Geohazard risk management for municipal planning in the Corangamite region, Victoria, Australia

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Abstract: The Corangamite region covers an area of approximately 13,340 km² and is located in south western Victoria, Australia. The population of approximately 400,000 persons is growing at 5.2% per year, and is served by nine municipalities within the region. The region's diverse range of landscapes and climatic conditions, result in a variety of geological hazards including landslides, soil erosion of all forms, coastal erosion, dryland salinity, potential acid sulphate soils, reactive soils and ground subsidence. These geohazards are increasingly recognised as a constraint on future urban development and a threat to the economic, social and environmental health of the region.

Evaluation of the impacts of geological hazards by State government authorities, research institutions and consultants has been inconsistent, both in hazard identification and risk assessment methods. As a result, municipal planning authorities have lacked a consistent framework with which to assess the potential impacts from these hazards and those associated with new developments which may interact with the hazards.

The use of risk assessment techniques for the management of landslides in Australia advanced significantly after the publication of the Australian Geomechanics Society's landslide risk management concepts and guidelines in 2000. These guidelines in turn were based on the Australian/New Zealand Standard on Risk Management. Similar risk management techniques have now been developed by the authors for the assessment of soil erosion and salinity for particular use by municipalities within the Corangamite region. An evaluation of the nature and extent of landslides, salinity and erosion in the Corangamite region is detailed. The adopted methods of the risk management for each geohazard are described including a comparison of their applicability and an assessment of limitations with each method.

Résumé: La région de Corangamite est formée d'environ 13 000 km² au sud-ouest du Victoria en Australie. La population d'environ 400 000 habitants s'accroît à un rythme de 5,2% par an, et est constituée de neuf municipalités. La grande variété des paysages et des conditions climatiques de la région entraîne une série de risques naturels, notamment des glissements de terrain, l’érosion du sol sous toutes ses formes, l’érosion côtière, la salinité des terres arides, des sols sulfate acide, des sols réactifs et la subsidence du sol. Ces risques naturels apparaissent de plus en plus comme une entrave au développement urbain futur et comme une menace pour la santé économique, sociale et écologique de la région.

L’évaluation des conséquences des risques naturels par les autorités gouvernementales d’État, les établissements de recherche et les conseillers a été menée de façon irrégulière, que ce soit au niveau des méthodes d’identification des risques naturels, ou au niveau des méthodes d’évaluation des risques. En conséquence, les services de l’urbanisme municipaux ont manqué d’un cadre cohérent leur permettant d’évaluer les impacts potentiels de ces risques et eux associés aux nouveaux développements qui pourraient découler de ces risques.


Un bref compte-rendu de la nature et de l’étendue des glissements de terrain, de la salinité et de l’érosion dans la région de Corangamite est fourni. Les méthodes de gestion des risques adoptées pour chaque risque naturel sont détaillées, y compris une comparaison de leur applicabilité et une évaluation des limitations de chacune d’entre elles.

Keywords: risk assessment, geological hazards, erosion, landslides, salinity.

INTRODUCTION

Geological hazards or geohazards can be defined as any Earth processes that are harmful to humans and the environment. Geohazards can be either natural whereby such process have been occurring for long periods of geologic time, or anthropogenic where human activity can effect normally benign processes to cause a problem.

The study area - the Corangamite region - is located within an area of South Western Victoria, Australia. The population of approximately 400,000 persons is growing at 5.2% per year, and is served by nine municipalities within the region. Regional issues relating to water quality and soil health are administered by the local catchment authority - the Corangamite Catchment Management Authority (CCMA).

The region's diverse range landscapes and climatic conditions, result in a variety of geological hazards including landslides, soil erosion of all forms, coastal erosion, dryland salinity, flood, earthquake, potential acid sulphate soils,
expansive soils and ground subsidence from groundwater pumping. These geohazards are increasingly recognised as a constraint on future urban development and a threat to the economic, social and environmental health of the region. Further information on some aspects of the distribution and impact of erosion and landslides within the region can be found in the companion paper presented at this conference (Dahlhaus et al., 2005).

Evaluation of the impacts of geological hazards by state government authorities, research institutions and consultants has been inconsistent, both in hazard identification and risk assessment methods. As a result, federal, state and municipal planning authorities have lacked a consistent framework with which to assess the potential impacts from these hazards and those associated with new developments which may interact with the hazards. In order to address this problem, the CCMA is currently developing a Soil Health Strategy (SHS) to provide a consistent framework for the management of a number of these geohazards within the region.

