Where there is little historic data on which to assess the conditional probabilities ($P_{S:T}$) it is useful to use inferred relationships known as mapping schemes. These link qualitative and quantitative terms for probability. Table C7 shows a scheme which has been used widely in dams risk assessment in Australia.

Table C7 was developed for use in dams risk assessment, by Barneich *et al.* (1996) from Military Standard (1993), using Baysian theory to assess historical data. This was done by a group of dams and geotechnical experts, and reviewed by Professor A. Cornell. It has been used and validated in other areas such as pavement management systems, environmental risks at mine sites and seismic risk analysis projects. Experience shows the table helps in obtaining consistent estimates of conditional probabilities within event trees.

Table C7: Mapping scheme linking description of likelihood to quantitative probability (Barneich *et al.,* 1996)

| **Description of Condition or Event** | **Order of Magnitude of Probability Assigned** |
|---|---|
| Occurrence is virtually certain | 1 |
| Occurrences of the condition or event are observed in the available database | $10^{-1}$ |
| The occurrence of the condition or event is not observed, or is observed in one isolated instance, in the available database; several potential failure scenarios can be identified. | $10^{-2}$ |
| The occurrence of the condition or event is not observed in the available database. It is difficult to think about any plausible failure scenario; however, a single scenario could be identified after considerable effort. | $10^{-3}$ |
| The condition or event has not been observed, and no plausible scenario could be identified, even after considerable effort. | $10^{-4}$ |

**c) Complete a review of the assessed frequency in relation to the implied cumulative frequency of the event occurring within the design life and known performance within the area.**

Practice Note Appendix C Likelihood table has included the "Implied Indicative Landslide Recurrence Interval". The correspondence to the Approximate Annual Probability is not strictly correct, especially at low probability values. As discussed by Moon and Wilson (2004) the recurrence interval has a connotation about long periods of time based on long periods of evidence. The reality is that data in relation to the annual probability values of about $10^{-4}$ or less will be limited. "However, because likelihood evidence relates to years not abstract numbers (e.g. year of last slope movement, return period of landslide inducing rainstorms), many practitioners find it easier to think in terms of 'landslide recurrence intervals' and then convert the judgments to annual probabilities" (Moon and Wilson, 2004).

The inclusion of likelihood terms for annual probability values of less than $10^{-4}$ is considered to be appropriate to allow for differentiation, particularly where the probability of spatial impact may be quite different for different hazards. This also offers easy differentiation for hazards where the probability of landsliding is barely credible, for example on a plateau area remote from any escarpment or possible regression (except over geological time) and having relatively gentle slopes underlain by competent strata the probability is likely to be less than $10^{-6}$pa.

### 5.4.3 Assessment of Travel Distance and the probability of spatial impact ($P_{(S:H)}$) of the elements at risk

For most risk assessments it will be adequate to estimate travel distance using empirical or simplified methods. Only in very detailed studies of large and important landslides would it be necessary or useful to use methods such as finite element or distinct element analyses to estimate deformations of individual slides, or to use numerical methods to model debris flows or rock avalanches. Hungr *et al.* (2005) provides an overview of methods for estimating travel distance.

For rotational landslides which remain essentially intact, the method proposed by Khalili *et al.* (1996) or experience with landslides in similar geological, topographic and climatic conditions can be used to estimate the displacement. This method is based on the principle of conservation of energy assuming the factor of safety at failure is unity, adopting the residual strength and the slope geometry to estimate the displacement. The results compare reasonably with case studies. The displacements are greatest for "brittle" failures i.e. where there is a large loss of strength on shearing. The strength loss may be best measured in undrained strength terms, e.g. for soft clays peak and remoulded strengths should be used and for saturated loose (collapsing) granular fills where liquefaction may occur, post liquefaction strengths should be used. For non-circular surfaces, the method may overestimate displacements. Deformation may be modelled for more important projects using finite element, finite difference or distinct element programs.

There is a degree of uncertainty in the methods available for estimating travel distance. Judgment will also have to be applied when consideration of travel direction is relevant in relation to the landslide impacting a particular element at risk. (Such consideration is most likely to be relevant for boulder falls or similar.) For individual allotment assessments, a best estimate or slightly conservative approach may be used, though for more detailed risk assessments, the uncertainty in travel distance and /or travel direction should be modelled as shown in the example presented in Table C8.

Table C8: Example of modelling uncertainty in travel distance and the probability of spatial impact ($P_{(S:H)}$).

| Travel Distance Range metres | Estimated Probability the Travel Distance will be in this Range | Probability of spatial impact ($P_{(S:H)}$) assuming the element at risk is 32 metres below the landslide |
|---|---|---|
| <20 | 0.2 | 0 |
| 20 to 30 | 0.6 | 0 |
| 30 to 40 | 0.2 | 0.2 |
| | Total 1.0 | Total 0.2 |

The probability values could be further modified by the conditional probability associated with travel direction, where this is appropriate. For example, if a rockfall is assessed to have a variety of possible trajectories, only some of which will result in spatial impact on the element at risk, then application of the conditional probability for the trajectory would be applied to the travel distance probability.

# C6 CONSEQUENCE ANALYSIS

## C6.1 ELEMENTS AT RISK

No further comment.

## C6.2 TEMPORAL SPATIAL PROBABILITY ($P_{(T:S)}$)

Roberds (2005) gives a detailed account of how to estimate temporal spatial probability where the elements at risk are mobile. AGS (2000, 2002) Appendix E gives details for the case of traffic travelling on a road.

For most assessments involving persons at risk in a building, the practitioner should make an estimate of temporal spatial probability based on the use of the building. This should include assessment of the probability of non-evacuation which may be used as a conditional probability. The landslide velocity and possibility of forewarning of the landslide failure will be relevant considerations.

The assessment may need to be based on a regulator’s notional occupancy for a dwelling, not necessarily the client’s proposed occupancy. For example, a client may wish to build a holiday house with relatively low occupancy factors (particularly for the time of year most likely to have a landslide event). However, a subsequent owner may be occupying with an average family on a fulltime residential basis. The later occupancy would be more critical and should be adopted for assessment purposes for the development.

## C6.3 EVALUATION OF CONSEQUENCE TO PROPERTY

### C6.3.1 Estimate the extent of damage likely to property arising from each of the landslides

The assessment of vulnerability and damage to property is subjective, and there is little published information. The Practice Note Appendix F has some data but note that for property this represents the judgements of those doing the study and is not a record of actual vulnerability. There are some general points which should be considered:

- Landslides which move slowly (particularly those with a near planar, horizontal surface of rupture) may cause little damage to structures on the landslide, though those structures which are on the boundaries of the landslide will experience differential displacement.
- For stuctures on the landslide, the rate of movement is less important for damage to the structures, except insofar as it affects the time rate of damage, than it is for loss of life.
- For stuctures below the landslide, the velocity of the landslide has a major effect on the damage and hence vulnerability. Hence structures which are near the toe of a landslide which will travel a long distance are likely to experience a high velocity impact and will suffer extensive damage (high vulnerability), and structures which are near the limit of the travel (or run-out) of the landslide will experience low velocity impact by only part of the landslide mass and will probably suffer “minor” damage (low vulnerability).