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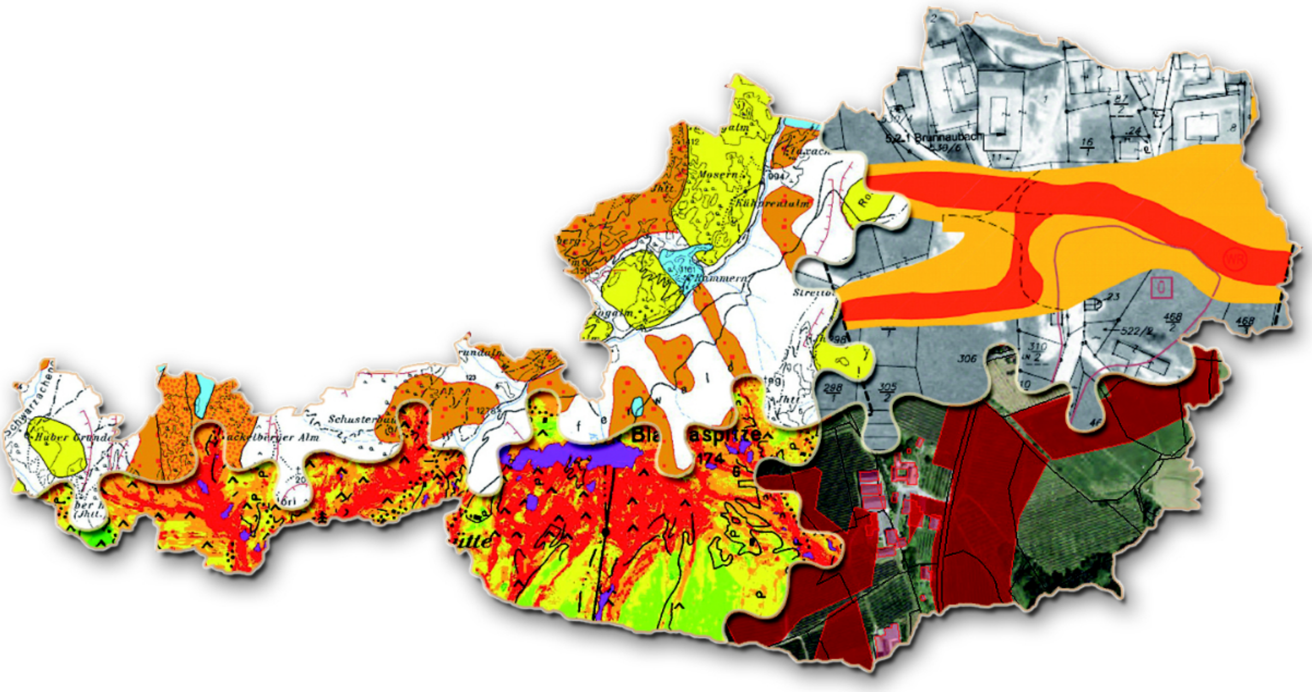
Joachim Schweigl and Javier Hervás



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Landslide Mapping in Austria

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1. INTRODUCTION

1.1 Rationale of the study

Within the framework of the European Union's Thematic Strategy for Soil Protection and the related proposal for a Soil Framework Directive (Commission of the European Communities, 2006a, 2006b) the Institute for Environment and Sustainability of the Joint Research Centre (JRC) of the European Commission and the Geological Survey of the Federal State of Lower Austria (*Amt der Niederösterreichischen Landesregierung*) have jointly undertaken a study of landslide inventories, susceptibility, hazard and risk maps available in Austria in 2008. The EU Thematic Strategy, which regards soils as valuable not only as a natural resource but also as the platform for development of human activities, considers landslides as one of the main threats to European soils. In order to preserve soils and their function, the strategy calls for identification of areas at risk from soil threats, thus including landslides, using comparable approaches throughout EU Member States, as well as for risk reduction and mitigation measures. This study is also particularly relevant to Austrian authorities, organisations and individuals dealing with landslide mapping and, in general, with landslide risk management throughout the country.

In this study, a review of available publications was carried out followed by the analysis of the response to a questionnaire sent to most organisations dealing with landslides in Austria (see Annex 1). Such analysis was complemented by discussions with the respondents and other landslide experts in Austria. Finally, some recommendations to improve landslide risk management in the country are provided.

1.2 Landslide occurrence in Austria

Landslides are a relevant natural hazard in Austria, whose occurrence is conditioned by a number of factors, such as lithology, tectonic structure, geomorphology (mainly slope angle and aspect) and land use. Lithology can be considered the most important of these factors, especially its weathering effects. The geomorphological setting of Austria extraordinarily increases the possibility of landslide occurrence, as the Alps constitute 62% of the territory, and the foothills at the base of the Alps and Carpathians cover 12% (Fig. 1). On the other hand, main natural triggering factors of landslides in Austria include long lasting heavy rainfall and rapid snow melting. Seismic activity is low; therefore it cannot be regarded as a relevant trigger for landslides.

The geological map of Austria (Fig. 2) shows the main lithological and stratigraphical units. In the north-eastern part, red colours represent the hard rocks of the Bohemian Massif, where generally no landslides occur. In these crystalline rocks only some rock falls along the main river banks and tectonic fault scarps are present. Further to the South, the Molasse zone (white and light yellow colours), dominated by fine to coarse grained sediments of the Tertiary Basin of the Alps, represents two aspects: The coarse-grained parts are stable, whereas the fine-grained sediments like the Schlier Formation or the Zellerndorf Formation are often affected by slides and settlements. Next, the Helvetic and Penninic units (orange and green), especially the Flysch Formation, are often affected by slides and flows (e.g. Gschliefgraben in Upper Austria; Fig. 5). The Northern Calcareous Alps (blue colour) include mainly thick Triassic platforms, which are the origin of many rock falls, and the Gosau, Raibl, Lunz and Werfen Formations, where many slides occur. The Lower Austroalpine Units, especially the Quartzphyllite and micaschist formations, are often affected by slides. The Middle Austroalpine Units, e.g. the gneiss units, show also very large rock falls, rock slides and rock avalanches (e.g. Köfels in Tyrol). In the southern alpine formations, especially in marl units, large slides and flows occur (e.g. Reppenwand slide in Carinthia).

Fig. 1. Map of Austria showing relief, main rivers, federal states and capitals

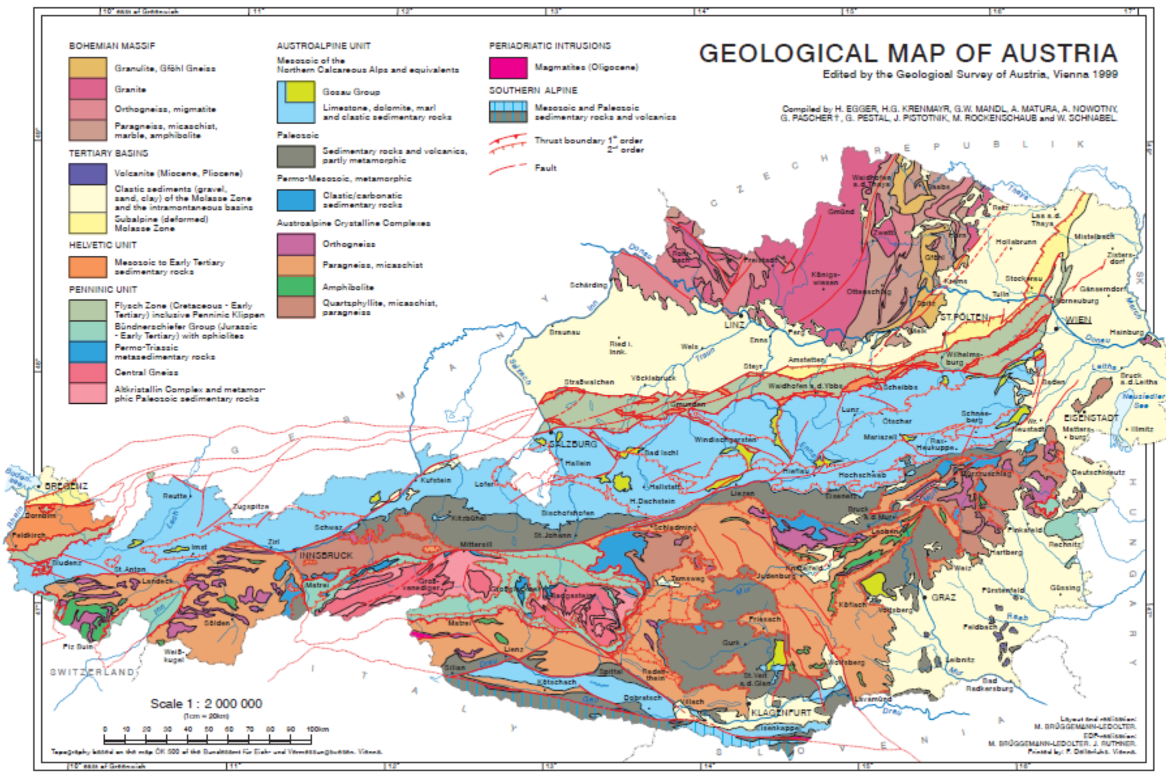


Fig. 2. Geological map of Austria (Source: Geological Survey of Austria, GBA)

Because of the above mentioned specificities, the territory of Austria is often affected by landslides. This greatly influences the activities of the Austrian authorities dealing with natural hazards. Not only in the past but also today landslides cause high economic and life losses in Austria. Abele (1974) documented more incidents of huge rock slides and rock falls in the northern and southern Calcareous Alps (*Kalkalpen*) than in the crystalline central Alps. Following examples illustrate the severity of landslides in Austria.

The giant rock slide in Köfels, Tyrol, most recently interpreted as a rock avalanche (e.g. Hermanns et al., 2006), with a reported volume of 3,880 million m^3, covers an area of 12.87 km^2 and has a length of 4,631 m (Brückl et al., 2001). It occurred 8710 years B.P. in the crystalline rocks of the metamorphic Ötztal-Stubai complex, and is the largest landslide of the Alps in such rocks (Prager et al., 2008).

The Tschirgant rock slide occurred 3050 years B.P. in the limestone and dolomite formations of the Northern Calcareous Alps, in the Inn valley in Tyrol. It covers an area of 13 km^2 and has a volume of 240 million m^3 (Patzelt and Poscher, 1993; Fig. 3).

Fig. 3. The large rock slide source area of Tschirgant (Source: H. Kautz, 2002 – Archive of Geological Survey of Austria, GBA)

The Dobratsch rock slide in the Southern Calcareous Alps of Carinthia was initiated by an earthquake reported January 25, 1348. With a volume of 30 million m^3, it affected an area of 7 km^2 and caused 2000 fatalities. The flood wave triggered by the rock slide caused another 5000 victims. Altogether, earthquakes caused rock slides and falls covering an area of 24 km^2 (Brandt, 1981).

The rock slide and topple reported September 12, 1920 at Sandling, on the border of Styria and Upper Austria, involved 7 million m^3 of rock (limestone and dolomite). A part of the Sandling mountain on the Northern Calcareous Alps slid down (Bammer, 1984).

In September 1966 during a flood event, the Gradenbach landslide in Carinthia produced a 1.3 million m^3 debris flow which destroyed dozens of buildings along the river Gradenbach and caused casualties. The main reason for this landslide is a huge depression ("Sackung") which causes the mountain slope sinking very slowly to the valley bottom. This circumstance causes unstable material sliding into the river Graden. In total the landslide covers an area of 2 km² and reaches a maximum depth of 200 m, with a volume of about 150 million m^3. Since 1979, a geomonitoring system measures the movements. The average movement rate documented so far is approximately 10 cm per year (Gottschling, 1999).

Fig. 4. Scarp crown of the Sibratsgfäll landslide (Source: R. Supper 2002 – Archive of GBA)

The slide of Sibratsgfäll at the Rindberg in Vorarlberg is one the largest historical slides in Europe. The slide event, reported in May 1999, covered a 2.4 km long and 1.1 km wide area, with a volume of 70 million m^3 (Fig. 4). Unusually heavy and long lasting rainfall triggered the movement. According to the damage reports, 17 houses and a church were destroyed, as also 6 km of roads, 65 ha of forest and 85 ha of grassland. The highest movement rate recorded was 1 m per day (Czurda et al., 2002; Hoffmann and Jaritz, 2006). The slide is located within the Feuerstätter nappe of the Flysch Unit, which consists of marls, sandstones, clay schists and clay bearing limestone. Radiocarbon (C14) dating of trees within the slide mass proves the activity of this slide for more than thousand years.

The rock fall of Eiblschrofen at Schwaz in Tyrol occurred on 10 July 1999. A dolomite mass of 150,000 m³ fell down (Fig. 5). 286 inhabitants in 55 houses had to be evacuated (Poscher, 2002). There are several hundred km of ancient tunnels in this dolomite complex and active underground mining. A collapse of the old mine could have been the reason for this landslide. Further works for the protection of this area had to be initiated, which involved additional costs of 15 million Euro.

In August 2005, a flood and debris flow at Stubenbach, a tributary river to the Inn, deposited 65,000 m³ of debris in the central part of Pfunds in Tyrol and destroyed or damaged 47 buildings. The damage incurred is reported to exceed 11 million Euro. All flood and debris flow events in August 2005 including whole of Austria caused a reported loss of 555 million Euro (Bundesministerium für Land- und Forstwirtschaft, Umwelt und Wasserwirtschaft, 2006).

Fig. 5. Eiblschrofen rock fall, Tyrol. View down from the headscarp (Source: J.F. Schneider 2007, IAG-BOKU Vienna)

The complex landslide of the Gschliefgraben in Gmunden (Upper Austria) was reactivated in November 2007. Weathered marls of the Helvetic Units formed a 500 m long and 100 m wide sliding mass, covering an area of approximately 400,000 m^2 (Fig. 6), with a volume of over 3,800,000 m^3. Some houses and infrastructure were damaged and inhabitants of 74 houses had to be evacuated as the earth flow moved at up to 4 m per day. In total the Austrian Service of Torrent and Avalanche Control, which manages the protection works, spent so far 11 million Euro. The landslide is still active.

Fig. 6. Landslide of Gschliefgraben. Completely destroyed dams are shown in the foreground. (Source: M. Lotter, 2008 – Archive of GBA)

1.3 Regulatory framework in Austria

At the moment there is no appropriate state law or technical norm for all natural hazards in Austria, especially for mass movements. As a result, there exist several landslide inventories and other landslide related maps, published by many public and private organizations. Only four natural hazards, floods, avalanches, debris flows and earthquakes are documented by specific regulations. Floods, avalanches and debris flows are regulated by the state law for forest of 1975 (Forstgesetz 1975, BGBl. Nr. 440/1975), as also by executive order 1976 (Verordnung des Bundesministeriums für Land- und Forstwirtschaft 1976), including guidelines for hazard zones 1993. Earthquakes are regarded in the Austrian technical code, the ÖNORM B4015 (2007, Design loads in building - Accidental actions - Seismic actions), ÖNORM S9001 (1978, Mechanical oscillations and vibrations), ÖNORM S9010 (1982, Influence of mechanical oscillations and vibrations on people) and ÖNORM S9020 (1988, Vibrations of buildings). Besides, the state law of mining, Mineralrohstoffgesetz 1999, BGBl. I, Nr. 38/1999 deals with natural hazards including landslides.

The state law, Forschungsorganisationsgesetz BGBl. I, Nr. 47/2000, regulates the work of the Austrian Geological Survey. Especially § 18 reinforces the Survey's task for data collection and assessment of natural hazards. The earthquake inventory and maps are published by the Central Institute of Meteorology and Geodynamics (*Zentralanstalt für Meterologie und Geodynamik*) in Vienna for all regions of Austria. The flood, debris flow and avalanche inventory is documented by the Austrian Service for Torrent and Avalanche Control (*Forsttechnischer Dienst, Wildbach- und Lawinenverbauung,* WLV) for the whole of Austria. This institution also publishes flood and avalanche hazard maps throughout Austria, using same legends and definitions. These documentations report also some types of landslides, such as rock falls, slides or debris flows.

Most of the landslide inventories, databases and maps in Austria contain also documentations of other mass movements like settlements, collapse and dolines. Sometimes also mining areas are present in such inventories because they are particularly prone to mass movements (for example dolines, collapse) and they are important for spatial planning and construction activities.

2. WORK METHODOLOGY

2.1 Literature review

In order to find out which documentation, including landslide maps and reports, was available in Austria, a review of all related publications was first carried out. The initial review showed that only few papers provide a general overview of landslides in Austria or in the Alps (e.g. Abele, 1974; Gattinger, 1980; Tollmann, 1986; Gruner, 2006; Prager et al., 2008). Most reports and papers report only certain local landslides (e.g. Brückl et al., 2001; Weidinger et al., 2007; Van Husen and Fritsch, 2007; Ruff and Czurda, 2008). However, it is not the purpose of this paper to provide a summary of all reported landslides in Austria.

The first paper to mention here is that by Abele (1974) about fossil and recent, large rock falls and rock slides in the Alps. It documents fairly accurately rock falls occurred in the Northern Calcareous, Central and Southern Alps in Austria. A very short overview of landslides in Austria is given in documentations about the Geology of Austria (Gattinger, 1980; Tollmann, 1986). Prager et al. (2008) provide a recent review of fossil landslides in Tyrol and its surrounding areas. Schwenk (1992) and Gottschling (2006) published an overview of all types of landslides occurred in Lower Austria between 1950 and 1990. In this period, 1138 landslides were studied and reported by several experts.

The most recent overview is provided by the Geological Survey of Austria (Koçiu et al., 2007). It includes a new web-database of important well documented landslides in all of Austria, as also the GEORIOS database, which contains major part of digital data. However, many landslide related data are still archived in paper form. In December 2008 the database contained 65,000 entries, some 30,000 of which corresponded to mass movements. Extensive literature about single landslides in Austria can be found on the web-database of GBA "Mass movements" (Weidinger et al., 2007).

In addition, the Research and Education Centre for Forest and Natural Hazards (*Bundesforschungs- und Ausbildungszentrum für Wald und Naturgefahren*, BFW) in Vienna studies and publishes landslides associated with forests and torrents (Andrecs and Hacker, 2005).

2.2 Questionnaire

In addition to the literature review, we analyzed feedback from a questionnaire sent to the organisations dealing with landslides in Austria. This was accompanied by further discussions with some experts involved in the responses and a review of the maps submitted by them.

The questionnaire on available landslide data and maps in Austria was written both in English and German, and was divided into four main chapters: 1. Questions about inventory of landslides, 2. Questions concerning landslide susceptibility maps, 3. Questions about landslide hazard maps and 4. Questions about landslide risk maps. The questionnaire is included in Annex 2 of this report.

2.3 Main definitions

A landslide can be simply described as the movement of a mass of rock, earth or debris along a slope (Cruden, 1991). This concept and the English terminology in the widely used landslide classification by Varnes (1978) and Cruden and Varnes (1996), based on type of movement primarily (fall, topple, slide, spread, flow, complex) and type of geological material secondarily (rock, debris, earth), are used in the report when analysing or interpreting questionnaire responses, maps and databases available only in German language. As a result of this and due to sometimes imprecise or incorrect usage of the own German terminology in the reviewed documentation, some minor deviations from the original expressions might have appeared during the translation process. This applies also to the type of landslide maps depicted or reported (i.e. inventory, susceptibility, hazard and risk maps), even though briefly defined in the questionnaire for clarity.

- A landslide inventory is a collection of data on past and current landslide occurrences. As Hervás and Bobrowsky (2009) point out, ideally such an inventory should at least contain data including a unique identification code, geographical and administrative location of the landslide, landslide type, state of activity, occurrence or reactivation date(s), volume and/or surface extent, soil-bedrock type involved, slope angle, triggering mechanism and surveying date. Additional information about the impact would be beneficial. In most cases however, all this information may not be available, as most of the existing inventories only contain a subset of the required data. Nowadays, most recent landslide inventories are stored in digital spatial databases. However, the content, symbology (map representation) and scale of available landslide inventories differ significantly. Certain symbols for instance are largely dependent on the size of landslides in respect to the map scale.

In Austria, older inventories before 1950 rarely provide accurate information about landslides and maps. The reports on landslide events normally contain only the general term “landslide”, the date of the event and the number of life and economic losses. The location of the event remains mostly unclear. If the size of a reported landslide is less than 200 m in length, usually it is not represented on a map in full scale but as a discrete symbol (e.g. a point), also because most topographic maps in Austria were available in maximum 1:25,000 scale, thus not suitable to delineate smaller landslides.

- Landslide susceptibility refers to the propensity of an area to landslide occurrence. A landslide susceptibility map displays the probability of occurrence of landslides of a particular type at a given location. This spatial probability, either qualitatively or quantitatively determined, is usually expressed on maps in qualitative terms (e.g. nil or low, medium, high) and depicted as zones (polygons in digital maps) filled in with colours ranging from cold hues representing lower landslide susceptibility to warm hues for higher landslide susceptibility zones.

  Among landslide potential maps, susceptibility maps are the most abundant worldwide. Approaches to landslide susceptibility mapping mainly include heuristic methods (geomorphological mapping- and weighting-based approaches), landslide density mapping, statistical (probabilistic) approaches and physically based methods. Recent overviews or reviews of approaches to landslide susceptibility mapping as well as to hazard and risk mapping can be found, among others, in Glade et al. (2005), Guzzetti (2006) and Hervás and Bobrowsky (2009).

- Landslide hazard maps show the probability of occurrence of landslides of a particular type and magnitude at a given location within a reference period of time. Therefore landslide hazard assessment differs from susceptibility assessment by considering also the magnitude of the event and, more importantly, the frequency of occurrence or reactivation.

- Landslide risk maps generally show the probability (often expressed annually) of landslides causing casualties, damage to property and infrastructure, and interruption of services and economic activities. In landslide risk assessment it is usually considered the exposure (as the amount and value of the elements at risk, such as population, buildings, a road or railway, a vehicle or a train passing by, etc.) and vulnerability (as the degree of loss of these elements) in addition to the landslide hazard.

3. LANDSLIDE MAPPING DATA AVAILABLE IN AUSTRIA

In this chapter, an overview of the available data and programmes regarding landslide mapping (mainly landslide inventories and susceptibility or hazard maps) is provided for each major organisation responsible for landslide mapping in Austria either at national or regional level. It should be noted that no information was supplied for the few landslide risk maps available, which are known to be compiled so far for remediation works and research in local, small areas. A full list of organisations with contact details is given in Annex 1.

3.1 Nationwide mapping data and databases

In Austria, six major organisations operating at national level collect data on landslides and publish various types of landslide-related maps and databases. This information supports authorities in decision making regarding e.g. spatial planning, transportation network risk management, civil protection, etc. These organisations are the Geological Survey of Austria (*Geologische Bundesanstalt*, GBA), the Austrian Service for Torrent and Avalanche Control

(*Forsttechnischer Dienst, Wildbach- und Lawinenverbauung*, WLV), Joanneum Research, AlpS (*Zentrum für Naturgefahrenmanagement*) and the Austrian Railways (*Österreichische Bundesbahnen*, ÖBB). Another organisation, the Austrian Highway Company ASFINAG, also deals with landslide investigation and mapping. However, no data were provided for this survey.

On the other hand, the departments of Geology and Geomorphology of the Universities of Innsbruck, Salzburg, Graz and Vienna are known to have single landslide maps and datasets. Also the Institute of Alpine Natural Hazards of the University of Agriculture (Boku) in Vienna has collected data on landslides and floods. However, in this study, these and other relevant Austrian university departments were not asked to provide information because they do not systematically collect landslide data or publish maps for authorities.

3.1.1 Geological Survey of Austria (*Geologische Bundesanstalt*, GBA)

GBA in Vienna is by law the organisation in charge for collecting landslide data in Austria since 1978. This mission has been reinforced by a new Austrian research law (*Forschungsorganisationsgesetz*) in 2000, which deals also with other natural hazards.

