

Connecting diverse landslide inventories for improved landslide information in Australia

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Abstract. The evolution of the Australian Landslide Database (ALD) was driven by the need for a nationally consistent system of data collection in order to develop a sound knowledge base on landslide hazard and inform landslide mitigation strategies. The use of ‘networked service-oriented interoperability’ to connect disparate landslide inventories into a single ‘virtual’ national database, promotes a culture of working together and sharing data to ensure landslide information is easily accessible and discoverable to those who need it.

The ALD overcomes obstacles that traditionally hamper efforts of exchanging data, such as variations in data format and levels of detail, to establish the foundation for a very powerful and extensible coordinated landslide resource in Australia. Such a resource synthesises the capabilities of specific single-purpose inventories and provides a suitable basis for further investment in data collection and analysis.

The approach is centred upon a ‘common data model’ that addresses aspects of landslides captured by different agencies. The methodology brings four distinct components together: a landslide application schema; a landslide domain model; web service implementations and a user interface.

The successful implementation of these components is demonstrated in connecting three physically separate and unique landslide event databases via the web. This allows users to simultaneously search and query remote databases in real time and view data consistently. The ALD is now a joint initiative across local, state and national levels with all levels contributing to a national picture. At implementation, this approach resulted in an immediate 70 per cent increase in the total number of landslide events reported nationally.

The interoperable approach establishes a platform to support improved landslide risk assessments and informed mitigation decisions through its ability to collate and characterise large volumes of information. In using a common data modelling methodology the landslide domain model provides the capacity to extend the approach across other natural hazard databases, and also to integrate data from other domains. A key example is the potential to directly link the landslides model with the international ‘GeoSciML’ geosciences data model for geology.

Keywords. Landslides, common data model, interoperability, inventory database, standards, national approach, distributed search, Australia.

1. Policy toward a co-ordinated approach in Australia

In 2001 the Council of Australian Governments (COAG) commissioned a review to identify the strengths and weaknesses of arrangements for managing natural disasters in Australia. Australian Governments comprise three levels, and although each level has different responsibilities, all levels work together to govern Australia. The levels are referred to as Australian or Federal, State/Territory and Local. COAG is

the peak intergovernmental forum in Australia, comprising the Prime Minister, State Premiers, Territory Chief Ministers and the President of the Australian Local Government Association (ALGA). It forms the highest level of policy development in Australia. Their review into disaster relief and mitigation identified the need for a coordinated and more comprehensive approach to natural disaster management in Australia. The review report advocated a fundamental shift in focus beyond relief and recovery towards cost-effective and evidence-based disaster mitigation (COAG 2004). The shift from disaster response and reaction to the anticipation and mitigation of natural disasters aims to create safer, more sustainable Australian communities while reducing risk, damage and losses from natural disasters in the future (Prestipino, 2004). COAG (2004) details 66 Recommendations, including 12 Reform Commitments that all three levels of Australian government in principle support. The process for addressing these and measuring their success are part of an ongoing development.

The COAG review, through Reform Commitment 2, specifically highlighted the need to establish a consistent approach to data collection, research and analysis across all levels of government for a greater understanding of natural disasters and disaster mitigation. This reform commitment requires new, innovative approaches in both the governance and the science of natural disaster management and requires consideration of both ‘top-down’ and ‘bottom-up’ approaches for implementation.

2. Drivers for coordinated landslide data in Australia

The importance of data collection as a fundamental requirement in reducing natural hazard impacts is reiterated in a report identifying natural hazard risk analysis requirements compiled by Geoscience Australia in 2007. Geoscience Australia is an Australian Government agency that produces geoscientific information and knowledge to enable the government and the community to make informed decisions about the exploration of resources, the management of the environment, the safety of critical infrastructure and the resultant wellbeing of all Australians.

The report ‘Natural Hazards in Australia: Identifying Risk Analysis Requirements’ highlights gaps in knowledge and data that constrain more rigorous and systematic natural hazard risk assessments. The report explains that data collection is a long term investment which requires the ongoing support of all levels of government, the private sector and the community. Inadequate data is identified as severely limiting the ability to analyse and effectively reduce the impact of natural hazards (Middelmann, 2007). Furthermore, the adoption of best practice guidelines and methods is explained as an essential step in minimising landslide impacts in Australia and greater work in the areas of landslide inventories, the ongoing maintenance of databases and also landslide database model development was identified as

important to this.

The importance of establishing landslide inventories is further highlighted in a series of national benchmark guidelines on landslide risk management published by the Australian Geomechanics Society (AGS) in 2007. The AGS is a professional society that plays an advocacy and leadership role in landslide risk management. The AGS guidelines provide information, advice and guidance to better understand, manage and reduce landslide hazard to people and property. The guidelines recommend 'landslide information be entered into inventories to underpin all successive risk analyses, research and land use decisions' and that 'the local council, or other regulator, maintain an inventory of past landslide events and make this information available to practitioners' (AGS, 2007c).

