team show that for this Kampala case, urban growth and disregard of planning will have a stronger effect on flooding and flood related problems than any possible future climate change. In Lubigi catchment the best flood reduction effect is expected from a mix of 'hard engineering' measures in the central valley, 'green engineering' on the hills slopes, together with improved urban planning strategies and housing regulations (Fig. 7.3).

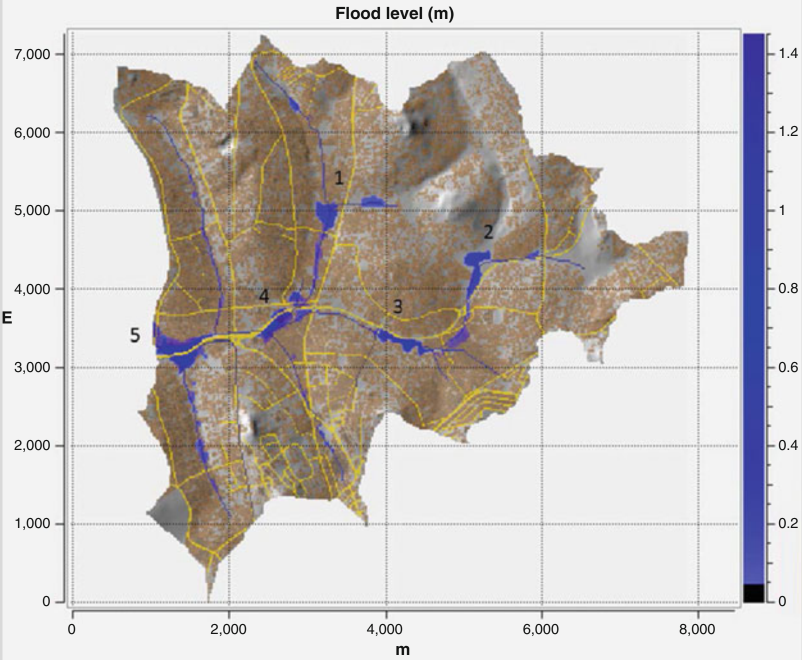

Fig. 7.3 Flooding hotspots [*blue colors*: recurrent flood water depth in meters] in Lubigi catchment based on multiple scenario analyses (Sliuzas et al. 2013a; used with permission)

7.4 Spatial Decision Support for Eco-DRR

An ideal DSS for Eco-DRR would allow for exploring different options and arriving at a decision, for example for a particular intervention measure. The essence of a decision was very well captured by Von Foerster (1992 p.14) when he stated that, “Only those questions that are in principle undecidable, we can decide.” In other words: only if we feel that there is a trade-off between our options, because no single option is the best, are we making a decision. Since this sense of trade-off will remain, we remain undecided. Therefore, a DSS should not just describe our physical or societal environment in tables and maps in the way that databases and information systems do. Nor should it describe the behavior of our environment the way models – such as ecosystem models, rainfall runoff models or landslide risk assessment models – do. A DSS should capture the ‘undecidable’, i.e. the trade-offs (Ackoff 1981) of often nested, chained, and poorly structured decisions. DSSs – as a class of software tools – can support decision makers both when judgment about trade-offs is important in the decision making process and when the human information processing capacity limits the decision making process. When such DSS address spatial decision problems using geographical data we speak of Spatial Decision Support Systems (SDSS), which help us decide between spatial alternatives (Rauscher 1995).