Within GBA, the Department of Engineering Geology catalogues and documents geological natural hazards at nationwide scale. A recent overview of the landslide activities of GBA is given by Koçiu et al. (2007).

GBA produces landslide inventories, susceptibility and, since very recently, hazard maps. An inventory of approximately 30,000 documented mass movements, including mainly landslides, exists in analogue format (printed data sheets and paper maps) in the archives of the GBA. So far, a major part of this dataset has been digitized within the project GEORIOS (Georisiken). A small part of these data are published on the web. As result of these projects, GBA provides currently two spatial databases: The GEORIOS database and the webGIS database "Massenbewegungen in Österreich". It should be noted that in German the term "Massenbewegungen" can refer either to landslides or to mass movements. The latter include landslides, settlement, dolines, sinkholes and subsidence. However, the webGIS database contains only landslides, even if named "Massenbewegungen", while the GEORIOS database includes mass movements (Fig. 7, 8, 9).

As a consequence of different data sources, descriptions and mapping methods the GEORIOS database does not include harmonised information, while the webGIS database is harmonized. However, data such as landslide classification, information on origin, triggering factors and general characteristics of the landslides are consistent in both databases.

GEORIOS

The GEORIOS database contains 65,000 entries, 30,000 of which correspond to mass movements, mostly landslides. In the database maps, landslide features such as boundaries, scarps and hummocks or graben are represented as points, lines or polygons, depending on their size. Also depending on the scale landslides are represented as points or areas (polygons). Elements of landslides like scarps, tension cracks, etc. are displayed as lines.

The maps are available in the ArcGIS environment. The database currently uses Oracle as relational database management system, but GBA plans to migrate to MS SQL for both databases in the future. The inventory map scale depends on the original data and maps and ranges from 1:25,000 to 1:50,000.

Fig. 7, 8 and 9 show examples of a datasheet and attribute table of the GEORIOS database and maps in ArcGIS. On the database maps different types of mass movements are shown (Fig. 7, 9). Polygons represent either landslide undifferentiated areas or landslide deposits (where only these have been found); see legend in Fig. 9 for details. Thus, in certain areas only deposits of ancient landslides can be found, like in Fig. 9. The database contains different types of landslides, such as rock falls, slides, earth flows, debris flows, creep processes, Sackung and complex landslides, which are divided in subclasses. Areas affected by settlements and some geomorphological features, such as scars, large hummocks and graben are also displayed in the GEORIOS maps.

The database mask (Fig. 8) contains information about type of landslide, person who mapped it and the one who entered it in the database, geological formation, tectonic unit, data source, hydrogeology of the area, date and number of events, exact geographic position and a description of the geometry of the landslide, monitoring, studies and remediation works, when available.

The GEORIOS database, which is only available in the GBA headquarters in Vienna, can be accessed by public administration officials as well as scientists, engineers and practitioners working for public administrations. All maps and ancillary data are described in German. The database is due to be completed in 2009, and will be regularly updated with incoming data from new projects and field surveys.

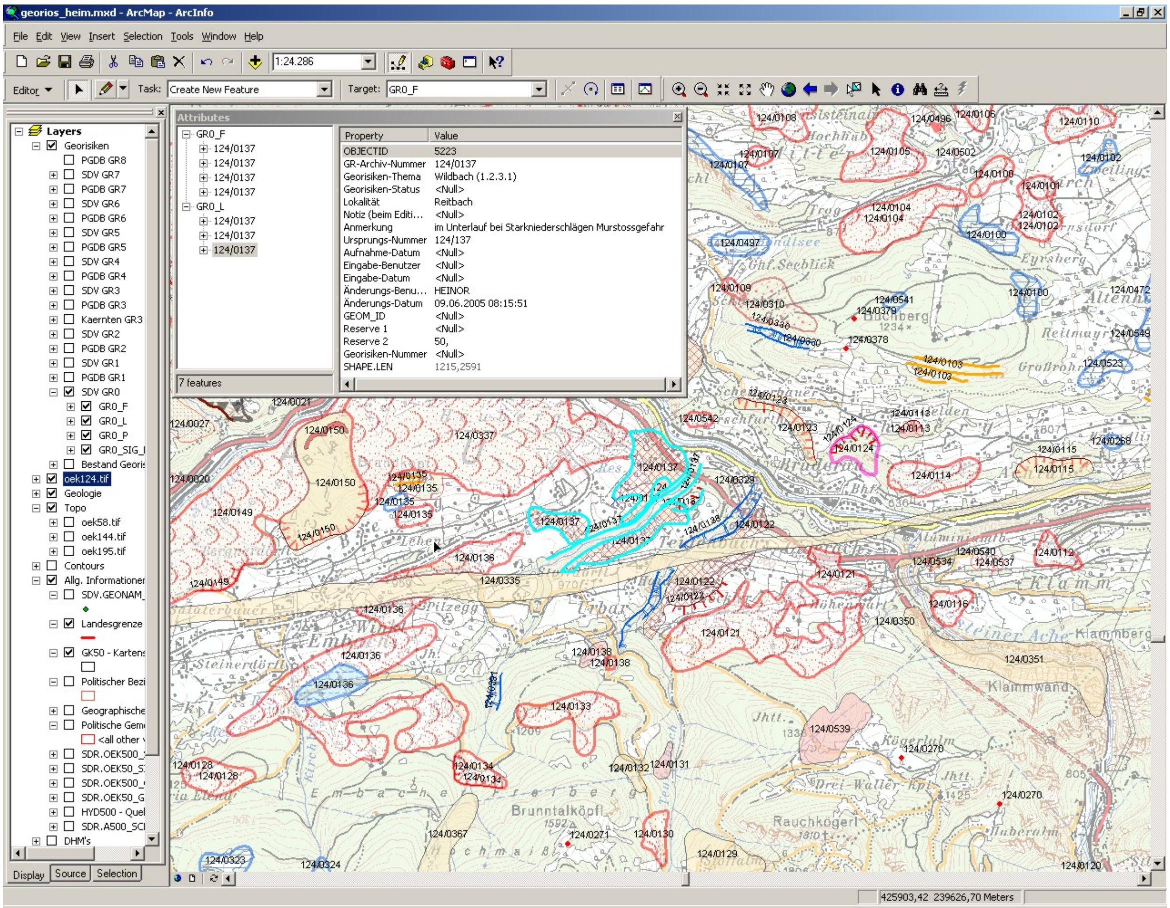


Fig. 7. Landslide map of the GEORIOS database on ArcGIS. Original scale 1:25,000 (Source: GBA)

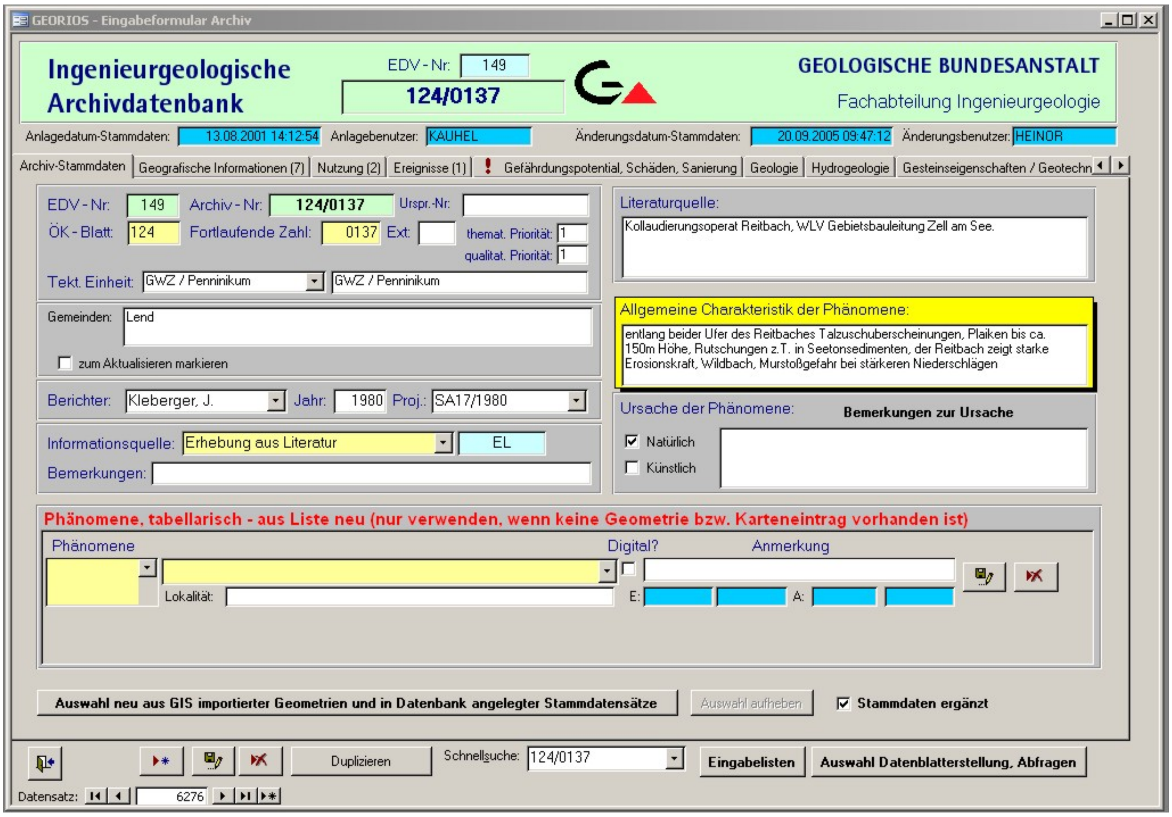


Fig. 8. Input mask of MS Access of the GEORIOS database. *Allgemeine Charakteristik der Phänomene* stands for general characterisation of the mass movement event, *Informationsquelle* stands for source of the information, e.g. in this case the slides and erosion areas where found in a report by WLV; *Ursache der Phänomene* stands for triggering factor (Source: GBA)

Mass movements (Massenbewegungen) web database

As of December 2008 the web database contains 822 landslide entries corresponding to large or relatively large landslides. All these landslides are published, investigated and well known in public.

This database always contains information about the type of landslide, local name for the landslide, locality, literature references, web-links and information about single movement or reactivation events, if available. Fig. 10 shows a screenshot of the database sheet for the Eiblschrofen rock fall in Tyrol. In the web mapping application (Fig. 11) landslides are represented as points. Here the maximum zooming scale is 1:300,000.

The development of the GEORIOS and the Mass Movements digital databases started in 2002 by continuously entering past landslide analogue data and maps archived since 1978. The web database is updated every week, and is accessible by the general public through a webGIS application in English and German at http://www.geologie.ac.at.

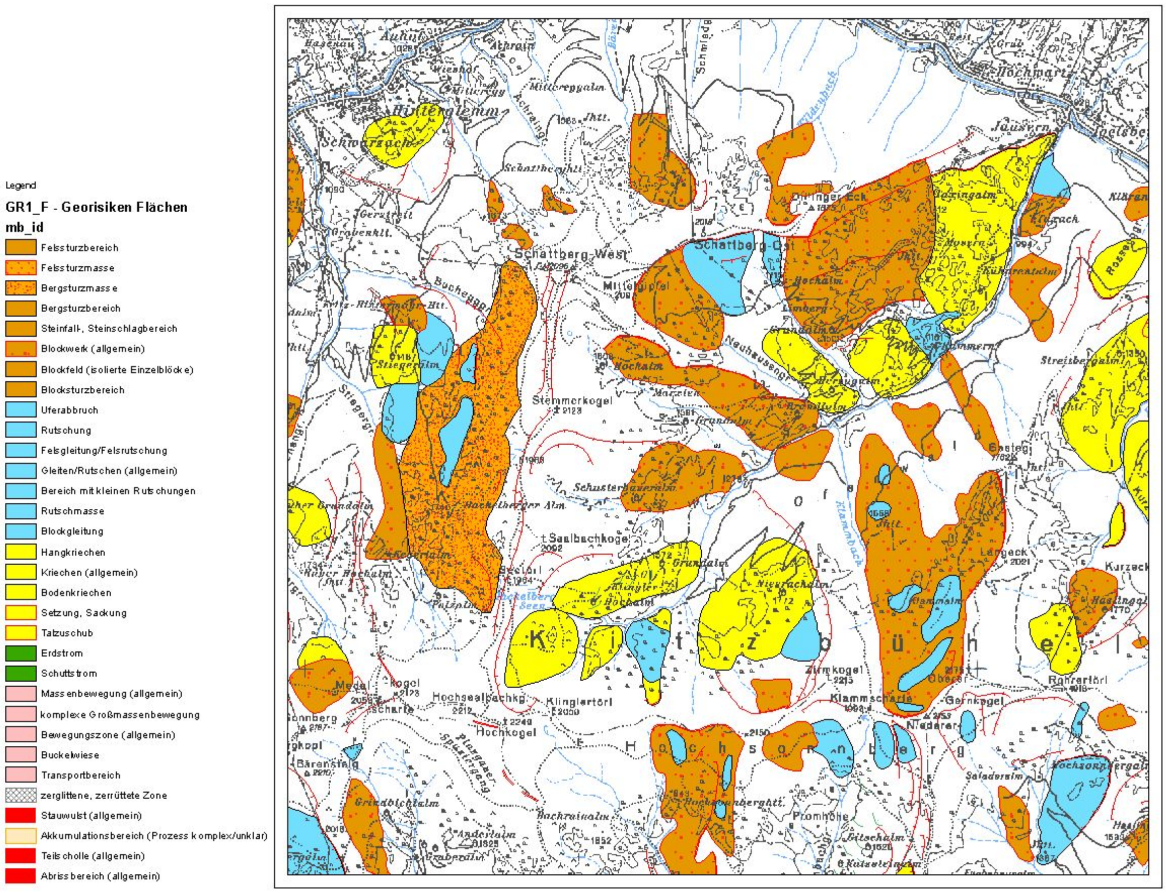


Fig. 9. Landslide inventory map extracted from the GEORIOS database. Brown polygons represent rock falls of different size and rock fall deposits; blue polygons show slides of various types; yellow patterns denote creep, settlement or sackung; green areas represent flows of different material size; pink denotes complex movements and undifferentiated landslides; red patterns show areas of accumulation or detachment of landslides. Felssturzbereich: medium-size rock fall in general; Felssturzmasse: deposit of medium-size rock fall; Bergsturzmasse: deposit of large rock fall or slide, Steinfall-, Steinschlagbereich: small rock fall in general; Blockwerk: deposit of small rock fall; Blockfeld: deposit of single, isolated boulders; Uferabbruch: torrent slope slide; Rutschung: slide of soil or detritus; Felsgleitung/Felsrutschung: rock slide or glide; Gleiten/Rutschen: glide/slide (in general); Bereich mit kleinen Rutschungen: area with small slides; Rutschmasse: sliding mass; Blockgleitung: spread; Hangkriechen: slope creep; Kriechen (allgemein): creep (in general); Bodenkriechen: soil creep; Setzung, Sackung: settlement; Sackung, Talzuschub: rock creep; Erdstrom: earth flow; Schuttstrom: debris flow; Massenbewegung (allgemein): mass movement (in general); komplexe Großmassenbwegung: complex large mass movement; Bewegungszone (allgemein): area of movement (in general); Buckelwiese: area with buckles; Transportbereich: transport area; zerglittene, zerrüttete Zone: area which was weathered by slides and tectonics; Stauwulst (allgemein): accumulation ridge (in general); Akkumulationsbereich: accumulation area; Teilscholle: sliding mass piece; Abrissbereich: detachment area. Original scale 1:25,000. (Source: GBA)

Fig. 10. Extract of the webGIS database interface "Mass movements in Austria" showing the rock fall of Eiblschrofen in Tyrol. It includes literature references, web-links, region, date of event, landslide types and locality (Source: GBA)

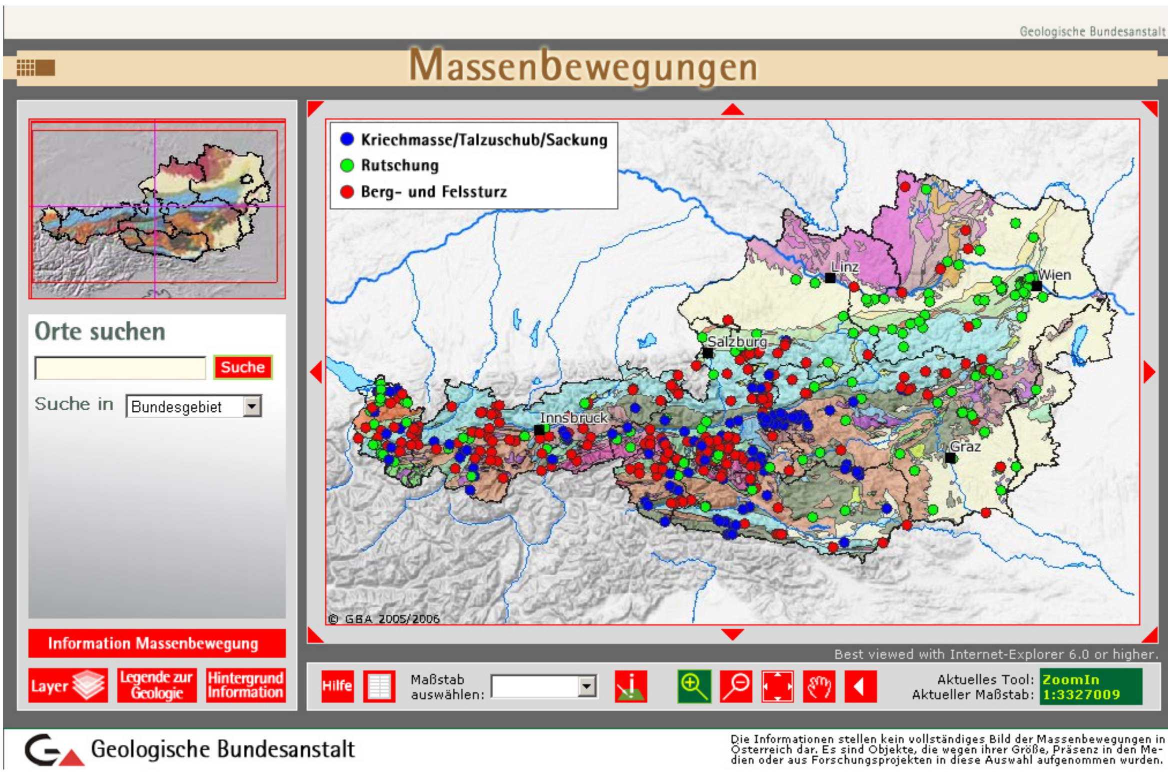


Fig. 11. Screenshot of the overview map of the webGIS database "Mass Movements in Austria". Kriechmasse/Talzuschub/Sackung: creep mass/rock creep/Sackung; Rutschung: slide; Berg/Felssturz: large/medium rock fall or rock slide. Display scale 1:3,000,000 (Source: GBA, http://www.geologie.ac.at)

Landslide susceptibility and hazard maps

The GBA has produced digital landslide susceptibility maps at scales of 1:50,000 and 1:200,000. The 1:50,000 maps were generated for small regions in Carinthia and Styria using artificial neural network analysis. The free software JAVA_NNS 4.2 was used for this purpose. As neural network was used a feed/forward multilayer *Perzeptron* with one or more hidden layers. In the resulting maps two levels of susceptibility are differentiated: susceptible and non susceptible. The 1:200,000 maps were produced for the whole federal state of Carinthia using a heuristic approach. This methodological approach was supported by data from geological maps and GTL maps (engineering geological maps with geotechnical characteristics of lithological units) and knowledge of local landslide experts. In the resulting maps, four landslide susceptibility levels, namely stable, low, medium and high, are shown separately for falls/topples and slides (Fig. 12).

In addition to the above mentioned maps, in the region Gasen / Haslau (Styria) GBA, in cooperation with the Institute of Geography of the University of Vienna, produced landslide susceptibility maps at 1:30,000 scale over an area of 60 km^2 using a qualitative approach with parameter maps and a quantitative approach with multivariate statistics. These approaches are described in internal reports of GBA and in a master thesis of the University of Vienna (Petschko, 2008).

GBA also produces digital landslide hazard maps, which show the hazard potential for slides. To generate these maps, various sources of information were used including landslide temporal frequency, remote sensing data (e.g. laserscan and aerial photographs), and also historical archives of Austrian Torrent Control, municipalities and Church. Nevertheless, historical data on landslides in Austria are poor.

The digital hazard maps were produced at 1:10,000 scale in a recent project using ArcGIS software (Spatial Analyst, 3D Analyst and Arc Scene). They were generated for different areas with a maximum extension of 30 km^2.

At the moment the landslide susceptibility and hazards maps are only available for internal use of GBA and the Carinthia administration. They are available only in German. GBA has not produced landslide risk maps.

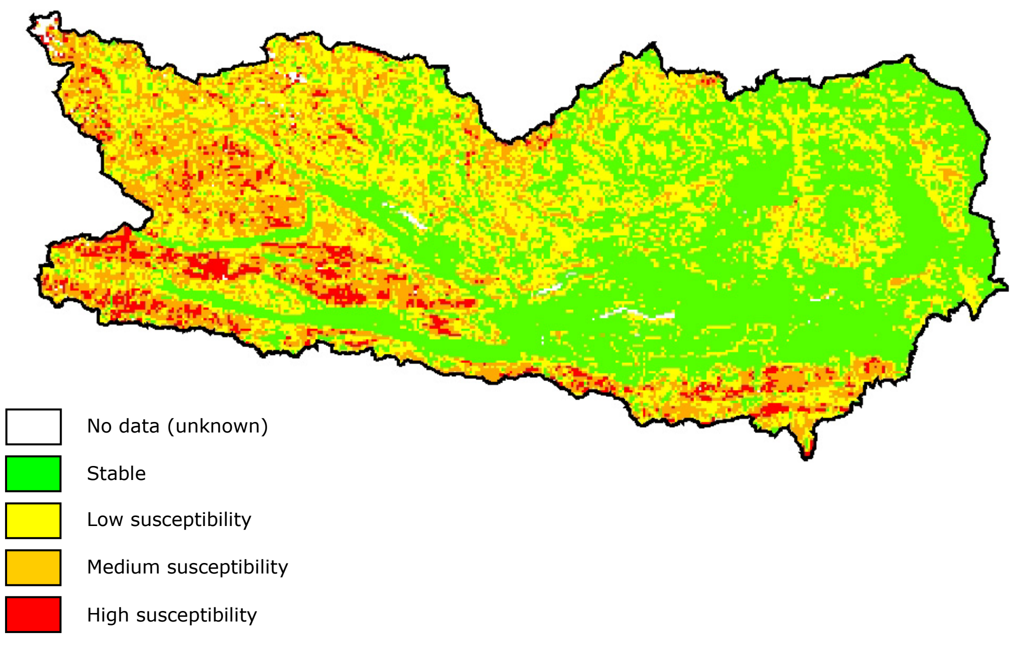


Fig. 12. Landslide susceptibility map of Carinthia showing four susceptibility classes (Source: GBA). For details see the chapter of local government of Carinthia. Original display scale 1:750,000

3.1.2 Austrian Service for Torrent and Avalanche Control (WLV)

The Austrian Service for Torrent and Avalanche Control (*Forsttechnischer Dienst, Wildbach- und Lawinenverbauung,* WLV) is working in the whole of Austria. In each federal state there are one or more independent units (Gebietsbauleitungen) documenting torrents, rivers, floods, avalanches and landslides. The headquarters report to the department IV/5 of the Ministry of Agriculture, Forestry, Environment and Water Management at Vienna.

The landslide data and maps of WLV are regulated by the Austrian forest law (Forstgesetz 1975), the Austrian hazard zone regulation (Gefahrenzonenplanverordnung 1976) and the different spatial and construction laws (Raumordnungsgesetze und Bauordnungen) of the nine federal states.

