Impacts of Climate Change on Urban Infrastructure & the Built Environment

A Toolbox

Tool 4.5: Overview of an MCA-Based Decision Tool

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Contents

1. Introduction

1.1 Background

This document gives details one of a number of tools developed to assist Councils, and others, in taking account of long-term climate change effects in their on-going asset development and management, with the broad aim of making urban infrastructure more resilient to climate change effects.

The tool described here [Tool 4.5] is based on the Multi-criteria Analysis (MCA) approach promulgated by the NZ National Asset Management Steering Group in the document "Optimised Decision Making" (NAMS, 2004). The underlying techniques used in formulating the tool described here are widely used in many different contexts. Here, however, the tool has been developed and demonstrated (Oldfield S.G, 2011) specifically for prioritising and planning against increasing rainfall-initiated landslide hazard. The tool could be adapted relatively easily for other applications.

Designing and developing infrastructure to be more resilient to climate change does not require fundamentally different solutions, rather the designs need to take account of the changing frequency and magnitude of these effects.

Detrimental climate-related effects influence design through increased 'loading' requirements, and add to other uncertainties because the rate and magnitude of the changes in climate are not known with certainty. Increased uncertainty means that making the 'correct' design choice in any particular context is more challenging that it would otherwise be.

1.2 Purpose of Tool

The MCA-based tool is specifically designed to allow prioritisation of actions to prevent or mitigate the impact of landslides based on the level of risk they present, taking account of climate change.

1.3 Obtaining this Tool

Contact the author of this report for information about obtaining and using this Tool.

2. Overview of the Decision Tool

The Decision Tool described here is based on a multi-stage Multi-Criteria Assessment (MCA) methodology. Multi-Criteria Analysis is perhaps the most ubiquitous of all formal methods of decision-making. In this tool the MCA methodology is applied firstly to prioritise geographical locations for attention and then again to select the most appropriate means of reducing the risk at the selected location.

The tool is presented and illustrated here for its application to rainfall-induced landslide risk, but the same methodology could be applied, in part or in total, to other hazards. However, the full process as described is likely to be most applicable to location-specific hazards such as landslides, rather than wider area hazards such as flooding.

2.1 Basis of Multi-Criteria Assessment Process

In the MCA process, decisions are guided by rating the alternative solutions to a problem against a set of chosen criteria. In Stage 1 the locations are first prioritised for attention and in Stage 2 the risk reduction ('mitigation' or 'remediation') options are determined for these locations.

The selection criteria are chosen to cover all the factors that distinguish what is 'good' and 'bad' about the solutions. These criteria can include both tangible factors (i.e. a measurable property), and intangible factors (e.g. a property that can only be defined subjectively).

The individual scores for an option are combined in some way (usually a weighted sum) to provide an overall measure of preference for each solution. The contribution that each criterion gives to the sum of scores for an option is weighted to reflect the choice by decision makers on the relative importance of the different criteria.

The scores may be seen as surrogates for measures of value for the criteria, allowing combination of the effects of diverse criteria with different units. The weights represent beliefs about what is important in a particular situation or to a particular group of individuals.

The MCA scoring and weighting process is illustrated in Figure 2.1.

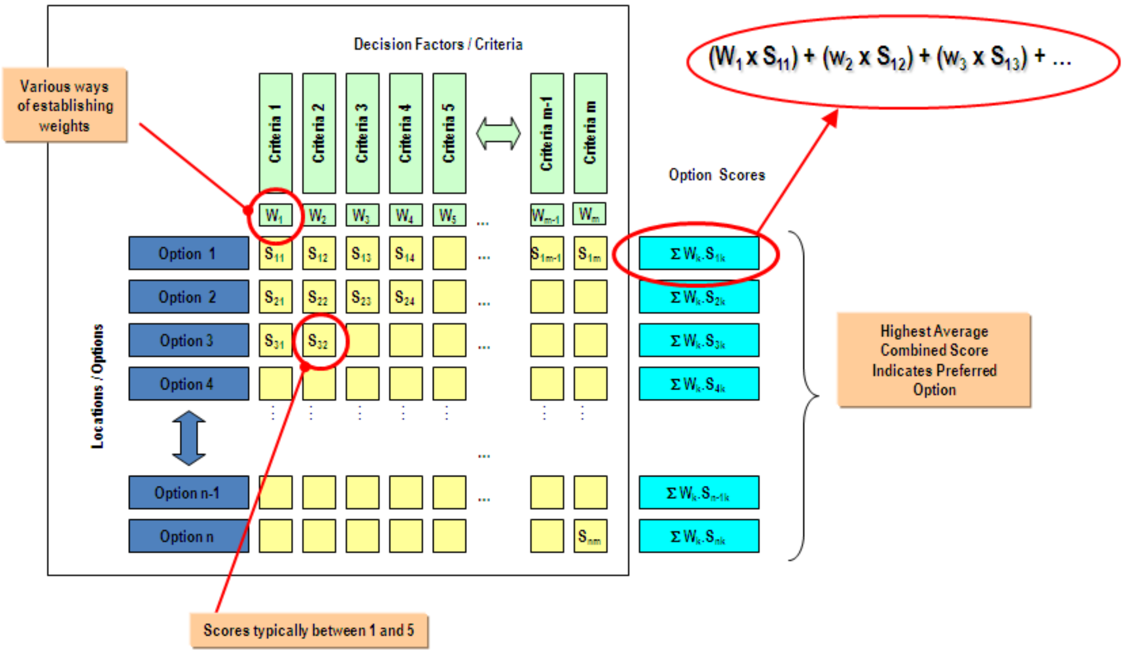

Figure 2.1: Schematic of MCA evaluation process

The MCA Decision Tool applies the basic MCA process, illustrated above, in two stages as shown diagrammatically in Figure 2.2 and described below using the example of rainfall-induced landslides in the Wellington region.

