A useful data source should be the local council (or regulator) who may have a "database" of experience, though it may be somewhat informal. Councils (regulators) are encouraged to set up a landslide inventory in accordance with AGS (2007a) which should be updated with reports of landslides and the damage resulting. Where information becomes available to Council through reports that may have intellectual property rights limitations (copyright), then a summary of salient data and reference to the holder of the copyright would be appropriate. The Council has an obligation to make such data readily available to practitioners working in the area to enable them to be fully informed. Provision of such data enables the practitioner to better understand the local conditions and performance history and will enable the regulator to reduce potential exposure to liability issues. Appropriate disclaimers or privacy considerations may also have to be observed.

Relevant maps and aerial photographs may be available from other government departments/ agencies. Images available on the web, such as from "google earth", may assist.

For studies of larger areas (rather than individual lots), aerial photographs may form a useful data source. Air photo interpretation using stereo pairs can assist with slope morphology and identification of geological features. Examination of aerial photographs, if available, taken over a number of years may assist in determining site and landuse changes that may have occurred with time at the site or surrounding area. Evidence of past instability may be available from such photographs. Often the small scale of available aerial photographs will limit detail, particularly at the level of individual residential lots.

C5.2 FIELD INVESTIGATION REQUIREMENTS

The investigations completed need to be sufficient to provide confidence in the geotechnical model, notwithstanding the uncertainties inherent. Table C1 lists the questions to be addressed in landslide investigations (Fell *et al.,* 2000).

Table C1: Questions to be addressed in slope stability and landslide investigations (Fell *et al*., 2000)

1	Topography?	1.1	In the landslide source and potential travel path.
		1.2	Effect and timing of natural and human activity on the topography.
2	Geological setting?	2.1	Regional stratigraphy, structure, history (eg. glaciation, sea level submergence and emergence).
		2.2	Local stratigraphy, slope processes, structure, history.
		2.3	Geomorphology of slope and adjacent areas.
3	Hydrogeology?	3.1	Regional and local groundwater model?
		3.2	Piezometric pressures within and around the slide?
		3.3	Relationship of piezometric pressures to rainfall, snowfall and snowmelt, temperature, streamflows, reservoir levels, both seasonally and annually?
		3.4	Effect of natural or human activity?
		3.5	Groundwater chemistry and sources.
		3.6	Annual exceedance probability (AEP) of groundwater pressures.
4	History of movement?	4.1	Velocity, total displacement, and vectors of surface movement?
		4.2	Any current movements and relation to hydrogeology and other natural or human activity?
		4.3	Evidence of historic movement and incidence of sliding (eg. lacustrine deposits formed behind a landslide dam, shallow natural slides, or failures of cuts and fills).
		4.4	Geomorphic or historic evidence of movement of slope or adjacent slopes.
5	Geotechnical characterisation of the slide or potential slide?	5.1	Stage of movement (pre failure, post failure, reactivated, active).
		5.2	Classification of movement (eg. slide, flow).
		5.3	Materials factors (classification, fabric, volume change, degree of saturation).
6	Mechanisms and dimensions of the slide or potential slide?	6.1	Configuration of basal, other bounding, and internal rupture surfaces?
		6.2	Is the slide part of an existing or larger slide?
		6.3	Slide dimensions, volume?
		6.4	Is a slide mechanism feasible?
7	Mechanics of shearing and strength of the rupture surface?	7.1	Relationship to stratigraphy, fabric, pre existing rupture surfaces.
		7.2	Drained or undrained shear?
		7.3	First time or reactivated shear?
		7.4	Contractant or dilatant?
		7.5	Saturated or partially saturated?
		7.6	Strength pre and post failure, and stress-strain characteristics.
8	Assessment of stability?	8.1	Current, and likely factors of safety allowing for hydrological, seismic and human influences?
		8.2	AEP of failure (factor of safety ≤ 1)?
9	Assessment of deformations and travel distance?	9.1	Likely pre failure deformations?
		9.2	Post failure travel distance and velocity?
		9.3	Likelihood of rapid sliding?

Whilst such questions are aimed at the investigation of specific existing landslides of a moderate to large size, they are also useful to keep in mind for an assessment at a walk-over level such as for an individual residential block.

The applicability of various investigation methods is ranked in Table C2 (Fell *et al.,* 2000) for different types of slopes.

Table C2: Application of site investigation methods to slope classes (Fell *et al*., 2000)

SITE INVESTIGATION METHOD	NATURAL SLOPES			CONSTRUCTED SLOPES				
	Small/ Shallow	**Medium**	**Large**	**Existing Cut**	**Existing Fill**	**New Cut**	**New Fill**	**Soft Clay**
Topographic mapping and survey	A	A	A	A	A	A	A	A
Regional geology	A	A	A	A	A	A	A	A
Geological mapping of project area	B	B	A	A	B	A	B	C
Geomorphological mapping	A	A	A	B	B	B	B	D
Satellite imagery interpretation	D	D	C	D	D	D	D	D
Air photograph interpretation	A	B	A	C	C	C	C	C
Historic record	A	B	B	A	B	B(2)	B(2)	B(2)
Dating past movements	B	C	B	D	D	D	D	D
Geophysical methods	C	C	B	C	C	C	D	C
Trenches and pits	B	A	B	B	B	B	B	C
Drilling/boring	C	A	A	C	B	B	B	A
Downhole inspection	C	B	B	C	D	C	D	D
Shafts and tunnels	D	C	B	D	D	D	D	D
Insitu testing of strength and permeability	C(3)	C(3)	C(4)	D	B(3)	C	C	A(3)
Strength and permeability monitoring pore pressures, rainfall, etc	C	A	A	A	A	C	C	A(5)
Monitoring of displacements	C	B	A	B	B	B(5)	C(5)	A(5)
Laboratory testing	C	A	B	B	B	B	C	A
Back analysis of stability	C	B	A	C	B	B(2)	C(2)	C(2)