This paper looks at the use of methods developed in the CCMA region for risk assessment techniques as applied to landslide, erosion and salinity. Aspects of risk methodology are detailed for each hazard, and the applications and limitations of the method are discussed.

OVERVIEW OF THE CORANGAMITE REGION

The Corangamite region covers an area of approximately 13,340 km² and is located in south western Victoria, Australia (Figure 1). The broad geomorphic land forms of the Corangamite region include the Western Uplands, the Western Plains, and the Southern Uplands. Topography varies from deeply dissected valleys in the Otway Ranges to broad, flat landscapes on the plains. Annual rainfall varies from 470mm in the east of the region to up to 1900mm in the Otway Ranges situated in the southern sector of the Corangamite region (Dahlhaus et al., 2005).

Although a diverse range of geohazards exist throughout the region, only three forms considered to be the most significant forms of land degradation in the Corangamite region will be explored in detail in this paper. These are: landslides, erosion and salinity.

A diverse range of climatic conditions, landscapes and soil units exist within the region, almost all types and forms of land degradation are possible. The land degradation processes have been persistent throughout geological time and continue to be active, although they are generally episodic in nature. They include landslides (or mass wasting), sheet and rill erosion, gully and tunnel erosion, wind erosion, stream bank and waterway erosion, coastal erosion processes, and soil salinisation (or dryland salinity).

Major areas of landslide susceptibility and activity within the Corangamite region include the northern coast of the Bellarine Peninsula (east of Geelong), the Otway Ranges and coastline in the south, the dissected plains of the Heytesbury Region in the south west, and the flanks of the major river valleys including the Barwon, Moorabool and Leigh Rivers which drain the central and northern area of the region.

The distribution of and type of erosion varies across the Corangamite landscape zones. The vast majority of gully erosion occurs in the three catchments in the north of the region – the westerly Woady Yaloak River catchment (40%), the central Leigh River catchment (23%) and the easterly Moorabool River catchment (22%). Sheet and rill erosion is more widespread, with the greatest number of sites mapped in the Moorabool River catchment (25%) followed by the Woady Yaloak River catchment (17%).
Although salinity has been a significant feature of the landscapes of the Corangamite region for at least 20,000 years, it has increased significantly following widespread land-use change associated with European settlement over the past 200 years. At present, 20,538 hectares of saline land are mapped in the Corangamite region and the area continues to expand (Dahlhaus, 2004). Increasing salinity in rivers, streams, lakes and wetlands constitutes a significant threat to the region’s water supplies and environmental assets. In the lower Moorabool River, the salinity has approximately doubled over the past 26 years of monitoring, threatening the urban water supplies of the region’s two major provincial cities. Threats to environmental assets include wetlands of international significance listed under the Ramsar Convention and international migratory bird treaties.

Based on the predictions of increasing salinity, the Corangamite region was nominated as one of the priority regions in Australia, under the National Action Plan for Salinity and Water Quality (CoAG 2000). A new Corangamite Salinity Action Plan sets challenging targets for 12 salinity management areas to protect the region’s assets from damage or deterioration due to salinity (Nicholson et al., 2003). The salinity management actions are based on the response of the groundwater flow systems implicated in the salinity process (Dahlhaus, 2004).
The evaluation of impacts of geohazards in the Corangamite region

The evaluation of the impacts of geological hazards within the Corangamite region by State government authorities, research institutions and consultants has been inconsistent, both in hazard identification and risk assessment methods. As a result, municipal planning authorities throughout the region have lacked a consistent framework with which to assess the potential impacts from these hazards and those associated with new developments which may interact with the hazards.

The use of risk assessment techniques for the management of geohazards in Australia advanced significantly after the publication of the Australian Geomechanics Society's landslide risk management concepts and guidelines in 2000 (AGS 2000). These guidelines in turn were based on the Australian/New Zealand Standard on Risk Management AS/NZS 4360:2004. Whilst the AGS guidelines provide a suitable framework with which to assess landslides in the Corangamite region other significant geohazards such as erosion and salinity lacked similar risk management techniques. In an attempt to define a consistent process for the evaluation of geohazards within the Corangamite region, the authors have now developed comparable risk assessment techniques and management strategies for soil erosion and salinity for particular use by municipalities.