3. Brief overview of landslide inventories in Australia

Landslide inventories represent a fundamental base of knowledge used in susceptibility, hazard and risk mapping, and are also an essential part of any landslide zoning (AGS, 2007a). It is acknowledged that this activity should be done thoroughly and that those responsible establish a system for gathering data that can be incorporated into zoning studies (AGS 2007b). It is also acknowledged that the ongoing collection and analysis of landslide and related data is a vital exercise, and the provision of funding for ongoing maintenance of these databases presents a challenge (Osuchowski & Mazengarb, 2007).

With few exceptions, it is believed the activity of recording landslides in Australia is undertaken on a short-term 'as needs' basis. Landslide databases range in geographic scope and levels of detail and typically capture only the data required to target a specific purpose. Common themes are apparent between databases and there is a basic agreement on the concepts, although the methods by which data are organised and described vary considerably.

Implications are that information cannot readily be compared or aggregated with other sources and access is not widely available. It is also believed that as a result there is duplication of effort among landslide researchers independently attempting to fill information gaps.

4. The Landslide Database Interoperability Project

In light of the Australian policy environment and the aforementioned drivers, Geoscience Australia instigated the Landslide Database Interoperability Project (LDIP) as a pilot study in 2005. The project aimed to demonstrate that interoperability could be feasibly adopted as an approach to support a nationally consistent system of data collection, research and analysis across all natural hazard databases in Australia. This approach was pursued by Geoscience Australia in its capacity as technical advisors on Reform Commitment 2 to Emergency Management Australia (EMA). EMA is the Australian Government agency responsible for matters relating to emergency management.

Three landslide databases were initially targeted as part of the interoperability pilot; a national database managed by Geoscience Australia, a regional (state-wide) database managed by Mineral Resources Tasmania and a local database managed by the University of Wollongong. The collaborative effort represents a continued endeavour to improve the historic record of landslide events in Australia

and to ensure this information is widely available and accessible to those needing it.

The key enablers of the interoperable approach adopted by Geoscience Australia were the decisions to establish the system upon a common *conceptual data model* and adopt *common vocabularies* for key aspects of this data model.

5. Requirements in improving the ALD

Prior to the establishment of the LDIP (which includes the 'virtual' ALD), the national landslide database for Australia was a single database maintained solely by Geoscience Australia. The 'evolution of the ALD' describes the shift from a single organisation developing and maintaining a national database to a collaborative and shared approach aimed at improving awareness and availability of landslide data. The ALD as described here is indeed a 'virtual' database, enabled through a web-interface. It is important to note that Geoscience Australia continues to maintain a national database, and that this database is linked into the virtual ALD.

In order to bring together natural hazard knowledge and improve the accessibility and discoverability of data, the evolution of the ALD was presented with a series of requirements that included:

1. Facilitate consistent data collection nationally, whilst acknowledging and incorporating existing data collection efforts.
2. Develop models and tools to support those collecting data and also those seeking to establish landslide databases.
3. Reduce resource requirements for the development, implementation and maintenance of databases in future.
4. Facilitate extensions to the database to allow for the capture of new or additional landslide detail.
5. Support the implementation of a range of alternative data formats.
6. Support linking the ALD to other separate, but related datasets to allow the query of relationships between landslide events with datasets such as earthquake occurrences, rainfall, soils, geomorphology and geology to aid susceptibility, hazard and risk assessments.
7. Consider broader objectives, including the type of landslide or other hazard information required in future, and how landslide databases might be later utilised or called upon to support these requirements.
8. Provide a data model within an 'all hazard' scope for capacity building across other natural hazard domains.

The broader vision for the way in which landslide and other natural hazard datasets could be managed are analogous to several of the stated visions of the INSPIRE initiative

underway in the European Union. These visions include: 'data should be collected once and maintained at the level where this can be done most effectively'; 'it should be possible to combine spatial information and share it between many users and applications'; and, 'it should be possible for information at one level to be shared between all different levels', regardless of whether information is detailed for risk assessments or general for strategic purposes (INSPIRE, accessed 24 July 2008).

6. Interoperability as solution

Interoperability is the ability for components of system to work together in a common way. It provides the means to link data, information and processing tools between different applications, regardless of their underlying software, hardware systems and geographic location. This means that 'interoperable databases' can be described as databases that exist in different locations and are owned by different agencies, but can be accessed through a common interface and present data using common semantics and terminology. It is acknowledged that interoperability applies to many different aspects of a system. However, in this context, a client is allowed to use multiple data sources without additional configuration or functionality modification by database custodians. Each data source behaves like the others, in a predictable fashion.

This provides a system to bring all the databases together for comprehensive and coordinated information, without needing any additional manual data management processes or the development of functionality to access new data sources. This concept requires the implementation of a 'common interface' which is illustrated in Figure 1. The common interface is the key to enabling independent database custodians to share selected pieces of information with others, while maintaining full ownership, management and the original format of their data.