7.4.1 Dealing with Uncertainty: Modelers’ and Decision Makers’ Perspectives

In the context of disaster risk reduction, DSSs not only support the judgment about trade-offs, but also about the uncertainty related to hazards and risk. Even if uncertainty is minimized by the quantification of risk – and hence becomes, by metaphor, a “controllable island in the sea of uncertainty” (Nowotny et al. 2001 p.14) – DSSs still need to support decision making in a sea of uncertainty. This uncertainty can be further distilled to (i) uncertainty due to variability, i.e. stochastic or ontological uncertainty, and to (ii) uncertainty due to limited knowledge, i.e. epistemic uncertainty (van Asselt and Rotmans 2002). However, this is a modeler’s perspective on uncertainty. Ambiguity is an additional source of uncertainty (Brugnach et al. 2008), which is defined here as the “existence of two or more equally plausible interpretation possibilities” (Dewulf et al. 2005 p. 115), as is often resulting from clearly different (stakeholder) perceptions about what is at stake (Dewulf et al. 2005). These three concepts of uncertainty and risk are illustrated in Box 7.4 using a recent study by Petr (2014) about changes in the provision of forest ecosystem services in British national forest estates, under the influence of climate change-induced drought effects on stands of tree species.

Box 7.4 Scenarios for Uncertain Climate Change and Yield Decline in British Forests

Source: Petr (2014)

In 2009 a climate change projection for the UK was released (Murphy et al. 2009). It was the first probabilistic projection for the UK, considering two spatial resolutions (25 and 5 km) and temporal resolutions over 30 year periods, starting from the 2020s (2010–2039) until the 2080s (2070–2099).

For the calculation of total probable risk of tree yield change, spatial and temporal resolutions, both probabilistic data of moisture deficit and drought vulnerability response curves for forest stand yields of three tree species (i.e. *Sitka spruce*, *Scots pine* and *Pedunculate oak*) were used. Total probable risk is expressed as the sum of all probable yield changes of a tree species in each of the spatial and temporal ranges (Petr et al. 2014).

Given the uncertainty of future climate change scenarios, three scenarios by the Intergovernmental Panel on Climate Change (IPCC 2000) were used to prepare risk maps of Britain for each decade. The resulting tree yield changes were translated to predict the loss of ecosystem service provisions until the end of the 21st century (especially production and carbon sequestration) and with predicted losses of up to 50% for some species in certain localities (Petr et al. 2014). If ecosystem service functions continue to decline during the 21st century, existing adaptation options – such as the tree species currently selected or area expansion of tree species – will reach their expiry date. Beyond this point of expiry, policymakers will need to shift to new policy options to achieve a required adaptation. The described approach follows a method of 'dynamic adaptation policy pathways', introduced by Haasnoot et al. (2013) for decision making in a context of uncertain changes.

When forest planners in Scotland were exposed to the policy pathways options and the possibility to assess expiry dates of certain species choices, their framing of adaptation was observed to diverge (Petr et al. 2015). For instance, forest planners in two districts decided as a group that expiry dates for keeping spruce, which is the dominant tree species in all districts, occurred much later, which varied from their individual decisions. This gives reason to suspect that individual planners frame the role of climate change in species choice differently in terms of urgency, and for some reason seem to ignore this ambiguity in a collective decision, i.e. when they decide together.

7.4.2 An SDSS That Addresses Risk Uncertainty

Using a spatial decision support system for Eco-DRR, we first of all expect to be able to assess disaster risk. But we also expect the availability of tools to make judgments about trade-offs between different spatial and temporal criteria regarding alternative ecosystem services and other possible interventions that can reduce disaster risk. Finally, we expect to be able to assess uncertainty, both from a modeler's and decision maker's point of view. Stochastic uncertainty is typically addressed using methods for sensitivity analysis. Epistemic uncertainty and ambiguity can be addressed using different models or different decision problem formulations. Scenario development plays a crucial role, both for varying exogenous variables that could affect intervention options (Engelen 2000) in different ways (epistemic uncertainty) and to express ambiguity.

These characteristics have also been considered in the development of the RiskChanges SDSS that is presented in more detail in the next section. RiskChanges allows for the assessment of risk while assuming multiple scenarios (e.g. population growth, development policies) that can affect different intervention alternatives at different moments in time, while SMCE is applied for the assessment of trade-offs of different interventions and scenarios. Stochastic uncertainty is addressed through the probabilistic nature of the hazards. Since RiskChanges is an open system that can be used for any disaster risk assessment, the definition of alternatives and their indicators allows for dealing with epistemic uncertainty and to some extent variation in the framing of problems or risks and alternative solutions.