The following sections describe the basis for risk assessment as defined by the current Australian/New Zealand Standard and detail the specific risk assessment frameworks formulated for the main geohazards within Corangamite, i.e. landslides, erosion and salinity.

GENERAL PRINCIPLES OF RISK MANAGEMENT USED FOR GEOHAZARD ASSESSMENT

The general process of risk management used in the formulation of the specific frameworks for landslides, erosion and salinity is best described by reference to the following definitions contained in the Australian/New Zealand Standard on Risk Management AS/NZS 4360:2004.

- **Risk Management:** The culture, processes and structures that are directed towards realizing potential opportunities whilst managing adverse effects.
- **Risk Management Process:** The systematic application of management policies, procedures and practices to the tasks of communicating, establishing the context, identifying, analysing, evaluating, treating, monitoring and reviewing risk.

The main elements of risk management are shown in Figure 4 which is taken from AS/NZS 4360:2004. In general, the risk management process can be described as comprising three main components:

- Risk Analysis (incorporating Hazard Identification, Frequency Analysis, Consequence Analysis and Risk Estimation).
- Risk Evaluation.
- Risk Treatment.

In essence the process involves answering the following questions:

- What might happen? (Assess the likely modes of land degradation).
- How likely is it? (Assess the probability of occurrence).
- What impact, damage or injury may result? (Assess the consequence of the hazard).
- How important is it? (Assess the significance of the impact in relation to the regulatory criteria and public opinion).
- What can be done about it? (Assess treatment options including management and mitigation options)
Risk Analysis
The context of the assessment is established whereby the scope of the assessment, the nature of the methodology and the criteria against which risk is to be evaluated are to be defined and fully communicated at the start of the assessment.
Hazard identification identifies what, why and how things can arise as the basis for further analysis. The identification process should be broad so that all possible risks are considered.
Risk analysis is undertaken after hazard identification and involves the estimation of both hazard and likelihood (in this case a probability based likelihood and the consequence of occurrence). The combination of these two elements provides an estimation of the level of risk i.e. 
Risk=Function (Likelihood and Consequence).

Risk Evaluation
The levels of estimated risk are compared against pre-established criteria. Criteria may be in terms of qualitative criteria for a qualitative approach or may involve a numerical level of risk against criteria which may be expressed as a specific number. Risks can then be ranked so as to identify management priorities.

Risk Treatment
If levels of risks are low they may fall into the acceptable category and require no further treatment. However, if risk levels are moderate or higher, they will require some degree of risk treatment and/or risk mitigation. In these cases, specific management plans may be required to be developed and implemented.
In some cases levels of risks may be of such a degree that the proposed development is unacceptable and may not proceed.
In addition, other important elements of the risk management process present at all times of the assessment include monitoring and review of the performance of the risk management process and communication and consultation with stakeholders during appropriate stages of the assessment.

LANDSLIDE RISK MANAGEMENT (LRM) IN THE CORANGAMITE REGION

History of control
Historically, there have been few planning controls for managing landslide risk within the majority of Corangamite region. The exception is Colac Otway Shire located in the south-central sector of the region where landslide hazards have been long recognised but the formal landslide risk management approach has only recently been adopted.
In response to ongoing concerns within the former Shire of Otway (now amalgamated into Colac Otway Shire (COS)) the Geological Survey of Victoria (GSV) undertook a landslide hazard study of the Otway Ranges in the early 1980’s (Cooney 1980, 1982). Formal planning controls commenced in August 1984 with the approval of the Shire of Otway (Ocean Road) Interim Development Order (IDO).
The IDO gave the responsibility for planning to the Shire’s Planning Officer for residential areas (“Village Zones”), and to the Ministry for Planning and Environment (MPE) in all other areas. Under the conditions of the IDO, applications for planning permits in areas designated prone to landslides were referred to the GSV and the Land Protection Service (formerly the Soil Conservation Authority) for comment. Subsequent restructures of State Government departments, amalgamation of municipalities and changes in planning laws has modified the procedures for landslide risk management in the Shire.

Referrals to the Department of Primary Industries (DPI) for landslide assessment in the Surfcoast Shire have been made in the past, but no formal planning controls within the Victorian Planning Scheme have been implemented to date. Similarly issues in the past relating to the occurrence of landslide have also been managed on a case by case basis in the Corangamite Shire and the City of Greater Geelong but without a formal framework for assessment or a structure under each municipality’s planning scheme.