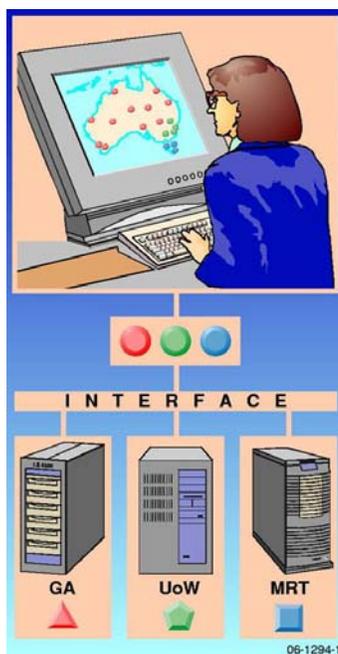


Fig. 1 Concept of the common interface and data transfer

7. A common data model as a strategic approach

Within the context of Geoscience Australia's national role in hazard management, landslides are important because they represent a significant risk to communities. It is reasonable to assume this perspective is common to most other jurisdictions, and hence a common landslide model will be of interest to others if it supports the hazard mitigation function. It was therefore important to take a step back from the immediate application requirements of the landslide inventory and assess how the information fits within a bigger 'all hazards' picture. For example, landslides and landslide investigations typically have a strong geospatial component, and therefore landslide data is often displayed and managed with databases and GIS technology. This is also true of other natural hazards, such as earthquakes, bushfire or flood. In such circumstances, it is believed to be both convenient and efficient to develop models and encodings that leverage developments in geospatial standards (Cox and Richard, 2005).

It was clear that the use of international standards and the adoption of a 'common data model' could indeed support requirements for a sound knowledge base on natural disasters and disaster mitigation in the future. Such an evolution is facilitated by the strategic decision to use a standardised approach to developing a common data model within the ALD, and gaining experience in applying it through practical implementation.

8. Overview of project scope

The LDIP aims to establish a common data service standard across multiple agencies holding landslide inventories. The project was explicitly designed to exercise and consolidate an emerging methodology for designing such data services. The project scope covers establishment of the data standards in a multi-stakeholder environment, with deployment of the service occurring in what is explained as 'ad-hoc service architecture'.

This means that there were no external constraints that the ALD needed to conform to, beyond the requirement of using OGC Web Feature Service implementations which are described further. The nature of a pilot project necessitated that some important aspects were beyond scope. For example: formal specification of service profiles; registration of services; conformance testing; service lifecycle requirements; environment testing; migration or upgrade procedures in addition to policy and governance requirements of the ALD.

Specific requirements in the development of a landslide application schema are described, followed by technical aspects of project methodology with a particular emphasis on the common data model. The benefits and advantages in bringing technical components together, in addition to the related tools to support those collecting data are also described.

Sections 9, 10, and onwards from 14 are recommended to general readers. Section 11, 12 and 13 which describe the architectural significance of 'landslide object entity', the landslide model, and web service implementation, are intended to provide additional detail on technical aspects of the approach.

9. Specific Requirements of a Landslide Application Schema

An application schema is analogous to a common

language or a set of definitions which describes how data is structured and expressed. It also determines how data is related to one or more domains and describes the content aspect of how a user will search and query landslide data and the way in which it is presented to them.

In creating a landslide application schema for the ALD, many specific landslide models needed to be synthesised into one common 'rich' landslide model. It became clear that no single database contained the information needed for representation across three different levels of detail. Therefore, it was important to identify who the different users of landslide data are and assess what type and level of information is required by them for decision making. It was also important to ascertain whether the type of data currently being collated in inventories is useful to decision makers, and whether the value of landslide inventories could be increased with additional data capture. To address some of these questions the scope of the application schema broadened and was developed under the auspices of a 'landslide inventory framework'. The framework considers current and future needs of landslide database custodians, in addition to research requirements and also the requirements of policy and decision makers. Many agencies and individuals contributed to the development of the landslide inventory framework which is described in Osuchowski et al, *in draft*.

The landslide application schema is a subset of the landslide inventory framework. A subset was utilised to meet immediate landslide database requirements for the ALD pilot. It represents an agreed, systematic way of describing landslide information common to the three databases.

The application schema identifies similar information described uniquely across a range of databases and draws out the common elements to label data consistently, implementing international standards where available, and using agreed vocabularies in lieu of international standards. For example the schema adopts the work of the International Association of Engineering Geology (IAEG), International Geotechnical Societies UNESCO Working Party on World Landslide Inventory (WP/WLI) and the International Union of Geological Sciences Working Group on Landslides (IUGS/WGL). Cruden and Varnes (1996) and recommendations of AGS (2007a; AGS, 2007b) were also incorporated. It is also acknowledged that international developments or updated baseline modules may replace components of the application schema in future. For example relevant components of the IFFI Project (Trigilia et al. 2007) may be adopted, in addition to the work underway by the Joint Technical Committees (JTC1 and JTC2) as described in Toll (2007).

10. Project methodology

Given a desire to create interoperable access to multiple databases, the project methodology needed to address a process of reaching agreement on the semantic content (i.e. model and vocabularies) and common data transfer formats capable of expressing this content.

Adopting International Standards Organisation (ISO) Models

The ALD adopted a best practice codified by the International Standards Organisation (ISO) Technical Committee 211: Geographic information/Geomatics 19100 series of standards. This body of work has been applied to the

GeoSciML domain (the International Union of Geological Sciences developed language for exchange of geological map features) and is being applied more broadly to the entire domain of environmental information in the European Union (INSPIRE).