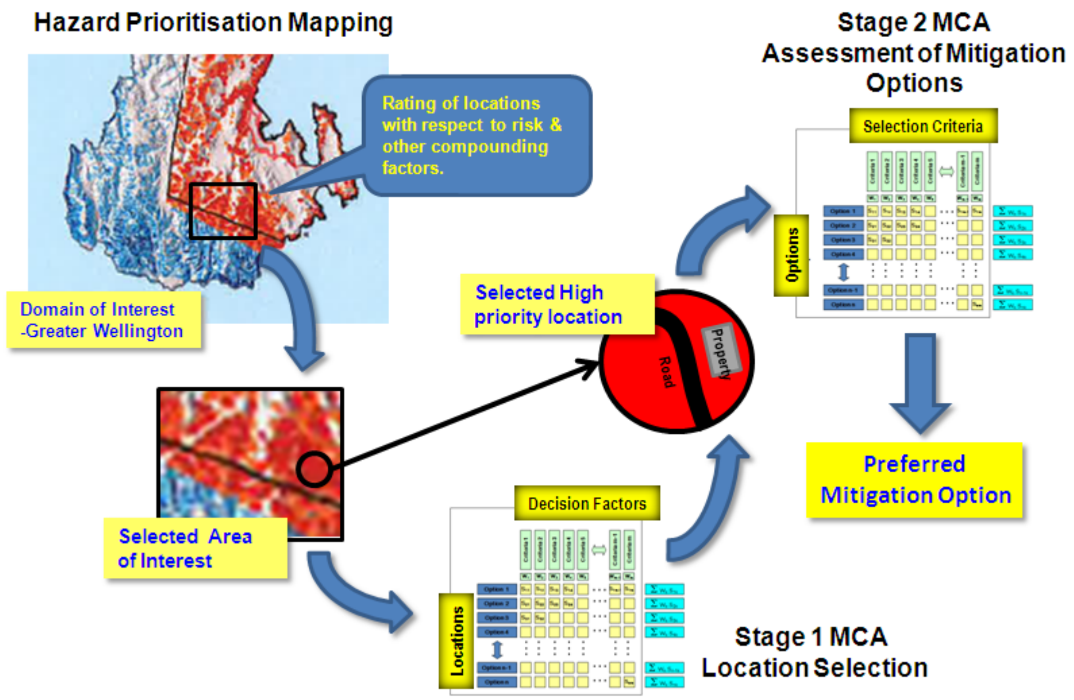

Figure 2.2: Representation of two-stage MCA process

2.2 First Stage MCA – Prioritisation of Locations for Attention

At this stage, the options being assessed are the different locations and the criteria are the factors which determine the level of landslide hazard or risk.

In the first stage of the MCA process, the area of interest (i.e. in this example the Wellington Region) is sub-divided into a mesh of cells (say 10m by 10m). The probability of a landslide is predicted in each cell from the ground slope and severity of the rainfall events, using local historical records as a guide. This information was provided for the Wellington Region by NIWA and GNS for the purposes of demonstrating the tool [see the Tools in Bin 2.3]. The consequences should a landslide occur in any particular location are then predicted, and are dependent on the buildings, services and other infrastructure assets which could be damaged.

Combining the landslide probability with the likely extent of damage on a spatial basis provides a measure of landslide risk from which 'high risk' areas for priority attention can be identified. In practice, generating estimates of the potential damage on a spatial basis is relatively demanding in terms of data and resources. For expediency, therefore, the initial identification of priority areas was undertaken on the basis of the known landslide hazard in the Wellington region. Consequence estimates were then sought only for the priority areas.

The RiskScape package [Tools 3.2 and 3.3] is planned to enable spatial estimates of landslide risk to be mapped more easily. However, this capability was not available at the time of writing and the methods described here provide a less data-intensive alternative.

The Wellington Region, used to illustrate this Tool, is comparatively large so the area prioritisation process was completed in two steps. Initially, a larger area of 500m by 500m was used to rank the hazard likelihood of each grid cell and so identify areas of high landslide hazard. The landslide risk (a combination of the hazard likelihood and damage caused) was then evaluated in these high hazard areas using the finer 10m by 10m grid. The cells were ranked according to the level of risk, with the objective of prioritising locations for adaptation in the second stage of MCA, as described below.

2.3 Second Stage MCA – Identification of Preferred Mitigation Measures

The second stage of MCA is applied to the priority high risk locations (identified in the first stage) and used to identify risk reduction ('mitigation' or 'adaptation') measures that are appropriate to the high risk location, eventually identifying a preferred option.

The options in the MCA at this second stage are the alternative mitigation methods for reducing landslide risk. The criteria are the issues that need to be considered in identifying the best remedial option given the local circumstances.

There are numerous ways of reducing landslide risk and so, once again, the Tool allows the user to select appropriate solutions in two steps. The first step involves screening the widest possible range of solutions, eliminating those that are either not viable or are ineffective for the location. The remaining short-listed potential solutions are then assessed using the classical MCA process as described above.

A separate Toolbox Option Screening Tool [see Tool 4.2] has been developed for the first stage of short-listing viable adaptation options. This Tool contains a long list of different generic types of actions that could be taken to reduce landslide risk. These are rated in the MCA Decision Tool for their relevance to some key context-specific factors, such as the slope of the ground and the surface rock type (in the case of landslide risk). Given knowledge of these characteristics for the location of interest, the adaptation options that are most relevant for the location can be identified. The screening tool provides facilities for the user to define new or hybrid options based on modifications to or combinations of other options.

The Option Screening Tool [Tool 4.2] is designed to provide a justifiable record of the choices made. It is intended to be used either by a single user or in an interactive workshop environment. It provides a simple basis for reducing the options to a manageable number for more detailed treatment using the MCA process. As with all assessment methods based on subjective judgement, it should only be used as a guide in the decisions to be made.

The shortlist of viable options generated by Tool 4.2 may then be developed in more detail in MCA Decision Tool by allowing a more in-depth comparison and rating of options using the MCA process, as illustrated in Figure 2.2.

2.4 Data Needs

The basic data needs for the MCA-Based Decision Tool methodology to be applied to the management of rainfall-induced landslide hazard are as follows:

a) Current rainfall and future predicted rainfall taking account of climate change. It is also important to factor in the antecedent conditions as landslides tend to occur when the ground has a high moisture content [see Tool 2.3.2]; and

b) Ground slope, land-use and vegetation cover; this information is likely to be readily available to a Council in GIS form.

Information (a) and (b) are used to predict the annual probability (likelihood) that a landslide might be expected to occur at any particular location. In the current example, predictions are based on past records of landslides that impacted the Wellington road network, as provided by Wellington City Council, and landslides that impacted properties provided by EQC [see Tool 2.3.2]. At the time of writing this Tool the EQC data was not available.

Predicting the impact of a landslide requires location-specific information on what could be damaged if a landslide occurs. In an urban setting a relatively high level of detail is required [see Tool 2.3.2, for example].

The choice of cell size used to map spatial data will depend on the extent of the area under consideration and the resolution of available detail. A base cell of 10m by 10m is convenient, if this level of detail can be justified, as at this scale the road carriageways and individual houses can be readily resolved on a map. If the region or area of interest is large, or the level of available detail is poor, then a larger cell size may be used initially to assist prioritising smaller areas for more detailed analysis, as in the current example for Wellington.

For smaller areas of high landslide hazard, typically say 4 hectares in size, the following additional localised information needs to be collected in order to estimate the likely impact of a landslide:

c) Buildings and infrastructure, roads, utility services etc. that could be exposed to landslide hazard; this information is often held by Councils and/or emergency management agencies;

d) Localised landslide hazard-enhancing factors, e.g. areas of recent vegetation clearance, the presence of surface water flows, evidence of slope movement or other ground instability etc.; and

e) Presence of existing slope stabilisation and risk reduction measures, e.g. benching of slopes, rock-bolts or shotcrete etc.

Asset information in (c) above is used in the MCA Decision Tool to determine the likely impact of a landslide at any particular location. Information from (d) and (e) are used to update base hazard and consequence information for local factors that enhance or reduce landslide risk.

Information required in (c) and (d) above can be obtained by performing a 'ground-truthing' survey of the chosen area. Such a survey can be conducted by driving along the roads and recording relevant information. A video recording of routes can be very effective as a means of checking and geo-referencing captured information after a landslide event.

