Risk assessment models for post-mining land use

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ABSTRACT

Open-cut coal-mining has been conducted in the Bowen Basin region of central Queensland for almost five decades, disturbing 95,600 ha of agricultural land by 2006. Approximately one third of the area disturbed by mining has been rehabilitated to pastures or bushland. However, none of the rehabilitated land has yet been assigned a specific end-use. This research project develops an approach for assessing end-use risks for the region's mined land, and develops risk assessment models for selected end-uses.

First, a web-based survey of stakeholders was used to identify risks to be assessed. The risks identified were surface erosion, sub-surface erosion, bushfires, weeds and feral animals. The survey also identified possible end-uses of bushland and grazing. Second, conceptual risk models were developed based on the risk assessment concepts of likelihood and consequence specified in the Australian and New Zealand risk assessment standards. Likelihood was modelled using site characteristics and management factors that influence the occurrence probability of risks (e.g. surface erosion), while consequence was modelled using a set of site condition indicators and condition thresholds (changes in root-zone water-holding capacity, soil erodibility, vegetation ground cover, soil organic matter, and transition probability to a non-preferred ecosystem type).

The factors influencing likelihood and consequence for each risk have been integrated using Bayesian networks. The next step in model development will be to parameterise the Bayesian networks using existing equations, empirical data-sets, or expert opinion where data are not available. The parameterised models will be used to assess grazing and bushland end-uses against erosion, bushfire, weed and feral animal risks for rehabilitated mined land sites, with the purpose of identifying the relative risks associated with each end-use and the land management scenarios under which risks can be minimised.

1. INTRODUCTION

Mining is a temporary land use, ceasing when the economically-extractable resource is exhausted. Today's society demands that the environmental consequences of mining are also temporary. Society's concern for the environment is evident in the existence of legislation requiring mining companies to protect the environment during mining and to restore the post-mining environment to an acceptable status. Mining companies also have an eye to their 'social licence to operate', declaring their environmental credentials in terms such as 'minimal impact', 'sustainability', and 'restoration of the prior ecosystem'. While many environmental considerations refer to the operational phase of the mine's life, the ultimate questions of sustainability relate to the environmental legacy of the mining activity. Can the land be used for its prior use after the mine has closed? If not, what alternate uses are appropriate?

Choice of post-mining land use is driven firstly by government legislation. In the decades since the first United Nations Conference on the Human Environment in 1972, there has been a marked shift in public opinion demanding environmental responsibility across a range of human activities including mining (Bell 1996; Bradfield *et al*. 1996; EPA 2006; Hannan and Bell 1993). This has resulted in a tightening of government controls. Developed countries have led this change, with government regulation of areas such as mine safety, prevention of toxic spills, and agreed mined land rehabilitation processes. Legislation typically requires rehabilitation of mined land to a condition that will minimise any negative social, economic and environmental consequences and to sustain an agreed end use. However, the nature, depth and strength of regulations and the ability to enforce environmental obligations varies between jurisdictions (Brereton 2002).

In Queensland, Australia, the government stipulates that the four broad goals of rehabilitation are to return mined land to a condition that is: safe, stable, has no adverse off-site impacts, and sustainably supports a beneficial end use acceptable to stakeholders (EPA 2006). Consequences of non-compliance include retention of security deposits and reduction of company credibility in relation to further applications to mine. The Queensland regulator also encourages certification of rehabilitated mined land on a progressive basis. Progressive certification permits rehabilitated land to be 'signed off', releasing the company from further responsibility for that land while mining continues on other parts of the mining lease. Progressive certification would require satisfying the regulator that risks to the sustainability of the proposed post-mining land use have been identified and are acceptably low. In this paper we propose a risk-based approach to post-mining land use assessment with the aim of reducing the uncertainty of mine closure and the potential cost of repair of land degradation caused by inappropriate post-mining land use.

1.1. Study Region

The Bowen Basin in Queensland (Figure 1) contains the largest coal reserves in Australia and the world's largest deposits of bituminous coal (DME 2010). In 2006 (the most recent year for which data are available), the total area disturbed by coal mining was 95,600 ha and the area rehabilitated was 26,700 ha (DERM 2007). Land disturbance from coal mining has occurred at a rate of 5,019 ha per annum, and land has been rehabilitated at a rate of 1,831 ha per annum (DERM 2007).