The core of the interoperability approach selected is a common *conceptual model* developed in Unified Modelling Language (UML). ISO 19000 series standards provide the rules to specify how the model may be described as well as how it can be implemented in XML as a GML (OGC 2004) application schema. The adoption of these standards means the data model is established using a specific methodology, which in turn allows the automated production of implementation schemas which themselves follow standards that software vendors can support.

In simple terms, this means a system developer is not required to describe or document this entire process, or any of the standard building blocks, and XML schemas can be automatically generated in a form that enables a user to predict the structure of the model. Such an approach provided a significant head start to the development of a landslide data model. Specialisation of the common model from this point for landslide inventory requirements was still needed; but it was significantly simpler than modelling the whole evidence-based observational process.

Adopting Open Geospatial Consortium (OGC) Models

It is important to note that many databases, irrespective of subject matter, require the same type of information to be described (consider for example the expression of location, position, scale, dimensions etc.). These components are not specific to landslide databases, but generic to the way any spatial data is stored. Common modelling standards mean that the conceptual model can potentially re-use 'common patterns' and link directly to related domain models without continually redefining each concept of interest. This also provides a rigorous and flexible platform for future evolutions of the data model, and therefore provides the functionality to extend components of the landslide application in future if needed.

The ALD adopted the Open Geospatial Consortium (OGC) Observations and Measurements (O&M) model to provide a common pattern for describing evidence-based observations. This decision encapsulated much of the typical metadata scattered through different databases into a single, powerful component of the data model. Furthermore, experience with implementation of the O&M model was available, so the most complex aspects of the model were known to be feasible.

ISO and OGC models for hazards

The ALD represents an early adopter of the aforementioned ISO and OGC standards, and as such there are few ready-to-use building blocks specific to the application domain already published. For example, one component that would be used if it were available is a meta-model for hazards. Nevertheless, spatial concepts (i.e. ISO) and the process of recording observational metadata (i.e. O&M) are well-supported and available as modules that can be directly included.

Customising the common data model for landslides

It was acknowledged that *different parts* of the model will be defined by different processes and communities, and that

interoperability is required *within* the landslides domain and *between* landslide data and related information sources.

The methodology that emerged during this project refines the basic ISO approach by developing the model as clearly defined ‘packages’ which reflect this separation between landslide-specific concepts and potentially re-usable models for certain aspects. This allows for particular components to be addressed as separate modules or packages within a formal data model.

As an example, direct and indirect landslide cost and damage are described within the ALD, but it is acknowledged cost and damage are a requirement of many other natural hazard databases. Therefore, these components could be standardised internationally (as an available model component) and applied across all natural hazard domains, or all other domains that deal with cost/loss and damage. The same is true for capturing monitoring data for landslides. For example the action of monitoring is analogous to many domains such as water quality, contamination, etc.

Where external standards exist for these packages they can be directly referenced. However, as highlighted in the development of the application schema, some local definitions were created for interim solution purposes. Given the project aim was to demonstrate the domain modelling process and the utility of interoperability, many packages have been sketched out. These can be replaced with a more fully modelled packages owned by the relevant communities of interest.

The common data model generated is referred to here as the ‘Landslide Model’. Future refinements will allow integration of GeoSciML, and other related domain models as they become available.

11. Architectural significance of landslide object identity

The assignment of a unique identifier to a particular landslide allows multiple aspects of the landslide to be represented differently in different systems, or different views into the ALD.

In the Landslide Model, this is represented by having an abstract “identity carrier” (Atkinson et al. 2007) which may be represented with simplified geospatial views (such as a point or polygon for example). These can then be further specialised by providing a list of summary attributes to characterize the ‘state’ of the landslide.

The seemingly simple pattern in Figure 2 is a significant departure from common current practice that treats a specific representation (point or polygon) as the *master record* and uses it to assign *identity*. Instead, the identity is established, and properties added to a implementing representation (LandslideLoc) to create a convenient object with the set of properties we want for a particular application. The landslide itself remains the same, even if different application view it differently.

This chosen approach provides the same representation as the traditional approach during the implementation stage, but forces the recognition that the landslide identity is potentially independent and can be represented differently in a different context, without having to include the entire model.

In other words if we agree that such a thing as a landslide exists, we can assign it an identity, and then link further details to landslides using this identity. This means that different views of landslide data can be supported. One key

advantage of this is the ability to have a common ‘index’ of landslides in the ALD linked to much richer details held by individual project databases.

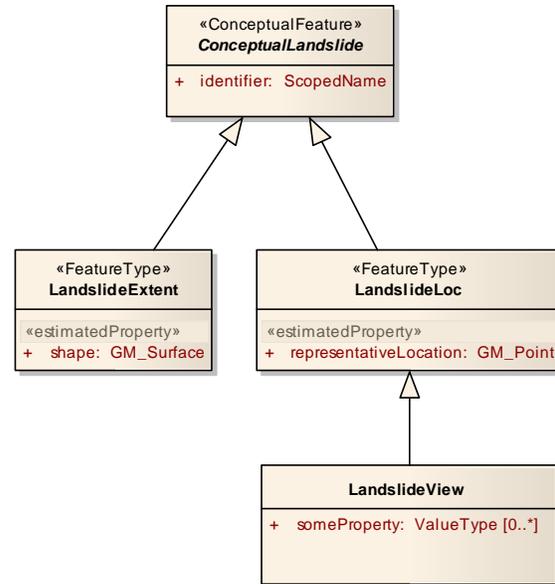


Fig 2. Identity and representation separation

12. Landslides Model

The core of the Landslides Model is a summarised characterisation of an inventory record, linked to a rich model of landslip events using an observation based evidence pattern. This means that a landslide can be linked to a history of landslip ‘events’ and at least one event is assumed for all landslides. This event can be linked to detailed information about the observation procedure, primary evidence and multi-media resources.