NOTES: (1) A – Strongly applicable, B – Applicable, C – May be applicable, D – Seldom applicable.
(2) In similar areas.
(3) SPT, CPT, CPTU.
(4) Permeability.
(5) During construction.

The driver / purpose of the field investigations is to understand the geotechnical model, possible landslide causes and triggers. Field investigations should start with a walk-over survey, including diligent field mapping to record the geomorphic features. These should be drawn to scale on plans and sections to provide a sound methodology of observation which can then lead to a preliminary geotechnical model and an understanding of the slope forming processes applicable. Subsequent subsurface investigations help refine the preliminary geotechnical model.

Moon and Wilson (2004) advise "particular skills and knowledge bases relevant to developing slope models include understanding of:

- Slope failure mechanisms.
- Landslide travel distances and speeds.
- The relationship between landslides and the intensity and duration of rainfall.
- Landslide hydrogeology.
- Landslide formation process rates."

References are given by Moon and Wilson (ibid) for examples of the above.

The scope of work may vary depending on the level of the study completed, even within the complying scope. Indicative levels of study would be:-

- **Reconnaissance:** to establish the broad topography, evidence of past instability and geology on a regional scale or as a screening process to aid determination of scope of subsequent studies.
- **Walk-over:** to establish site (or area) specific topography and detailed observation of relevant features such as outcrops, topographic form and evidence of past instability. Some initial subsurface investigation may also be completed.

- **Preliminary design:** to provide sufficient data to enable the concept designs to be selected from possible alternatives based on the risk management requirements.
- **Detailed design:** to enable design of risk control measures to be optimised and to remove sufficient uncertainty such that the design will be satisfactory.
- **Construction:** to confirm the design assumptions and allow modification to the design sufficient to address departures from the assumed geotechnical model.

Not all levels of study will be applicable for every project. For example, for some cases completion of a walk-over investigation may be sufficient to allow detailed design to be completed satisfactorily. For more complex projects, the investigations may be completed in stages (for different levels) to enable the geotechnical model to be progressively refined and uncertainties reduced. The levels of study form a continuum and furthermore the scope will vary from project to project.

The appropriate level for residential LRM should be set out in the regulator's policy and should be at least to a walk-over level but with subsurface investigation as needed to establish the subsurface profile. Preliminary and/or detailed design level investigations may only be warranted once the consent conditions have been set. Such consent conditions may include the requirement to complete the more detailed investigations so that the risk control measures may be properly designed and constructed.

The prescriptive requirements given in the Practice Note are considered to be "best practice" for LRM of individual lots or possibly for subdivision assessments. They would also be applicable for investigation of a particular landslide or area, but should be completed to a more comprehensive level.

Monitoring of ground water levels and responses to rainfall events would be ideal. However, practical limitations (including cost and time) limit how often such monitoring is likely to be completed. Frequently a qualitative assessment is likely to be sufficient. For stabilisation by subsurface drainage some monitoring before and after installation of the drainage measures will be required to enable the effectiveness of such drainage to be assessed.

If a practitioner does not comply with the requirements of a policy, then it should be fully documented in the report as to why not.

C5.3 LANDSLIDE CHARACTERISATION

No further comment.

C5.4 FREQUENCY ANALYSIS

5.4.1 Techniques for Frequency Analysis

i) *Main Techniques*

The Practice Note outlines the main techniques which are routinely adopted. AGS (2000) Appendix C provides further discussion. Lee and Jones (2004) and Picarelli *et al.* (2005) provide more detailed discussion and examples from published papers.

ii) *Limitations for Historical Analysis*

The Working Group notes that, in Australia, gathering of historical knowledge is not usually as easy or fruitful as it should be. Experience shows that local government seldom has a complete listing and records become difficult to retrieve, whilst local papers tend to concentrate on "the human aspect" with little factual documentation, not even of date and time of a landslide event, nor the extent and nature of the landslide. Notwithstanding this, a listing of landslide events (as a basic inventory) is of relevance and aids in assessment of likelihood. Much of the data on the incidence of landslides is held by consultants who work in the area. There would be considerable benefits if local government authorities gathered the data held by all the consultants who work in their area and established an inventory which could be accessed by all.

Within Australia an inherent limitation is likely to be the relatively short time period that development has been exposed to landslides. Historically, original development tended to avoid problem areas based on common sense and possibly trial–and-error. If historical records are limited to say 30 years, then the frequency of single events will be limited to a basic 1 in 30 probability (about 0.03), though this may be modified by the probability of trigger events during that period, and response within a population of similar landslides in similar geology and geomorphology. Table C3 shows the length of historical record required to estimate return periods with selected reliability.