**Evolution of LRM in Australia and the AGS guidelines**

Slope instability and landslide issues occur in many parts of Australia and as such many landslide hazard zoning maps and associated requirements have been prepared by local government authorities (e.g., Cairns, Gold Coast, Maroochy Shire, Lake Macquarie, Pittwater Wollongong Yarra Ranges, Hobart). Regulations and requirements varied from area to area and no formal national process was available 20 year ago. Whist risk assessment methods were being applied mainly in Sydney at this time, the overall process of risk management was relatively new to most practitioners and the quality of reports varied significantly.

In an attempt to foster uniformity in the description of landslide risk, the paper “Geotechnical Risk Associated with Hillside Development” (Walker et al., 1985) was written by a sub-committee of the Australian Geomechanics Society (AGS) Sydney Group for use primarily within the Sydney Basin (Newcastle, Sydney, Wollongong, Lithgow). Given the lack of other documents on the subject, this methodology was soon adopted in other areas of Australia.

However, significant discrepancies were apparent with the 1985 approach and given the need for a truly national approach to landslide risk management, a sub-committee of the National committee of the AGS was set up to review requirements and establish a new guideline for landslide risk management.

The need for such guidelines was emphasised with the tragic loss of 18 lives in the Thredbo landslide in NSW in 1997 and the subsequent paper “Landslide Risk Management Concepts and Guidelines” was published in the Australian Geomechanics journal in March 2000 (AGS 2000).

Whilst it is not the intent of this paper to fully describe the process of the AGS method, the process for landslide risk assessment and management was established based on the generic framework contained in the Australian/New Zealand Standard of risk management (AS/NZS 4360:1999) and concepts detailed in Fell & Hartford (1997). Significant advances over the earlier approach included:

- Establishment of uniform risk terminology
- Definition of a general framework for landslide risk management
- Guidance on methods to be used for risk analysis
- Provision of information on acceptable and tolerable risk for loss of life.

The process of landslide risk assessment is currently undergoing a further review by a national AGS taskforce and a series of documents including a practice note, slope management and maintenance guidelines, and landslide hazard mapping guideline are planned for completion by the end of 2006 (Leventhal 2005).

**Recent developments in LRM in the Corangamite region**

A major review of Colac Otway Shire’s landslide risk management procedures was commenced in September 1999 as part of a three year land capability study. The project included a review of previous studies and geotechnical assessments, the establishment of a database of existing mapped landslides and the generation of new data in the form of topographic and climate surfaces. The initial review of landslide risk management was extended and resulted in production of a number of reports (Dahlhaus & Miner 2000, 2001). Key recommendations included:

- A significant extension of the previous planning overlay to include all areas of landslide susceptibility
- Adoption of the AGS guidelines for LRM
- Changes to the planning schedule incorporating new procedures and exemptions

The planning scheme amendment known as the C8 amendment was subsequently sent to the Minister for Planning in late 2003 for approval. Further changes have since been recommended and the revised amendment is currently in the final stages of approval.

No further changes to any of the other municipalities approach to landslide risk management had been undertaken until the recent SHS being developed by the CCMA. One of the aims of the Corangamite SHS is the development of a standard approach to issues relating to both erosion and landslide throughout the Corangamite region. This is being addressed through the development of standard Erosion Management Overlays (EMO) within the planning schemes of individual municipalities identified as having a number of susceptible areas within their local government area.

Extensive mapping of landslides from ortho-corrected aerial photographs has been undertaken by the University of Ballarat and these incidences have been added to a revised and greatly expanded landslide and erosion database (Dahlhaus et al. 2005).
This information is then being used to calibrate a regional landslide susceptibility maps at 1:100,000 produced by DPI (Robinson et al. 2001) and a series of larger scale susceptibility maps are currently being developed. These maps will be initially produced at 1:25,000 scale and then incorporated into the planning overlays at a scale consistent with each municipality's planning needs.