The Landslide Model provides for observations about landslip events, such as when, why and how much. It also provides for observations directly on the current state of the landslip such as the type of material involved, style of movement, and the state of landslide activity (active, suspended etc.) for example. Finally, it supports a class of observations shown in Figure 3, which summarise the event history, through a series of procedures which may come to be standardised in the future.

A characteristic that might be summarised as an example is the cause of the landslide. It is acknowledged this may in fact vary during different events, but nevertheless a decision is made to characterise the landslide in a particular way. Without prohibiting a particular way of interpreting complex event history, the model elegantly allows the full set of events to be described as well as the chosen characterisation to be extracted. This is simply another form of observation, determining a characterising value using the set of evidence available rather than a direct field measurement.

The model is then implemented using an inventory record structure incorporating each characteristic that is desired to be searchable within the inventory through a user interface, as

well as a rich chain of standardised observation records linked to these different aspects. Such a model turns out to be quite simple to implement and highly flexible.

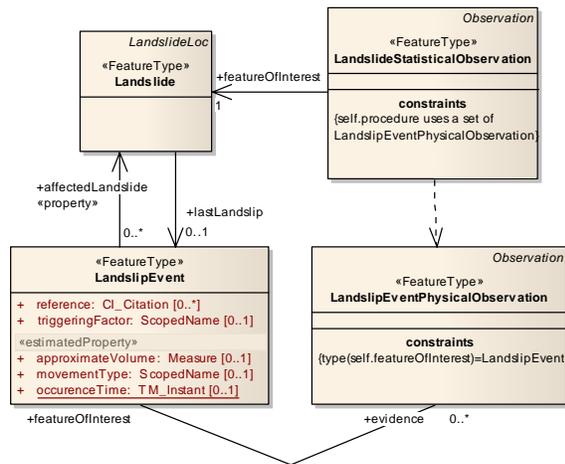


Fig 3. Observations on landslides

The final sophistication proposed is to provide a basic pattern for linking between the landslide inventory and other application domains through a *contextual setting* object that can be populated with cross references to any information deemed relevant to the geospatial setting of the landslide (Figure 4).

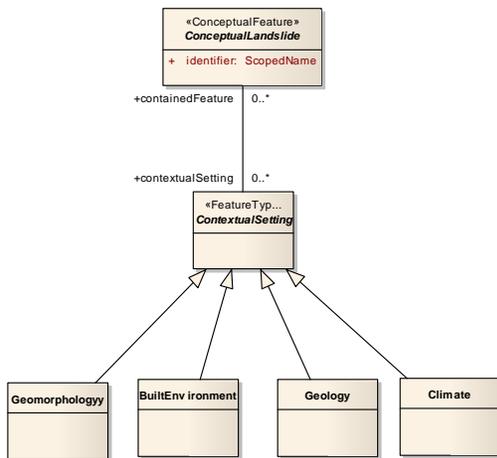


Fig 4. Contextual setting examples

GIS layers can be overlaid and attributes linked to each landslide record for any information that might prove to be of interest. For example, geomorphology (slope, aspect etc), soils, monitoring, geology, climate, weather records etc could all be linked to a landslide inventory. No specific model for describing this is proposed, but the model provides an extension point for adding in such information at any time in the future. The Landslide Model can be accessed from: www.seegrid.com.au/

13. Web Services Implementation

The use of the ISO data modelling approach allows the generation of Geographic Mark-up Language (GML) application schemas for XML base data transfer. Alternatives could have been created, but such ad-hoc approaches often create difficulties for wider adoption, and require the maintenance of a new set of specifications and also the creation of specialised software.

Requirements for ensuring compatibility with other databases and datasets dictated the use of Open Geospatial Consortium (OGC) Web Services, and in particular Web Feature Services (WFS) and Web Map Services (WMS). Web services expose functionality and data through the web and provide users with on demand access to spatial map data.

OGC WMS was adopted for visualization and map query. This provides pictures of maps to applications and users. For example a user is able to request information by specifying a geographic area. This provides the ability for maps to be created with 'up to date' data using appropriate map symbolisation strategies developed by the data owner. Regardless of the amount of data involved, only a simple image is sent across the Web. Therefore, WMS is appropriate for views of the scope, distribution and availability of data, rather than the details of the data itself.