7.5 RiskChanges: A Web-Based SDSS for Analyzing Changing Hydro-Meteorological Risk

RiskChanges is a new SDSS that enables the geographical analysis of the effect of risk reduction planning alternatives on the reduction of current and future risk. It supports decision makers in selecting 'best alternatives' for intervention. The RiskChanges SDSS is developed in the context of two EU-funded research projects: the INCREO project (www.increo-fp7.eu) and the CHANGES project (www.changes-itn.eu). This overview of RiskChanges is drawn from the presentation and description of the system by van Westen et al. (2014).

RiskChanges is targeted at three main groups of stakeholders involved in risk assessments. The envisaged end-users of RiskChanges include agencies involved in planning of risk reduction measures, and that also have the capacity to analyze and visualize geographical data at the municipal level. Examples are civil protection organizations that develop plans for disaster response; expert organizations involved in the technical design of structural measures (e.g. dams, dikes) and/or the development of non-structural and ecosystem-based risk reduction measures; organizations with a development planning mandate. A second group of stakeholders involves information providing organizations that are responsible for the production, the provision and monitoring of hazard-related information (e.g. flood scenario maps). A third main stakeholder group involves organizations that typically provide information (e.g. cadastral, transportation) about elements at risk.

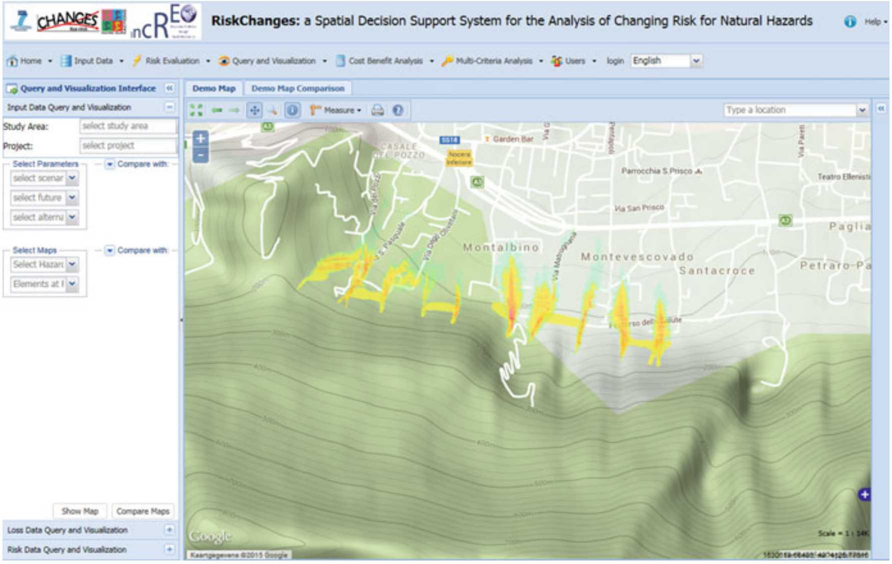

Fig. 7.4 Opening screen of the web-based RiskChanges SDSS (Source: CHANGES project website)

RiskChanges is a web-based system, designed based on open-source software and following open standards. RiskChanges is available online in the CHANGES project website. Its opening screen is shown in Fig. 7.4. It is possible to use RiskChanges for multi-hazard risk assessment at different spatial-temporal resolutions, in different countries and within different legal settings.

