A predictive GIS methodology for mapping potential mining induced rock falls

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Chapter 6

Summary and Conclusions
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6.1 Summary

Developing pre-mining methodologies for assessing mine subsidence impact on cliff lines is vital for all underground coal mines and must be included in the SMP processes. Improving the ability to assess the potential impact and the evaluation of alternative mine plans and orientations, prior to mining, undoubtedly can be valuable for SMP approval and any decision-making process carried out during mining activities. The primary objective of this thesis is to provide a quantitative GIS based methodology for the mapping of potential mine subsidence impacts on cliff lines. The thesis presents a GIS based methodology with the following characteristics:

- A data driven technique for impact assessment during the preliminary stages of mine design when the field data is limited.
- Identification of pertinent controlling factors in rock fall occurrence phenomena.
- The analysis of the level of influence for each controlling factor, weighting and combining evidential factors using the weights-of-evidence method.
- The mapping of the probability of a rock fall occurrence within the area of interest.
- Using GIS capability to generate visual interactive formats including maps, photos, graphs and tables.
The proposed methodology was developed using the weights-of-evidence method within the GIS to derive a probabilistic model of rock fall potential associated with mining induced subsidence. The weights-of-evidence method employs the Bayesian approach to combine different datasets.

The Appin area in the Southern Coalfield of NSW was used as a case study and two models were created based on different mine layouts for the proposed Douglas Park mine area. In the first configuration, longwall panels were planned to extend beneath the steep sided areas of the nearby Nepean River, and a second configuration in which the mine layout was modified so that mining does not occur directly beneath or within 50 m of the steep slopes. This approach allows for the comparison of rock fall potential based on different mining configurations.

The studies commenced with the identification of the geometry of the problem, its objectives, available models, available data, and the model limitations. Selecting reasonable evidential themes was the next step. Then the GIS based data inventory with the evidential factors (slope, cliff height, plan and profile curvature, slope aspects, structural geology, distance from watercourse and distance from mine workings) was developed. This step included data editing, manipulation and formatting.

During the primary weighting step, two weights ($W^+$ and $W^-$) were calculated for each of the respective evidential themes to quantify the spatial association between the training points and the evidential themes. The value of $W^+$ indicates the level of the positive correlation between the training points and the pattern of the evidential
theme. Conversely, $W^-$ defines the level of negative correlation. The Contrast ($C=W^+ - W^-$) represents an overall measure of spatial association between the training points and the evidential theme, thus combining the effects of the two weights.

Each theme was further reclassified based on detectable cut-offs to provide a final theme in binary or ternary formats. Fault and dyke themes were ignored due to poor data quality. The classified themes were weighted again to provide the final weights for each theme. The weighted themes were combined to provide response themes, representing the probability of the occurrence of rock falls within the area of study.

6.2 Conclusion

One of the most significant benefits associated with the GIS based weights-of-evidence method is the role it can play in mine configuration and the development of subsidence management plans. The ease with which alternate models can be produced, for example in which the location of the longwall panels have been modified but other factors are constant, demonstrates the capabilities of both GIS and probabilistic modeling for mine layout evaluation. The results shown here indicate that rock fall potential along the cliffs of the Nepean River is greatly reduced if mining does not extend directly beneath the cliff areas.

The probabilities for rock falls in the cliff sections nearest to the alternate mine layout are similar to those of cliff sections that are quite distant from any workings. This suggests that rock fall susceptibility associated with the New Douglas Park mine layout will be similar to background levels. Ideally, a detailed survey of historic
natural rock falls in the area could be undertaken to quantify the actual background ‘natural’ rock fall potential in the region.

The GIS based weights-of-evidence approach is particularly flexible when compared to other modeling approaches (for example, knowledge-driven approaches) because it is possible to construct a model with limited predictors. For instance, in the case study a small portion of the factors relevant to mining-induced rock falls was considered. Nevertheless, despite the incomplete understanding of the physical mechanisms involved, and the inability to quantify spatially all of the pertinent factors, the method offers an empirical prediction of relative susceptibility to mining-induced subsidence along the cliffs of the Nepean River.