OGC WFS was adopted to allow the delivery of detailed information (as 'spatial features'). WFS also enables the execution of a selection query by a user. It delivers individual features that may be integrated and used as spatial data layers in the client's system. A critical part of the system design was teasing out the 'information model' which underlies the assumptions and desired outcomes. In distributed, interoperable, systems it is crucial to analyse in detail the queries that will be used to invoke remote services, and the responses (such as a producing a table, graph, summary report, etc.). In simple terms, this means understanding how data is going to be queried, and then ensure the right controls are in place to pull this information out and present it to the user. Queries are utilised in order to define the features to be displayed on a map and features included in reports.

An XML representation of data using GML is at the core of various web-service interfaces defined for access to geospatial data by OGC such as WFS. GML is an XML specification for spatial information.

An open-source implementation (Geoserver) was adopted for the pilot due to the availability of plug-in capabilities to support GML application schemas, and in particular the OGC O&M model, the most complex part of the model. Therefore, an advantage in using standard modelling methodology is that it allows the use of off-the-shelf model components and implementation technologies. Further benefits to the end user in the ability for the system to adopt OGC WFS and WMS are described.

14. User interface

The user interface acts as a 'spatial index' of available landslide data and enables reporting, download and mapping functions (such as maps, summary reports, aggregated reports and also summaries of landslide data over regions or study areas). The availability of these functions demonstrates that interoperability between disparate landslide databases is achieved.

Three point-of-truth databases with different data models

were mapped completely using a single web feature service and application schema and implemented using an IMF web mapping platform. A web-based application supports the query, mapping and reporting of national landslide data by seamlessly querying the three point-of-truth landslide databases, presented as a ‘virtual’ national landslide database. The common application schema represents an integrated, national view of landslide locations together with common data for each landslide.

The application supports the ability to access a record in a point-of-truth landslide database via a representation of that feature in the virtual national database. The landslide feature is represented in the common application schema.

In simple terms, the interface is essentially where landslide data from each host database is mapped to the application schema to be translated into the commonly agreed format. This process is what allows a user to view information from different databases in a consistent fashion. It also allows the user to aggregate information across different databases.

The ALD user interface is displayed in Figure 5 and can be accessed from: www.ga.gov.au/hazards/landslides.



Fig 5. User interface for the interoperable ALD displaying a spatial index of data accessed from host databases

15. Query and reporting functionality

Users are able to select the number of databases included in the query and have the option of executing a basic or advanced search. Users can define the spatial extent of their search in several ways; by drawing a bounding box, searching the map extent or selecting a predefined region.

Queries can also be filtered to narrow down the number of landslides returned. The landslide fields currently activated to provide this functionality include landslide ID, landslide date and also information related to landslide type (movement type and material class), cause (both human and natural contributing factors and trigger factors) and damage (such as number buildings damaged, buildings destroyed, fatalities, injuries, and type of direct and indirect damage). This means a user can narrow down their search to, for instance, only include all debris slides or flows that occurred with a contributing factor of wave erosion in the last year.

The reporting functionality includes both tabular and downloadable reports. Tabular reports include basic lists of results in addition to cross-tabulation reports.

Reports can be downloaded in a range of data formats such as PDF, GML, KML or CSV formats (KML allows users to utilise the functionality of Google Earth in visualising results). For numerical fields, a count is displayed in the report table indicating the number of landslides returned or the total number of injuries, fatalities, etc.

Pre-defined queries were adopted for maps, reports and download in the pilot (which also required the implementation of data query models). Pre-canned reports allow for quick reference to the most common reports and any other ‘standard’ reporting that is generated or required on a statutory, frequent or regular basis. For example: an individual collecting data for a ‘State of the Environment Report’ can run a query on the number and impact of landslides within a particular region over a particular timeframe and in addition to having the most up-to-date information available immediately at their fingertips, the results are provided as a formatted table which can be downloaded.

Future work in area of reporting may include more sophisticated reporting options that allow a user to customise the summary and cross-tab reports. For example: a user may select and de-select parameters displayed in report, and also specify whether results are displayed as reports, tables, maps, graphs or statistics.

16. Advantages of adopting interoperability to users

The most important advantage of the interoperable approach adopted for users is the increased volume of information it enables. A range of other benefits presented to the users through this approach are described.

- Provides an automatically updated single point of access to landslide information available within Australia, which increases the availability, accessibility and discoverability of data.
- Users are able to simultaneously search and query remote landslide inventories regardless of where they are hosted or how different are their spatial coverages, scales and data models may be.
- Data is accessed in real time, through live links. Therefore, data presented is as up-to-date as each of the host databases. This means that all new landslide events or updated details added by database custodians are available immediately, ensuring the latest information is constantly available.
- Data is presented consistently to users, enabling the comparison of data across databases, landslide characteristics or locations. This allows data to be compared and contrasted within a landslide domain.
- Detailed information can be accessed for detailed purposes (such as a single landslide event) or generic information can be accessed and aggregated for strategic purposes (in aggregating details for many landslide events), providing basic, intermediate and

sophisticated levels of data.

