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Landslide consequence analysis – mapping expected losses in the Göta river valley

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ABSTRACT: Landslide risks are expected to increase with climate change in large parts of Sweden due to increased annual precipitation, more intense precipitation and increased flows combined with dryer summers. In response to this climate threat and on commission of the Ministry of Environment the Swedish Geotechnical Institute has initiated a risk analysis project for the most prominent landslide risk area in Sweden: the Göta river valley. Human life, settlements, industry, contaminated sites, infrastructure of national importance are important elements at risk.

Focusing on the consequences of landslides this paper aims to show the process and structure of this regional consequence analysis by presenting suggestions on how to describe, quantify, value, total and visualize widely different consequences. The consequence analysis is GIS-aided in using existing databases for quantification and estimation of values, in calculating expected monetary losses and within visualization. The goal of the consequence analysis is to produce a map of geographically distributed expected losses, which can be combined with a corresponding map displaying landslide probability.

Keywords: landslide, consequence, economic valuation, GIS, risk analysis

1 INTRODUCTION

1.1 *Sweden facing climate change*

A national inquiry on climate change impacts concludes that Sweden will be heavily impacted by climate change, and that adaptation should start immediately (SOU 2007:60). Expected climate change in Sweden includes; increased precipitation during the autumn, winter and spring; winter precipitation increasingly falling as rain; dryer summers; increase in most intensive rainfall; higher flows and more frequent floods in western Götaland but also occasions with potential less water flows and water levels in some rivers (SOU 2007:60; Bergström et al., 2010).

The risks for floods, landslides and erosion are expected to increase in large parts of the country. Greatly increased risks for these natural hazards justify stronger initiatives for preventive actions (SOU 2007:60). In response to the results of this national inquiry the Swedish Government has commissioned the Swedish Geotechnical Institute to investigate and map the landslide risks in one of the country's most landslide-prominent areas: the Göta river valley (Hultén et al. 2007).

1.2 *The Göta river valley*

In south-west Sweden the Göta river valley, running from Lake Vänern in the north to Göteborg in the south (Figure 1), is the most frequent landslide area in the country, with a number of landslides occurring each year.