Soils of the region are of two main types: Heavy, black, self-mulching clays, and dispersive duplex soils (the duplex soils are highly vulnerable to water erosion). The rainfall pattern is summer dominant, consisting of erratic, high intensity storms. This seasonal variability in rainfall is accompanied by long-term variability, which results in extended droughts punctuated by shorter periods of intense rainfall and flooding. The erratic, high intensity rainfall events along with the presence of dispersive soils make the landscape particularly prone to water erosion.

The natural ecosystem is dry sub-tropical savannah woodland, which has been extensively modified since the introduction of cattle-grazing over 150 years ago. Exotic pasture grass species, notably buffel grass (*Cenchrus ciliaris*), Rhodes grass (*Chloris gayana*) and green panic (*Panicum maximum*) have become naturalised.

The technique of open-cut mining practised in the Bowen Basin involves exposing the coal seam by removing the topsoil and overburden from a strip of land. The topsoil is stockpiled for later rehabilitation work. The overburden is placed to one side of the first strip, allowing excavation to follow the deepening coal seam towards the west. Once the exposed coal has been removed, subsequent strips of topsoil are removed, with overburden material being blasted back into the adjacent empty pit. This incremental strip mining produces a series of elevated ridges of overburden oriented north-south, resulting in a saw-tooth pattern when viewed in cross-section.

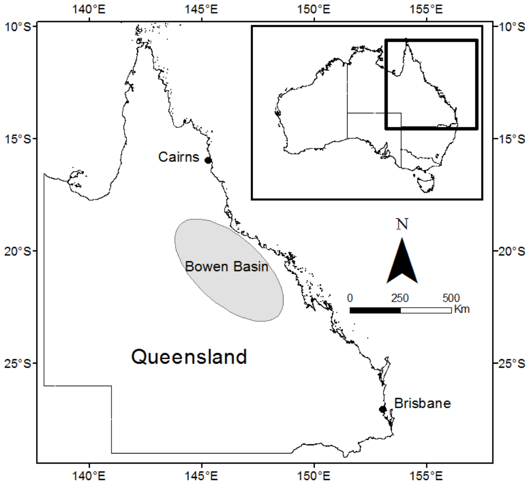


Figure 1. Location of the Bowen Basin within Queensland, Australia.

Mined land rehabilitation practised in the region has followed a fairly standard system. Firstly, the saw-tooth ridges are smoothed using bulldozers, and trucks may be used to backfill the valleys with additional waste rock. When slope angles have been reduced to specified levels, the whole landscape is covered with approximately 30 cm of the stockpiled topsoil, and seeds of native trees, shrubs and grasses are sown. Historically, approximately half of the area disturbed by mining in the Bowen Basin has been rehabilitated to pasture for cattle grazing and half to bushland (Williams 2001). The major land degradation risk associated with cattle grazing is a reduction of vegetative ground cover, and subsequent exposure of the soil surface to water erosion. Despite this, no formal assessment of the sustainability of grazing or other land uses on rehabilitated mined land has been conducted. While regulations require mining companies to assess post-mining land use sustainability, the mechanism for doing so and the factors that should be considered are not specified. Previous reports have called for better integration of post-mining land use planning with life of mine planning, effective consultation with stakeholders, and a use of risk assessment in mine closure planning (ANZMEC/MCA 2000; Cobby 2007; Finucane 2008).

1.2. Risk modelling framework

We followed the general structure for risk assessment defined by Standards Australia (AS/NZ 2004), where risk is defined as a function of the ***likelihood*** of a hazard occurring, and the ***consequence*** if it were to occur (Figure 2). Using a similar approach to that employed by McNeill et al. (2006), the likelihood of a hazard occurring (such as soil erosion) is conceptualised as being driven by site characteristics that influence site ***susceptibility*** as well as ***land management***. Consequence is conceptualised as being driven by site ***sensitivity*** to the hazard and its ability to ***recover*** from the hazard. Sensitivity and recovery in the risk modelling framework is assessed by five site condition indicators: root-zone water-holding capacity, soil erodibility, vegetation ground cover, soil organic matter, and transition probability to a non-preferred ecosystem type. These indicators are similar to those used in Landscape Function Analysis (LFA), which assess a site's ability to retain water, fertility and surface stability (Tongway and Hindley 2004).