- Drill down functionality means that all levels of government, geotechnical professionals, emergency managers, land use planners, academics and also the public are able to access different levels of information from the same source data.
- Removes need to locate, access and interrogate isolated landslide databases or to separately identify and contact multiple individuals where landslide information is needed.
- Overcomes technical difficulties to promote the sharing of data to improve knowledge and broadens the capabilities and usefulness of information captured at different scales, leading to a solid foundation for investing greater efforts in data collection.
- Results can be displayed as reports, tables, maps and also potentially graphs and statistics and users can access multi-media such as photographs, videos, published papers, landslide risk management reports, site studies, sketches etc.
- Data can also be queried against datasets such as topography, geology, rainfall and geomorphology (this was outside the scope of the pilot).
- An interoperable approach also enables more sophisticated client interaction and promotes a culture of coordinating, sharing, aggregating and making information available. It also strengthens relationships and enhances collaboration across multiple levels of government, academia, and also practitioners or consultants providing their expertise to regulators or other clients.
- There is no limit to the number of landslide databases that can be linked into the ALD interface (the interface neither stores or records data).

17. Advantages to database custodians

Database custodians do not need to have their databases available online to enable interoperability, although access to internet services is required. This means that in many cases, custodians have greater options in viewing their data spatially.

Database custodians retain full autonomy of their data as they continue to manage and maintain their databases in the same way. They are also able to define the level of information they would like to share with others, and have the ability to restrict access to particular database attributes that contain information considered sensitive or confidential.

Sharing data also raises awareness of landslide hazard within their jurisdiction to others, and also reduces potential for replication of effort through increased efficiency and effectiveness in sharing information and resources

18. Tools to provide support for data collection

To reduce maintenance requirements and encourage landslide data capture, Geoscience Australia developed a multi-tier online data entry tool based upon the landslide

application schema (Figure 6). While presently undergoing testing for the improved data capture, it is envisaged this tool will be available online. In an online capacity and in its simplest form, this tool will allow individuals in Australia to contribute landslide information to the ALD via a website. Contributions will be reviewed, edited and uploaded by Geoscience Australia.

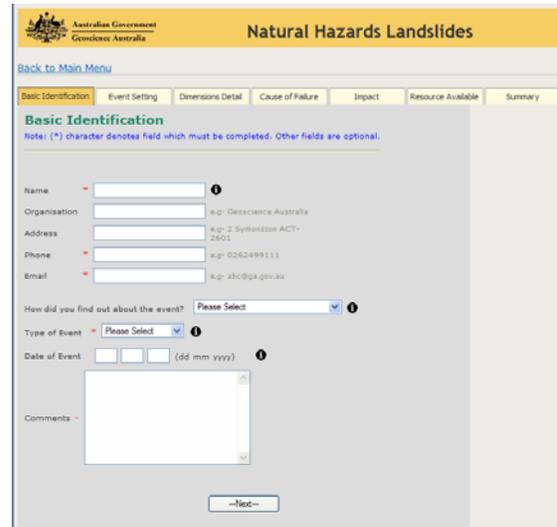


Fig 6. Online data entry tool prototype

Two additional approaches are being considered for the future. The first requires the implementation of a user registration process (i.e. username and password), and seeks to provide direct support to those who would like to maintain a landslide database, but do not have sufficient resources to do so. The approach is centred upon allowing others to utilise the functionality of the ALD (via Geoscience Australia's national database) to maintain their own inventory databases remotely via the web. For example, through the online tool and registration process, parties will have the ability to create, edit and delete their own landslide records and also have complete custodianship of the information they contribute.

The second approach is targeted to those who would like to maintain their own database, but would like to utilise the efforts of the LDIP in establishing their database. For example the online tool, application schema and data model would be packaged and provided to individuals or agencies to use on their desktop. This is also advantageous in more easily allowing for interoperability as the common vocabularies are built into such tools. Individuals may have more options for viewing their own data as well as having the ability to compare landslide data with other jurisdictions or states. For this approach it is important the pilot be moved from a demonstrator to a 'production' state. This is further described in Section 19 and 20.

19. Benefits in also adopting a 'top-down' approach

While a bottom-up approach is feasible for a small number of databases, it presents some challenges when being applied across numerous data sources. For example, many landslide databases utilise complex 'free text' descriptions in their databases which present difficulties in mapping a field to an agreed format. This means that the same information might

be described differently in different places. Consider for example: debris flow, debris-flow, debris/earth flow, or complex debris earth slide flow.

Mapping such descriptors to a common format in the ALD proved to be time-consuming. For example, every instance a unique descriptor, such as those described above, is found, then that specific term needs to be directed or mapped to the agreed format. The agreed format for 'debris flow', was to describe the type of material as a separate instance to the style of movement. This means that two columns are used to classify a landslide in its simplest sense, whereas only one column is used in some host databases. Spelling errors also needed to be treated in the same fashion.

This means that for a landslide classification that reads 'complex wet debris flow', four different terms are mapped to four columns to describe the landslide. The interface finds all instances of 'complex wet debris flow' and maps: type of material with 'debris', type of movement with 'flow', landslide style with 'complex' and water content with 'wet'.

While the method adopted enables data to be produced to a nationally consistent format, a 'top down' approach that encourages the use of standards from the onset of establishing databases provides greater flexibility and usefulness. This would also allow simple and direct mapping from new host databases to the ALD in future.