Since 1975, the WLV has an inventory of landslides for the whole country, which currently contains over 1000 landslides. For each landslide there is a description of the triggering factors and the susceptibility and ancillary information in the area. The most recent landslides (younger than 10 years) are in digital format, while the older ones are still in paper format. The digital versions are based on CAD, ArcView and ArcGIS combined with Oracle. The map scale ranges from 1:50,000 to 1:25,000 (overview maps) and from 1:5000 to 1:2000 (detailed maps). In the overview maps the landslides are shown as points and lines; in detailed maps, as areas. The landslides are mapped by field survey and investigation of historical data.

Also since 1975, the Austrian Service for Torrent and Avalanche Control produces hazard maps for floods, avalanches and debris flows within torrent buffer areas. The hazard maps for floods and debris flows (Fig. 13) are produced by field survey and computer simulation software and consider a 100-year return period for the events. In addition, the hazard maps display “purple” reference areas, which represent a protective function and its efficiency should at least be maintained at the present level.

The WLV has also landslide susceptibility maps based on a heuristic approach. The landslide areas are mapped in field surveys, mostly when the landslide is near or influenced by a torrent. An expert decides from fieldwork, literature review and historical archives if an area is susceptible to landslides or not. On the maps, the areas susceptible to landslides are enclosed by brown borders. Within these polygons a letter indicates the type of landslide, mainly grouped as slides (R) and falls (ST) (see Fig. 14). It is possible to add also other types of landslides using other letters. On the susceptibility maps, only one class/level of susceptibility is represented.

Both landslide susceptible areas and hazard areas for floods, avalanches and debris flows are mostly presented on the same map (Fig. 14).

One part of the landslide susceptibility and hazard maps is digital and the other in paper format. Some local regions, e.g. “Bucklige Welt” in Lower Austria, are not yet mapped. The digitalization and mapping of the whole Austria will be completed in 2010. However, there is still an issue that databases and maps of the Austrian Service for Torrent and Avalanche Control represent only a minor part of the landslides existing in Austria, because only those within torrent buffer areas are considered.

Apart from debris flows the WLV has no hazard maps for other types of landslides. The hazard maps are stored in the same digital database as the inventory maps. Also risk maps for floods, avalanches and debris flows exist, but only for small localities.

The WLV data, which are only documented in German, are publicly available free of charge at municipalities, district authorities (*Bezirkshauptmannschaften*) and local government offices. In some states (e.g. Styria) all data and maps are available in a digital database. The others states will follow in the next years.

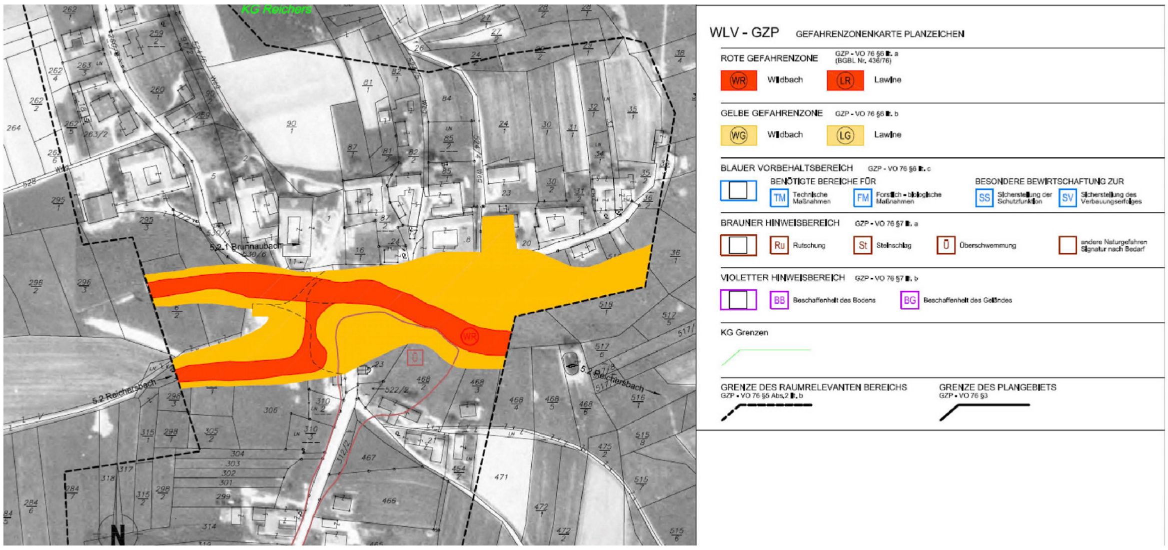


Fig. 13. Hazard map of floods and debris flows. Red area means high hazard of flood and debris flow; yellow area, middle hazard of flood and debris flow, with land register map and black and white aerial photo at 1:2000 scale as background. WR: torrent red area; WG: torrent yellow area. In the red zones all construction activities are forbidden due to high risk. In yellow zones buildings are allowed under certain conditions, damages of objects are possible, but not high. For avalanches there are also the same two classes: LR for red area and LG for yellow area. There exist blue reservation areas (*Blauer Vorhbehaltsberei)* which are dedicated to implement forestry, biological or technical measures, for example a protection dam. (Source: WLV)

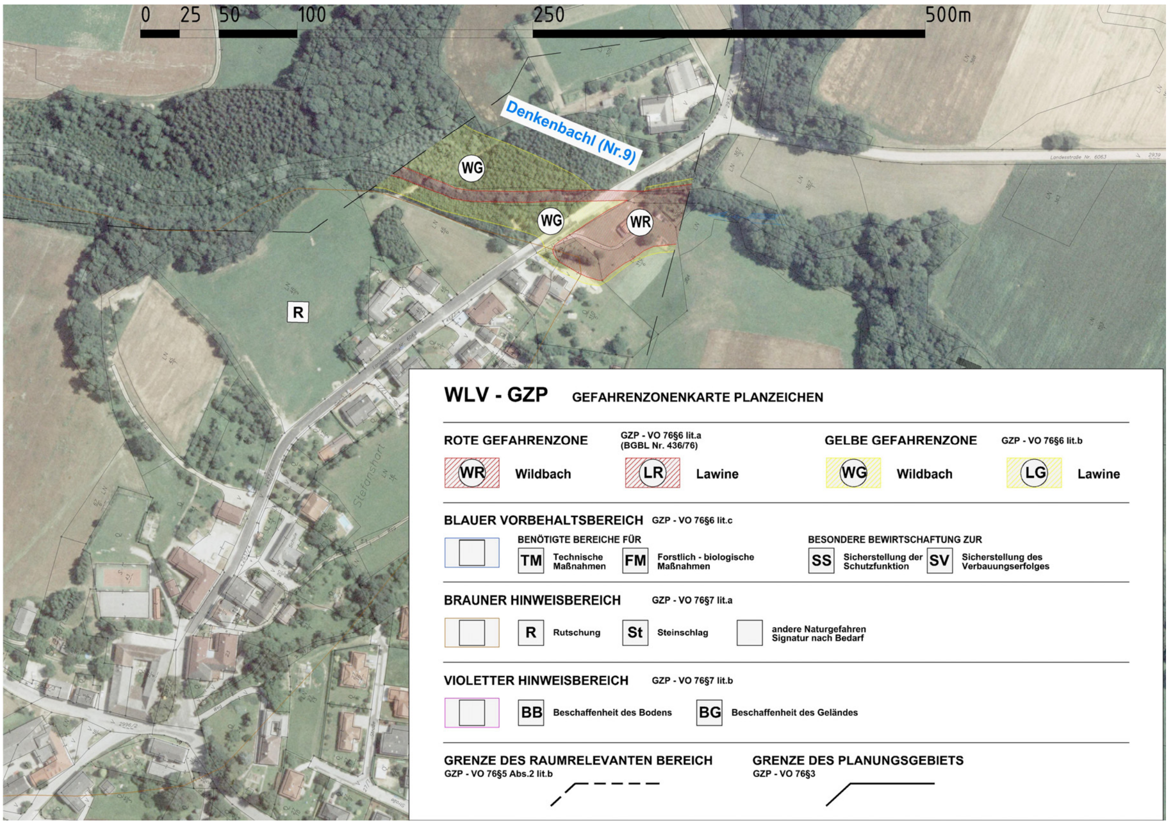


Fig. 14. Extract from the hazard map for floods and debris flows and the landslide susceptibility map of the municipality of Ardagger (Lower Austria). Red and yellow areas are hazard zones of floods and debris flows; brown polygon: landslide susceptibility area. Red with WR: red high hazard zone of torrent and debris flow; red with LR: red high hazard zone of avalanche; yellow with WG: yellow medium hazard zone of torrent; LG: yellow hazard zone of avalanche; Blauer Vorhbehaltsbereich: blue reservation area for protection works *Brauner Hinweisbereich*: brown landslide susceptibility area, with R: slide and flows, St: rock falls, without other mass movements or erosion phenomena (Source: WLV, Melk)

3.1.3 Joanneum Research

Joanneum Research is a private research institute of the Styria government in Graz. This organisation is mainly funded directly by the Styria government and through research projects (see http://www.joanneum.at). Joanneum, in cooperation with other institutions, has produced digital databases and maps of landslides of three different regions in Austria as a result of the following research projects:

1) Risk analysis of geological natural hazards in the alpine space (commissioned by the government of Styria and the Austrian Ministries of Science and Agriculture and Forestry, 2001). The study area was the Schladminger Tauern in Styria (Fig. 15, 16).
2) ASSIST-Alpine Safety, Security and Informational Services and Technologies" (EU 6th Framework Programme, Priority "Aeronautics and Space" – GMES, 2007). The study area was the Verwallgruppe in the Lechtal Alps in Tyrol (Fig. 17, 18).
3) Estimation of the risk of slides and slope movements in Gasen/Haslau in Styria (commissioned by the Ministry of Agriculture and Forestry, Austrian Service for Torrent and Avalanche Control, in cooperation with the Geological Survey of Austria, the Research and Training Centre for Forests, Natural Hazards and Landscape and GeoLith Consult, 2007).

The size of the study areas ranges between 60 and 300 km^2. Information about landslides is not systematic: mostly only type, location and area of extension (as polygons) are represented. Only in project 3 (Gasen/Haslau) a qualitative result is available with respect to the certainty of classification based on remote sensing data without ground verification. This was described in three steps: assured, supposed or indicative. All three projects have separate digital databases done with ArcGIS.

The database of project 1 (Schladminger Tauern) contains 256 landslides, that of project 2 (Lechtaler Alpen) 1060, and the database of project 3 (Haslau) includes 1051 landslides. The map scales for the three projects are 1:50,000 (Fig. 15), 1:25,000 and 1:5000 respectively. Project 1 maps cover an area of 300 km^2; project 2, 120 km^2, and project 3 a total area of 60 km^2. Thus these databases cover only a very small part of Styria and Tyrol, and they do not include all existing landslides in the studied areas.

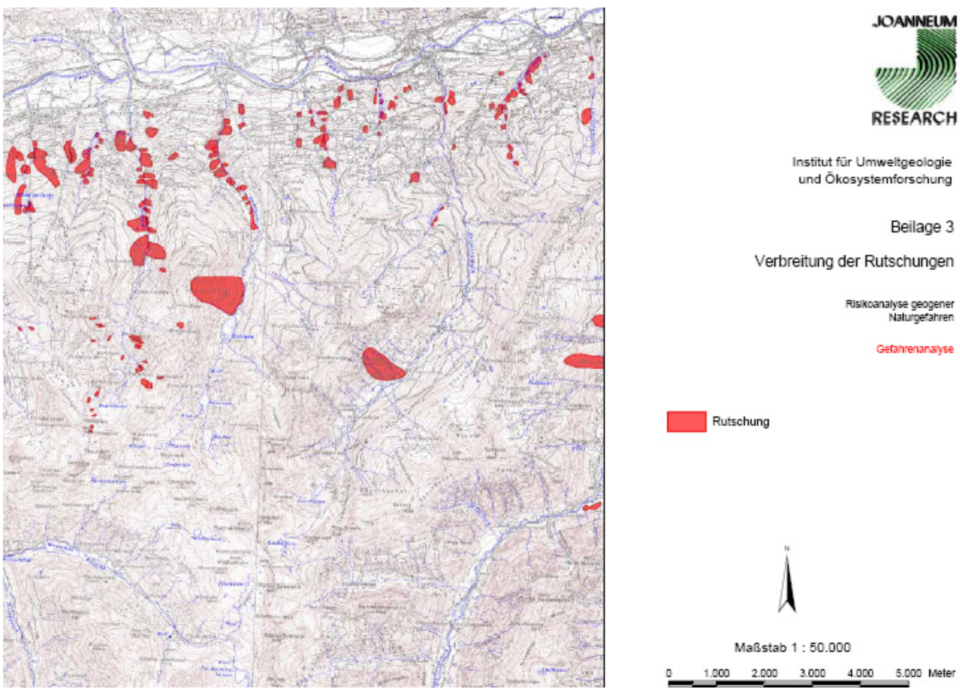


Fig. 15. Distribution of existing slides for project 1, Schladminger Tauern, Styria. Key: Rutschung: slide (Source: Joanneum Research)

The digital database for project 1 was created in year 2000, that of project 2 in 2006, and the database of Gasen/Haslau in 2007. The databases were not later updated by Joanneum Research due to expiry of the project work.

The data and maps of project 3 (Gasen/Haslau) are stored in the digital GEORIOS database of the GBA (see chapter 3.1.1, Fig. 7, 8, 9) and updated regularly.

In addition, Joanneum Research has produced landslide susceptibility maps on ArcGIS as a result of project 1 (Schladminger Tauern) and project 2 (Lechtaler Alpen). Project 3 only delivered landslide inventory maps. Afterwards the University of Vienna, in collaboration with GBA, produced landslide susceptibility maps at 1:30,000 scale of Gasen/Haslau using a statistical approach. A brief outline of the methodological approach of Joanneum Research follows:

- Project 1: Generation of susceptibility maps (zonation maps) at 1:10,000 scale of selected catchment areas (the study area covered 30 km^2) on the basis of statistical methods (logistic regression). Logistic regression is a statistical model used for the prediction of the probability of occurrence of an event by fitting data to a logistic curve. It makes use of several predictor variables that may be either numerical or categorical. Specially designed statistics programs are required for the calculation (Proske et al. 2001).
- Project 2: Generation of a susceptibility map at 1:25,000 scale of the whole study area on the basis of statistical methods combined with thematic information derived from remote sensing data (VHR satellite data and LiDAR). The study area of this project had an extension of 200 km^2. The susceptibility maps were produced by using the combination of two methods: The weights of evidence (Bonham-Carter et al., 1989, see also 3.2.1) and a method by van Westen (1993). Weights of evidence is a quantitative method for combining evidence (facts) in support of a hypothesis. In spatial application the evidence could be geological zones divided into more classes. The method by van Westen (1993) is based on pairwise map crossing of parameter maps with a landslide occurrence map in order to evaluate the importance of each of the maps. Weighting factors are introduced which are a measure of the amount by which mass movements within a class are over- or under-represented. The weight values for the variable class are added to produce a susceptibility map.

In both projects five susceptibility classes are shown on the maps.

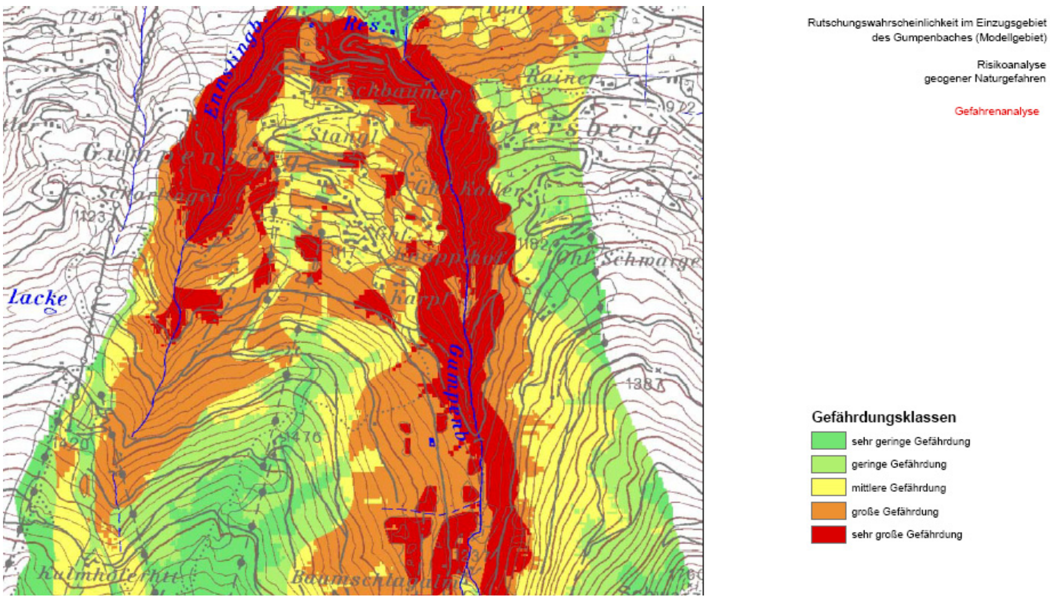


Fig. 16. Landslide susceptibility map of Schladminger Tauern, Styria (project 1) showing susceptibility classes, from very high (in red) to very low (in green). Original scale 1:25,000 (Source: Joanneum Research)

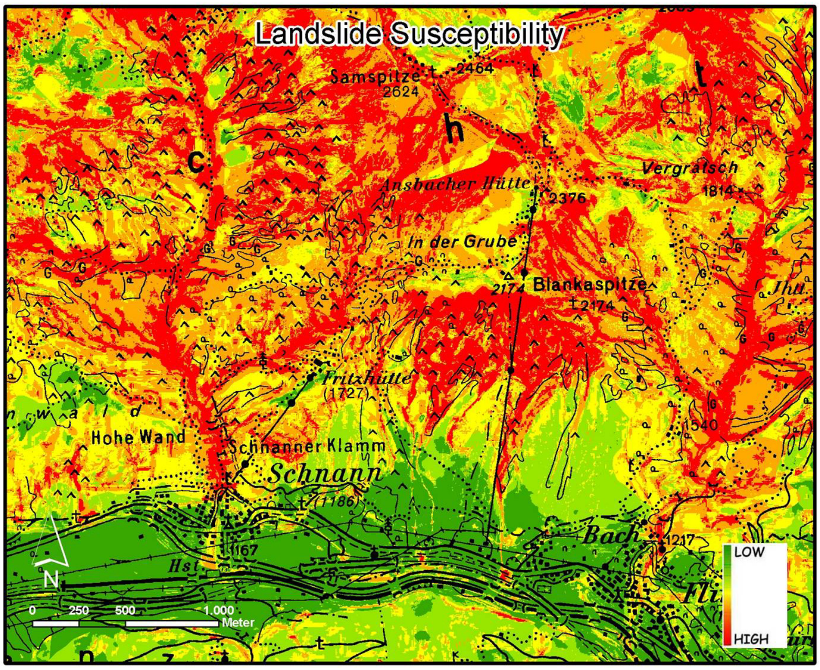


Fig. 17. Landslide susceptibility map of the Schnann area in Tyrol from the project ASSIST. Five susceptibility classes are depicted, from very high (red) to very low (green) (Source: Joanneum Research)

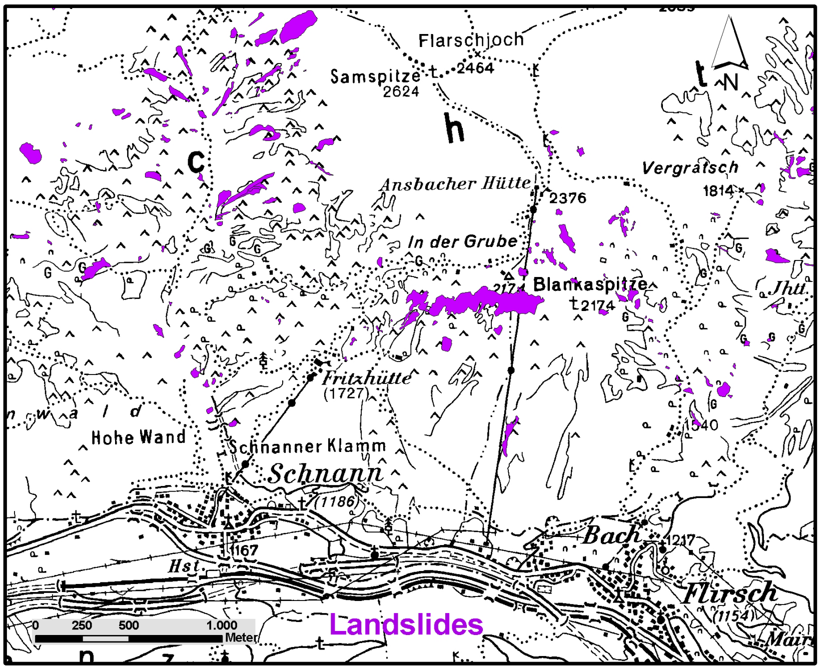


Fig. 18. Landslide inventory map of the Schnann area in Tyrol from the project ASSIST (Source: Joanneum Research)

Joanneum Research has neither produced landslide hazard nor risk maps. The data are neither available on the web nor in English, but they can be consulted at the offices of the relevant commissioners (ordering government offices).

3.1.4 AlpS

AlpS (*Zentrum für Naturgefahren Management GmbH*) is also a privatized research centre for natural hazards under control of various universities, the Tyrol government and private companies in Innsbruck (see http://www.alp-s.at/v2/www/home/home.php).

AlpS has produced a landslide inventory database (Fig. 19, 20). The database contains information on type of landslide, type of process, locality, coordinates, lithology, age and bibliographical references. In total, the inventory contains more than 600 documented landslide events, especially debris flows. It is a digital MS Access database linked with ArcGIS. The map scale of the inventory is 1:200,000. Landslides are represented on the maps as points, other symbols and colours depending on process type and age (paleo, recent, unknown, etc.).

The database contains recent and fossil landslides, mainly in the region of Tyrol and surrounding areas, covering an area of approximately 30,000 km^2 (see also Prager et al., 2008). All well-known and large landslides are represented in this inventory; smaller and hardly reachable landslides are not recorded. There exist, however, many non recorded landslides in this area. The database has been created in recent years and last updated in April 2008. It is not available on the web, and it is available only in German. Further information is provided by Prager et al. (2008).

AlpS does not have landslide susceptibility or hazard maps, or landslide risk maps. The methods used by AlpS for landslide mapping and risk management for single small study cases are described in a special report of the Austrian Service of Torrent and Avalanche Control and in reports by BUWAL, Switzerland (Heinimann et al., 1998; Lateltin et al., 2005).