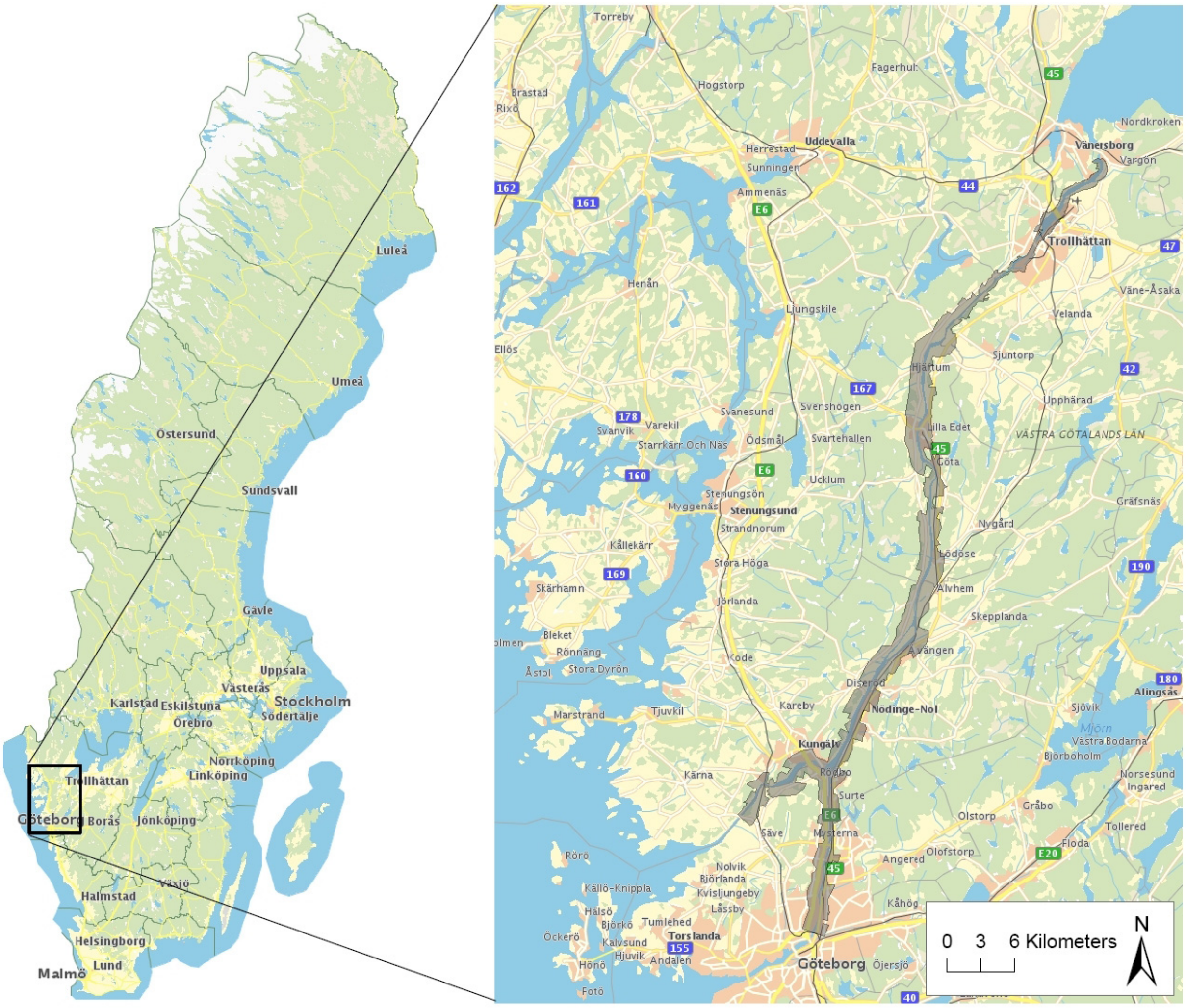

Figure 1. The Göta river valley with the landslide risk study area marked in dark grey. The river passes six municipalities on its way from Lake Vänern to the sea.

In general the landslides are small and shallow and occur as a result of erosion. However a number of large landslides have occurred during the past 100 years, some of them with human casualties and extensive property damages (e.g. Alén et al. 2000; Hultén et al. 2007).

Geologically the prerequisites for landslides formed during and following the latest glaciation period, when deep layers of clay formed in the river valley which was submerged in the sea during this period. Since the material was mainly deposited in a marine environment, quick clay is common in the area. Quick clay is a soil with high water content and weak bindings between the clay particles. Vibrations or a small initial landslide can cause a quick clay layer to collapse and liquefy, resulting in a large rapid landslide with potentially severe consequences (e.g. Andersson-Sköld et al. 2005)

The valley has a long history of anthropogenic activities such as settlements, shipping, harbours and industry and there are numerous areas with contaminated soil. Roads and railroads of national importance stretch along the river bank for several kilometres.

1.3 *The Göta river valley land slide risk analysis*

The ongoing Göta river risk analysis project covering an area of around 300 km^2 (Figure 1) started in 2009 and will be finished by the end of 2011. The results from the risk analysis will be presented in reports, maps and open access GIS presentations. The primary aim with the analysis is to be used as a basis for discussions on prevention and climate adaptation measures and for risk analyses on national level. But it can also serve as the basis for the land use planning of municipalities and government agencies and be used in the surveillance of the safety along the Göta river valley. Results will also help determining which minimum and maximum flows should be allowed in this regulated river.

In addition to extensive geotechnical field investigations and handling complex geotechnical issues this overview risk analysis project involves developing methods for quantitative consequence analysis. The consequence analysis includes identification, quantification, economic valuation and visualisation of consequences for widely different elements at risk. Van Westen et al. (2008) states that GIS has determined the current state-of-the-art in landslide and hazard risk assessment. In this project GIS is used when gathering and viewing data from existing databases for quantification, when estimating values, calculating expected monetary losses and for visualization purposes.

This paper aims to show the process and structure of this regional, and thereby relatively large-scale, consequence analysis for landslides by presenting suggestions on how to describe, quantify, value and visualise these widely different consequences with the aid of GIS.

2 STRUCTURE OF CONSEQUENCE ANALYSIS

The primary step in the consequence analysis is to identify the elements at risk. Once the elements at risk to be included in the study are settled upon, the proposed method for consequence analysis is divided in six parts, as illustrated in Figure 2.

In the inventory phase, data regarding each element at risk is gathered for the studied area; national registration records for living and working; real property map, electricity grid map etc.

Possible methods for economic valuation of each element at risk are studied and selected in the valuation phase. The expected degree of loss is assessed in the vulnerability phase. For real property it describes the value of damages caused by a landslide. For people it is the probability of death for a person who is in the landslide area at the time of the landslide.