6.3 Limitations of the methodology

There are significant limitations, however, with the results and the application of the weights-of-evidence method to rock fall potential modelling in general. These limitations are associated with:

- the availability of data for evidential themes,
- the quality and nature of the training point data concerning recent and historic rock fall events, and
- the lack of field verification and model validation.

The reliability of the model results could be greatly improved with the inclusion of additional evidential themes such as the degree of weathering, jointing, or undercutting, or the presence of loose blocks or geological features such as faults and
dykes. These themes, and more, are known to be highly relevant to cliff susceptibility in relation to subsidence in this area (Waddington Kay and Associates, 2002). However, many of these parameters are, at best, difficult to quantify and record spatially. For instance, the extensive fieldwork that would be required in order to map the presence and magnitude of jointing or weathering, in both the source area (within which the training points are located) and the region for which the predictions are to be made, would make the application of a rapid GIS based model redundant. The results, therefore, should be interpreted as a relative guide for rock fall potential, and field observations of local cliff properties and the occurrence of mining-induced fractures are required for a more accurate measure of overall susceptibility. In particular, it is assumed that the model will generally underestimate rock fall potential if measures of intrinsic cliff instability, which include the aforementioned factors, are not included.

Another limitation associated with the evidential themes, in particular the DEM, relates to the timing of the events. The one metre DEM used in these analyses was derived after the rock fall events. The values of the evidential themes (slope, cliff height, distances to workings and watercourses) at each training point site will therefore reflect the post-rock fall surface and may therefore not accurately reflect the surface conditions associated with susceptible areas prior to rock falls. Considerable inaccuracies in the original training point data, (eg. the recorded rock fall locations) limit the usefulness and precision of the model results. The greatest inaccuracy relates to the representation of the rock fall locations; in this instance, each rock fall is mapped as a single point, and therefore only occupies one cell (1 m$^2$) in the model.
This may under represent the true distribution and extent of rock fall activity, and consequently led to the underestimation of probabilities. Extensive fieldwork and/or careful air photo interpretation would be required to accurately map the extent of the original cliff line involved in each rock fall. Although not feasible in this instance, this enhancement could be readily incorporated into similar studies at other locations.

The accuracy associated with the spatial location of each training point is also prone to error, due mainly to the limitations of non-differential GPS based mapping. These spatial inaccuracies, along with spatial errors that are intrinsic to the DEM, introduce an unquantified element of uncertainty to the results which is heightened by the limited sample size for training points. This element of uncertainty is increased by the use of evidential themes that are highly spatially variable, such as slope and cliff height. Even a small positional error in the training point location can lead to a large misrepresentation of source values for slope and cliff height, whereas other evidential themes like distance to river or distance to workings, which do not exhibit strong spatial variability, are less sensitive to positional errors.

Without field verification the case study results cannot be validated. The relatively small number of training points used in these analyses does not allow for the partitioning of the original dataset into training and validation points. This indicates that the factors used in the model are not sufficient to fully quantify rock fall potential, and it is very likely that highly site specific, local parameters that can only be measured from field observations, such as weathering and undercutting, are crucial factors.
Overall, the GIS based weight-of-evidence model presented in this thesis should therefore be seen as a preliminary step in evaluating alternative mine layouts but an important early step in the mine planning process. Because of its ease of application, the method is suitable for trialing different layouts where suitable training point data are available. Numerous intrinsic uncertainties, however, limit the reliability of the weight-of-evidence method when used to predict rock falls; comprehensive field studies and modeling are recommended for more robust impact prediction and assessment.

### 6.4 Recommendations for future study

The GIS based weight-of-evidence method presented in the case study demonstrates how the potential impacts of different mine layouts on surface features can be accessed, especially in situations where limited spatial data is available.

Some form of field mapping and observations will be necessary to validate the model result. Also, additional data can be collected and used for future studies using the techniques; these data can be collected during subsequent mining activities. Using sufficient data allows division of the original dataset into training and validation points. Other future studies must includes:

- Optimum selection of unit cell size for available training points in a given area.
- Development of pre-processing procedure for detection outliers and evidential themes.