7.5.1 *Different Risk Assessment Workflows*

RiskChanges can be used for four different types of risk assessment workflows:

1. *Analyzing the current level of risk*. Using geographical data about natural hazards, elements at risk and their vulnerability, it is possible to perform an evaluation of current (multi-) hazard risk level.
2. *Analyzing 'best' alternatives for risk reduction*. In this workflow, stakeholders first identify a number of risk reduction alternatives – structural, non-structural, ecosystem-based – and request expert organizations to provide them with updated hazard maps and information about elements at risk and their vulnerability reflecting the consequences of these alternatives. The new risk level is analyzed and compared with the current level of risk in order to estimate levels of risk reduction. A subsequent evaluation of costs and benefits (in financial terms and/or in terms of other constraints) per alternative helps to make a

selection of a 'best' risk reduction alternative. Note that this workflow can also be used in a case of 'best' disaster response planning, or as the basis for early warning system design.

3. *Evaluating the possible consequences on risk of different future scenarios.* In this workflow, the effect of possible future risk scenarios of population growth, land use change, climate change or other trends that cannot be controlled by the (local) planning organizations involved in the risk assessment are analyzed.
4. *Evaluating how different risk reduction alternatives can lead to risk reduction under different future scenarios.* This is the workflow in which current risk, the potential effect of risk reduction alternatives, and the different future scenarios come together.

Central to RiskChanges is risk assessment. The RiskChanges system itself does not include facilities to generate natural hazard maps and maps of elements at risk; relevant information is produced outside the system. Hazard maps and information about elements at risk can be uploaded using the system's *Data input module*. After data preparation, they are fed as input data into the system's *Risk Evaluation module*. A spatial risk assessment can be carried out ranging from simple exposure analysis to quantitative analysis resulting into risk curves. After a loss calculation, users can opt for different types of risk assessments, for example hazard-specific or specific elements at risk, concentrating on economic risk or population risk, for identified risk reduction alternatives and future scenarios. In a *Cost-benefit analysis module* users can analyze the costs of identified risk reduction alternatives, also taking into account how costs and benefits may change in time (for example depending on future scenarios). A *Multi-Criteria Analysis module* supports the users in determining the most optimal risk reduction alternative using a spatial multi-criteria evaluation approach. Thus, the pros and cons of different engineering-oriented, ecosystem-based and other non-structural risk reduction alternatives can be critically evaluated and contrasted. The results of risk assessment are presented using RiskChanges' *Visualization module*, as maps but also in the form of risk curves, tables and graphs. This also includes tools for the visualization of temporal changes.

7.6 A Role for Geo-information in Eco-DRR

Over the years the use of geo-information in disaster risk reduction has moved from a mere focus on the generation of hazard and risk maps by specialists for specialists to the use of geo-information in processes of collaborative decision-making and planning of risk reduction strategies. As is also shown in the examples used in this chapter, in practice often a mix of both structural and non-structural measures, of engineering and ecosystem-based interventions, are considered as part of strategies to cope with expected future risk scenarios.

If we want to find out what will be the effect of alternative risk reduction measures, how ecosystem services can play a role in this context, and how they compare to other types of interventions, then there is a clear role for geo-information in the field of Eco-DRR. Moreover, the use of geo-information also facilitates the communication between different stakeholder groups, including hazard and risk specialists, land users, development planners, decision makers, local communities and the public in general.

Using SDSSs, it is not only possible to assess disaster risk, but also to make judgments about the trade-offs of different ecosystem services and other possible risk reducing interventions. It is envisaged that the use of the RiskChanges SDSS will support the provision of relevant geographical information about risk and changes in risk, and thus provide input for structured risk reduction planning, disaster response planning, and spatial development planning.

Of course a number of challenges to SDSS implementation in the risk reduction context remain. They concern, for example, data availability, the proper linkage of different components of an SDSS, user guidance and the presentation of outputs of a decision making process. In addition, an important implementation-related challenge is about participatory development: how to engage users in the development of a decision support mechanism. If these challenges can be properly addressed, RiskChanges can play an important role in supporting the selection of 'best' alternatives for multi-hazard risk reduction, under different future scenarios, and including Eco-DRR options.

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