The information listed in (a) to (e) above is best incorporated within a GIS for ease of analysis. NIWA and GNS are in the process of developing RiskScape [see Tools 3.2 and 3.3] for the prediction of rainfall-induced landslide risk from this type of information. As this capability is still under development, the spreadsheet approach described in this Tool (see Section 3 below) provides a simplified alternative.

2.5 Outputs Generated to Aid Decision-Making

Figure 2.3 (left hand side) shows a digitised map of the Wellington region, colour-coded according to the predicted landslide hazard (for a specific range of severity rainfall events).

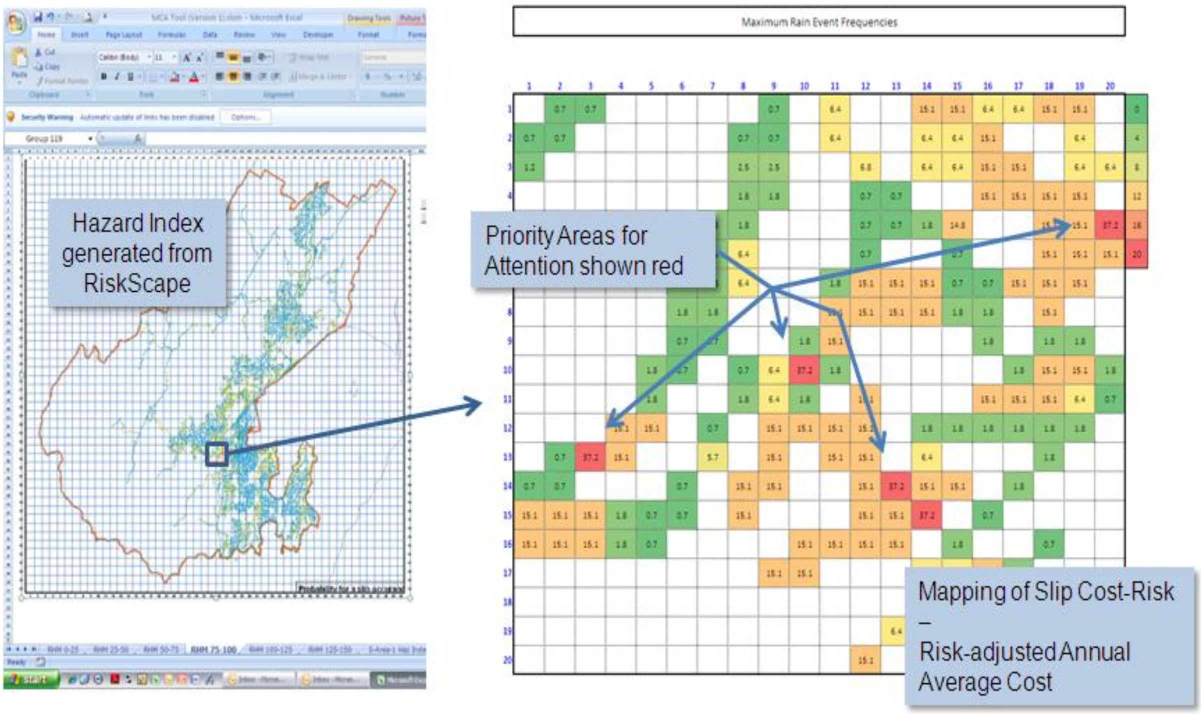

Figure 2.3: Illustration of landslide risk mapping output

On the right hand side of Figure 2.3 is an enlargement of a small area of Wellington showing the localised landslide risk. The red squares indicate where the risk is highest. These are the priority locations for remedial action identified in Stage 1 (see Figure 2.2).

Having identified the high risk locations, a preferred set of risk reduction measures is identified through a systematic consideration of alternatives (Stage 2 in Figure 2.2). The preferred solution from the shortlisted candidates is the one with the highest score for the chosen assessment criteria. This is illustrated in Figure 2.4.

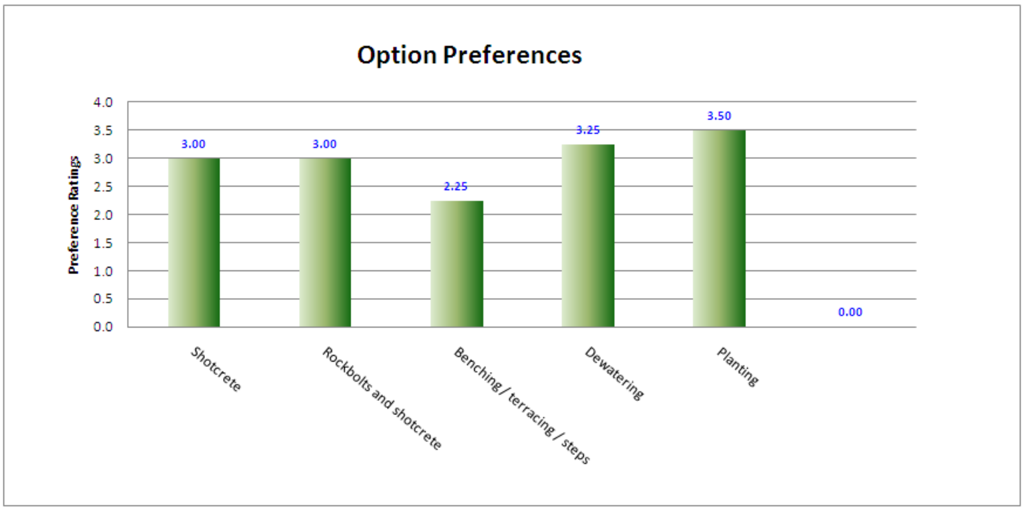

Figure 2.4: Illustration of preference amongst alternative solutions

In the above illustration, “Planting” has scored highest overall rating and therefore is preferred over the other four options. In reality, other measures may well be combined with planting to give the best possible solution. These hybrid solutions can themselves be assessed in the same way.

2.6 Assumptions and Limitations

The overriding assumption in applying the MCA Decision Tool in the context of landslides is that it is reasonable to establish priorities for the management of landslide hazard on the basis of risk using past history as a guide. Other key assumptions implicit in applying the MCA-based Decision Tool are as follows:

a) Landslide hazard likelihood can be predicted using empirical relationships based principally on rainfall (taking account of antecedent conditions and climate change effects) and terrain slope [see Tool 2.3.3];

b) The level of impact resulting from landslides can be consistently derived from expert judgement based on limited knowledge of the location-specific vulnerabilities and guided by suitably couched guidance; and

c) The effectiveness of different landslide remedial actions can be quantified to the degree that a preferred solution can be identified for a specific location using expert opinion.

One of the major advantages of the MCA methodology is its ability to be applied at different levels of detail. This means that the technique can be adapted to suit the level of information available. However, one of the method's main weaknesses is the lack of explicit treatment of uncertainty. These uncertainties arise because:

- Landslide hazard and risk is predicted from empirical relationships based on limited data and a relatively small number of indicator factors [see Tool 2.3.3]; and
- The effect of the indicator factors cannot be measured nor easily determined from fundamental science; instead, reliance is placed on subjective judgement by experts.