A standard schedule is also being developed for use across the Corangamite region and a process adopted that will provide uniformity to landslide risk management within the region. Key elements of the CCMA landslide risk management approach include:

- The production of planning overlays supported by a series of 1:25,000 susceptibility maps across the region.
- The recognition of limited resources within municipalities to assess specific technical issues relating to landslide hence the need for a robust process and procedure based on sound risk management methods and ongoing training and education.
- The dissemination of all available information on landslide via reports and a web-based information system.
- The role of consultants in undertaking assessments in accordance with the current AGS framework

**Challenges and comments**

The challenges in implementing a standard system of landslide risk management across the region include:

- The development of a new standard regional scheme whilst respecting the existing planning schemes (COS).
- The individual desires and motivations of municipalities to implement new planning controls for an issue they may not have previously identified as a significant issue within their local government area.
- The need for an extensive database on incidences to allow defensible estimates of likelihood and the justification to allow an ongoing commitment to populate such databases.
- The difficulty in translating regional data sets and susceptibility maps (1, 100,000 to 1:250,000) to a scale that can be consistent with the planning requirements of the individual municipality (often 1:5000 to 1:10,000).
- The role of central government agencies supporting the process through the provision of technical support.
- The need to be consistent with the changing framework of AGS landslide risk assessment and management through developments at the national level.

**EROSION RISK MANAGEMENT (ERM) IN THE CORANGAMITE REGION**

**History of control**

Following widespread clearing of native vegetation during the late 19th century and early 20th century, a series of droughts coupled with a shortage of labour during the Great War led to general neglect of farmlands and an increase in soil degradation. Over-stocking of farms during the economic depression of the 1930s coupled with another drought left many areas severely eroded and neglected, and the impact on rural communities was devastating. This situation led to the establishment of the Soil Conservation Board following the passing of the *Soil Conservation Act* 1940. The Soil Conservation Board was superseded by the Soil Conservation Authority (SCA), established under the *Soil Conservation and Land Utilization Act* 1958, which gave the SCA much greater powers to implement soil erosion control measures. Under the 1958 Act, the SCA’s charter was to prevent and mitigate soil erosion, to promote soil conservation, to determine matters relevant to the utilisation of all lands, to attain these objectives and to foster efficient development and use of water resources by land owners.

The SCA was a very effective organisation, with a substantial body of soil conservation officers and research scientists who were engaged in the rehabilitation eroded lands and the prevention of soil erosion throughout the entire Corangamite region. However, by the mid 1980s, a series of government department amalgamations led to the eventual demise of the SCA. Remnants of the organisation’s authority survive in the DPI, but the statutory responsibility for soil conservation and erosion control is now within the *Catchments and Land Protection Act* 1997, under the jurisdiction of the CCMA.

Although generic planning control in the form of an EMO exists at a Statewide level, in reality, very few erosion planning controls exist for individual municipalities throughout the CCMA region. Although several municipalities have implemented the generic EMO, most aspects of the requirements under this planning overlay are vague and no methodology for assessment is specified.

**Evolution of the CCMA’s ERM guidelines**

A key element of the CCMA’s SHS included a pilot study aimed at implementing an EMO for the City of Greater Geelong. The initial phase of this study quickly identified the lack of a suitable methodology as a major limitation to a consistent approach to erosion risk management.

Erosion hazard assessment systems have been developed by the state forestry agencies in Australia, which evaluate the propensity of the landscapes to develop erosion under varying land use. These systems consider all major forms of erosion and are usually multi-factor processes which include energy source, terrain setting, resistance force and management practices. However they are usually region specific and produce either a qualitative ranking or estimate of erosion. (Ryan et al. 2003)
Whilst such systems can be utilised to provide valuable insight in the magnitude and possibly the likelihood of occurrence of erosion along with other specific erosion models (e.g. USLE and WEPP) they fail to include adequate consideration of the consequences of the erosion, estimation of risk as defined in the Australian standard, the adoption of evaluation criteria, and discussion of appropriate risk treatment and mitigation options.

Similarly other erosion assessment systems have also been developed in the past. Of these, the report “Guidelines for minimising soil erosion and sedimentation from Construction Sites in Victoria” (SCA 1979) and the appropriate soil erosion assessment section of the “Road Drainage Design Manual” (MRQ 2005) both utilise excellent processes for assessing the magnitude of erosion. However they also fail to include the later stages of risk management in the assessment and ultimately fail to provide a full framework for erosion risk management.

As result, the study commissioned by the CCMA developed a method for erosion risk management based heavily on the principles contained in the AGS risk management guidelines for landslide and the Australian standard for risk management (Miner 2005). The proposed model for erosion risk management is shown in Figure 5 and consists of the three main components of risk management, i.e. risk analysis, risk evaluation and risk treatment.