Exposure describes the degree of exposure of each element at risk, e.g. how people divide their time between work, home, school, etc. at different physical addresses. These phases are followed by GIS calculations, and finally the results can be visualized in a number of ways. Here we present the GIS based work procedure for some selected elements at risk in the Göta river valley: human life and properties.

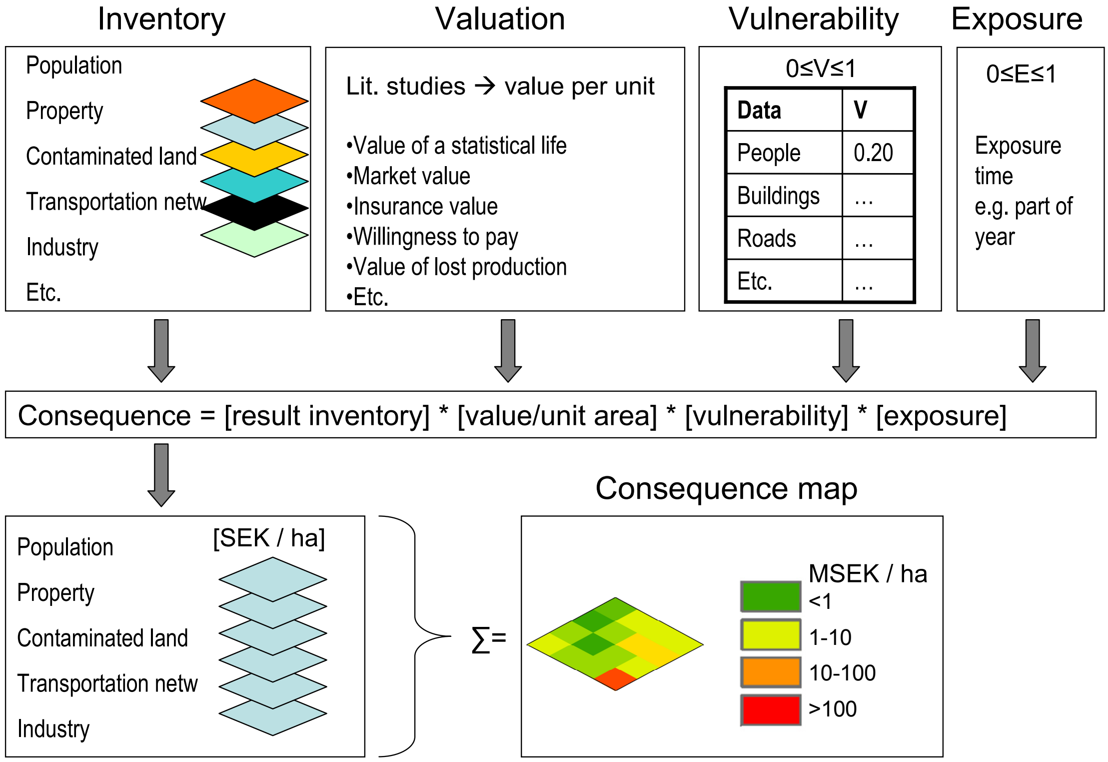

Figure 2. Illustration of the phases in the consequence analysis. The figure is adapted and improved from Falemo et al. (2010).

3 ELEMENTS AT RISK

Previous in use methods for landslide consequence assessment in Sweden were semi-quantitative with consequences scored on a four-grade scale based on type scenarios and included only human life, transportation, buildings and environment (e.g. Alén et al., 2000, Berggren et al., 1991, Hultén et al., 2007). A wider spectrum of consequences, improved transparency, economic valuation and improved visualization possibilities were the main aims when developing the new method.

The consequence categories included in the present investigation are:

- Human life
- Property
- Transportation
    - Road
    - Railroad
    - Shipping
- Environmental risk activities
    - Industrial activities (Seveso, EMIR A, B, C)
    - Contaminated land (MIFO)
- Life lines
    - Energy and telecommunication
    - Water and sewage systems
- Nature and cultural environment
- Business community

The consequence categories have been selected with inspiration from van Westen et al. (2008). This article focuses on human life and property.

4 GIS FOR INVENTORYING

A case study mapping landslide consequences for human life and property in Ale municipality is the basis for the following chapters 4-6 (Falemo & Axelsson 2011). The case study area is 100-1000 m wide and 30 km long.

A GIS format real property map with information on taxation values and property types provided necessary information for valuing land and buildings (Figure 3). Properties without taxation values (e.g. schools, sports halls, care centres) were investigated separately through contacts with the county council and Ale municipality to find information on gross floor area and building use. This information was added to the GIS.