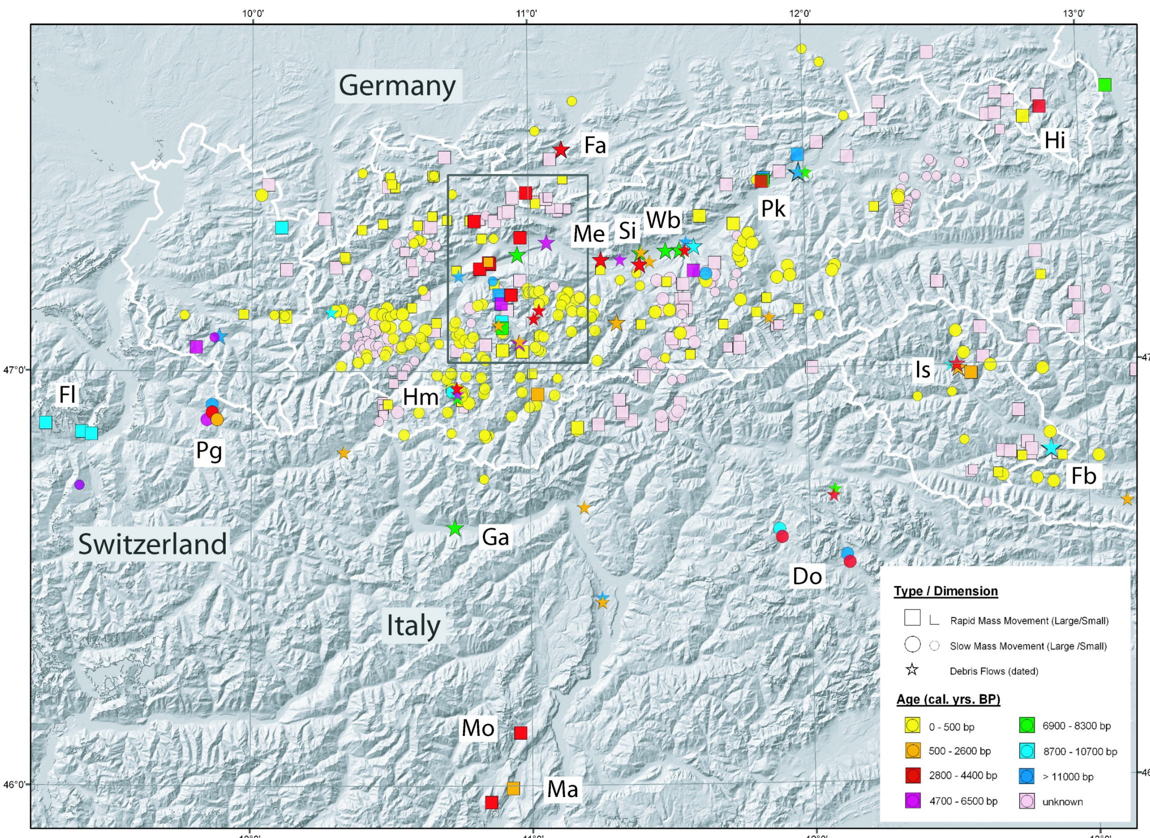


Fig. 19. Overview map of fossil and recent landslides in Tyrol and surrounding areas. Outside Tyrol only fossil landslides are shown. Display scale 1:2,000,000 (from Prager et al., 2008, Fig. 12)

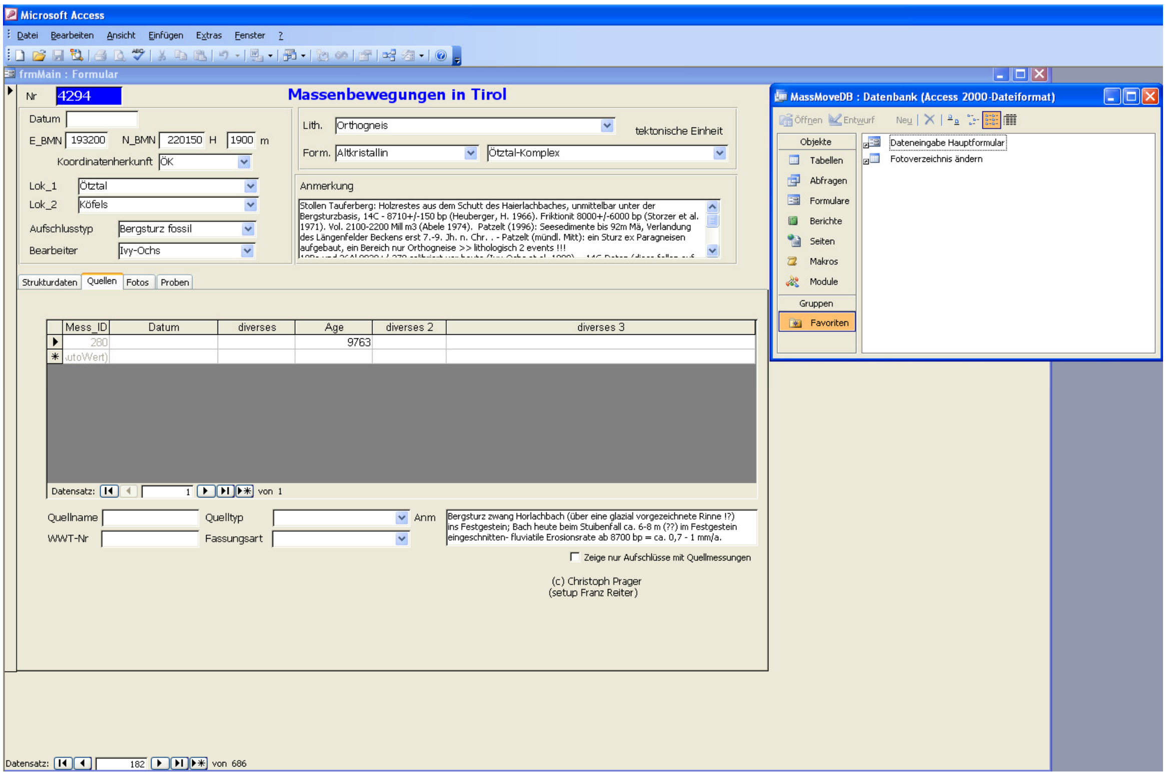


Fig. 20. MS Access database of landslides of AlpS. Massenbewegungen: landslides. Lith.: lithology; Form: Formation; tektonische Einheit: tectonic unit; Anmerkung: Notes; Lok1 and 2: locality; Auffschlusstyp: type of outcrop, in this case type of landslide; Bearbeiter: name of person mapping the landslide; Strukturdaten: description of the landslide; Quellen: springs, streams; Proben: samples (Source: AlpS)

3.1.5 Austrian Railways (OBB)

Within the Austrian Railways (OBB) organisation there are two companies dealing with landslides, OBB Infrastructure Service AG (*ÖBB Infrastruktur BetriebsAG*) and OBB Infrastructure Construction AG (*ÖBB Infrastruktur Bau AG*). Only OBB Infrastructure Service AG provided detailed information for the survey.

Austrian Railways (OBB) do not have a landslide inventory. However, they have reports with data and maps of single landslides, as well as hazard maps of different railway tracks in Austria. The single railway stations record all events affecting the railroad in their district, including also landslides.

Based on fieldwork and the above mentioned reports and maps in paper form the OBB has generated digital landslide susceptibility maps at 1:25,000 scale of the whole railway network of Austria (6000 km), using ArcGIS (Fig. 21). These maps show three susceptibility classes. The area of investigation starts from the railway track on both sides up to a minimum 500 m distance or maximum to the next water divide. The maps are produced by a heuristic approach using GIS tools. OBB used the existing geological and geomorphological maps, the above mentioned event records, geotechnical studies and single field surveys to produce the digital landslide susceptibility maps.

The maps are not accessible to the general public and are only available in German. They were produced between 2007 and 2008, till the project finished. From June 2008 to 2010 they are producing digital landslide susceptibility maps of the railway network at scales from 1:5,000 to 1:10,000. The OBB has neither landslide hazard nor risk maps.

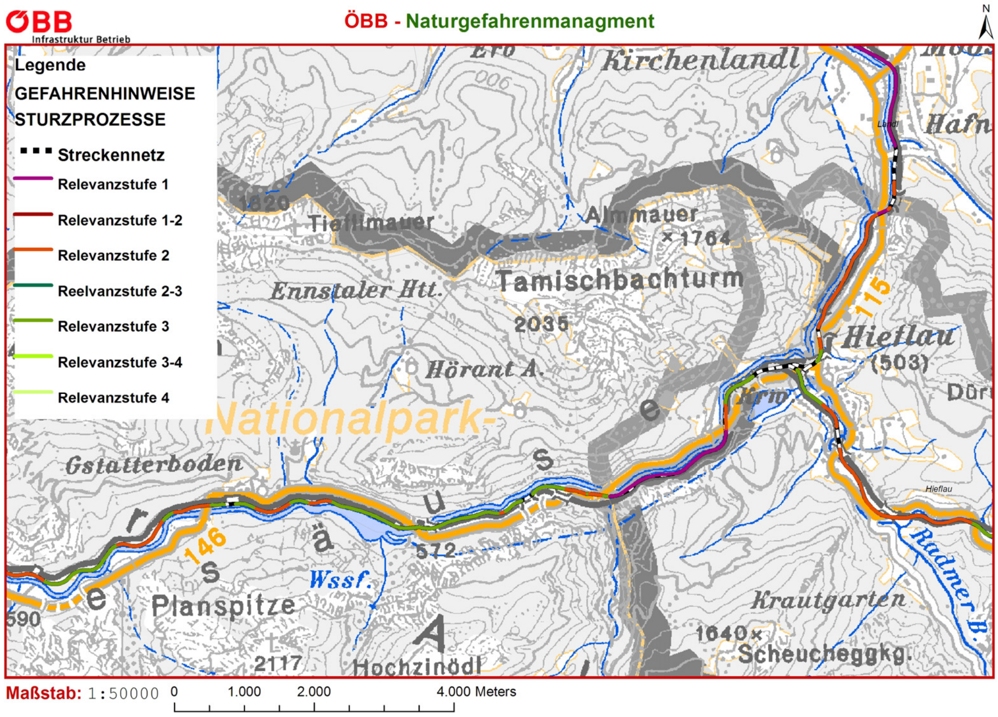


Fig. 21. Landslide susceptibility to rock falls along railway corridors, expressed as priority level for further investigations. The black and white dashed line is the railway track, the orange line with the number (146) represents the state road. The priority polygons are divided into 4 classes, magenta to green. Magenta is associated with zones were detailed investigations and field studies are most urgently needed; orange: high priority for further investigations; blue: further investigations necessary; green: no further investigations needed (Source: ÖBB BetriebsAG)

3.1.6 Other organisations dealing with landslides in Austria

There are some other organisations in Austria which also deal with landslides. The Austrian Motorway company called ASFINAG is in charge with remediation and control of many landslides affecting motorways and highways in Austria. Unfortunately, they did not provide any feedback to the questionnaire. We assume that they do not have landslide inventory, susceptibility, hazard or risk maps. They have certainly event and geotechnical reports of landslides occurred along their roads.

Another organisation which did not provide information was the Tyrolean Section of the Austrian Service of Torrent and Avalanche Control, which has a geological survey working in the whole Austria. It is known, however, that they have landslide inventory maps.

The Research Centre of Forest and Natural hazards of the Ministry of Agriculture, Forestry, Environment and Water Management (*Bundesversuchs- und Forschungsanstalt für Wald und Naturgefahren des Bundesministeriums für Land- und Forstwirtschaft, Umwelt und Wasserwirtschaft*) in Vienna also did not answer our questionnaire. However, some research work on landslides in Austria in the last years was published by Andrecs and Hacker (2005).

Last but not least we have to mention the universities in Austria that have geological, geotechnical and geomorphological institutes. These are located in Vienna, Graz, Salzburg and Innsbruck. All of them certainly have carried out studies and produced maps of landslides in Austria (e.g. Heuberger, 1975; Van Husen and Fritsch, 2007). Just few of them are also producing landslide susceptibility maps over very local areas, mainly for research purposes (e.g. Department of Geography and Regional Research, University of Vienna).

3.2 Regional maps and databases

3.2.1 Burgenland

Burgenland is the easternmost federal state of Austria bordering on Hungary, having a total area of 3,965 km^2. In this province, the landslide data and maps are collected and produced by the Geological Survey of the Department of Culture and Science (*Abteilung 7, Kultur, Wissenschaft, und Archiv*) of the federal state government.

In Burgenland, an inventory of landslides does not exist, but there are digital landslide susceptibility maps. Single records and reports of landslides in paper form are available in the archive of the Geological Survey. The Austrian Research Centers at Seibersdorf, financially supported by the federal state government, are producing landslide susceptibility maps since 2005. Until now 70% of the province is mapped. The project will end in 2009.

In the past few years an increasing number of landslides have occurred in Burgenland, where mostly infrastructure and buildings in the southern part of the province were affected. The object of the project "landslides: trigger analysis, susceptibility maps and guidelines for spatial planning" of Austrian Research Centers is the systematic collection of data on historical and recent landslides and their triggering factors. The probability for future landslides is calculated with spatial statistical methods over the extent of the study area. The generated landslide susceptibility maps should be a useful tool for spatial planners. Most of the project data are provided by government organizations. These are geological maps from the Geological Survey of Austria at scales of 1:200,000 to 1:50,000, data from land cover/use from the European Corine Land Cover database, 10 m resolution digital elevation models (DEM), orthophotos and topographic maps. Also field work and contact to local authorities was done (see also Klingseisen et al., 2006).

For the prediction of landslide susceptibility based mainly on morphological and geological factors, the probabilistic method called "Weights of Evidence (WofE)" was chosen (Bonham-Carter et al., 1989; see also section 3.1.3). It works with the assumption that future landslides would be triggered or influenced by the same or similar controlling factors as already registered landslides. In ArcGIS Desktop, the method is accessible as part of a Natural Resources Canada's ArcGIS extension Arc-SDM (Arc-Spatial Data Modeler), which is freely available from the website www.ige.unicamp.br/sdm. In the project, five factors were analyzed for correlation with landslide events: Geology, land use, slope angle and aspect and terrain roughness. Slope angle in % was calculated and divided into 10 classes with a range of 5% for each class. The aspect (slope orientation) shows a certain degree of correlation with the occurrence of landslides. Aspect was calculated from DEM and classified in steps of 45 degrees. The terrain roughness describes the ratio between surface area and horizontal area. It was retrieved from the DEM using the ArcView extension "Surface Areas and Ratios from Elevation Grid" (Jenness, 2004; Tagil and Jenness 2008).

The landslide susceptibility maps on a scale 1:25,000 are in digital and paper format (Fig. 22, 23). They display the occurred landslides (only slides, as they are the dominant landslide type in Burgenland) and areas prone to future landsliding, estimated with the above mentioned method. Based on the probability of landslide occurrence the following areas are distinguished: high susceptibility, susceptibility, susceptibility not excludable, no susceptibility, susceptibility by shallow and local events. The probability of landslide occurrence is expressed as value between 0 and 1. The type of landslide is not shown on the maps, but it is reported in the database.

The susceptibility model used was calibrated with 130 landslides mapped in the field in different representative geological units and locations. They account for more than 90% of the landslides. So far the maps of southern and middle Burgenland with the districts of Guessing, Jennersdorf and Oberpullendorf are finished.

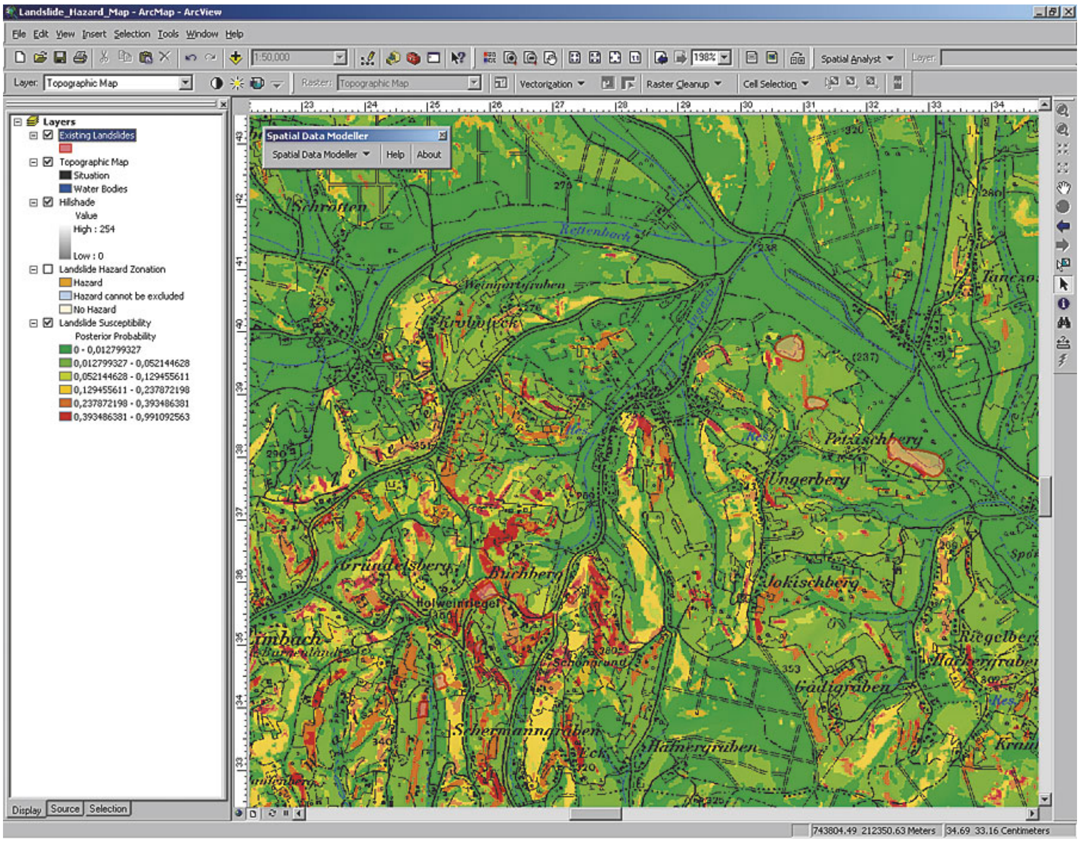


Fig. 22. Landslide susceptibility map of Burgenland. Scale 1:50,000 (Source: Klingseisen et al., 2006)

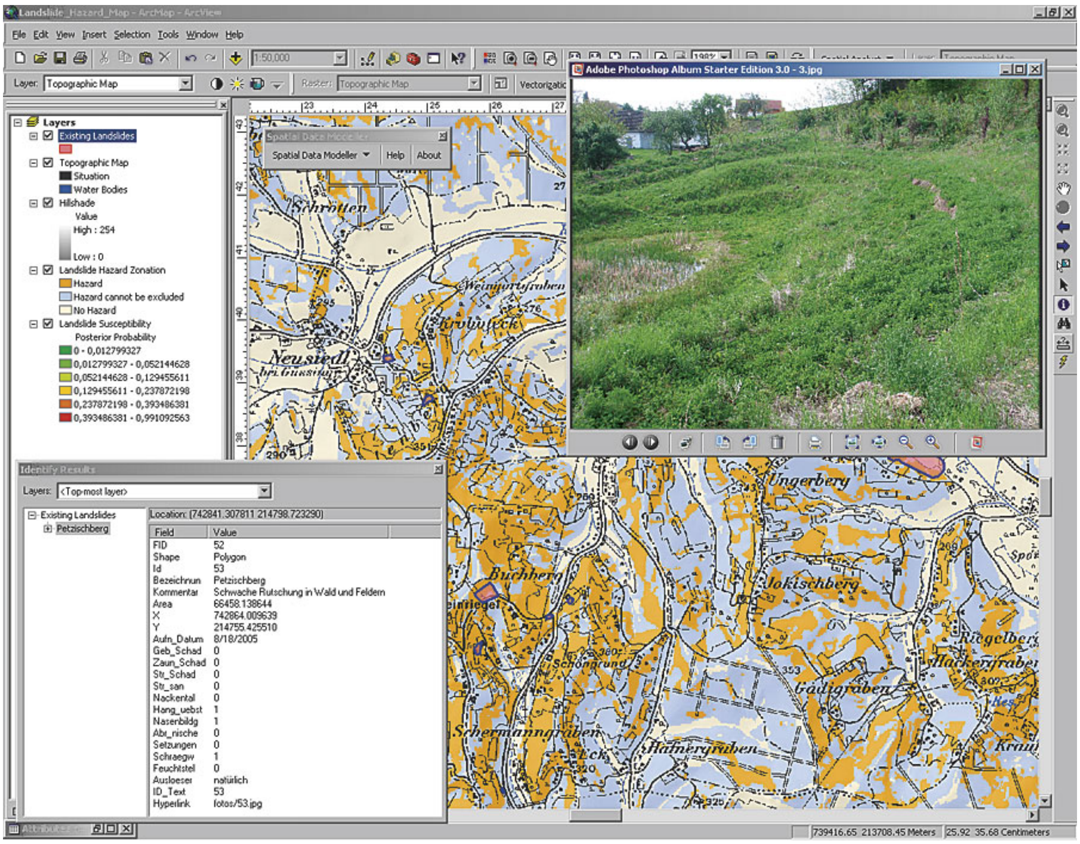


Fig. 23. Landslide susceptibility map of Burgenland with priority zonation. Scale 1:50,000 (Source: Klingseisen et al., 2006)

The landslide susceptibility maps and the database are only in German language and confidential until the end of the project, so not available for people outside of the local government of Burgenland. Obviously the data are not published on the web except some scientific publications of the Austrian Research Centers.

In Burgenland no landslide hazard or risk maps exist, except the hazard risk maps of floods and debris flows of the Austrian Service for Torrent and Avalanche Control (see chapter 3.2). In this state, there is no existing law for landslide databases and maps. Some information about the project of the landslide susceptibility maps in Burgenland is available on the web, partially in English (Klingseisen and Philipp, 2006) and at the website of Austrian Research Centers (http://www.arcs.ac.at/downloads/Hangrutschung.pdf and http://www.natural-resources.at/default.asp?mode=jumplang&id=3&lid=2).

3.2.2 Vienna

Vienna (*Wien*), capital of Austria and federal state all in one, is the smallest province with 414,9 km^2, but has the highest population. Vienna is located in the eastern part of Austria and is surrounded by Lower Austria.

Within the local government of Vienna, the Department of Bridge and Civil Engineering (MA 29, *Magistratsabteilung für Brücken- und Grundbau*) has neither landslide inventory nor susceptibility, hazard and risk maps. They have a digital database with geology, outcrops, drilling sections and geotechnical studies. This database in German is partly not available to public and contains some reports on landslides (http://www.wien.gv.at/verkehr/grundbau/index.html). Also the departments of spatial planning, MA 21A and MA21B (*Magistratsabteilungen für Stadtteilplanung und Flächennutzung*) do not have landslide maps or spatial planning maps containing landslide areas.

3.2.3 Lower Austria

Lower Austria (*Niederösterreich*) is the largest federal state of Austria with 19,174 km^2. The landslide inventory and maps are managed and updated by the Geological Survey, which belongs to the Construction Group (*Geologischer Dienst der Gruppe Baudirektion*). The Geological Survey has a digital landslide inventory in German, not publicly available, however accessible via the intranet of the local government. This inventory forms part of a geological database of the whole Lower Austria containing landslide data and other mass movements, all type of geological and geotechnical reports, research projects and studies done in Lower Austria. There exists also a digital drill database like in Vienna.

The geological database is built on MS Access and ESRI's ArcGIS. It describes the type of landslide, location, damages, stratigraphic and tectonic units, etc. and is linked to the original report. The mass movements (including landslides) are shown on the ESRI Arc maps as point features, symbolised as triangles (Fig. 24, 25). Here, by pointing at a triangle the main information in the database is displayed (Fig. 26). The map scale ranges from 1:200,000 to 1:1000. The inventory was created in 2000 and is updated every month. As of December 2008 the database contains 1863 mass movements. There exist also landslides not yet in the inventory.

Lower Austria has started in 2007 a project to produce landslide susceptibility maps. Until now, 12 out of 573 municipalities have been mapped. Nearly the whole province should be covered by the end of 2013. The maps of the first 12 municipalities additionally contain all kind of mass movements, contaminated sites and mining areas.