The generic erosion risk methodology can be applied to all forms of erosion including sheet and rill, tunnel and gully, wind, stream bank and coastal dune movements.

**Challenges and comments**

The newly developed process of erosion risk management is yet to be implemented in practice and it is expected that ongoing modifications will be applied as the system is implemented progressively throughout the Corangamite region. To date, the development of viable erosion risk management methodology has encountered a number of specific issues not related to the allied process of landslide risk management. In particular, the following issues required careful consideration:

- Landslides are generally typified by a single discrete event with the possibility of some further reactivation in the future for some failures. Erosion is characterised by an ongoing development of a single erosion type with variable rates of occurrence throughout time.
- The magnitude and/or rate at which erosion occurs, is related not only to the susceptibility of the landscape to erosion (preparatory casual factors) but also to the nature of the initiating or triggering event (triggering casual factors). In many cases the rate of erosion may be episodic or only become significant on an infrequent basis.
- Consequences must be considered for all elements at risk including property, the general public and the environment.
- Risk estimation is not always a simple relationship i.e. Risk = Function (likelihood and consequence) and an assessment of the interrelationship of factors is difficult to assess.
- At present there is no published information on acceptance criteria.

The CCMA’s ERM process duly acknowledged the limitations in adapting risk management techniques to erosion, however solutions to these various problems were formulated and will be trialled and assessed as the use of the system becomes more widespread. Some aspects of the methodology to date include:

- Recommendation for the use of three separate levels of magnitude for each potential hazard to account for variability in triggers throughout time.
- Flexibility in the choice of methods or models used to assess likelihood of occurrence of erosion.
- The use of generic qualitative descriptors for consequence and example tables of how these terms might be applied to various elements at risk.
- Provision of example criteria for both qualitative and quantitative methods. In particular the concept of pre and post development estimates of erosion is introduced and the acceptance criteria of no net increase or a net decrease in erosion rates depending on the assessed level of risk.
Figure 5. Proposed Erosion Risk Management Methodology

Figure 6. Risk Avoidance at coastal cliffs with potential for erosion and slumping, Western Beach, City of Greater Geelong
SALINITY RISK MANAGEMENT (SRM) IN THE CCMA REGION

History of control

Natural salinity, termed primary salinity, has been present in the Corangamite landscapes for millennia (Dahlhaus & Cox 2005). Secondary salinity, which has been induced by widespread land-use change, has been recognised from the 1950s as an emerging problem in the Corangamite region. At the State level, salinity was formally recognised in the late 1980s, with the release of the State Salinity Strategy “Salt Action: Joint Action” in 1988. The strategy identified a number of regions and sub-regions which received priority attention through the preparation of strategies and management plans. The Corangamite region was one of these and the first Regional Salinity Strategy “Restoring the Balance” was subsequently produced in 1992 (Nicholson et al. 1992).

At present, the Corangamite Regional Catchment Strategy (RCS) (CCMA 2003) and the Corangamite Salinity Action Plan (SAP) - Regional Draft (Nicholson et al. 2003) are the base documents that provide a context for the need to manage salinity in the Corangamite region and in the municipalities. The identification of priority areas is based on the mapping of Groundwater Flow Systems (Dahlhaus et al. 2002) and the assets at risk using the Geospatial Salinity Hazard Asset Risk Prioritisation (GSHARP) process (Heislers & Brewin 2003). The SAP provides the management actions to address the risk to the assets, such as the development of Salinity Management Overlays (SMO) in the municipal planning schemes to address the salinity threat to urban development and the risk of urbanisation to saline assets (such as saline wetlands and estuaries).

Evolution of a salinity risk management framework

In urban development it is recognised that there are two possible salinity risks resulting from planning applications for developments or works, viz: the potential impact of salinity on the development at a site, and the potential impact of the development at the site on salinity elsewhere in the catchment. Thus, in developing the SMOs, there are potentially five categories which need to be considered:

- Areas currently affected by secondary salinity (e.g. saline groundwater discharge zones).
- Areas of primary salinity regarded as an asset (e.g. saline wetlands and estuaries).
- Areas not currently affected by salinity, but with a stated likelihood of experiencing secondary saline groundwater discharge within a given time-frame (e.g. where rising saline watertables occur).
- Areas where inappropriate land-use or development may adversely impact on primary salinity assets (e.g. where stormwater runoff may impact on a saline wetland).
- Areas where development or inappropriate land-use may ultimately initiate or exacerbate secondary salinity elsewhere in the landscape (e.g. where increased irrigation may cause saline watertables to rise).