The landslide inventory framework alluded to previously aims to provide guidance to others in the absence of current international standards for landside inventories. The framework creates the space to begin the capture of data needed, but which is not presently being captured in Australia. In creating a foundation for more targeted data collection in the future, the framework in combination with the common data model creates opportunities in supporting a 'top down' approach, through the dissemination of best-practice solutions in sharing data to inform landslide mitigation. The concept of such an approach is supported in AGS (2007b) which advises *"..the compilation and use of standard parameters for storage and reporting fields in landslide inventories has been the subject of an ongoing project initiated by Geoscience Australia. This work is addressing landslide inventory structure and includes generic categories whilst employing complex relational database structure...It is recommended that the future outcomes from this project...be considered as a new guide for the development of landslide inventories"*. p43

20. Next steps, vision and future goals

The next step is to further develop and move the LDIP from a demonstrator environment into a production environment. However, it is acknowledged that, concurrent to this, there lies a need to develop governance arrangements in order to support a production ready ALD. This stipulates the rules and processes to manage changes to vocabularies or the implementation of new packages or extensions for example. In addition, the development and linking of other components, such as geology (through GeoSciML), is required. This would allow a user to click on a geology map, identify a geological unit and formulate a request to the landslides data sources to highlight landslides with such geology.

At a minimum the demonstrator initiative provides Australia with a simple, centralised national landslide inventory. However, there is also considerable capacity for this initiative to provide State Governments with a simple

way to compile and maintain their own state-wide landslide inventories. These could then also be integrated as point-of-truth databases with the ALD. This would allow for a coordinated system of landslide capture, providing a picture constructed from the local or regional level up to the state level, and then from there to a national level (the ALD is currently linked directly to a state and also a local level database). This would also provide an extensible foundation for a reliable and comprehensive information base for sharing not only landslide data but also other resources. More importantly, the best and most up-to-date information across Australia would be widely accessible on demand.

Information required by geotechnical consultants for landslide risk assessments could be centralised in a similar fashion to provide practitioners with access to relevant information held within development applications or geotechnical reports for example. In Australia, geotechnical investigations occur as routine activities performed by local governments within processes for development approval. Local governments retain a great deal of information, although it is difficult to retrieve this information once it has been lodged (Osuchowski and Mazengarb, 2007). Such documents are in the public domain, and once included within a formal application they may be referred to (AGS, 2007d). This information is currently not referred to in landslide databases and it is also rarely synthesised across multiple jurisdictions. It is believed that access to such information would significantly improve the basic knowledge required to assess landslide frequency and occurrence (Osuchowski and Mazengarb, 2007).

The development of standardised databases targeted for risk management reports, geotechnical reports or development applications would allow relevant aspects of these datasets to be 'virtually' linked and searched spatially with landslide information (i.e. such databases developed as separate domains is required as this information is not specific to landslides but has application to a broader sphere of users). This would allow a user to draw a box in an area and pull out landslide information, in addition to completed reports or studies relevant to landslides in that area, allowing for successive investigations in one vicinity, to build on previous research (Osuchowski and Mazengarb, 2007).

The ability to implement a registration process would also significantly increase the scope of interoperable functions, such geotechnical information could be accessed via a login and password, and database custodians may select to share technical information amongst geotechnical practitioners while coordinating and controlling access.

The ALD forms the first building block of a vision much bigger and greater for the way in which Australians may access and use a wide range of disaster management information in the future. With continued sharing of data, the ALD can potentially become a single access point to all of Australia's landslide history, assisting the reduction of risk from landslides through the provision of information.

The ALD provides an insight into the outcomes possible when agencies interact and work with one another. A common data model approach has the potential to lead the way in the establishment of comprehensive natural hazard databases, with all levels contributing to a centralised virtual portal to inform natural hazard mitigation. Furthermore, responsibility for developing and maintaining up-to-date

information does not fall to a single organisation, but is a shared goal.

Conclusions

Information management methodologies play a powerful role in improving baseline information on landslides and other natural hazards. In particular, the implementation of networked service-oriented interoperability provides a successful model for this and the leveraging of international standards has allowed useful and relevant exchange of information.

The adoption of this approach has demonstrated how disparate landslide inventories can be brought together to establish nationally consistent data collection, through cross-agency collaboration. The approach has proven to be powerful as an underpinning tool in meeting the needs of the landslide community and provides a sound basis for a greater investment in data collection.

A combination of a bottom-up and top-down approach demonstrates how a nationally consistent system of data collection, research and analysis could be implemented in a broader, more encompassing capacity for landslide data in Australia. The application of a common data model in a 'bottom-up' capacity allows database custodians to share data while maintaining their existing data formats. The application of a common schema and use of standards in building new single-point-of-truth landslide databases forms the basis for a 'top-down' through providing guidance and direction.

The LDIP tackled challenges and requirements inherent to broader data capture and maintenance issues and developed a solution to enable inter-domain collaboration, and potentially also cross-domain collaboration in the future.

Collecting data once, maintaining it at the most effective level, and then sharing information across all levels and between different users and applications, will establish a strong foundation for 'a nationally consistent system of data collection, research and analysis to ensure a sound knowledge base on natural disasters and disaster mitigation'.

Such an approach established upon a common data model benefits not only the natural disaster community, but other domains as well, and most importantly, facilitates better communication between scientists and decision makers.

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