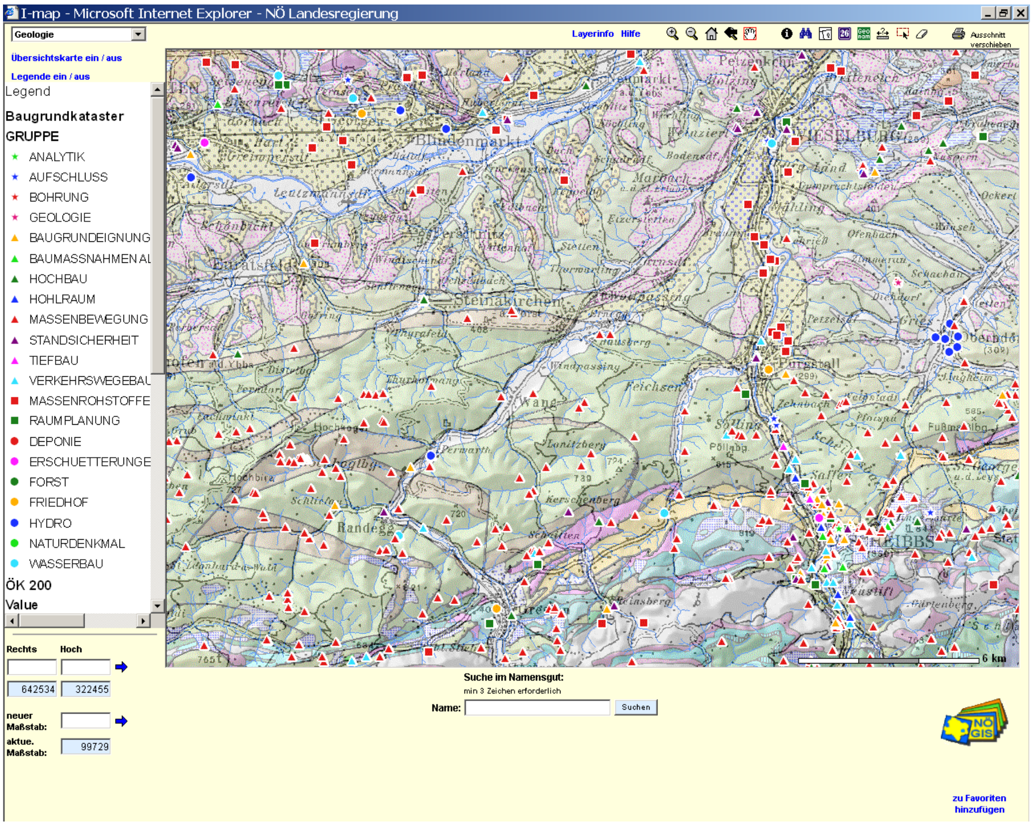


Fig. 24. Map extracted from the geological-geotechnical database of Lower Austria. Mass movements including landslides are shown as red triangles (Source: Geological Survey of Lower Austria)

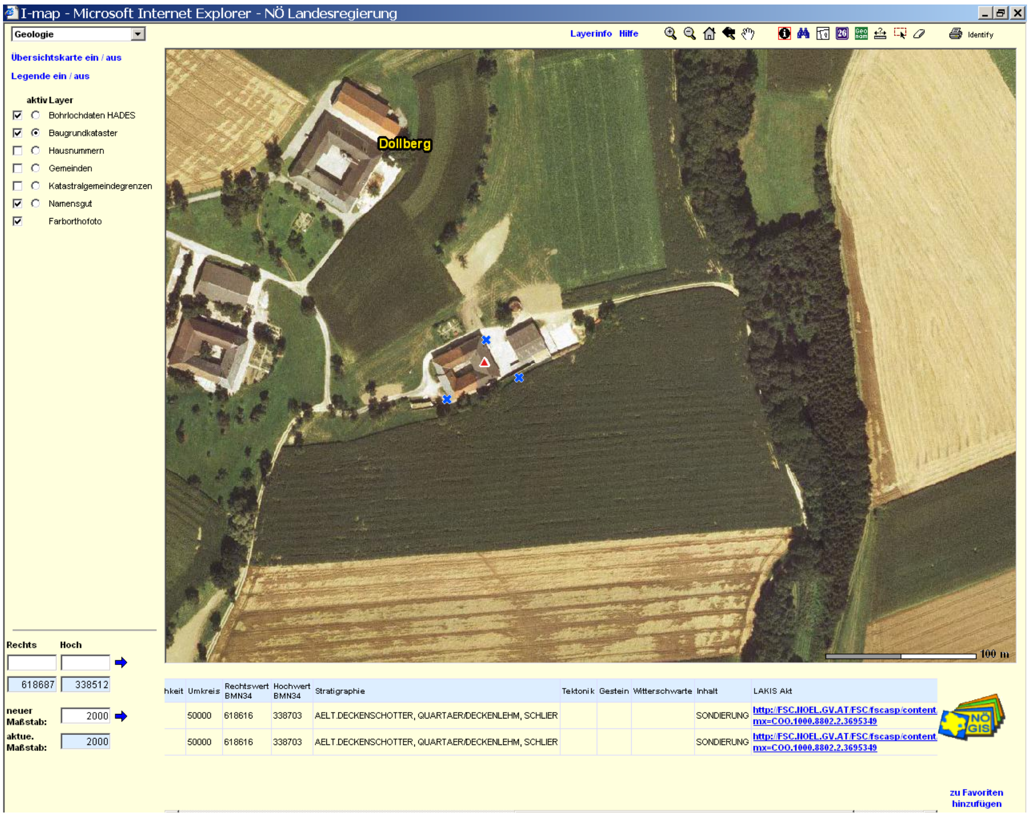


Fig. 25. Aerial photo with landslide (red triangle) and drilling locations (blue crosses), municipality of St. Valentin. In this case the whole building is affected by a slide. Extract of the geological database (Source: Geological Survey of Lower Austria)

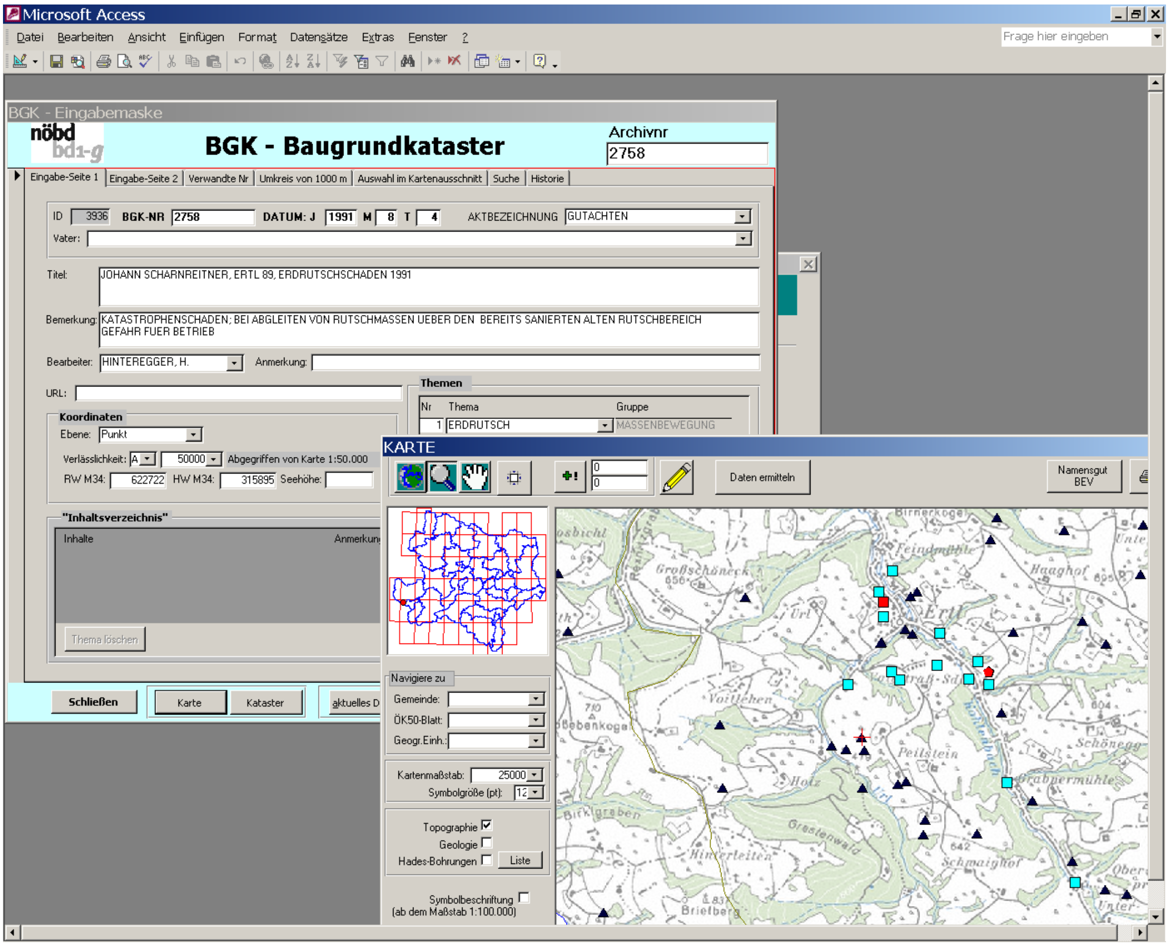


Fig. 26. MS Access mask of the geological-geotechnical database of Lower Austria. Black triangles represent mass movements including landslides. Display scale 1:25,000 (Source: Geological Survey of Lower Austria)

The susceptibility maps (Fig. 27, 28) were made using a heuristic approach based on scientific expertise on geology (lithology), historical data and the interpretation of DEM and aerial photos. They portray between three and ten classes of susceptibility at a scale ranging from 1:50,000 to 1:25,000. The maps are produced in digital format using ArcGIS and MS Access. They are in German language, and are not publicly available. By the end of the project in 2013 all susceptibility maps will be generated at 1:25,000 using a statistical approach.

Lower Austria has no landslide hazard or risk maps other than few local maps and the hazard maps for floods, debris flows and avalanche of the Austrian Service for Torrent and Avalanche Control (see chapter 3.1.2).

The landslide inventory including maps is available for public consultation on request, especially for experts working in geotechnical and geological fields. Landslide susceptibility maps will be accessible to the public after the end of the project. An English version is not planned. An overview of the landslides occurred until 1990 in Lower Austria is provided by Schwenk (1992) and Gottschling (2006).

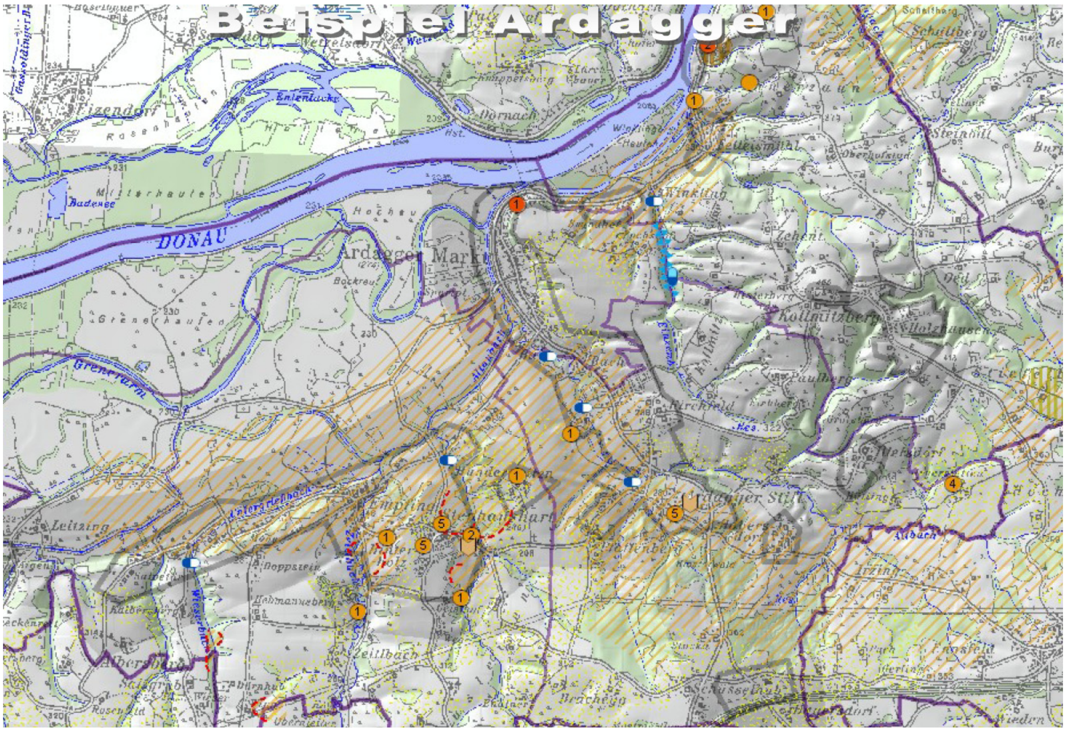


Fig. 27. Landslide susceptibility map of Ardagger, Lower Austria. All areas with orange lines are susceptible to landslides; numbers and colours indicate landslide type, activity and intensity. Original scale 1:50,000 (Source: Geological Survey of Lower Austria)

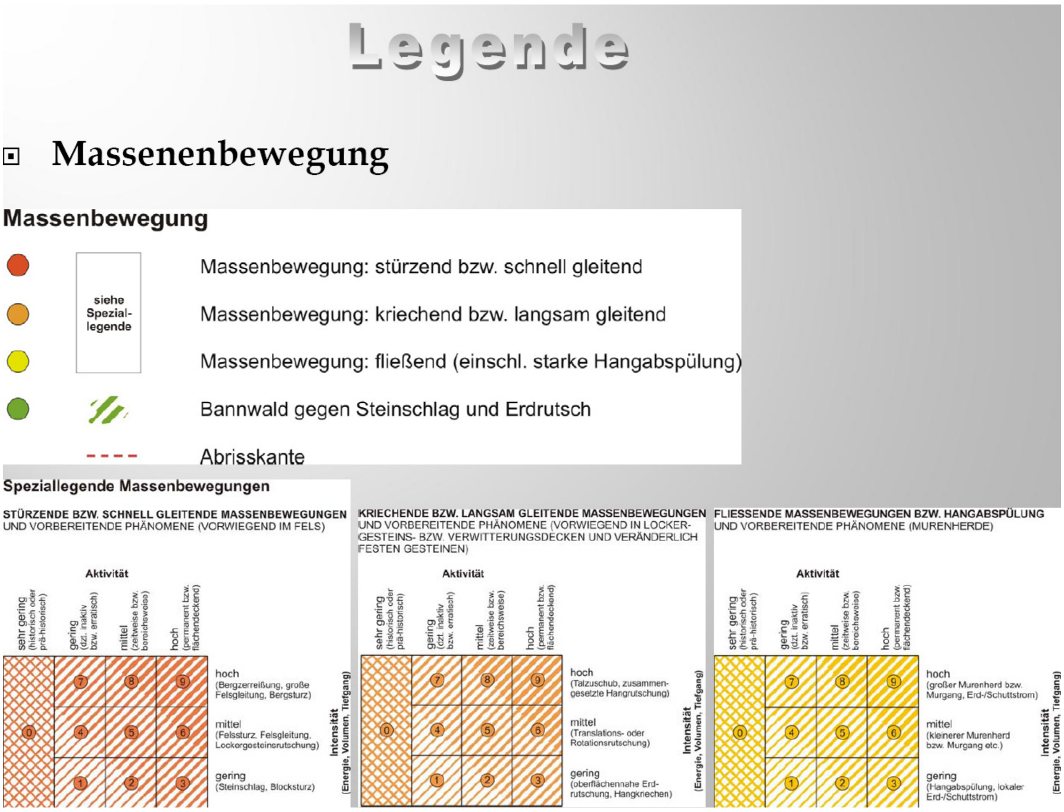


Fig. 28. Extract of the legend of the landslide susceptibility map in Fig. 27. Massenbewegung: mass movement; red circles: mass movement (fall, fast slide); orange circles: mass movement (creep and slow slide); yellow circles: mass movement (flow –mud slide, debris flow–); green circles: protective forest against rock fall and earth slide; red dashed line: scarp line. Aktivität: activity; Intensität: intensity (both three classes) (Source: Geological Survey of Lower Austria)

3.2.4 Styria

Styria (*Steiermark*) covers a total area of 16,392 km^2 bordering with Slovenia in the South. This federal state holds a large landslide inventory with maps. A part of the data is digital and the other in paper form. The paper data are hosted in different departments (Water, Roads). As of June 2008, the digital database of the LBD-GIS department contains 5813 slides. Landslides (at the moment only slides) are represented as polygons in ArcGIS at 1:5000 scale (Fig. 29). The database was created in 2005 and is updated every month.

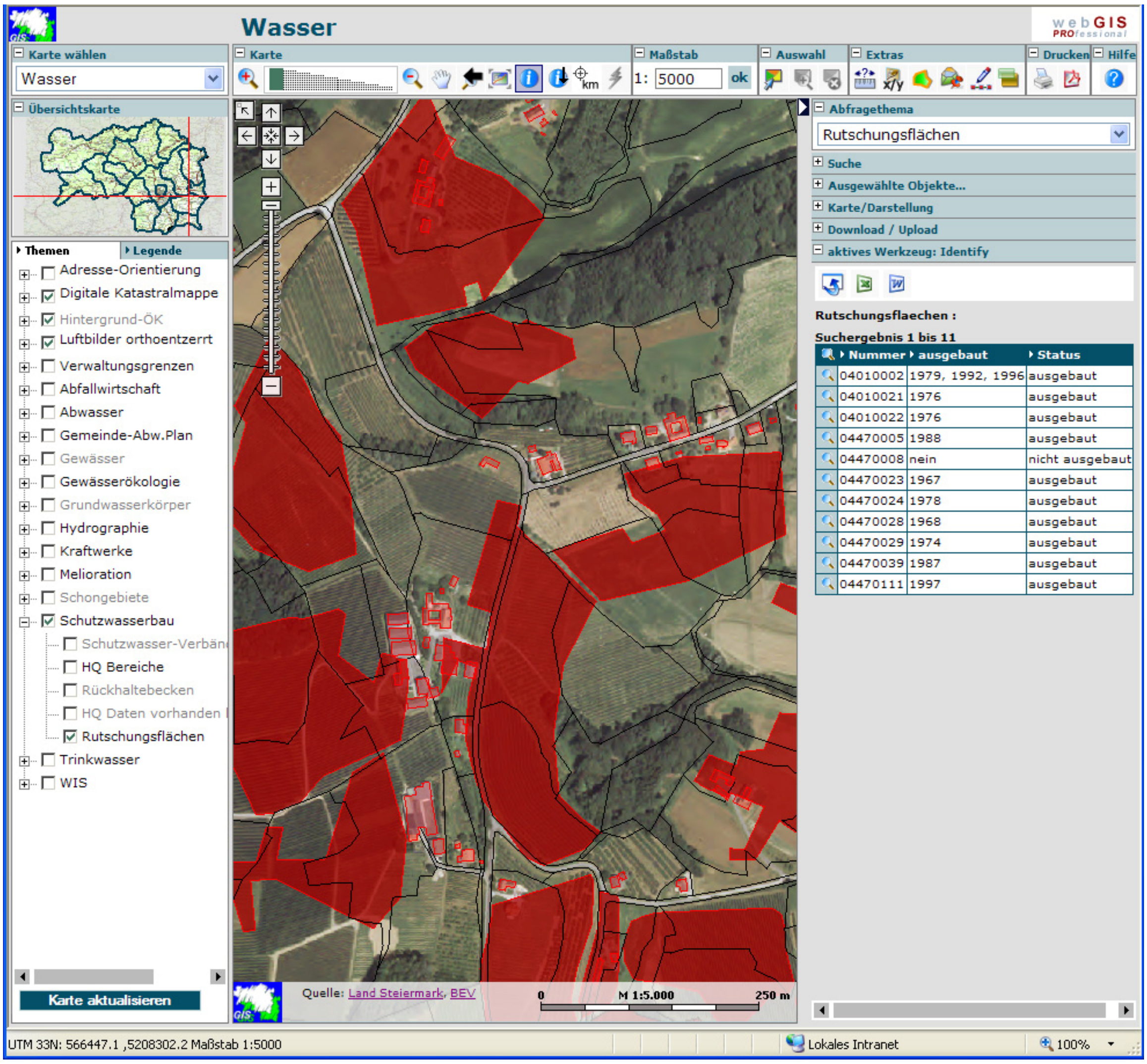


Fig. 29. Digital map of slides of Styria (Source: local government of Styria, LBD-GIS department)

The documented landslides cover approximately 60 km^2, thus amounting to 0.5% of the area of Styria. Non recorded landslides exist also in the province.

The Austrian Service for Torrent and Avalanche Control possesses digital landslide susceptibility maps of Styria as ArcGIS product. The maps, generated at 1:1000 to 1:5000 scale, include brown zones of landslide susceptibility. This digital database of WLV was developed between 2007 and 2008. Until now, approximately 40% of the region is covered.

The susceptibility areas are delineated by experts based on the knowledge of geology, historical events, slope factors and water conditions. These maps are available to the public on the web in German language (http://gis2.stmk.gv.at/gis2.stmk.gv.at/gis/da/init.aspx?kartensammlung=lfw&Karte=wlv_gefzo&Massstab=1000000). In Styria there exist also digital hazard maps for floods, avalanches and debris flows of the Austrian Service for Torrent and Avalanche Control (see also chapter 3.2).

However, only the digital database of the LBD GIS department is available on the web, but it contains also most of the WLV data on floods, avalanches and landslides.

Additionally, single landslide data and reports are collected or produced by the company Geolith Consult (http://www.geolith.at).

3.2.5 Carinthia

Carinthia (*Kärnten*) is the southernmost federal state of Austria, bordering with Slovenia and Italy. The total area covers 9,536 km^2. Carinthia's inventory of mass movements (chiefly landslides) contains 1189 events within a digital database based on ORACLE and ArcGIS and connected with a digital topographic map in raster format (Fig. 30, 31). The inventory is divided into 5 groups:

1) Fall events (illustrated with red symbols): rock boulder fall (single boulders), small rock fall (volume < 100 m^3), medium-sized rock fall (100 m^3 – 100,000 m^3), large rock fall (100,000 m^3 – 1 Mio. m^3), very large rock fall (1 Mio. m^3 or Area > 0.1 km^2).
2) Slide/glide events (illustrated with different brown symbols): small slide (area up to 250 m^2), middle slide (area up to 1000 m^2), large slide (area > 1000 m^2).
3) Flow events (illustrated with different dark blue symbols): earth flow, debris slide, debris flow.
4) Sinkholes (illustrated with green symbols).
5) Debris flows (events connected with channels, illustrated with light blue symbols).