Statistics Sweden provided national registration records in a 100 by 100 squared GIS raster layer, as well as a corresponding raster layer describing the amount of people employed in each square. Each address belongs to one square only, meaning all residents or workers belonging to this address are registered in the same square. In order to avoid unreal hotspots manual adjustments were made for large industries with many employees, distributing them evenly over the area of the industrial buildings.

The numbers of pupils in schools and pre-schools were collected and, in GIS, distributed evenly over the area of the property of each school. This generally works well but in some cases leads to improper scattering of consequences and so the results of this GIS operation must be controlled.

5 GIS OPERATIONS FOR QUANTIFYING CONSEQUENCES

5.1 *Quantifying property damage costs*

For properties with taxation values market values are calculated using purchase price / taxation value ratios (Figure 3).

The remaining properties are valued with calculated replacement cost ratios from an insurance company and are based on gross floor area and building use. An alternative is to extend surrounding property value per area unit from a property of the same building type to the property that lacks a basis for valuation. It is assumed that properties within a landslide area has the vulnerability factor 1, i.e. the full market value of the property is lost if it suffers from a landslide.

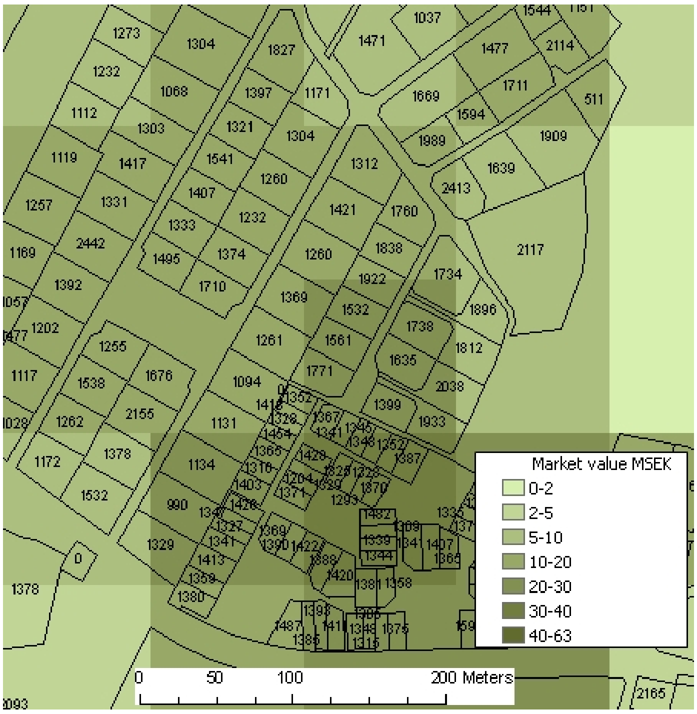

Figure 3. A real property map with taxation values in kSEK (shown in figure) and purchase price / taxation value ratios are the inputs for calculating market values. Market values are shown as raster data with the cell colour showing the value in MSEK of each 100 by 100 m cell. 1 SEK ≈ 0.1 €.

5.2 *Quantifying expected life losses*

Consequences for human life for the pupils are calculated using time-under risk ratios (exposure index describing how large part of the year is spent in the school building), conditional vulnerability (the probability of death for a person who is in the landslide area at the time of the landslide) and the value of a statistical life (VOSL). A more detailed description on calculating consequences for human life and a discussion on applying VOSL in this risk analysis have recently been presented in Falemo et al. (2010).

