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Categorising inconsistencies between national GIS data in Central Europe: case studies from the borders triangle of Belgium, the Netherlands and Germany

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Abstract: Operational environmental management of European landscapes requires geographical information which is valid and coherent across national borders and only takes natural boundaries as criteria for ordering. However, when combining GIS data from different countries, national borders appear as artificial breaks in many medium- and large-scale thematic GIS, for example, topographical, geological or soil information systems. Inconsistencies in GIS data can be categorised into three types: (1) country specific deviations, (2) inconsistencies due to different data surveying and management procedures and (3) errors. Some of the inconsistencies, such as national attribute names, can be ruled out by simple modifications of the data models without changing the structure of the national databases themselves. Others, such as soil typologies, have to be addressed by intensified co-operation between national authorities. It is concluded that for practical and financial reasons, pragmatic solutions are required in order to integrate national data into a European framework.

Keywords: GIS, Europe, cross-border, data integration, data inconsistency

1. Introduction

Geographical information systems (GIS) are among the most important tools for operational environmental management (Bähr & Vögtle, 1999). The GIS data that is used covers many different geo-ecological aspects like relief, land cover, geology, soils and hydrology, and the number of additional thematic layers is still increasing (Bastian & Schreiber, 1999). Yet for practical geo-ecological research and planning, medium and large scaled maps and information systems are required. But since most of these systems are provided by national authorities and they are confined to national borders.

However, future environmental management in Europe must be based on natural boundaries in order to fulfil the new guidelines produced by the European parliament. Moreover, for many geo-ecological questions watersheds will have to be regarded as ordering criteria (see, for example European Parliament and European Council for determining a framework for joint regulation regarding water management policy, 2000). This raises many issues, especially when dealing with watersheds that cross administrative borders.

This is why we here investigate the consistency of different national GIS data bases from the country triangle of Belgium, the Netherlands, and Germany. Our study is part of a project aiming at improving co-operation in the field of cross-border management of meso-scale river catchments (areas of 10 km^2).

We first investigate quality issues of the data, focussing on

- digital terrain models,
- land cover,
- geological features, and
- soil data.

Secondly, we categorise the different sorts of inconsistencies within and between national GIS. Finally, we discuss methods and measures for improving consistency along borders.

2. Geographic setting

The study area is situated in the country triangle of Belgium (Wallonia, a German speaking community), the Netherlands (Southern Limburg), and Germany (Northrhine-Westfalia). The rivers draining this area are tributaries to the Meuse River, which flows northwards to the North Sea. To the south, the study area stretches into the mid-mountain ranges of the Eifel-Ardennes Massif, while the northern part is part of the lowlands of the Rhine-Meuse-embayment (Figure 1).