We chose a Bayesian network (BN) to implement our risk modelling framework. The particular advantages of BNs over other modelling tools are (a) they are probabilistic models and are therefore well suited to predicting probabilities for likelihood, consequence and risk; (b) they can be used to integrate many quantitative and qualitative variables into a model and show their causal relationships; (c) they can be used in situations where uncertainty and variability is high, which is the case for post-mining land use risk; (d) they can be used to combine empirical data, expert opinion and known functions into a model, which is useful in situations where empirical data are sparse or are not available for all model variables; (e) they can be used for scenario and sensitivity analysis, which is useful in assessing post-mining land use risk where it is necessary to determine how risk varies with changes in land management and site characteristics; and (f) they support model updating as new experience is gained and therefore are well suited for use in adaptive management of post-mining land use risk.

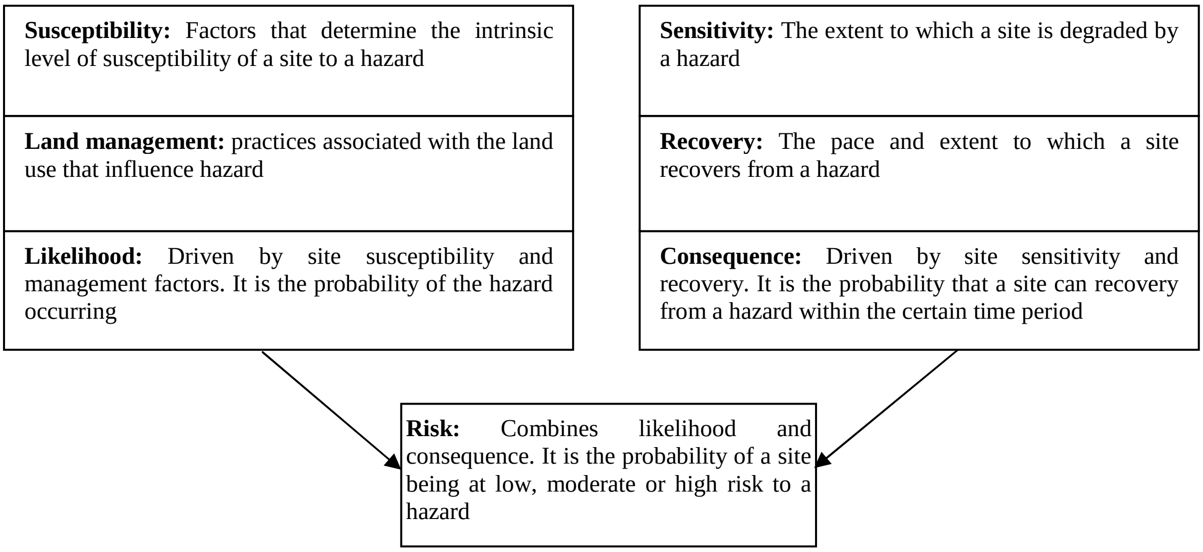
2. METHODS

2.1. Determining Post-Mining Land Uses and Hazards

An internet survey of stakeholder groups was conducted (using SurveyMonkey®) to determine the appropriate post-mining land use and hazards on which to focus the research. The stakeholder groups targeted were community and natural resource management groups within the Bowen Basin (such as the Central Highlands Regional Council and the Central Highlands Regional Resources Use Cooperative), an aboriginal group from within the Bowen Basin (the Fitzroy Basin Elders Committee), a farmer group (Agforce), government agencies (such as the Queensland Department of Environment and Resource Management), and mining industry representatives. The survey asked respondents to identify and rank their preference for post-mining land uses, and to identify and rank the hazards that they considered to be the most significant for each of these post-mining land uses in the Bowen Basin. Those post-mining land uses and hazards most commonly identified as high priority were selected and used as the basis for developing risk assessment models.

2.2. Risk Model Development

Experts from within the University of Queensland (UQ) who had experience in researching and managing the priority hazards identified in the survey were invited to participate in risk model development. At least one expert was identified for each hazard. Two sets of meetings were held with experts. The first was an individual meeting at which the purpose of the research and the risk modelling framework was explained. The expert was then asked to identify and rank site characteristics (influencing susceptibility) and site management factors (which can be attributed to proposed post-mining land uses) that they believed would influence the likelihood of occurrence of the hazard in which they had expertise (soil surface erosion for instance). After these meetings were held individually with experts, the information they provided was used to construct draft conceptual models for each hazard. The second set of meetings were workshops in which the individual experts were brought together in groups to review the conceptual models for each hazard and make adjustments. The purpose of getting experts to meet in groups was to encourage discussion during model review and to build consensus. During the group workshops, the consequence side of the risk modelling framework was discussed and variables already in the conceptual models for each hazard, plus new variables identified during discussion, were linked to the consequence indicators (root-zone water-holding capacity, soil erodibility, vegetation ground cover, soil organic matter, and transition probability to a non-preferred ecosystem type). The end result was the development of a conceptual model for each hazard according to the risk modelling framework (Figure 2).