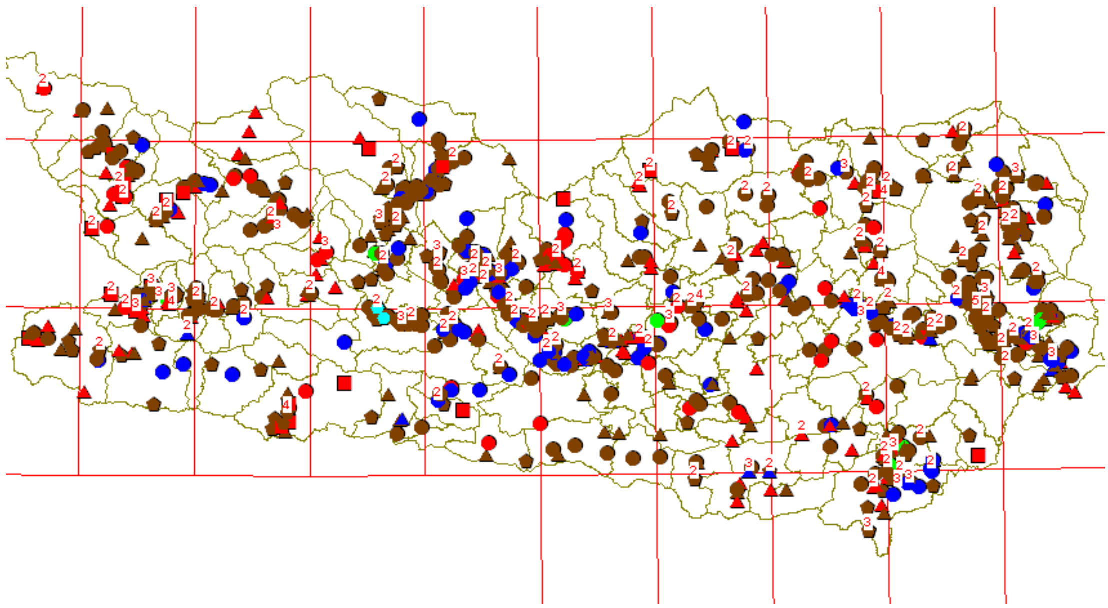
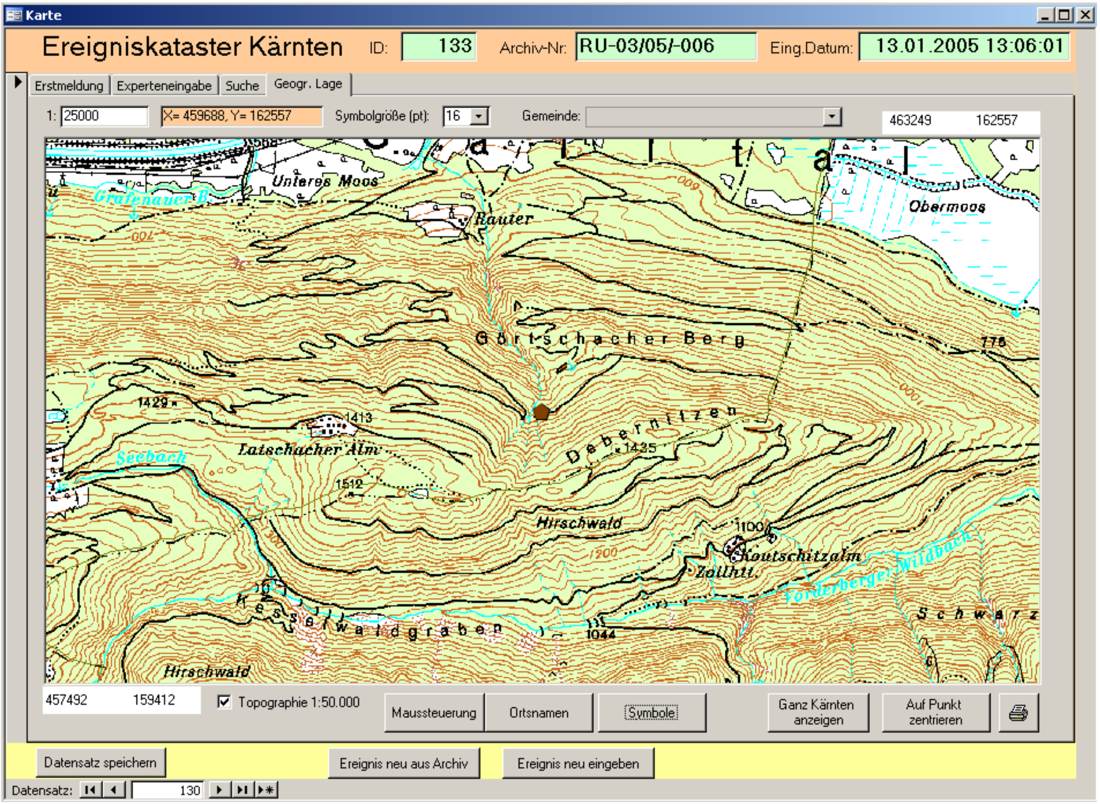


Fig. 30. Overview map of mass movements (chiefly landslides) in Carinthia. The frequency of events is represented by a number (Source: Geological Survey of Carinthia)



ART	BEWEGUNGSART	BESCHREIBUNG	GROESSE	SYMBOL
Blocksturz	Stürzen	Einzelblock 0,3 - 1 m³	klein	●
Steinschlag	Stürzen	Sturzmasse < 100 m³	mittel	▲
Felssturz	Stürzen	100 m³ bis 100.000 m³	mittel	■
Bergsturz	Stürzen	> 1 Mio. m³ oder > 0,1 km²	gross	⬣
Rutschung klein	Rutschungen	bis 250 m²	klein	●
Rutschung mittel	Rutschungen	bis 1000 m²	mittel	▲
Rutschung gross	Rutschungen	> 1000 m²	gross	⬟
Erdfall	Einstürzen	Fläche m²		●
Erdstrom	Fließen	Fläche m² / Kubatur m³		●
Schuttstrom	Fließen	Fläche m² / Kubatur m³ ; Block. Material		▲
Felssturz groß	Stürzen	> 100.000 m³ bis 1 Mio. m³	gross	⬟
Mure	Fließen	an Gerinne gebundene Massenbewegung		⬣

Fig. 31. Mass movement inventory map with legend of Carinthia. Scale 1:25,000 (Source: Geological Survey of Carinthia

In the inventory maps, landslides are represented as point features with different symbols and colours, depending on process and size. Created in 2003/2004, the last update of the inventory was in March 2008, still ongoing due to newly detected events.

Recent major 299 landslides occurred in 5.18 % of the area of Carinthia (Table 1). The remaining 890 historical landslides (inclusive fall and flow movements) may have occurred in another 10% of the area. Generally speaking, 15% of the area of Carinthia is affected by landslides considering that the well known 299 events represent an average dimension. There exist also not recorded landslides, mainly in alpine regions without infrastructures.

There is also a landslide inventory in paper form in the archive of the local government. The landslide data are conserved there and in the digital database (Fig. 32, 33, 34), which contains also landslide susceptibility maps.

Table 1. Summary table of landslide events in Carinthia. Art: type of landslide (Rutschung: slide; Erdfall: sinkhole; Erdstrom: earth flow; Schuttstrom, Mure: debris flow; Steinschlag, Bergsturz: rock fall etc. Anzahl der Ereignisse: number of events; Flächenangabe: total area in km²) (Source: Geological Survey of Carinthia)

Art	Anzahl der Ereignisse	mit Flächenangabe im EK
Rutschung_klein	430	104
Rutschung_mittel	216	93
Rutschung_groß	163	78
Erdfall	9	2
Erdstrom	131	18
Schuttstrom	21	1
Mure	3	0
Blocksturz	52	1
Steinschlag	137	1
Felssturz	26	1
Felssturz_groß	0	0
Bergsturz	1	0
Gesamt	1189	299

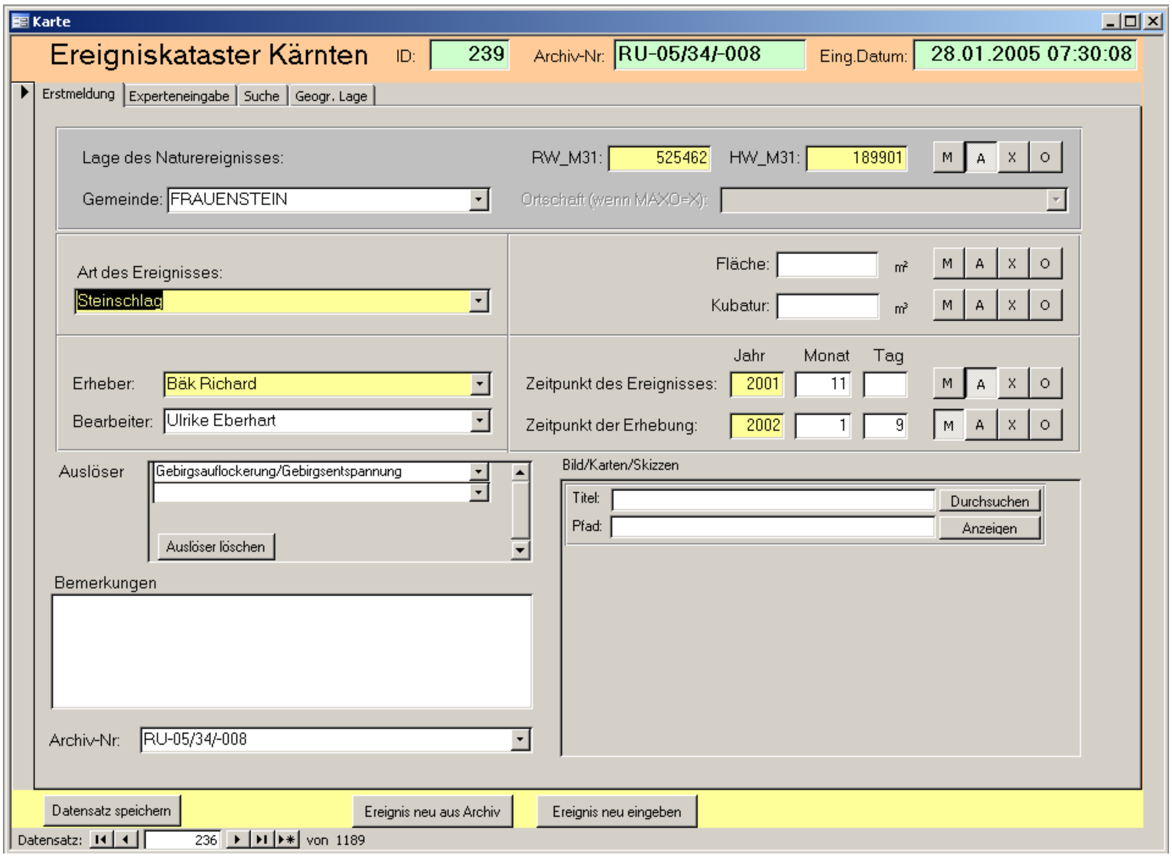


Fig. 32. Database mask of the mass movement inventory of Carinthia. Lage des Naturereignisses: location of the natural hazard; Gemeinde: municipality: Art des Ereignisses: type of event; Lage des Naturereignisses: location of the natural event (Source: Geological Survey of Carinthia)

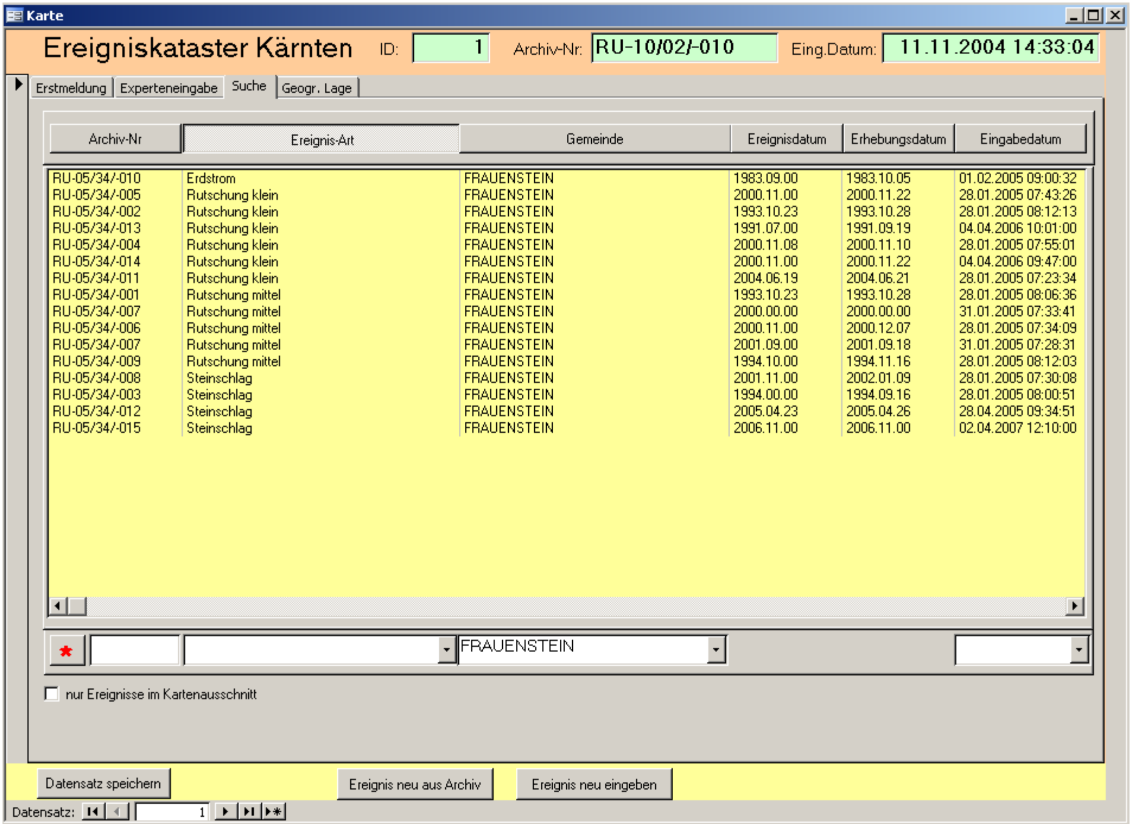


Fig. 33. Screenshot of the mass movement inventory of Carinthia. See also Fig. 32. Rutschung: slide; Steinschlag: rock fall (Source: Geological Survey of Carinthia)

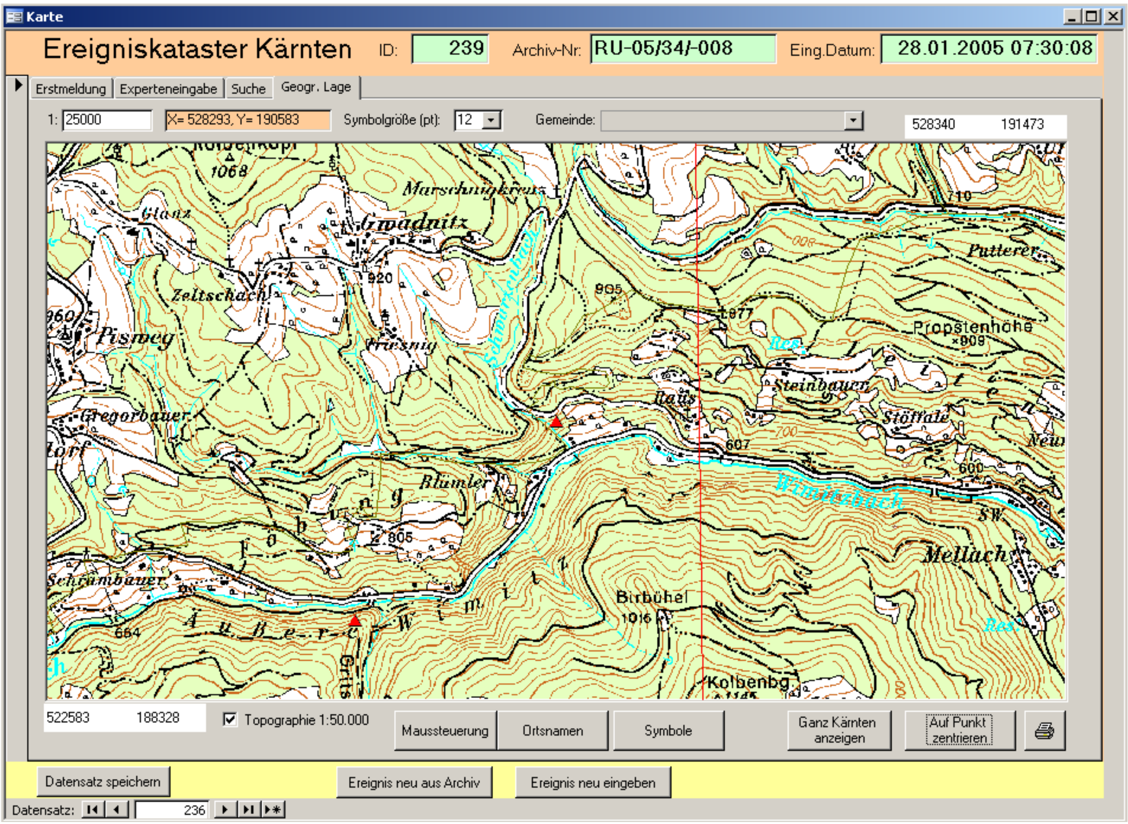


Fig. 34. Mass movement inventory map of Carinthia with land cover map in the background. Display scale 1:25,000 (Source: Geological Survey of Carinthia)

The landslide susceptibility maps (Fig. 35) are in digital format at 1:50,000 scale. They are based on expert judgement (heuristic approach) considering mainly the geology and geomorphology. A new project is in progress to generate detailed landslide susceptibility maps. Carinthia has no landslide hazard or risk maps.

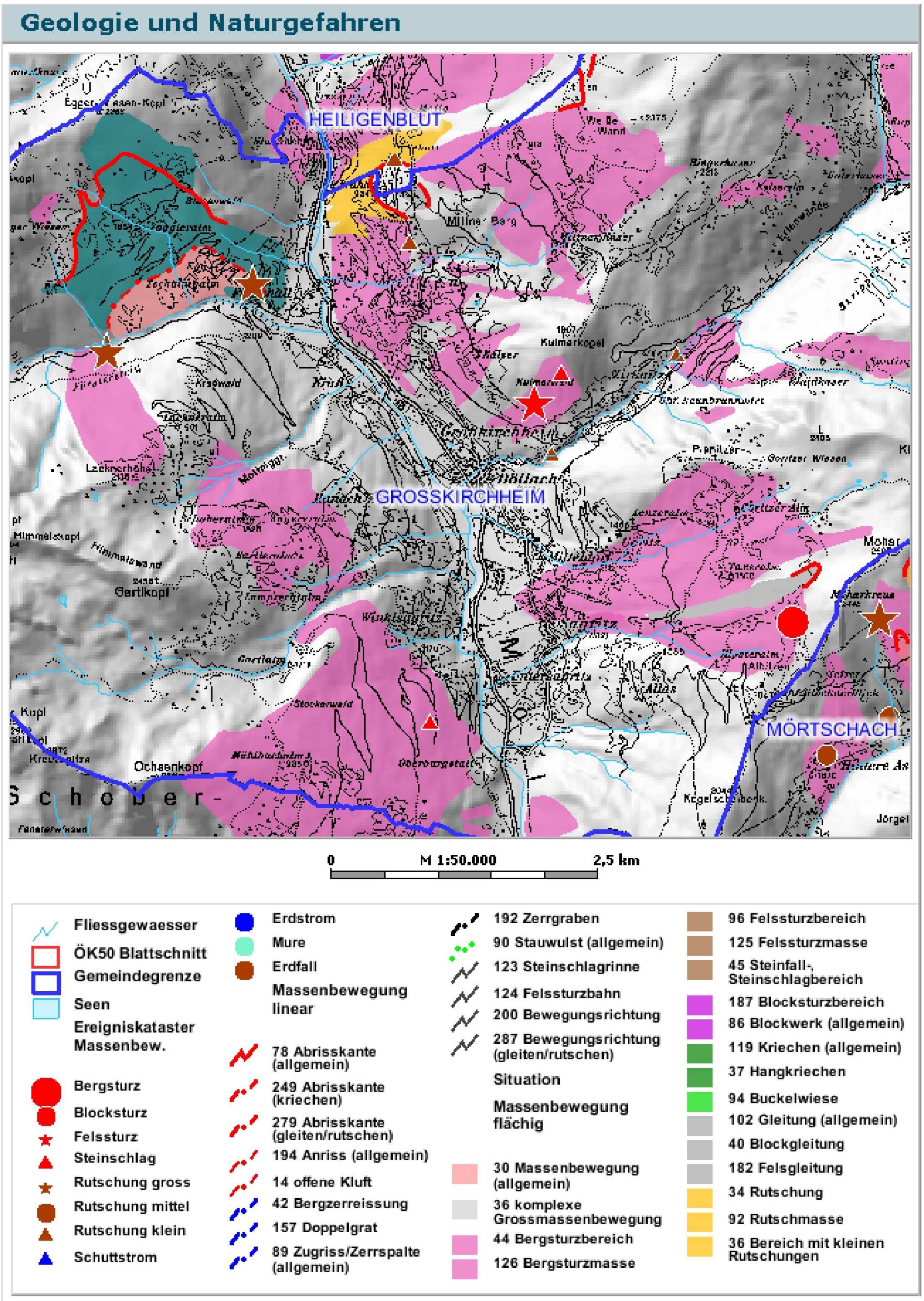


Fig. 35. Landslide susceptibility map of Carinthia. Bergsturz: rock fall (large); Felssturz: rock fall (medium); Steinschlag: rock fall (small); Rutschung: slide; Massenbewegung: mass movement; Gleitung: glide (Source: Geological Survey of Carinthia)

The mass movement inventory and landslide susceptibility maps are only accessible by public organisations in Carinthia via internet. Upon request a user account is provided also to ministry departments or geological institutes in Austria. An English version is not available yet. The regulations for landslides are defined by the spatial law of Carinthia, the state law for hazards and the soil protection report of the Alpine Convention.

Other organisations with databases including landslides in Carinthia are the Geological Survey of Austria (GBA), the Technical University of Vienna (TU Wien), the University of Graz, the University of Erlangen (Germany) and the Geological Survey of the Austrian Service of Torrent and Avalanche Control (WLV).

3.2.6 Upper Austria

Upper Austria (*Oberösterreich*) borders on Czech Republic and Germany, covering a total area of 11,980 km^2. Upper Austria has an analogue, incomplete archive in paper form of mass movements including landslides, with reports and maps on different scales. On top of this archive data, Upper Austria's government produced between 2005 and 2007 digital landslide susceptibility maps including data of other mass movements from the whole region. They were generated with ArcGIS in the scale 1:50,000. These landslide susceptibility maps cover only 30% to 50% of the entire region (444 municipalities), as the main area of investigation was reduced to the major construction and settlement zones covering only from 30 to 50 % of the municipality area. The map legend distinguishes falls (small rock fall, medium rock fall, large rock fall – *Steinschlag, Felssturz, Bergsturz*), debris flows (*Murgang*), glides (*Gleitung*), translational slides (*Translationsgleitung*), rotational slides (*Rotationsgleitung*), earth flows (*Erdstrom*), debris flows (*Schuttstrom*), creep processes (*Kriechprozesse*, slope creep - *Hangkriechen*), sackungen (*Sackung*, *Talzuschub* – large sackung), sinkholes (*Erdfall*, *Doline* – doline), and soil prone to settlements (*setzungsemfindlicher Untergrund*). Fine grained soils like the Schlier in the Molasse Zone, and also fenland, are often affected by settlements. Unstable underground is caused by human activity, for example by undermining a slope (*pseudostabiler Untergrund*). This expression refers to underground which has become unstable due to construction activity.

For each type of mass movement in the study area three classes of susceptibility were established, called "Prioritätenreihung" (priority classification) by Upper Austria:

- Zone A (red polyline): high priority of geological and geotechnical investigations. Geological risk in the area is high and cannot be mitigated. Detailed investigations have to be done before any construction planning can take place. Risks for construction activities are undesirably high.
- Zone B (orange polyline): medium priority of geological investigations. Geological risks can be mitigated. Detailed investigations have to be done, but the area can be used after more or less remediation works.
- Zone C (green polyline): low priority of geological investigations. No geological risk reported (Fig. 36).

The three above-mentioned susceptibility classes were defined based on intensity and frequency of landslides. Three classes of intensity (i.e. high, medium and low damages expected for buildings and infrastructure in the study area in case of event) and three classes of frequency (i.e. high, medium and low return period of the single landslide) were combined within a matrix (Table 2).

These maps can actually be considered as hazard maps because of the combination of landslide intensity with frequency. Considering the simplifications, however, neither field surveys nor remote sensing investigations and statistic calculations were used for susceptibility maps.

In the region, each municipality is provided with a report and a map at 1:50,000 scale of their area and an ArcView shape file with database. They have to organize all the further geological and geotechnical investigations in their problematic areas. The major part of Upper Austria is prone to settlements.