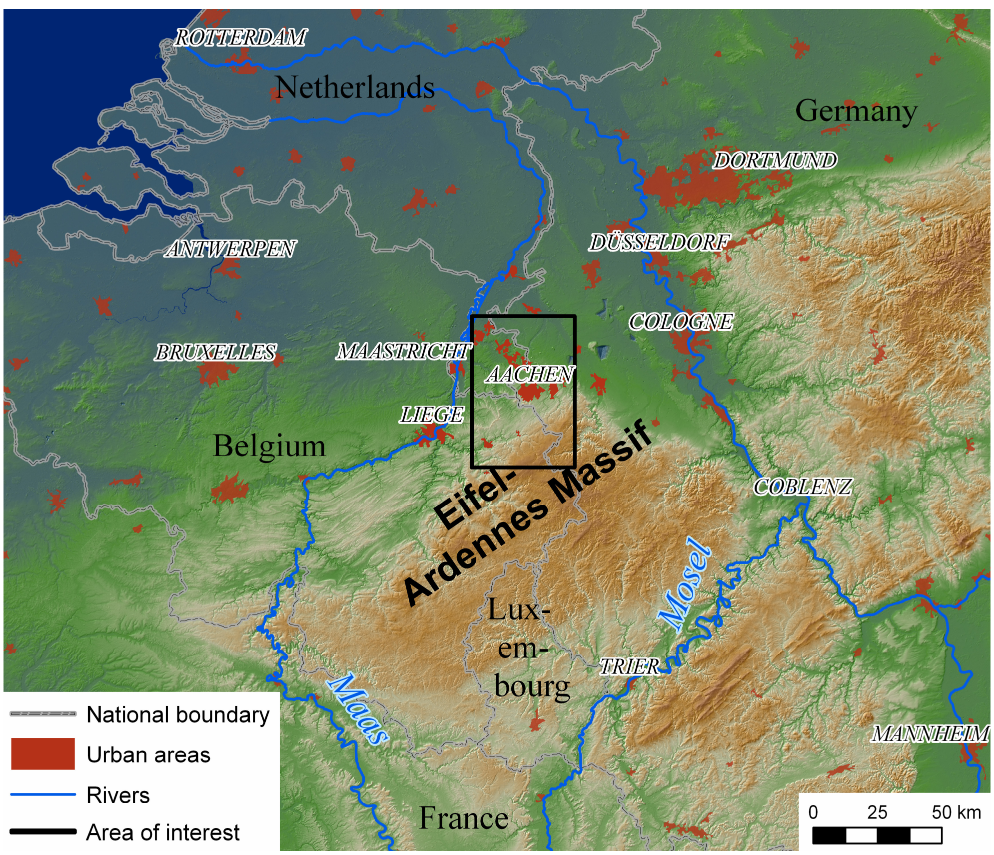

Figure 1 - The study area, at the northern margin of the Eifel-Ardennes Massif

3. Data and methods

We used geographic data from the official national data providers within the three countries involved. Details about the actual data sources can be found in the appendix. New GIS data had to be produced to fill gaps in only a few places. All GIS data processing was performed using *ArcGIS 9* with the functional level of *ArcInfo 9* (ESRI, 2004) and the *SAGA GIS 1.1* (Böhner et al., 2004).

Spatial coverage of national GIS data generally ends at administrative boundaries - like national borders, and as Figure 2 shows, these borders rarely resemble natural boundaries such as watershed edges. Cross-border data exchange and consistency is, therefore, crucial to regional water authorities, and so several strategies were applied in order to correct or to handle data inconsistencies, as discussed below.

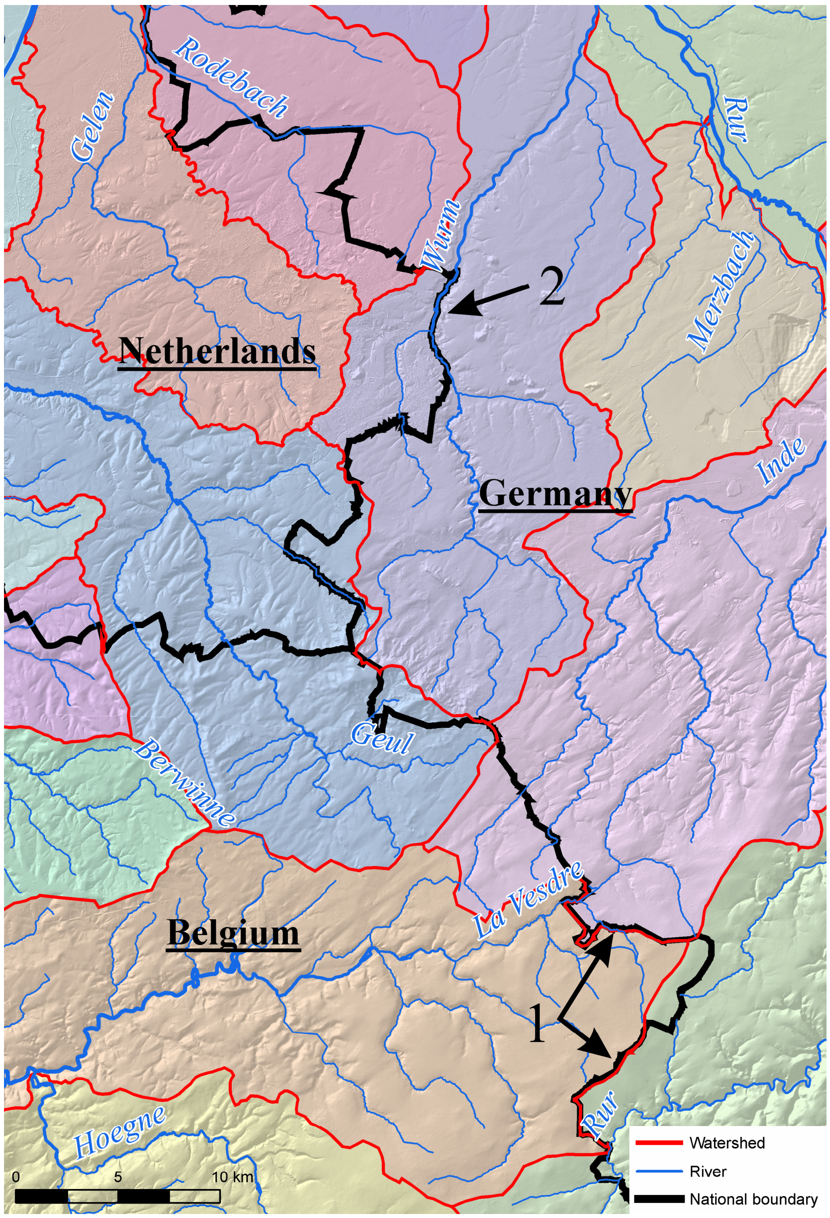

Figure 2 - Comparison of natural and national boundaries in the border triangle of Belgium, the Netherlands and Germany: Many watersheds (shown in different colours) and

rivers cross at least one national border. Only locally do national borders share segments of natural boundaries. For example, the Wurm River defines part of the border between the Netherlands and Germany (No. 1), while the watershed between the Rur and the Vesdre River is the same as some kilometres of the Belgian-German border (No. 2)

4. Case studies

4.1 Digital terrain models

Computer aided catchment analyses and hydrological modelling depends on high-quality elevation data (e.g. Bajat et al., 2005) and detailed catchment and flow characteristics can only be determined by digital terrain models (DTM). This is because the latter are largely free of artefacts and man-made topographical features.