The analysis of the salinity risk requires the estimation of both the likelihood of salinity impacting on the development and the likelihood of the development impacting on salinity. The guidance provided by the Risk Management Standard (AS/NZS 4360:1999) indicates that this estimation can be qualitative, semi-quantitative, or quantitative. The likelihood is then combined with the consequence of the impact of the salinity on the development and the consequence of the impact of the development on the salinity process in the region, to estimate the level of risk.

Typically, the estimation of likelihood would be established by a site investigation that would include a regional assessment of the hydrogeology and salinity processes. The investigation should establish the depth to groundwater, the salinity of the groundwater, the response of the groundwater system to hydrologic change, the landscape and hydrological setting and salinity of the soils. Most importantly, the historical trends of the groundwater levels need to be established and predictions made as to whether the groundwater is likely to rise or fall during the life of the development (taking into account the impact of regional land-use on the hydrology).

Qualitative estimation of likelihood may be stated in terms of probability. One example provided by the Guidelines to the Risk Management Standard is shown below (HB 436:2004).

Table 1. Example likelihood scale (probability) from HB 436:2004

<table>
<thead>
<tr>
<th>Descriptor</th>
<th>Description</th>
<th>Alternative Descriptor</th>
</tr>
</thead>
<tbody>
<tr>
<td>Probable</td>
<td>Can be expected to occur during the project</td>
<td>Good odds</td>
</tr>
<tr>
<td>Possible</td>
<td>Not expected to occur during the project</td>
<td>Low to even odds</td>
</tr>
<tr>
<td>Improbable</td>
<td>Conceivable but highly unlikely to occur during the project</td>
<td>Poor odds</td>
</tr>
</tbody>
</table>

Alternatively, a semi-quantitative or quantitative approach may be used where the site measurements may be combined to calculate a value for likelihood. As an example:

\[
\text{Likelihood} = \text{function} \left( \text{depth to groundwater}, \text{rate of rise of watertable}, \text{salinity of the groundwater}, \text{development design life}, \text{rate of change of land-use}, \text{soil salt store}, \text{etc.} \right)
\]

Similarly, the consequence of the predicted salinity on the development and the consequence of the proposed development on the salinity processes both need to be considered. This would typically involve an examination of the design elements such as the selection of construction materials, the nature of proposed site landscaping including the selection of plant species and watering systems, the proposed occupation rate and use of the development, the extent of impervious surfaces and the handling of surface water runoff.

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A qualitative estimation of consequence suggested by the guidelines is shown in Table 2.

<table>
<thead>
<tr>
<th>Descriptor</th>
<th>Description</th>
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<tbody>
<tr>
<td>Severe</td>
<td>Irreversible damage, huge cost</td>
</tr>
<tr>
<td>Major</td>
<td>Extensive damage, major cost</td>
</tr>
<tr>
<td>Moderate</td>
<td>Some damage, high cost</td>
</tr>
<tr>
<td>Minor</td>
<td>Little damage, low cost</td>
</tr>
<tr>
<td>Negligible</td>
<td>Negligible impact, no financial loss</td>
</tr>
</tbody>
</table>

Consequence may be quantified in terms of triple bottom line cost (i.e. economic, environmental and social value) as: site value, number of species lost, salt content of potable water, or other measures as appropriate.

The risk is then described as a function of the likelihood and the consequence. In a qualitative example, these may simply be combined in a matrix (from very low risk to very high risk). Alternatively, the level of risk can be calculated as a probabilistic equation. For example, the annual loss of property value might take into account the annual probability of a shallow saline watertable, the probability of the watertable being in contact with the building materials, the vulnerability of the building materials to salt attack, and the value of the property.

The objective of risk evaluation is to decide on whether the risk is acceptable, whether risk treatment is required, and to set priorities. The risk evaluation criteria are usually established by the standards (in the case of building codes and materials standards), the regulators (e.g. the municipalities, CMAs, or Environment Protection Authority), the asset managers (e.g. Parks Victoria), the client, or the owners. Risk evaluation often includes a consideration of issues such as cost of treatment, business or public confidence, public reaction, politics, availability of alternatives, environmental impact, availability of insurance, and fear of litigation.