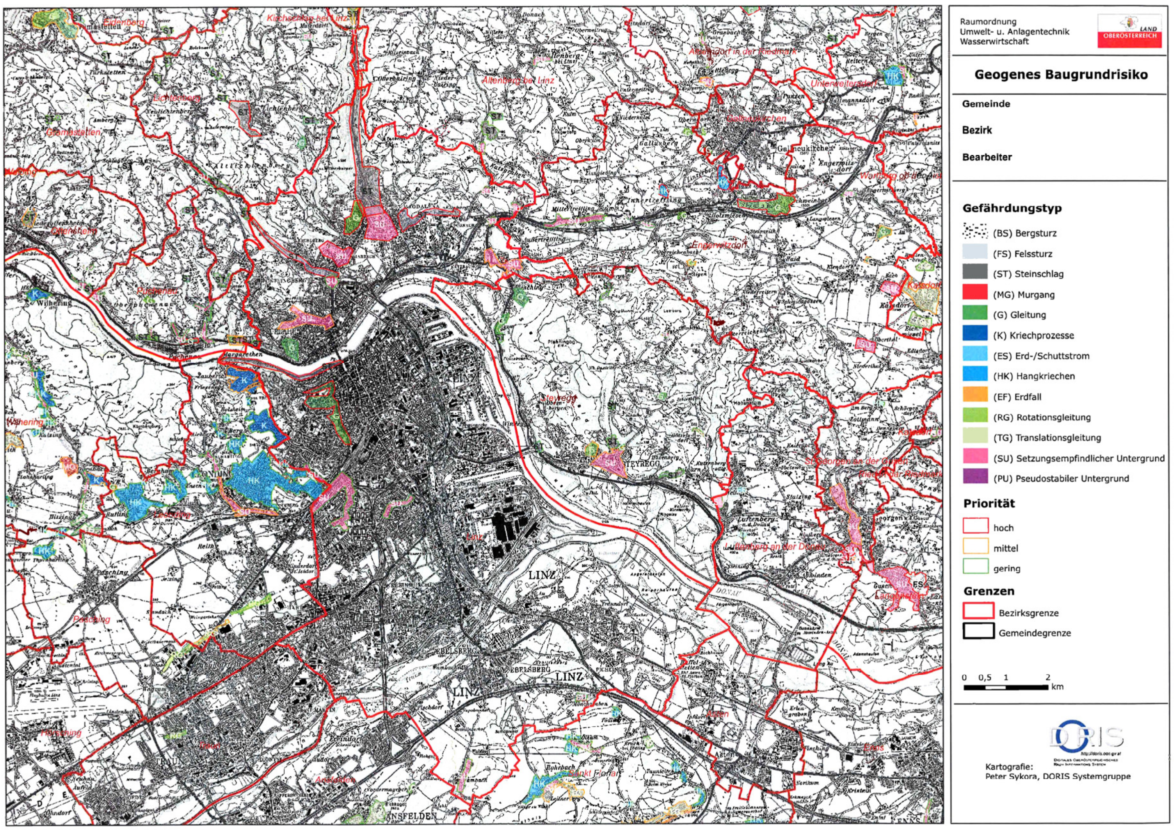


Fig. 36. Landslide susceptibility map of Upper Austria. Gefährdungstyp: type of hazard or type of mass movement; Priorität: landslide susceptibility class (hoch = high, mittel = middle, gering = low). Pseudostabiler Untergrund: unstable underground; setzungsempfindlicher Untergrund: underground affected by settlements; Translationsgleitung translational slide; Rotatationsgleitung: rotational slide; Erdfall: sinkhole; Hangkriechen: slope creep; Erd/Schuttstrom: = earth/debris flow; Kriechprozesse: creep processes; Gleitung: glide; Murgang: debris flow; Steinschlag: rock fall (small), Felssturz (medium), Bergsturz (large). (Source: Department of Spatial Planning of Upper Austria)

Table 2. Landslide susceptibility matrix of Upper Austria. Eintrittswahrscheinlichkeit: occurrence probability; Auswirkung: intensity; Priorität: priority / susceptility class: 1 = high (Zone A), 2 = medium (zone B), 3 = low (zone C) (Source: Department of Spatial Planning of Upper Austria)

Amt der OÖ Landesregierung GZ ------ **Beilage**
Geogenes Baugrundrisiko Prioritätenreihung

Eintrittswahrscheinlichkeit	Auswirkung / Intensität	Priorität
1	1	1
2	1	1
3	1	2
1	2	1
2	2	2
3	2	3
1	3	2
2	3	3
3	3	3

The registration or mapping of landslide susceptible areas has become mandatory by law of the federal state government. The landslide susceptibility maps are available only for local experts and authorities. They are documented only in German.

Upper Austria does not have specific landslide hazard or risk maps. However, hazard maps of floods, debris flows and avalanches produced by the Austrian Service of Torrent and Avalanche Control are also available for the region.

3.2.7 Salzburg

The federal state of Salzburg is located in the centre of Austria, borders with Germany and covers an area of 7,154 km^2. The local government possesses a digital inventory of mass movements, floods and avalanches which contains events recorded between 1971 and 2006. The inventory includes information on type of landslide, date of occurrence, location and volume. It is on ArcGIS and MS Access database, and contains 514 landslide events throughout the whole region (see also the final report of practical approach of DIS-ALP.pdf on http://www.dis-alp.org/, partly in English, Fig. 37, 38). The inventory map scale is 1:25,000 and landslides are represented as points. The database was last updated in 2006. There exist also non-recorded landslides in the region.

The landslide inventory is available for public, partly in English, on the websites http://www.dis-alp.org/ (project homepage including final reports) and http://www.dis-alp.org/.

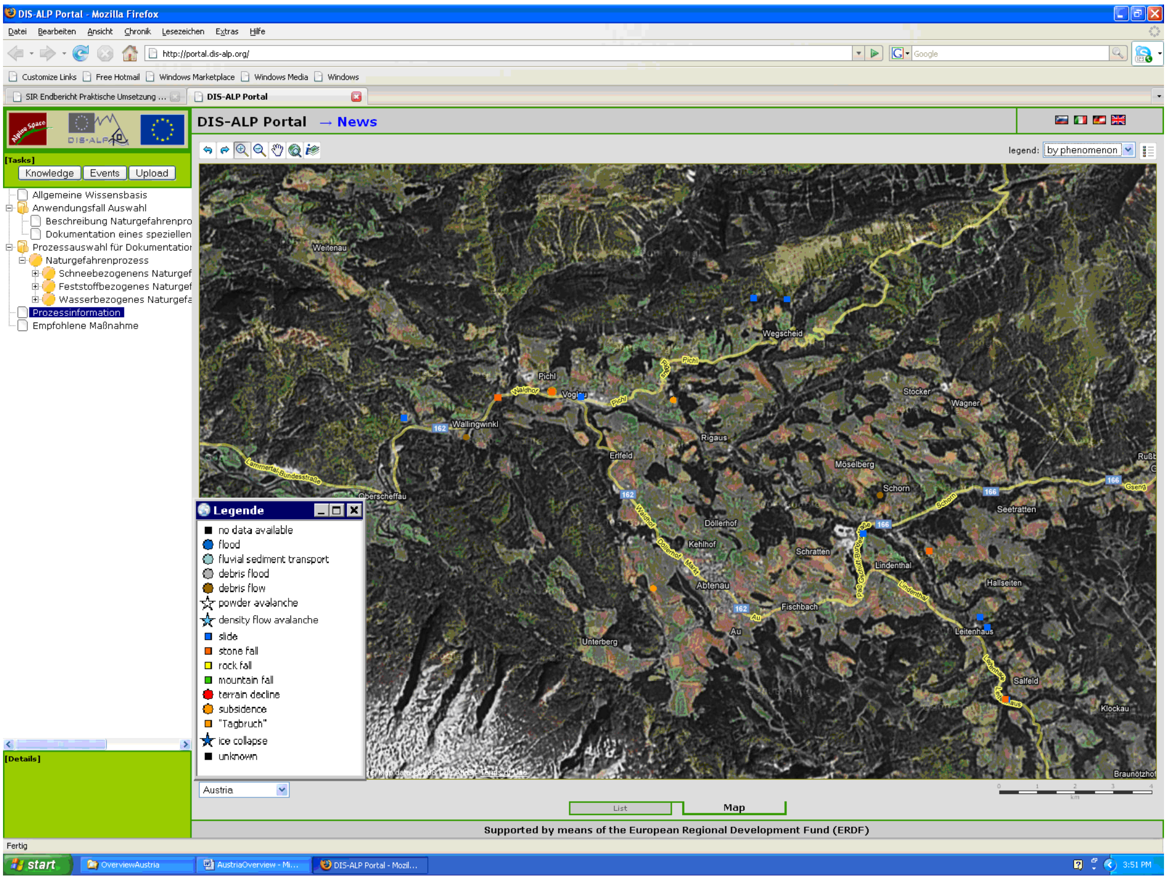


Fig. 37. Mass movement inventory map of Salzburg (Source: Geological Survey of Salzburg)

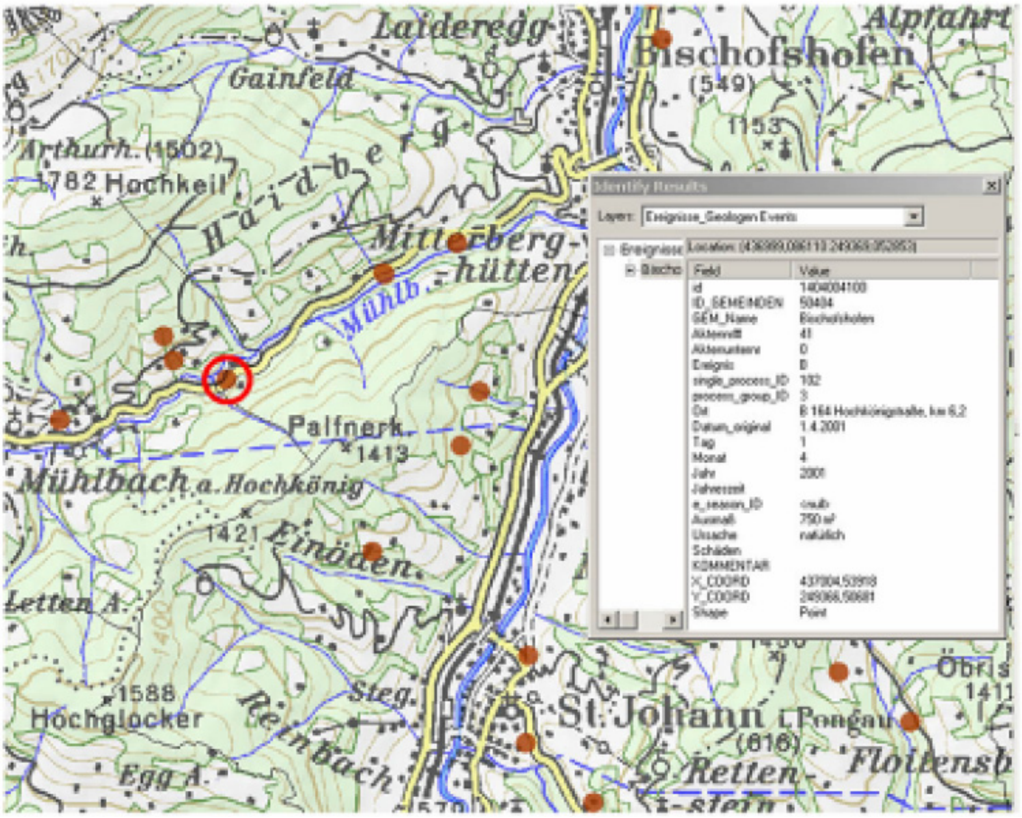


Fig. 38. Landslide map database of Salzburg. Original scale 1:25,000 (Source: local government of Salzburg). The inlet gives detailed information about single landslides, such as coordinates, surface, date of occurrence, etc.

The Geological Survey of Salzburg manages also a geological archive with landslide data. The archive contains all reports since 1971 which are represented on paper maps at 1:25,000 scale. The geological archive with 1200 reports and about 8000 drilling profiles is open to the public. The data are not available on the web and are only in German.

Salzburg does not have landslide susceptibility, hazard or risk maps. The region has no law enforcement for definitions and production of landslide inventories, hazard or risk maps. The hazard maps of floods, debris flows and avalanches existing in the region are generated by the Salzburg's branch of the Austrian Service of Torrent and Avalanche Control (see Annex 1).

3.2.8 Tyrol

Tyrol is divided in northern and eastern Tyrol covering an area of 12,648 km^2. It has a common border with Germany and Italy. Tyrol is definitely one the federal states in Austria suffering mostly from landslides (see e.g. chapter 1.2; Abele, 1974; Prager et al., 2008). There are over 2000 landslides recorded in the archives of the local government, universities, AlpS and GBA.

The local government of Tyrol, especially its Geological Survey, has neither landslide inventory nor landslide hazard and risk maps. They have only some single reports and maps of landslides in paper form. They consider that landslide inventories or zonation maps in general are not particularly useful for geological and geotechnical studies and for the management of natural hazards. However, the province section of the Austrian Service of Torrent and Avalanche Control (WLV) has generated hazard maps of floods, debris flows and avalanches of the whole province and some local landslide susceptibility maps. The Tyrolean Section of WLV has its own Geological Survey which is working for all WLV sections in Austria. They have certainly landslide data over Tyrol. Unfortunately, they did not respond to the questionnaire.

The private institutions AlpS and Joanneum Research have smaller digital databases and maps of Tyrol (see chapter 3.1). Additional landslide data for Tyrol exist within the two digital databases of the Geological Survey of Austria (GBA) and also at the Institute of Geography of the University of Innsbruck.

3.2.9 Vorarlberg

Vorarlberg represents the westernmost part of Austria and borders with Germany and Switzerland. The total area is 2,601 km^2. The local government has no landslide inventory, neither in digital nor in paper form. They provide single reports and maps and support university projects. Also a geological database with landslide data does not exist.

Vorarlberg has landslide susceptibility maps of separate areas not covering the whole region. The experience of the Vorarlberg experts has shown, however, that these maps, especially those produced only by computation on PC (i.e. using GIS tools, without field data and mapping) are not usable for applied technical work. Moreover, these maps do not replace a detailed investigation in the interested region. Vorarlberg experts consider that in case of natural hazards occurring, analysis of detailed geological maps and laser scan data together with field surveys is more useful to suggest mitigation or remediation measures.

The landslide susceptibility maps were produced by the Institute of Applied Geology of the University of Karlsruhe (Germany) and the geotechnical company Bertle in Schruns (Austria) for separate areas. The University of Karlsruhe produced digital susceptibility maps for slides and rock falls with ArcInfo GIS software on a scale of 1:25,000 (Fig. 39, 40). Bertle generated digital susceptibility maps for generic landslides, erosion and debris flows at 1:20,000 scale with ArcInfo/ArcGIS and ArcView software (Fig. 41). All maps are also available in pdf format.

In the University of Karlsruhe's maps five landslide susceptibility classes (from very low to very high) are distinguished (Fig. 39, 40). The maps were produced within a project commissioned by the local government of Vorarlberg between 1999 and 2003 (http://www2.agk.uni-karlsruhe.de/index_en.html). Information about the methods used can especially be found in Czurda et al. (2002), Ruff et al. (2002), Ruff and Czurda (2003, 2008) and Ruff and Rohn (2008).

In the maps of Bertle, produced between 1995 and 1997, seven susceptibility classes are shown (Fig. 41). In the susceptibility maps of the University of Karlsruhe the slides cover 481 km^2 (19% of the study area of the Bregenzer Wald and the Arlberg –a part of Vorarlberg–), and the rock falls 377 km^2 (15% of the study area). In the maps of Bertle, 538 km^2 (22%) of another area in Vorarlberg are covered by generic landslides and erosion zones together with debris flows.

The University of Karlsruhe generated landslide susceptibility maps by means of a qualitative index method (heuristic approach) using grid data (Czurda et al. 2002; Ruff and Czurda, 2008). The susceptibility maps were based on geological maps, geotechnical maps, digital elevation model (DEM) and precipitation distribution. The susceptibility to sliding was determined by an index method based on the data layers slope angle, slope aspect, slope curvature, lithology, distance to tectonic faults, vegetation and erosion. All data layers were handled as grids with a cell size of 25 m. The susceptibility to rock falls was evaluated in two steps: First, the dropout-zones were detected via DEM. Second, possible rock fall trajectories were calculated. The trajectories were then compared using a cost analysis procedure based on rolling friction (Ruff and Czurda, 2008). Bertle produced the landslide susceptibility maps by field mapping, interpretation of aerial photos and manual digitalization in ArcGIS.

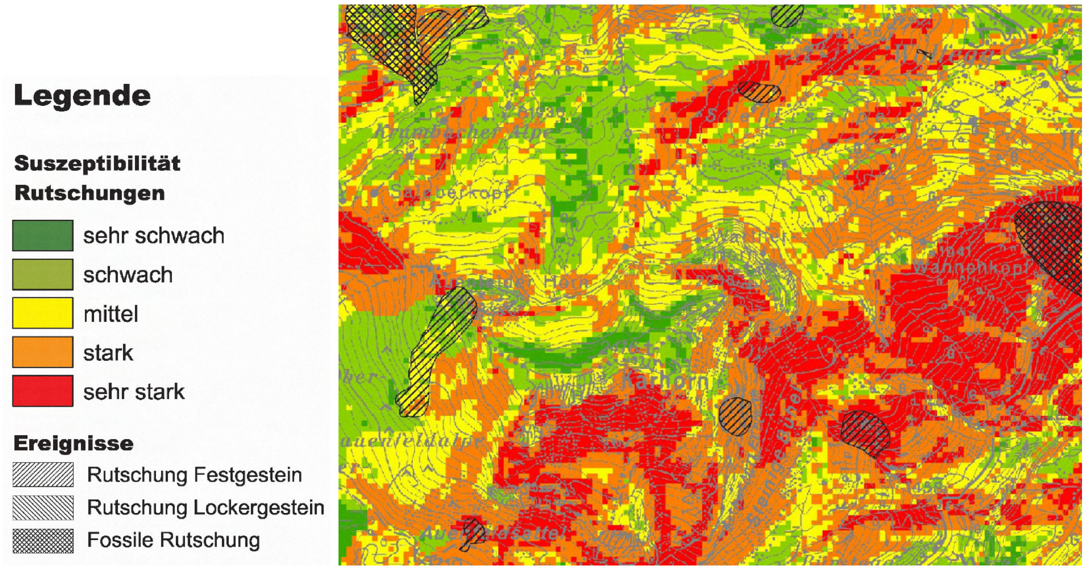


Fig. 39. Slide susceptibility map of an area in Vorarlberg, showing 5 susceptibility classes (e.g. sehr stark: very high). Original scale 1:25,000 (Source: Geological Survey of Vorarlberg)

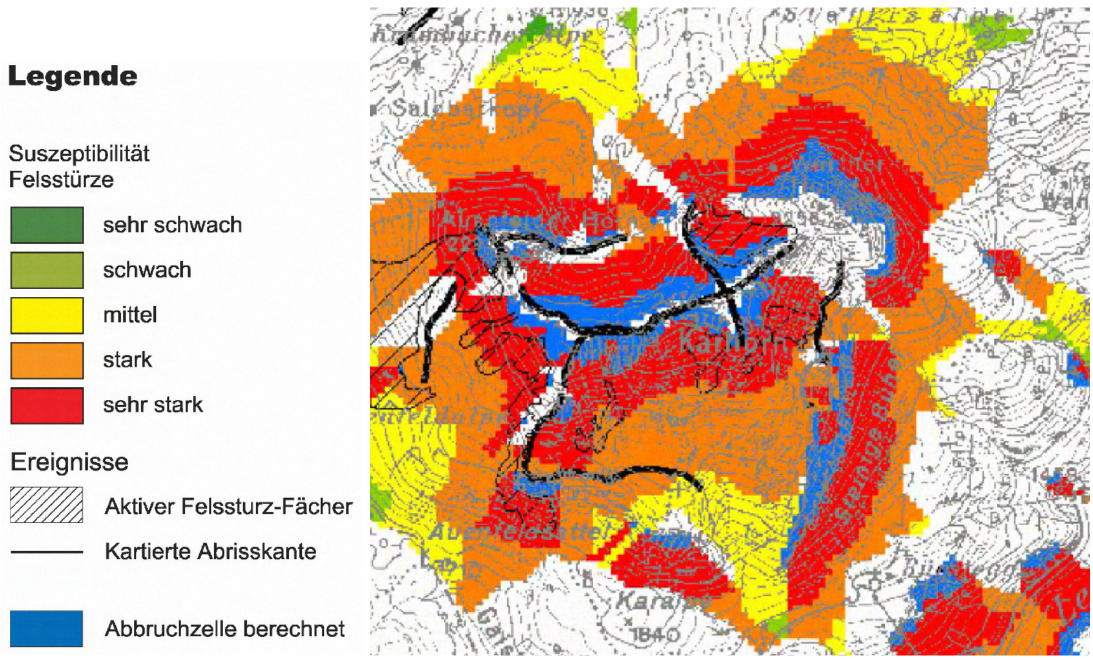


Fig. 40. Rock fall susceptibility map of an area in Vorarlberg. Original scale 1:25,000 (Source: Geological Survey of Vorarlberg)

The local government of Vorarlberg has neither landslide hazard nor risk maps. The existing landslide maps are only in German. They are available upon request, but not on the web. The management of landslides is regulated by the local spatial and construction law and by the state forest law.

The Austrian Service for Torrent and Avalanche Control has susceptibility maps of some landslides and hazards maps of floods, debris flows and avalanches over the whole region. The Geological Survey of Austria (GBA) also holds landslide data of Vorarlberg.

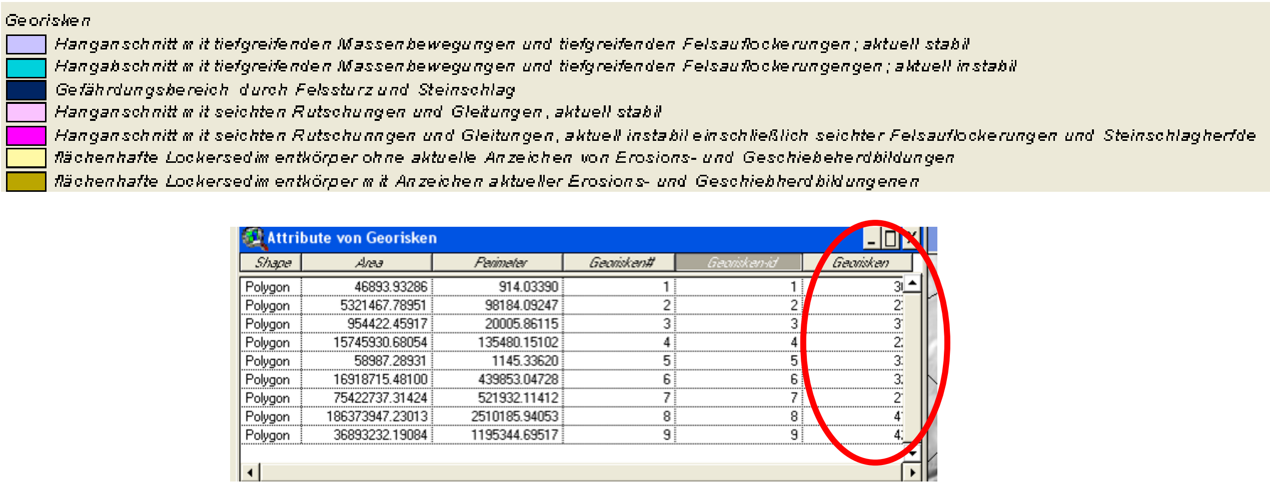


Fig. 41. Susceptibility map legend and example of an attribute table from the GIS database of Bertle. Georisiken (georisks) are circled (the term georisk is used for susceptibility) (Source: Geological Survey of Vorarlberg)

4. CONCLUSIONS AND RECOMMENDATIONS

In this study, landslide-related databases and map archives available at the main organisations dealing with landslides in Austria, both at national and regional (federal state) level, have been reported. The study shows that a great deal of information on landslide occurrence and, although to a lesser extent, on landslide susceptibility is available in Austria. Various types of landslide maps and ancillary data, mainly in the form of inventory and susceptibility maps, exist at the various administrations, although their coverage, scale, landslide classification used, content (and map legend), spatial representation (symbology) and accessibility differ from one another (see Table 3). Moreover, different methods have been used by various administrations to collect landslide information and, especially, to derive landslide susceptibility or hazard zonation maps. For generating susceptibility maps, however, heuristic (direct mapping and weighting-based) approaches have proved very popular in various organisations, with statistical zonation methods generally as a second choice.