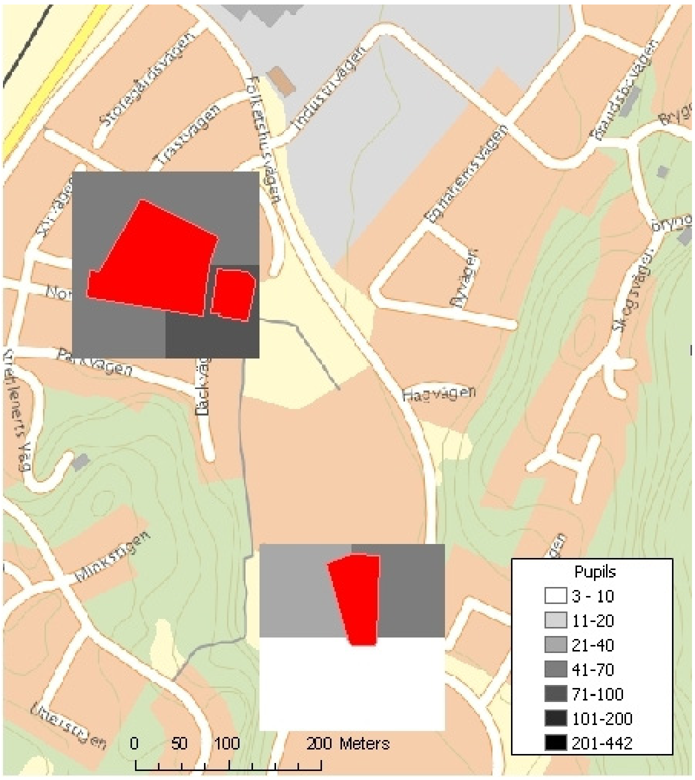

Figure 4. Three schools on separate properties are shown in red. The numbers of pupils of three schools have been distributed evenly over their respective property, and then this information is converted to raster data cells partially covering each school in proportion to the area covered by each cell. The cell colour shows the number of pupils associated with that cell.

Figures 4 and 5 show an example of calculating expected life losses for three schools. In Figure 4 the pupils in these schools have been distributed over the raster data cells partially covering each school in proportion to the area covered by each cell.

The expected life loss for pupils in these schools is obtained by multiplying this raster with exposure factor for pupils and by the vulnerability factor for people. The exposure factor expresses the likelihood of the pupils being in the school when the landslide occurs, so the results show yearly mean values for expected life loss.

Executing these calculations for pupils, employees and residents in the area results in the expected life loss map displayed in Figure 5. Diurnal (day/night) maps is a natural step towards a more detailed consequence analysis, and of course consequences for human life for a certain landslide depend on the time of the slide and what type of buildings are impacted (workplaces, schools or homes).

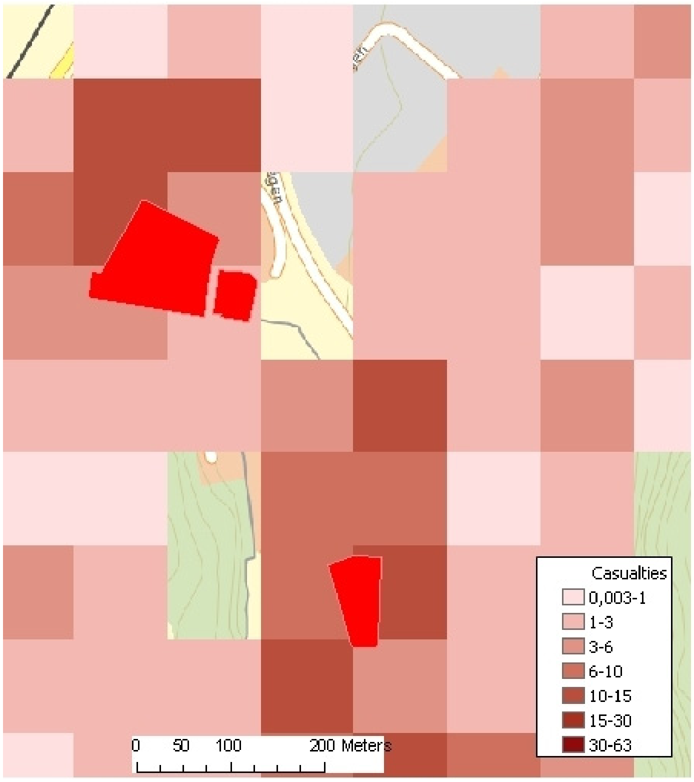

Figure 5. the expected life loss for pupils, employees and residents are shown as raster data. These consequences are calculated as a theoretical mean value of the year in relation to the exposure factors, as described above.

6 GIS FOR VISUALIZATION

There are numerous ways to visualize the results, and by providing a GIS database the results for each element at risk are available separately and as total expected loss measured in SEK/area unit (1 SEK ≈ 0.1 €). Two fictive examples covering the same area are provided here.

One possibility is to present expected economic losses as a raster layer similar to previous examples (Figure 6).

Another possibility is to use iso-cost lines to express the economic loss per meter river (Figure 7).

In the example the expected economic loss for a landslide extending from the river to the first iso-cost line is 1 KSEK per meter river. Maps showing expected life losses are also important output from the analysis.