Because priorities are set through the ranking (comparison) of options on a common basis, the effect of these uncertainties can be managed by ensuring a consistent treatment throughout. Thus applying some rigour in the MCA methodology is important in achieving robust solutions.

3. How to Apply the MCA-based Decision Tool

The application and use of the MCA Decision Tool is illustrated using a case study performed on the Wellington urban region (Oldfield, 2011). The presentations and descriptions given in this case study offer insight into the application of the tool for a relatively large urban area.

Where small areas are of interest, the process described here can be simplified e.g. by applying the location prioritisation MCA in a single step and using a less formal screening of remedial options.

3.1 Application Framework

The overall process used in applying the MCA Decision Tool is shown in Figure 3.1 and illustrated below with images and screenshots of the Tool (see Appendix A) from the Wellington case study (Oldfield, 2011).

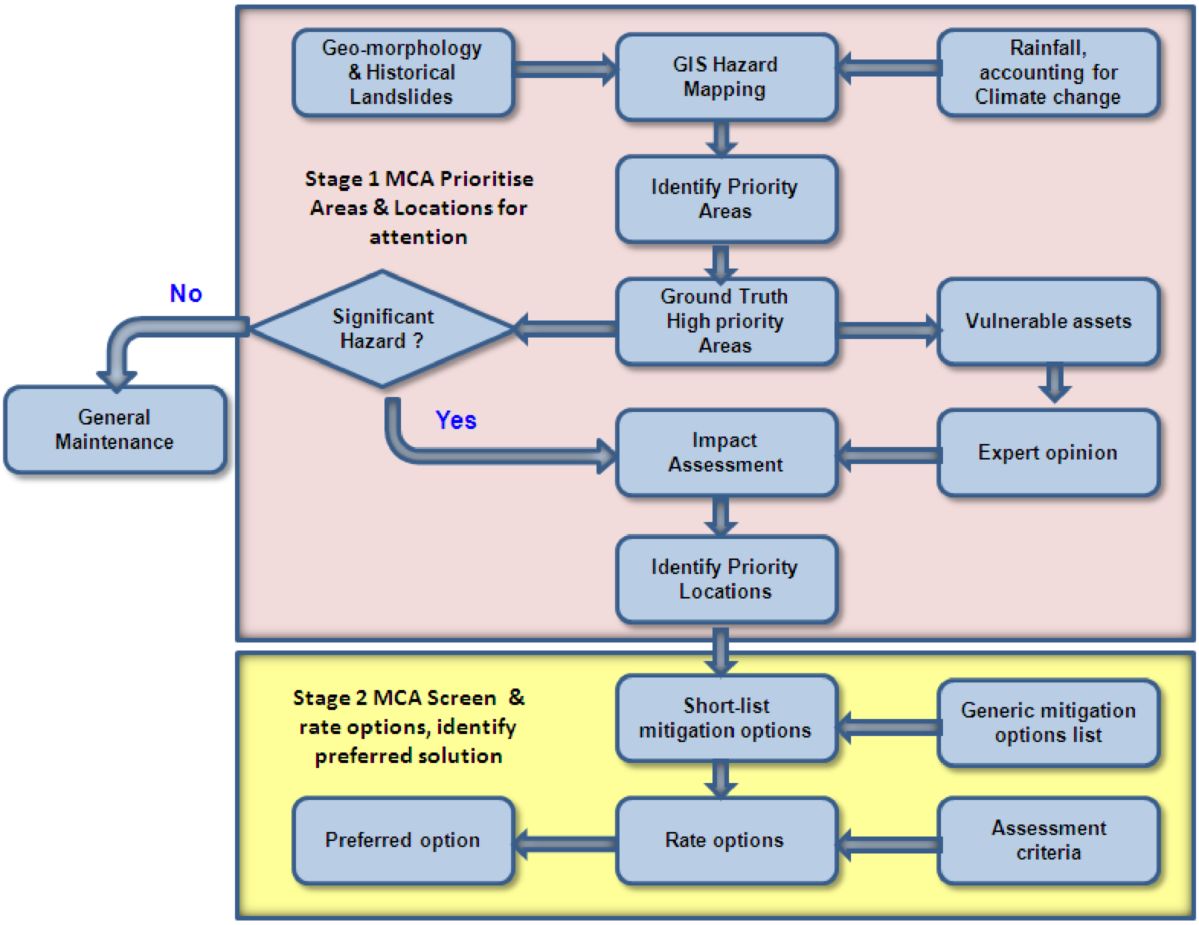

Figure 3.1: Generalised MCA Decision Tool framework

3.2 Tool Structure and Content

Figure 3.2 shows one of a series of landslide hazard maps of the Wellington Region, generated for a number of different ranges of rainfall events (Table 3.1).

Table 3.1: Defined rainfall event ranges used in the Wellington case study

0 to 25 mm/day	25 to 50 mm/day	50 to 75mm/day
75 to 100 mm/day	100 to 125 mm/day*	125 150 mm/day