Susceptibility: Factors that determine the intrinsic level of susceptibility of a site to a hazard

Land management: practices associated with the land use that influence hazard

Likelihood: Driven by site susceptibility and management factors. It is the probability of the hazard occurring

Sensitivity: The extent to which a site is degraded by a hazard

Recovery: The pace and extent to which a site recovers from a hazard

Consequence: Driven by site sensitivity and recovery. It is the probability that a site can recovery from a hazard within the certain time period

Risk: Combines likelihood and consequence. It is the probability of a site being at low, moderate or high risk to a hazard

Figure 2. Risk modelling framework.

3. RESULTS

3.1. Post-Mining Land Uses and Hazards

Two post-mining land uses were preferred by stakeholders; grazing and bushland (Table 1). Moreover, bushland would either be actively managed for specific purposes (ecosystem services, e.g. catchment water quality, biodiversity or conservation), or be left unmanaged. The priority hazards identified by stakeholders as likely to exist if rehabilitated mined land were used for grazing or bushland were surface soil erosion, sub-surface soil erosion, bushfires, weeds and feral animals.

Table 1. Stakeholder groups’ first preferences for post-mining land-use in the Bowen Basin.

Stakeholder group	Total responses	Number of responses according to first preference for post-mining land use					
		Bushland	Grazing	Forestry	Indigenous use	Military use	Other
Mine personnel	56	31	20	3	0	0	2
Government personnel	15	8	6	0	0	0	1
Catchment groups	6	3	1	0	0	0	2
Indigenous	7	3	0	1	3	0	0
Community	5	1	3	0	0	0	1
Landholders	10	0	8	0	0	1	1
Consultants	9	0	6	1	0	0	2
Total responses	108	46	44	5	3	1	9

3.2. Risk Models

In total, five conceptual risk models were developed, one each for surface soil erosion, sub-surface soil erosion, bushfires, weeds and feral animals. The results presented here are for one hazard – surface soil erosion. The model structure for surface erosion incorporates findings from the literature (drawing heavily from the Universal Soil Loss Equation (USLE)) (Wischmeir and Smith 1978) and consultation with experts. Rainfall erosivity, soil erodibility, topography, and vegetation cover were the four main factors found to influence the likelihood of surface erosion on rehabilitated mined land with site characteristics (such as plant available water-holding capacity (PAWHC), soil fertility, slope angle, topsoil sodicity and soil organic matter) and management variables (such as utilisation rate, controlled burning, and machinery load and soil moisture during earthworks) influencing these main factors (Figure 3).

For consequence, the indicators were root-zone water-holding capacity, soil erodibility, vegetation ground cover, soil organic matter, and transition probability to a non-preferred ecosystem type. An example of the root-zone water-holding capacity indictor is shown in Figure 4. Here, sensitivity is measured as the PAWHC deficit or surplus remaining after an erosion event, and recovery is measured as the recovery from a PAWHC deficit within a given time period. Recovery from PAWHC deficit is combined with recovery for the other consequence indicators (recovery from erodibility, cover and organic matter deficits) to determine overall site recovery, which in turn influences risk.

4. DISCUSSION

To complete the risk models, the next step will be to populate them with probabilities. Some of these will come from known functions (such as the USLE which combines topography, soil erodibility, rainfall erosivity, and cover to estimate surface soil erosion), some will come from empirical data (such as the relationship between site productivity and vegetation cover) and some will come from expert opinion (such as the relationship between time, site vegetation, PAWHC deficit and recovery from PAWHC deficit). Obtaining reliable expert judgements of probability will be a difficult task and require a structured probability elicitation process. Expert elicitation tools such as Cain's Conditional Probability Table (CPT) calculator (Cain 2001) will be useful in this process.

Model validation will be another step and is necessary to assess model reliability. This will not be a straight-forward task in our case because empirical data does not exist for many of the variables in our risk models (particularly on the consequence side of the models) and most validation techniques require comparing model predictions with known outcomes using independent data sets. In the absence of independent model testing data, two options seem possible – using experts to assess model predictions and the relative influence of model variables on predictions (using sensitivity analysis) and/or applying the risk assessment models within an adaptive management cycle (Nyberg *et. al*. 2006). Adaptive management (which is a cycle of planning, implementing, monitoring and reviewing) can allow Bayesian networks to learn from monitoring data and new experience and other authors have reported the usefulness of using Bayesian networks within an adaptive management context (Nyberg *et. al*. 2006; Howes *et al*. 2010; Henriksen and Barlebo 2008).