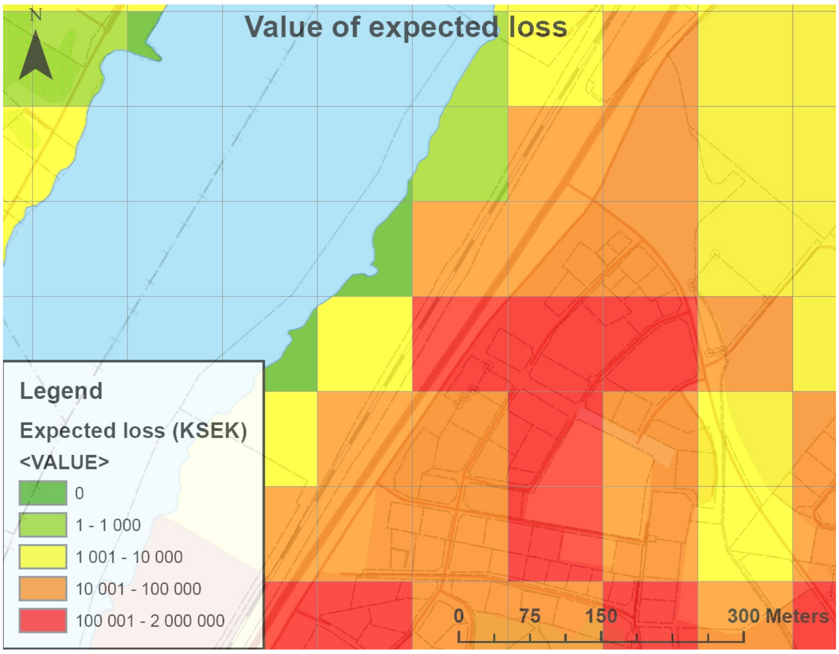

Figure 6. Expected losses visualized as a 100 by 100 meter raster.

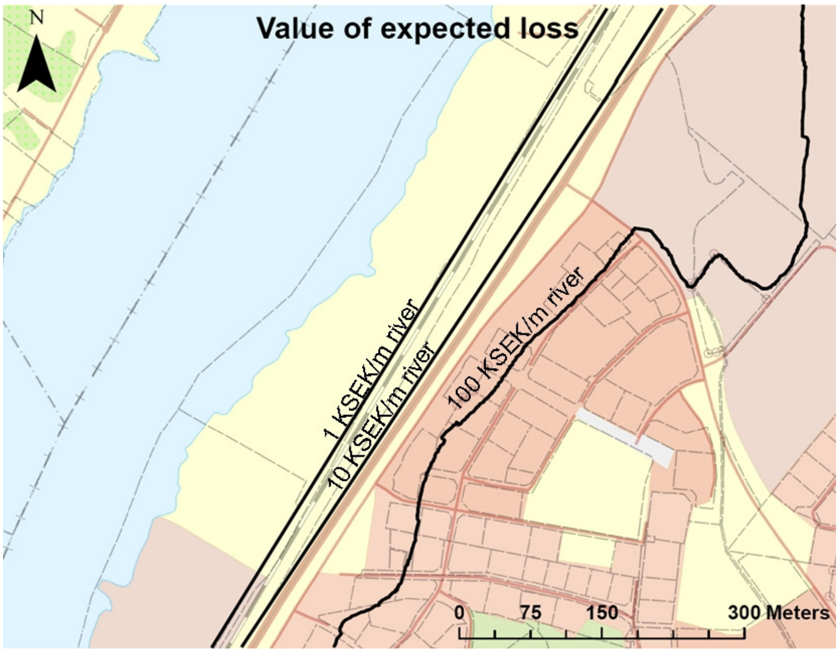

Figure 7. Expected losses expressed as iso-cost lines showing the expected cost of a one meter wide stripe perpendicular to the river extending from the river to each iso-cost line.

7 CONCLUSIONS

The methodology is found to be very useful and to describe consequences of landslides well. It is especially useful for case studies where the potential landslide's borders are known. We believe that the method also can be useful for cost benefit analyses (where and when are invested money most efficient). In such analyses it can be used for example when planning prevention measures for landslides and other natural hazards such as flooding. Using the presented GIS-aided methodology for consequence analysis facilitates updating input data and assures transparency. It is a useful tool when one wants to be able to present total as well as sector-based or category-based consequences, for example industrial activities or human life exposure. This visualization flexibility means that the data and results of the analysis can be useful to a wide spectrum of stakeholders, municipal planners and governmental organizations. It is further a valuable tool offering possibilities for detailing the analysis: seasonal and diurnal (day/night) variations maps etc. When the probability of a natural hazard or accident is known GIS is a strong tool for mapping not only the consequences but also the risks.

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