* See Figure 3.1 for the relevant landslide hazard map

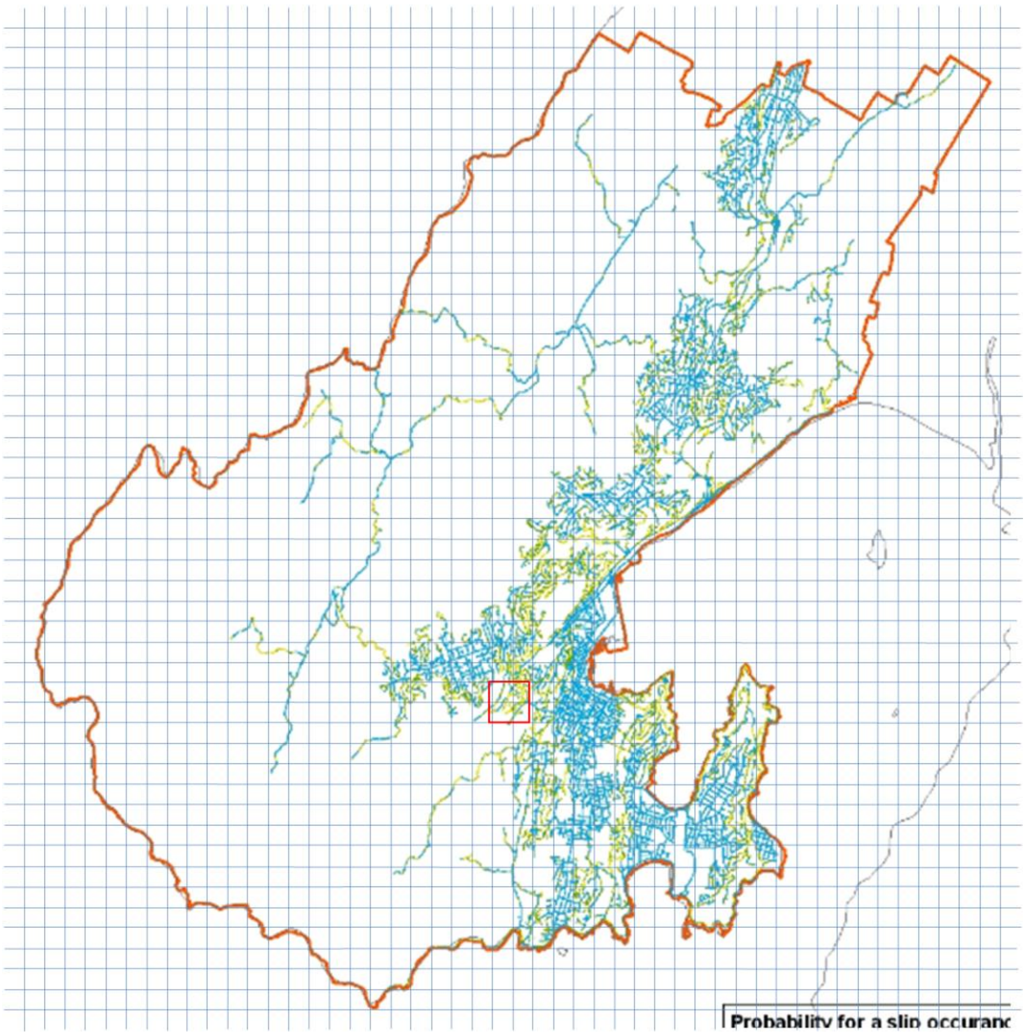

Figure 3.2: Example landslide hazard map of Wellington (rainfall event 100 to 125 mm/yr)

The hazard map gives the probability that a landslide (of any size) will occur within a particular area of known slope, given an assumed rainfall event. Analysis of the Wellington landslide data shows no particular correlation between slip size and the severity of the rainfall event. Rather, the number of slips in an area increases with increasing rainfall. The overall hazard is a combination of this landslide probability and the probability that the chosen rainfall event occurs [see Tools 2.3.3 and 2.3.4].

The spreadsheet-based MCA Decision tool contains a sequence of worksheets. Table 3.2 provides a description of each worksheet. Examples of screenshots from the Tool are given in Appendix A.

Table 3.2: Description of worksheets within the MCA Decision-Making Tool

Worksheet(s)	Description
Rainfall Hazard Maps (RHM) in mm/day *(One for each of the six rainfall ranges)*	A set of six worksheets, one for each of the six rainfall event ranges defined above (Table 3.1), containing landslide probability data supplied by GNS and downloaded from a GIS for the Wellington Study. Currently, hazard maps have only been generated using WCC historical landslide road clearance records. Mappings of the landslide hazard to buildings, using EQC claims records, are to be added later. Hazard maps provided by GNS were generated on a mesh grid of 10m by 10m cells but aggregated on to a coarser grid of 500m by 500m cells (see for example Figure A1, Appendix A), before being imported into the MCA Spreadsheet Tool for the purposes of identifying areas of high landslide hazard. The mapped data is listed to the right of the mapping on each of the six worksheets.
RHM Summary	The tabulated data from each of the six RHM worksheets are listed together on this worksheet. The rank scores for each column of event probabilities are also tabulated. The rank scores may be sorted to allow areas with a high hazard to be identified for priority attention. Cells that rank highly across all rainfall event ranges have the greatest priority. The selected high priority areas are then explored in more detail on subsequent worksheets.
Selected Area Hazard (Correction) Map *(One for each selected area)*	This worksheet is provided for the user to make local corrections or refinements to the event probability data imported from GIS. The worksheet contains three rows of map enlargements of the selected high hazard priority area of interest – one map enlargement for each of the six rainfall event ranges (see Figure A2, Appendix A). The first row of maps are generated by re-importing the landslide probability data from the GIS on the original 10m by 10m mesh grid cell size for the selected high hazard area only. The second row of maps of the same selected area is for the user to make corrections to the event probabilities in appropriate cells to account for known errors or omissions in the imported hazard mapping data, e.g. to account for existing slope stabilisation measures. The corrected hazard maps in the third row are generated from the maps above.
Ground Truthing Record (*One completed for each selected area)*	This worksheet is used to maintain a record of information recorded during a 'ground truthing' survey of the selected area of interest. The survey information is used to update the landslide probability data for local landslide hazard-enhancing features and for existing landslide remediation works (see the Enhancing and Mitigating Factor worksheets below). The survey can also be used to inform and locally refine the subjective assessment of landslide impacts on roads, buildings and infrastructure.

Worksheet(s)	Description
Selected Area (Consequence) Enhancing Factors *(One completed for each selected area)*	Copies of the selected area enlargement maps are provided on this worksheet for the user to enter modifying factors to account for increased or reduced levels of damage, above or below the 'typical average' level for a particular land-use type. A 'typical average' level of impact is computed for each land-use type and applied according to the cell's land-use type designation. Impacts may be higher than average if, for example, a particularly vulnerable or expensive asset is at risk. Impacts may be lower than average if assets are not vulnerable to landslides or of low value. A separate map is used for each distinct enhancement factor. A consolidated map is used to combine the different factors into a single modifying factor for each mesh cell (see Figure A2, Appendix A).
Selected Area (Consequence) Mitigating Factors *(One completed for each selected area)*	Copies of the selected area enlargement maps are provided on this worksheet for the user to enter modifying factors to account for reduced landslide impact owing to localised factors which reduce risk (e.g. existing slope stabilisation measures) or for other reasons that decrease the priority for remedial action to be taken (e.g. slips are known to be small and/or the damage inconsequential). A separate map is used for each distinct mitigation factor. One consolidated map is used to combine the different factors into a single modifying factor for each cell (see Figure A2, Appendix A).
Risk Evaluation *(One completed for each selected area)*	The components of landslide risk (likelihood and consequence) developed on the Selected Area worksheets above are brought together to predict the risk in each cell of the mesh grid covering the selected area (see Figure A3, Appendix A). These risk estimates may be ranked to prioritise high risk locations for possible remedial works.
Risk Mapping *(One completed for each selected area)*	This worksheet (Figure A4, Appendix A) is used to provide mappings of the landslide risk generated on the Risk Evaluation sheet. The MCA process does not include an explicit treatment of uncertainty so an implicit treatment is added in the presentation. The level of uncertainty needs to be defined by the user.
Screen Options *(One completed for each selected area)*	An interactive tool [see Tool 4.2 – Option Screening] is provided on this worksheet for shortlisting the potentially most effective landslide risk reduction measures from a long list of generic methods. Measures are shortlisted based on their relevance to a few predefined local characteristics (see Figure A5, Appendix A). This worksheet is designed for individual use or in a brainstorming workshop. The shortlisted measures are then passed to the MCA worksheet for final selection of a preferred solution.

Worksheet(s)	Description
MCA Options Assessment *(One completed for each selected area)*	This worksheet contains a MCA options assessment matrix (Figure A6, Appendix A). The options in this matrix are listed down the left-hand side of the matrix. These are shortlisted remedial measures identified on the Screen Options sheet. The assessment criteria are listed across the top of the options assessment matrix. A standardised set of criteria is provided, however, these can be modified to suit specific needs.
Lookup Tables	This worksheet contains the various lookup tables used in the hazard and risk evaluations on the various worksheets. These are intended to be generic and standardised factors which may require some customisation for different regional context.