In some maps and databases, landslides form part of broader information on mass movements or documented together with other hydro-geological hazards (e.g. floods, avalanches). It has been reported that the only mass movement inventory published on the web and in English is a subset of the database of the Geological Survey of Austria (GBA), which as of December 2008 included basic information of 822 recorded landslides over the entire country. This webGIS database, documented in German and English, contains only a small part of all the landslides existing in Austria.

Most of the landslide documentation in Austria is archived in the GEORIOS spatial database of GBA and at nine regional Geological Surveys. The region Upper Austria (*Oberösterreich*) has completed in January 2007 landslide susceptibility maps for its whole territory at 1:50,000 scale. The region Burgenland commissioned the Arsenal Research Centers of Seibersdorf to develop another digital database with landslide susceptibility maps 1:25,000. More than half of the work is completed and conclusion is scheduled in December 2009. Lower Austria (*Niederösterreich*) started last year with landslide susceptibility mapping and plan to complete the region in 2013. The region Carinthia (*Kärnten*) has recently generated a digital landslide susceptibility map at 1:200,000 scale and a digital landslide inventory for the whole region, jointly with the Geological Survey of Austria (GBA) within the project GEORIOS. The cell size of the raster values is 100 m to 500 m. GBA is now producing landslide susceptibility maps on larger scale.

Another important database includes the landslide inventory, landslide susceptibility maps and hazard maps for floods, debris flows and avalanches of the Austrian Service for Torrent and Avalanche Control (*Forsttechnischer Dienst, Wildbach- und Lawinenverbauung*). Various research institutes like alpS (Centre of Natural Nazard Management) at Innsbruck, Joanneum Research at Graz and the Bundesforschungs- und Ausbildungszentrum für Wald, Naturgefahren und Landschaft (BFW) at Vienna have also local landslide inventories.

In our study, differences between the nine federal states in their informatics standard become apparent: Carinthia seems well organised with state-of-the-art digital databases and maps, while others like Tyrol have only a small inventory in paper form or only a small part of their region studied and digitized. For some areas in Austria documented landslides are not digitized yet.

In Austria there is no state law or technical standard which regulates landslides or mass movements. Also, no federal state has generated so far landslide hazard or risk maps for areas larger than some km². The available maps are mainly restricted to municipality or single case studies.

In order to improve landslide management and consequently natural risk disaster management in Austria, whilst also complying with the EU Thematic Strategy for Soil Protection, the following actions are recommended to be undertaken by all public organisations:

- Adoption of a common landslide and mass movement classification in reference to the most widely accepted classification of Varnes (1978) and Cruden and Varnes (1996).
- Clear, harmonized definition of inventory, including maps, landslide susceptibility maps, landslide hazard maps and landslide risk maps.
- Standardization of a uniform legend and symbology of landslides and mass movements.
- Introduction of uniform datasheets for field survey of landslides.
- Production of a uniform database and maps for the whole Austria also with English headings.

Certainly the input and collaboration by most of the Austrian organisations working on landslides would be necessary to develop and manage efficient projects. One or two single organizations would not be able to do it.

Table 3. Availability of landslide maps in Austria

Organisation	Maps produced Digital (D) or Paper (P)	Coverage	Scale	Date Created	Accessibility
Geological Survey of Austria (GBA)	Landslide inventory (D) Landslide inventory (D) Landslide susceptibility *(D)* Landslide hazard (D)	National National (selected landslides) Regional Local	1:25,000 – 1:50,000 1: 300,000 1:50,000 – 1:750,000 1:10,000	Since 2002 Since 2005 Since 2005 Since 2006	Restricted Public (web) Restricted Restricted
Austrian Service for Torrent and Avalanche Control (WLV)	Landslide inventory (DP) Hazard maps	National National	1:50,000 – 1:25,000 1:5000 – 1:2000	Since 1975 Since 1975	Restricted Public
Joanneum Research	Landslide inventory (D) Landslide susceptibility (D)	Local (Styria, Tyrol) Local	1:25,000 1:5000 – 1:50,000	Since 2001 Since 2001	Restricted Restricted
AlpS	Landslide inventory (D)	Regional (Tyrol and surroundings)	1:200,000	Since 2005	Restricted
Austrian Railways (OBB)	No inventory, single reports Landslide susceptibility (D) Landslide susceptibility (D)	National: railway buffer zone National: railway corridors only National: railway corridors only	1:25,000 1:5000 – 1:10,000	2007 - 2008 2008 - 2010	Restricted Restricted
Geological Survey of Burgenland	No inventory, single reports Landslide susceptibility (D)	Burgenland Federal State	1:25,000	2005 - 2009	Restricted
Dept. of Bridge and Civil Engineering, Vienna Federal State	No inventory, single reports	Local			Restricted
Geological Survey of Lower Austria	Landslide inventory (D) Landslide susceptibility, heuristic (D) Landslide susceptibility, statistic (D)	Lower Austria Federal State Local Federal state	1:50,000 1:50,000 1:25,000	2002 - 2009 2008 2009 - 2013	Restricted Restricted Restricted
Construction group, GIS department, Styria Federal State	Inventory only for slides (D)	Styria Federal State	1:1000 – 1:5000	Since 2007	Public
Geological Survey of Carinthia	Landslide inventory (D) Landslide susceptibility heuristic (D) Landslide susceptibility statistic (D)	Carinthia Federal State Federal State Federal State	1:50,000 1:50,000 1:25,000	Since 2003 Since 2007 2008 - 2011	Restricted Restricted Partly public
Geological Survey of Upper Austria	Landslide inventory (D) Landslide susceptibility heuristic (D)	Upper Austria Federal State Federal State	1:50,000 1:50,000	Since 2005 Since 2007	Restricted Restricted
Geological Survey of Salzburg	Landslide inventory (D)	Salzburg Federal State	1:25,000	Since 2006	Public
Geological Survey of Tyrol	No inventory, single reports	Local			Restricted
Geological Survey of Vorarlberg	No inventory, single reports Landslide susceptibility heuristic, statistic (D)	Local	1:20,000 – 1:25,000	1999 - 2003	Restricted

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ANNEX 1

LIST OF MAIN ORGANISATIONS DEALING WITH LANDSLIDES IN AUSTRIA

Geologische Bundesanstalt (Geological Survey of Asutria)
Fachabteilung Ingenieurgeologie
Neulinggasse 38
A-1030 Wien
http://www.geologie.ac.at

Bundesministerium für Land- und Forstwirtschaft, Umwelt und Wasserwirtschaft
(Federal Ministry of Agriculture and Forestry, Environment and Water Management)
Abteilung IV/5 - Schutz vor Wildbächen und Lawinen; Bereich Gefahrenzonenplanung
(Department IV/5 - Torrent and Avalanche Control; Hazard Zone Mapping)
Marxergasse 2, 1030 Wien
http://www.die.wildbach.lebensministerium.at

Forsttechnischer Dienst für Wildbach- und Lawinenverbauung, Sektion Salzburg,
Bergheimerstraße 57
5021 Salzburg
leonhard.krimpelstaetter@wlv.bmlf.gv.at.

Joanneum Research
Institut für digitale Bildverarbeitung
Wastiangasse 6
A-8010 Graz
http://www.joanneum.at/en

AlpS Zentrum für Naturgefahren Management GmbH
Grabenweg 3
A-6020 Innsbruck
http://www.alps.gmbh.com

Österreichische Bundesbahnen (Austrian Railways, OBB)
ÖBB-Infrastruktur Betrieb AG (OBB Infrastructure Service AG)
Infra Service - Technik
Naturgefahren-Management
Elisabethstraße 9
A-1010 Wien
http://www.oebb.at

Amt der Burgenländischen Landesregierung
Abt.7-Kultur,Wissenschaft und Archiv
Europaplatz 1
A-7001 Eisenstadt
http://www.burgenland.at

Amt der Wiener Landesregierung
Magistratsabteilung 29
Brückenbau und Grundbau
Wilhelminenstraße 93
A-1160 Wien
http://www.wien.gv.at

Amt der Niederösterreichischen Landesregierung
Abteilung Allgemeiner Baudienst, Geologischer Dienst
Landhausplatz 1
A-3109 St. Pölten
http://www.noel.gv.at

Amt der Steiermärkischen Landesregierung
Fachabteilung 17 B Referat Wasserbau und Geologie
Alberstrasse 1
A-8010 Graz
http://www.steiermark.at

Amt der Kärntner Landesregierung
Abteilung 15 Umwelt
Unterabteilung Geologie und Bodenschutz
Flatschacherstrasse 70
A - 9020 Klagenfurt
http://www.verwaltung.ktn.gv.at

Amt der Oberösterreichischen Landesregierung
Direktion Umwelt und Wasserwirtschaft
Abteilung Grund- und Trinkwasserwirtschaft
A-4021 Linz • Kärntnerstrasse 10-12
http://www.land-oberoesterreich.gv.at

Amt der Salzburger Landesregierung
Landesbaudirektion, FA Geologie
Michael-Pacher-Str. 36
A-5020 Salzburg
http://www.salzburg.gv.at

Amt der Tiroler Landesregierung
Abteilung Allgemeine Bauangelegenheiten
Landesgeologie
Herrengasse 1-3
A-6020 Innsbruck
http://www.tirol.gv.at

Amt der Vorarlberger Landesregierung
Abteilung Raumplanung und Baurecht (VIIa)
Landhaus
A-6901 Bregenz
http://www.vorarlberg.at

ANNEX 2 – QUESTIONNAIRE

LANDSLIDE DATA AND MAP SURVEY IN AUSTRIA
DATEN UND KARTENAUFNAHMEN VON MASSENBEWEGUNGEN IN ÖSTERREICH

OBJECTIVES - ZIELE

The Joint Research Centre (JRC) of the European Commission, in collaboration with Amt der Niederösterreichischen Landesregierung, Abteilung Allgemeiner Baudienst, is conducting a survey of landslide inventories, susceptibility, hazard and risk maps available in Austria. The main objective of the survey is to know the state-of-the-art of landslide inventories and mapping in Austria, which is relevant to the EU Thematic Strategy on the Protection of Soils. In this strategy, landslides are considered one of the main threats to European soils. The strategy regards soils not only as a natural resource but also as the platform for development of human activities. In order to preserve soils and their function, the strategy calls for identification of areas at risk from soil threats, including landslides, and risk reduction and mitigation actions.

In order to meet the above-mentioned objective, your cooperation by answering the questionnaire below will be greatly appreciated. Your input to the questionnaire and the authorship of the complementary material we are requesting from you will be duly acknowledged in a report to be produced with the outcome of the survey. You will also receive a copy of this report.

QUESTIONNAIRE - Fragebogen

Name of Organisation / *Name der Institution*:
Contact person / *Kontaktperson*:
Address / *Adresse*:
Phone/e-mail, *Telefon/e-mail*:

1. **Does your organisation have an inventory of landslides, including slides, debris flows, rock falls and other mass movements?**
Haben Sie einen Kataster (Datenbank) für Massenbewegungen (Rutschungen, Muren, Steinschlag und andere Massenbewegungen)?
Ja (Yes) Nein (No)

1.1 If yes, please briefly describe the information provided for each landslide (or for most landslides):
Wenn ja, beschreiben kurz die Informationen zu den einzelnen Massenbewegungen (oder für die meisten Massenbewegungen):

1.1.1 How many landslides does the inventory contain?
Wieviele Massenbewegungen sind in der Datenbank vorhanden?

1.1.2 Is it in digital (i.e. a spatial or alphanumeric database) or in paper format (e.g. datasheets and/or maps)? Please specify:
Ist sie digital oder in Papierformat? Bitte erläutern Sie:

1.1.3 If digital, which spatial/alphanumeric database software do you use (e.g. ArcGIS, Oracle, Access, etc)?
Falls sie digital ist, welche Datenbank Software benutzen Sie (z.B. ArcGIS, Oracle, usw.)?

1.1.4 If including maps (in digital or in paper format), how are landslides represented on them (e.g. as point features, as lines or as polygons, or as combination of all of them depending on the size and type of landslides)?
Falls sie Karten enthält (digital oder Papierformat), wie sind die Massenbwegungen dargestellt (z.B. als Punkte, als Linien oder Polygone, oder als Kombination, abhängig von Grösse oder Art von Massenbewegung)?

1.1.5 What is the inventory map scale? *Wie gross ist der Kartenmassstab?*

1.1.6 When was the inventory created or last updated?
Wann wurde die Datenbank erstellt und zuletzt aktualisiert?

1.1.7 What is the approximate geographical coverage of the inventory (e.g. in Km^2 or in % with respect to the total extension of the region)?
Wie grosss ist die ungefähre geographische Abdeckung von der Datenbank (km^2 oder in % in Bezug der Gesamtfläche Ihrer Region, z.B. Bundesland)?

1.1.8 Do non-recorded landslides exist in the inventoried areas?
Gibt es auch nicht erfasste Massenbewegungen in Gebieten der Datenbank?

☞ Please send us an example of a datasheet or attribute table (if in a GIS) and a piece of a map showing landslides and the legend.
Bitte schicken Sie uns ein Beispiel eines Datenblattes oder der Attributtabelle (falls in GIS) und einen Kartenausschnitt mit Massenbewegungen und die Legende.

1.2 If not, does your organisation have a geological or geohazard database or paper maps where landslides are also included?
Falls nein, haben Sie ein geologisches Archiv oder ein geogenes Naturgefahrenarchiv, wo Massenbewegungen enthalten sind.
Nein (No) Ja (Yes)

1.2.1 If yes, please briefly describe what information and in which form is included for landslides, following the questions in section 1.1 (i.e. number of landslides, map scale, if in digital or paper format, database software used if in digital format, date of creation, geographical coverage, etc.).
Falls ja, bitte beschreiben Sie kurz welche Informationen zu Massenbewegungen vorhanden sind. Folgen Sie dabei den Muster von 1.1 (Anzahl von Massenbewegungen, Kartenmassstab, digital oder Papierformat, Datum der Erstellung, geographische Abdeckung usw.).

☞ Please send us an example of a datasheet and a piece of a map with landslides and the legend. *Bitte schicken Sie uns ein Beispiel eines Datenblattes und einen Kartenausschnitt mit Massenbewegungen und die Legende.*

Next sections deal with availability of landslide susceptibility, hazard or risk maps. In brief,

- by susceptibility maps we refer to maps showing zones where landslides (of a specific type) may occur in the future. For each zone, they also indicate the level of landslide propensity or probability.
- by hazard maps we refer to maps showing the probability of occurrence of an event of a specific type at a given location within a reference period of time. They are susceptibility maps showing also the temporal probability of landslide occurrence.
- by risk maps we refer to maps showing zones of expected damage and/or losses caused by landslides. Risk can be assessed and expressed either qualitatively or quantitatively, usually being a function of the landslide hazard level, the exposure (elements at risk) and the vulnerability of the elements at risk (i.e. the degree of loss).

Die nächsten Abschnitte haben mit der Verfügbarkeit von Gefahrenhinweiskarten, Gefahrenkarten und Risikokarten von Massenbewegungen zu tun. Kurz:

- Unter Gefahrenhinweiskarten (Prädispositionskarten) versteht man Karten, die Zonen zeigen, wo in Zukunft Massenbewegungen (eines bestimmten Typs) auftreten können. Für jede Massenbewegungszone geben sie auch den Grad der Anfälligkeit (Prädisposition) oder der Wahrscheinlichkeit für eine Massenbewegung an.
- Unter Gefahrenkarten verstehen wir Karten, welche die Wahrscheinlichkeit eines spezifischen Ereignisses an einen bestimmten Ort innerhalb einer gewissen Zeitspanne zeigen. Es sind Gefahrenhinweiskarten, die auch die zeitliche Wahrscheinlichkeit des Auftretens einer Massenbewegung beinhalten.
- Unter Risikokarten verstehen wir Karten, die Zonen zeigen, wo durch Massenbewegungen erwartete Schäden und/oder Verluste verursacht werden. Risiko kann entweder qualitativ oder quantitativ erfasst und dargestellt werden, gewöhnlich als eine Funktion des Grades der Massenbewegung, der Einwirkung (gefährdete Objekte, Exposition) und der Verwundbarkeit der gefährdeten Objekte (zB. ihr Grad des Verlustes).

2. Do you have landslide susceptibility maps?
Haben Sie Gefahrenhinweiskarten für Massenbewegungen?
Nein (No) Ja (Yes)

2.1 If yes, describe briefly their contents:
Wenn ja, beschreiben sie kurz deren Inhalte:

2.1.1 Are they in digital or in paper format?
Ist sie digital oder in Papierformat?

2.1.2 If digital, which GIS software do you use?
Falls digital, welche GIS software verwenden Sie?

2.1.3 What is the map scale? *Welcher Kartenmassstab wird verwendet?*

2.1.4 How many susceptibility classes or levels are shown on the maps?
Wieviele Empfindlichkeitsklassen oder Grade sind auf den Karten dargestellt?

2.1.5 When were the maps created or during which time period?
Wann wurden die Karten erstellt oder in welchem Zeitraum?

2.1.6 What is the approximate geographical coverage of the existing maps (e.g. in Km^2 or in % with respect to the total extension of the region)?
Wie gross ist die ungefähre geographische Abdeckung der existierenden Karten (Km^2 oder % der gesamten Fläche der Region)?

2.1.7 Which method/model was used to produce the maps?
Mit welchem Modell/Methode wurden die Karten erstellt?

2.1.8 Indicate the report, paper, book or website where the method/model used is described:
Nennen Sie uns den Bericht, die Zeitschrift, die Internetseite oder das Buch, wo die angewandte Methode/Mode beschrieben ist.

☞ Please send us an example of an attribute table (if in a GIS) and a piece of a susceptibility map and the legend.
Bitte schicken Sie uns ein Beispiel eines Datenblattes und einen Kartenausschnitt der Gefahrenhinweiskarte und die Legende.

3. Do you have landslide hazard maps?
Haben Sie Gefahrenkarten für Massenbewegungen?
Nein (No) Ja (Yes)

3.1 If yes, briefly describe the contents of the hazard maps.
Wenn ja, beschreiben sie kurz die Gefahrenkarte und die dazugehörige Datenbank.

3.1.1 What is the source of information on landslide temporal frequency (e.g. historical records, aerial photographs of various epochs, multi-temporal field surveys, field instrumentation, etc.)? Please specify also the time period of the records, observations or measurements? *Was ist die Quelle der Häufigkeit der Massenbewegungen (historische Berichte, Luftaufnahmen verschiedener Epochen, zeitlich aufeinanderfolgende Geländeaufnahmen)? Bitte schildern Sie auch die Zeitabstände der Aufnahmen, der Beobachtungen und der Messungen:*

3.1.2 Are landslide historical records frequent in your region?
Sind historische Aufzeichnungen in Ihrer Region häufig?

3.1.3 Are the hazard maps in digital or in paper format?
Sind die Gefahrenkarten digital oder in Papierformat?

3.1.4 If digital, which GIS software do you use?
Falls digital, welche GIS Software benutzen Sie?

3.1.5 What is the map scale? *Welcher Kartenmassstab wird verwendet?*

3.1.6 How many hazard classes or levels are shown on the maps?
Welche Gefahrenklassen oder -grade werden auf den Karten gezeigt?

3.1.7 When were the maps created or during which time period?
Wann wurden die Karten erstellt oder in welchem Zeitraum?

3.1.8 What is the approximate geographical coverage of the existing maps (e.g. in Km^2 or in % with respect to the total extension of the region)?
Wie gross ist die ungefähre geographische Abdeckung der existierenden Karten (Km^2 oder % der gesamten Fläche der Region)?

3.1.9 Which method/model was used to produce the maps?
Mit welchem Modell/Methode wurden die Karten erstellt?

3.1.10 Indicate the report, paper, book or website where the method/model used is described:
Nennen Sie uns den Bericht, die Publikation, die Internetseite, Zeitschrift oder das Buch, wo die angewandte Methode/Modell beschrieben ist.

☞ Please send us an example of an attribute table (if in a GIS) and a piece of a hazard map and the legend.
Bitte schicken Sie uns ein Beispiel eines Datenblattes und einen Kartenausschnitt der Gefahrenkarte und die Legende.

4. Do you have landslide risk maps?
Nein (No) Ja (Yes)

4.1 If yes, please describe them following the questions in section 2.1. Describe also briefly the method used to produce them (indicating if it is qualitative or quantitative and including a reference), the elements at risk (exposure) considered and their vulnerability.
Falls ja, bitte beschreiben sie diesen entsprechend den Fragen laut Kap. 2.1. Beschreiben Sie auch kurz die angewandte Methode (Angabe ob quantitativ oder qualitativ mit Quellenangabe), die betrachteten, exponierten Objekte, und deren Verletzlichkeit.

☞ Please send us an example of an attribute table (if in a GIS) and a piece of a risk map and the legend. *Bitte senden sie uns ein Beispiel einer Datentabelle (falls in GIS) und einen Auszug einer Risikokarte und die Legende.*

Accessibility, regulations and additional information

Zugänglichkeit, Regeln, und zusätzliche Informationen

5. Are the landslide inventory data or maps accessible to the public (either freely or at a cost)? Please specify which data/maps:
Sind die Datenbanken und Karten der Massenbewegungen öffentlich zugänglich (frei oder gegen Bezahlung)? Bitte sagen Sie welche Daten/Karten:

6. Are they also available on the web and/or in English?
Sind Ihre Daten auch im Internet und/oder auf Englisch verfügbar?

7. Is there a law or regulation that include the obligation of producing some type of landslide map and/or datasheet for land use planning (e.g. for restriction on construction) and/or civil protection purposes? If yes, please give the reference and indicate the major objective and date of entry into force:
Gibt es ein Gesetz (Norm) für die Erstellung von Datenblättern und Karten von Massenbewegungen im Zuge der Raumplanung (zB. Bauverbot) und/oder für Zivilschutz:

8. Do you know any other organisation in your region, including also universities, which might have produced landslide inventories, susceptibility, hazard or risk maps, even if over small areas? If yes, please indicate also a possible contact person:
Kennen Sie andere Organisationen in Ihrer Region, eingeschlossen die Universitäten, die solche Karten und Datenbanken von Massenbewegungen produziert haben, auch von kleinen Gebieten. Falls ja, dann geben Sie uns bitte Adresse und Kontaktperson:

Thank you for your collaboration. You will get copy of the project report and your collaboration will be acknowledged!
Danke für Ihre Mitarbeit. Sie werden den Projektbericht erhalten und Ihre Mithilfe wird erwaehnt werden.

☞ Please send your answers, the examples of datasheets, databases, maps and legends in digital form to:
Bitte schicken Sie uns Ihre Antworten, die Beispiele der Datenblaetter, Datenbanken, Karten und Legenden in digitaler Form an:

Javier Hervás (javier.hervas@jrc.it) and Joachim Schweigl (joachim.schweigl@jrc.it).
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Abstract
Landslides are a major natural hazard in hilly and mountainous regions of Austria. The delineation and characterisation of landslide hazard areas in the whole country using a harmonized approach is of the utmost importance to the implementation of risk reduction strategies, including also land use planning and mitigation measures, as suggested in the EU Thematic Strategy for Soil Protection. To this end, a study of landslide maps and ancillary data available mainly at national and regional (federal state) mapping organisations and research institutes in Austria has been carried out. The results show that, although not exhaustive, a great deal of information on landslides exists in Austria. Such information is mainly available in the form of landslide inventories and susceptibility maps, often making part of digital databases. These data are however widely spread in different administrations, mainly because of the federal structure of the country. Primarily as a result of this, these maps and databases show significant differences concerning the mapping approach used, landslide classification criteria, representation scale, legend and symbology, data format, etc. Accessibility to most of these data is at the moment restricted to public administrations, although there are currently initiatives to make them publicly accessible via webGIS. Finally, some recommendations to improve landslide risk management in the country are provided.

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