While some guidelines and tools are available for probability elicitation for BNs (see Renooij 2001 for example) there are very few guidelines available for developing BN structure from expert knowledge (Cain 2001 provides some guidance). In this research we used well established interview and group workshop processes (Carmen and Keith 2004) along with an established risk modelling framework (Figure 2). We found that having a modelling framework in place before consulting experts was important for structuring the expert knowledge capture process.

5. CONCLUSION

Risk assessment is an area of modelling in which BNs have intrinsic advantages since risk is often defined in terms of probability. For post-mining land use risk assessment BNs provide the ability to conduct scenario analysis to identify high risk and low risk land uses, and management scenarios that will minimise risk. The challenges we face in completing our risk assessment model are eliciting probabilities from experts and validation. We believe that best practice guidelines in the areas of model structure development and model validation where empirical data are sparse or absent would be a valuable addition to the BN literature.

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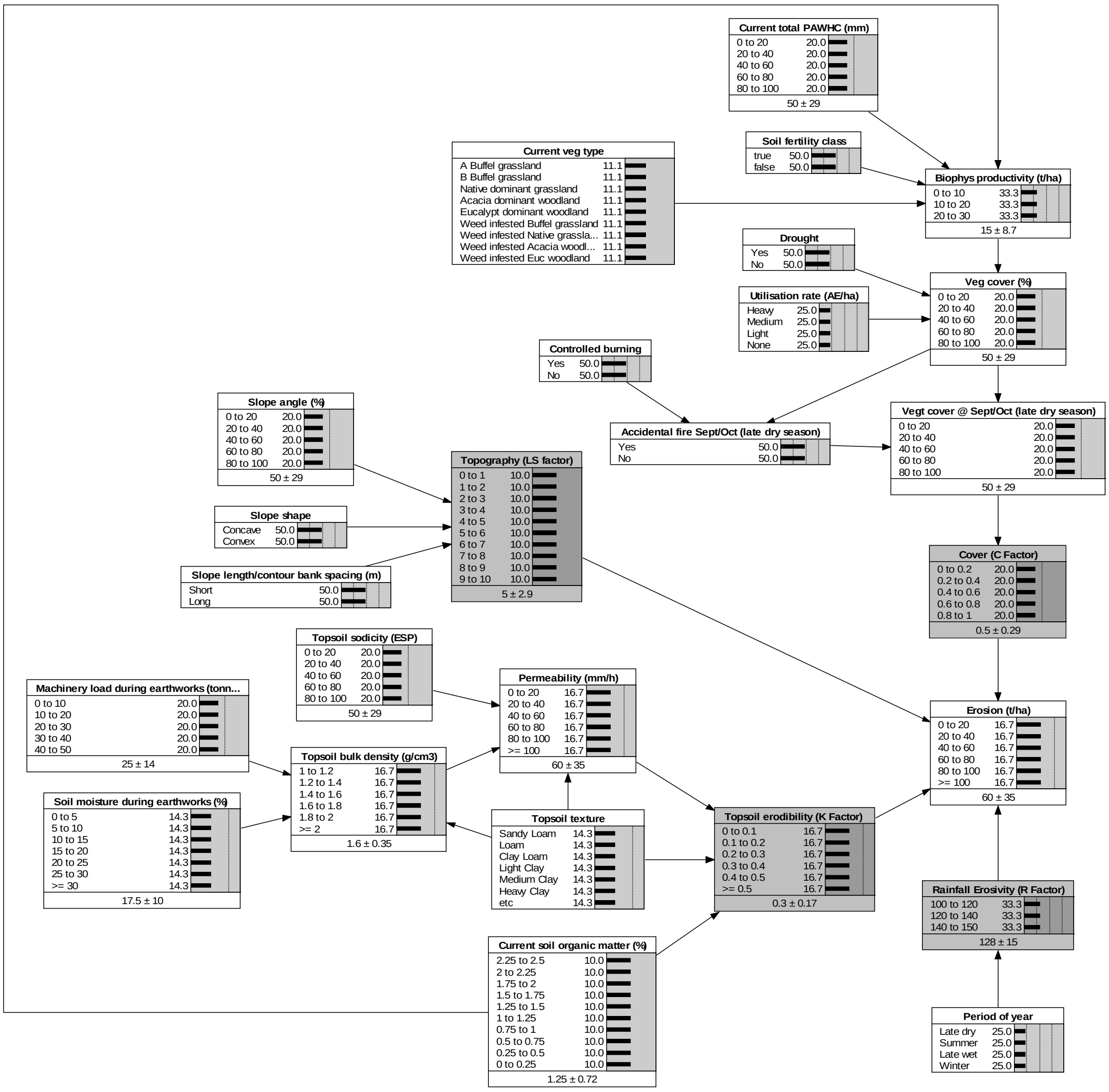