3.3 Illustrative Examples

The MCA methodology described in this Tool is demonstrated in the Wellington Landslide Case Study (Oldfield, 2011).

The case study illustrates:

- How priority landslide-prone areas for investigation and possible treatment can be established on the basis of risk;
- How different risk reduction options can be identified;
- Shortlisting the most relevant options for consideration; and
- Identifying a preferred solution.

4. References

AS/NZS ISO 31000:2009, Risk Management – Principles and Guidelines, Standards New Zealand, Wellington.

NAMS (2004) Optimised Decision Making Guidelines – A Sustainable Approach to Managing Infrastructure, NZ National Asset Management Steering Group Version 1.0.

Oldfield S.G. (2011) Toolbox Case Study – Wellington Landslide Hazard, MWH Report No Z1823604.

O'Hagan A, Buck C.E, Daneshkhah A, Eiser J.R, Garthwaite P.H, Jenkinson D.J, Oakley J.E and Rakow T. (2006) Uncertain Judgements - Eliciting Experts' Probabilities, John Wiley & Sons Ltd., London.

Appendix A: Example Screenshots from the MCA Decision Tool

The following are annotated computer screenshots of an illustrative application of the MCA-based Decision Tool to the assessment of rainfall-induced landslide risk in the Wellington region.

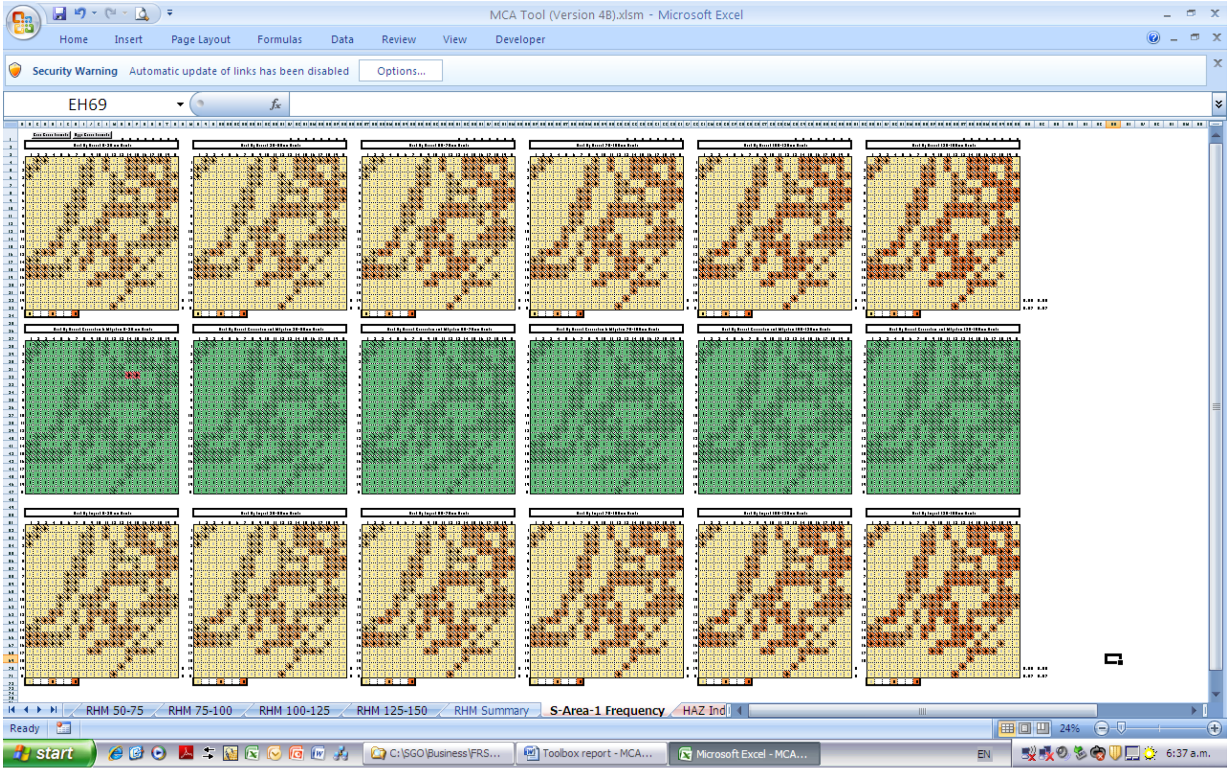

Figure A1: Selected area hazard maps

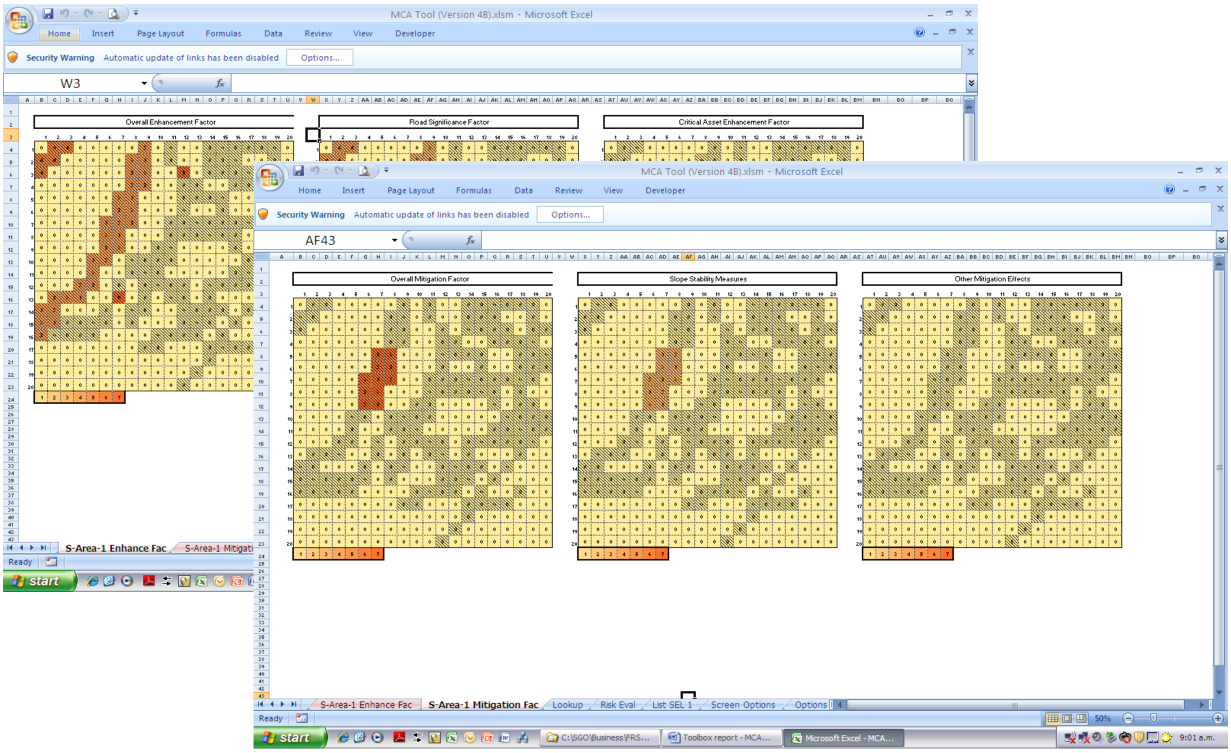

Figure A2: Enhancement and mitigation adjustments

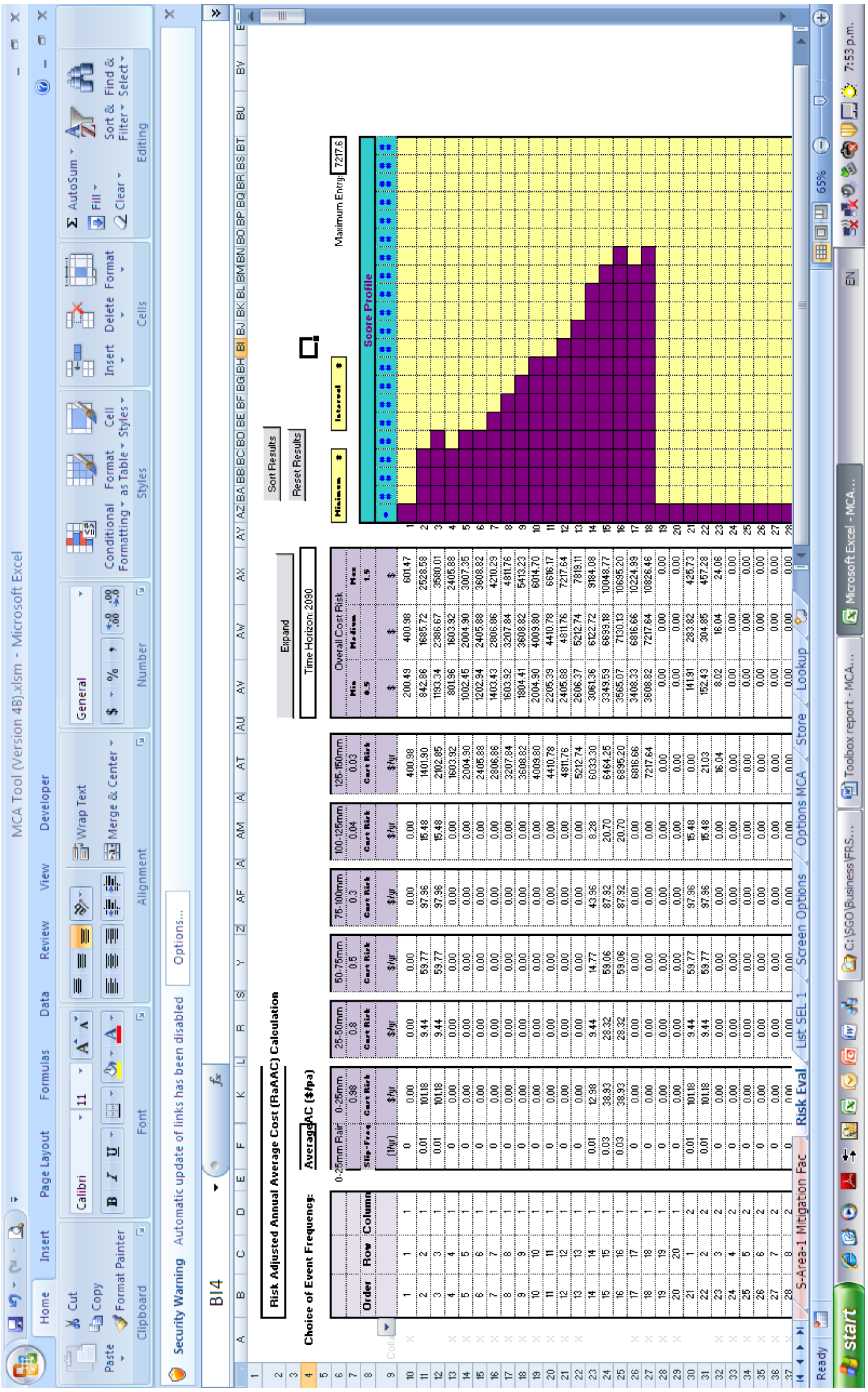

Figure A3: Risk evaluation worksheet

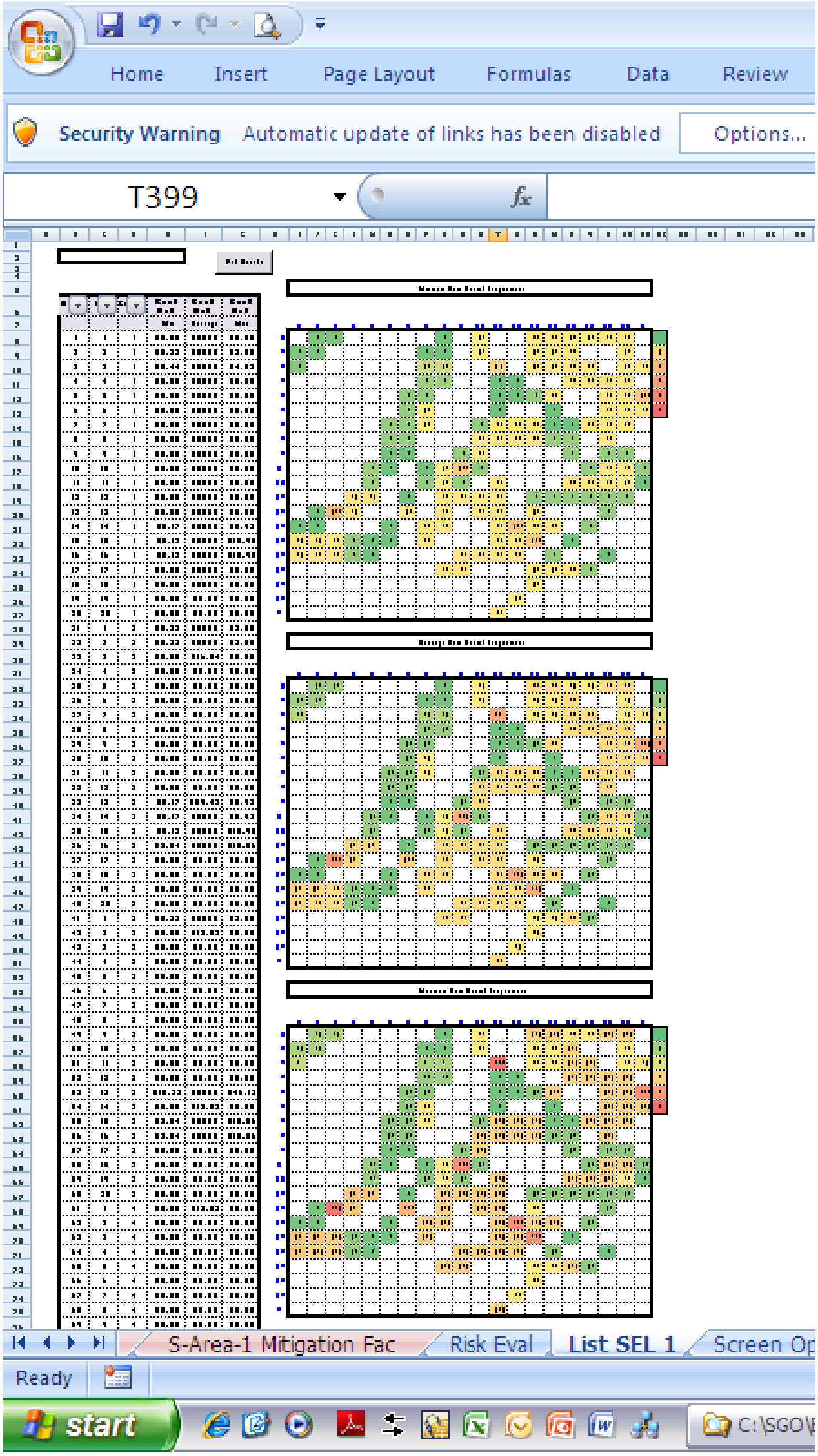

Figure A4: Landslide risk plots

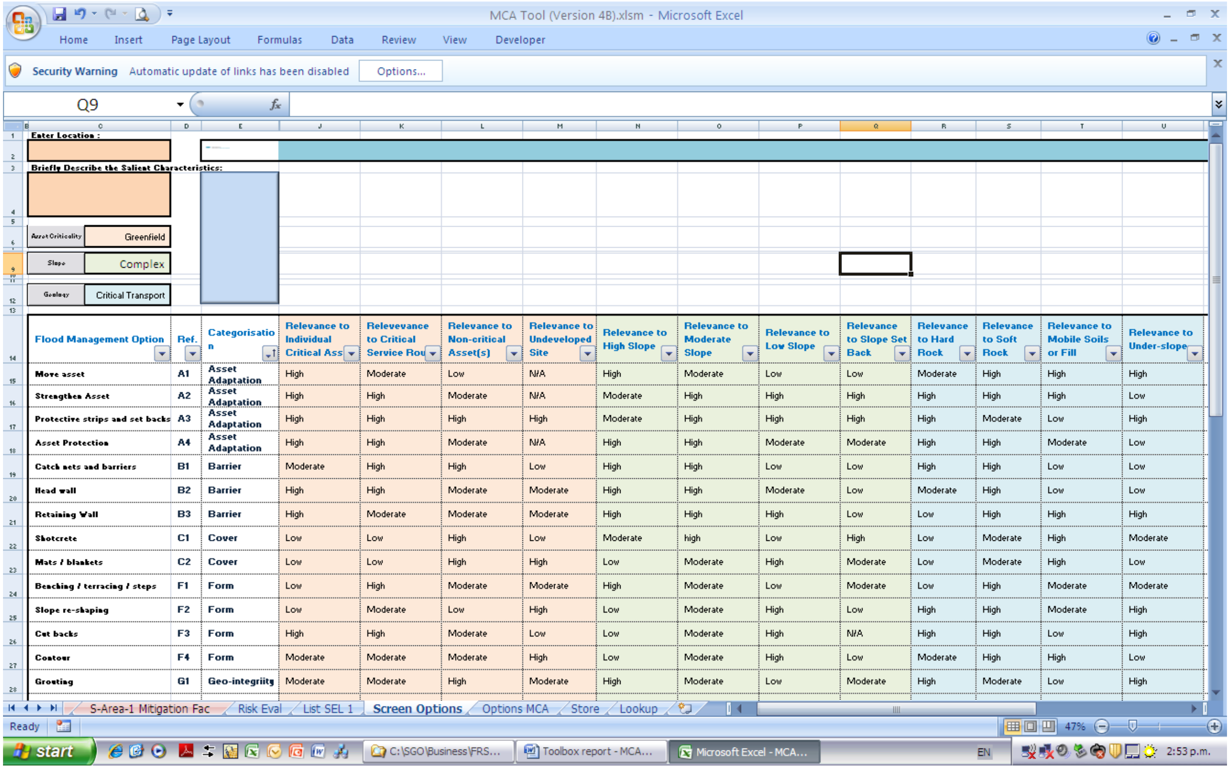

Figure A5: Tool for screening options

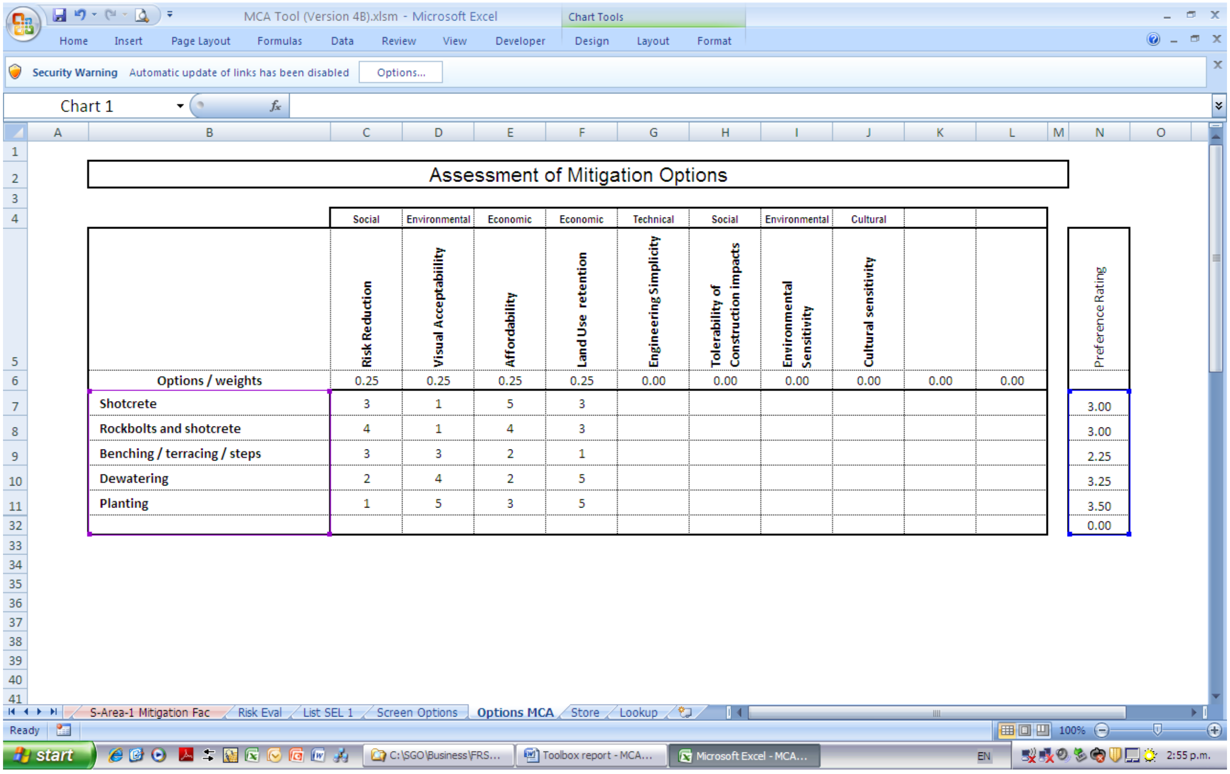

Figure A6: MCA options assessment matrix