The Standard and guidelines note that risk generally is categorised into three levels, viz: acceptable, tolerable and intolerable. An acceptable risk is one which fits with the specified criteria and does not need further treatment. A tolerable risk is one which is too high to be acceptable, but can be tolerated under certain conditions, such as where treatment measures are undertaken or liability is transferred. Intolerable risks are those which are unacceptable or too costly to treat.

Where a risk is unacceptable, a decision can be made to treat the risk to bring it within a tolerable range. Typical options for salinity would include:

- Accept the risk (e.g. No further treatment required)
- Avoid the risk (e.g. Planning scheme zoning to avoid salinity hazards)
- Mitigate the risk (e.g. Restrict development options to only certain types of development)
- Reduce the likelihood (e.g. Plant trees to reduce groundwater recharge)
- Reduce the consequences (e.g. Select appropriate salt-resistant building materials)
- Share the risk (e.g. Insurance)
- Retain the risk (e.g. Develop strategies for potential impacts in later years)
- Physically separate (e.g. Install barriers between the salinity and the development)
- Duplicate resources (e.g. Relocate threatened species for preservation)
- Transform the risk (e.g. Groundwater pumping and dispose of the saline water elsewhere)
- Postpone the risk (e.g. Further investigation, or install warning systems)

The selection of risk treatment should be considered in the context of the ‘knock-on’ effects elsewhere. For example, groundwater pumping is only acceptable where disposal options are available. The potential benefits of the treatment options, their effectiveness at reducing losses, their cost of implementation and their impact on other stakeholder objectives (including the introduction of new risks) need to be considered.

Throughout the risk management process, three elements are essential:

- Consult and communicate – from the very start of the process, consultation and communication is essential to clarify the roles and responsibilities of the stakeholders. Throughout the risk management process, regular communication is required to inform and educate stakeholders of the risk and risk treatment options.
- Monitor and review – monitoring and reviewing the risk assessment may be in the form of third-party audits as quality assurance. Regular monitoring of the effectiveness of the treatment is essential and should result in a regular reevaluation of the risks. This is particularly important in landscapes undergoing continuous land-use change which results in continuous hydrologic change.
- Recording the process – recording the risk management process is usually required as part of the legal and business requirements of an organization. The records should include a risk register and incident database.

Although the details are yet to be finalized, AS/NZS 4360:2004 provides a systematic, disciplined and rigorous approach to salinity risk management. It provides logical and defendable processes and practices for the assessment of salinity risk. It can inform the development of strategies and decision making to protect all classes of assets which are threatened by changes to salinity processes, even those where the salinity itself is the asset (e.g. a saline wetland or estuary).
SUMMARY AND CONCLUSIONS

The distribution and extent of three of the most significant forms of geohazards within the Corangamite region has recently been identified through the implementation of the CCMA’s SHS. In order to assess the impacts from these geohazards a consistent framework of risk management for each of these geohazards has been developed. These specific methods are based on the general principles of the current Australian/New Zealand Standard on Risk Management.

The three risk management methodologies, which have been described in detail, have adopted a similar approach and risk management framework, although many intrinsic differences and challenges remain for each of the methods. For example, landslide risk management is by far the most advanced of the methods but the application of the methods within the Corangamite region suffers from poor access to a limited incidences database which should ideally be used to justify defensible estimates of likelihood. Erosion risk management has only recently been developed and has yet to be tested in the statutory planning process. There remain significant challenges to overcome, in describing a hazard that can fluctuate with varying levels of triggering events, and a lack of evaluation criteria. The salinity risk management framework is still under development, and requires predictive tools to estimate the likelihood for a threat that is not event-based. In addition there are challenges in risk management of a geohazard that is viewed as both a threat to assets (such as roads and buildings), but also an asset within itself (in the case of groundwater dependent ecosystems and wetlands).

The challenges are many in implementing a consistent framework for geohazard risk management throughout the Corangamite region and acknowledged limitations exist with the current methodologies. However the authors believe the uniformity of the framework used in the development of each specific risk management method will ultimately benefit local municipalities within the Corangamite region in dealing with the impacts from such geohazards in a consistent manner.

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