Figure 3. Factors influencing the likelihood of surface soil erosion on rehabilitated mined land (grey nodes are main factors influencing surface erosion).

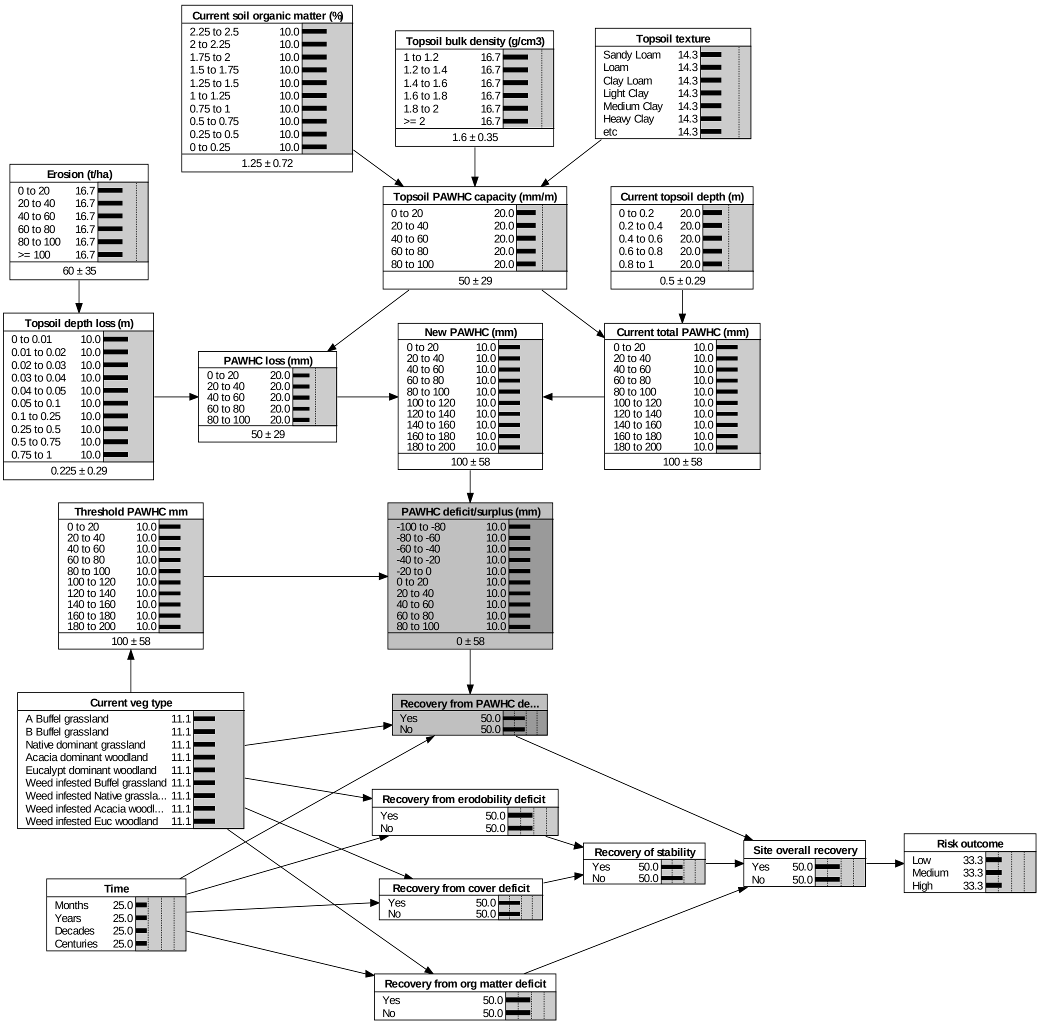

Figure 4. Factors influencing the consequence of surface soil erosion on rehabilitated mined land (only details for the root-zone water-holding capacity are shown - grey nodes represent sensitivity and recovery measures that make up consequence).