Table 1 summarises the main characteristics of the three DTM data bases that were used I this study. All data bases were provided as grids, and as with all national geographic data the DTM of each country is given in national geodetic reference systems. Moreover, the Belgian elevation data refer to the Niveau Oostende as zero while the Dutch and the German data are given relative to the Normaal Amsterdam Peil. Hence Belgian data are 2.3 metres lower than the Netherlands and Germany.

Country	Geodetic reference system	Zero height	Raster size	Survey method	Filter
Belgium	Belge Lambert 72	Niveau Oostende	10-50	Laser scanning, digitizing of isolines	yes
Netherlands	Rijksdriehoechstelsel	Normaal Amsterdam Peil	5	Laser scanning	no
Germany	Gauß Krüger, Zone 2	Normaal Amsterdam Peil	5-50	Laser scanning, digitizing of isolines, stereoscopic measurements	partial

Table 1 - Main characteristics of the digital terrain data in the area under investigation

These country specific differences can principally be equalised using re-projections and simple calculations. However, even after adjustment, a scar remains along the Belgian-German border (Figure 3). Moreover, residual height differences are unsystematic, with the neighbouring data being partially lower and partially higher as compared to the data on the other side of the border.

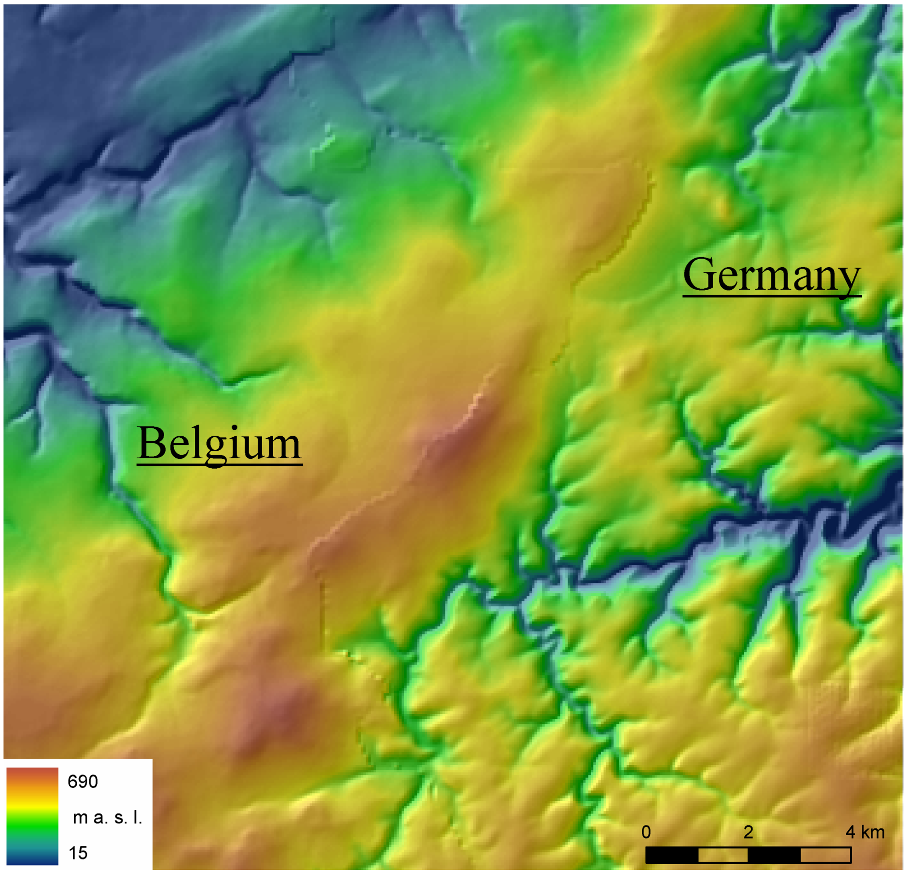

Figure 3 – Scar in a cross-border DTM along the border between Germany and Belgium: DTM re-sampled to 50 metres

Different surveying methods may account for this mismatch. Firstly, as summarised in Table 1, the methods and therefore the quality of the data vary even within the different national DTMs, except for the Dutch data. Secondly different parts of the DTM were surveyed in different years, and the consequence is artificial breaks, especially in dynamic areas like free meandering river sections, settlements or open cast mines. An example is given in Figure 4, No.1.

Further difficulties in using national DTM data as input for hydrological models arise from different filtering of the raw data (Table 1). The Belgian data do not show any anthropogenic features, the German data are only filtered for settlements while linear elements like roads remained in the data (Figure 4, No.2), and the Dutch data are unfiltered. As the filter algorithms are generally not documented, it is not possible to apply the same filter to all data in order to correct these differences.

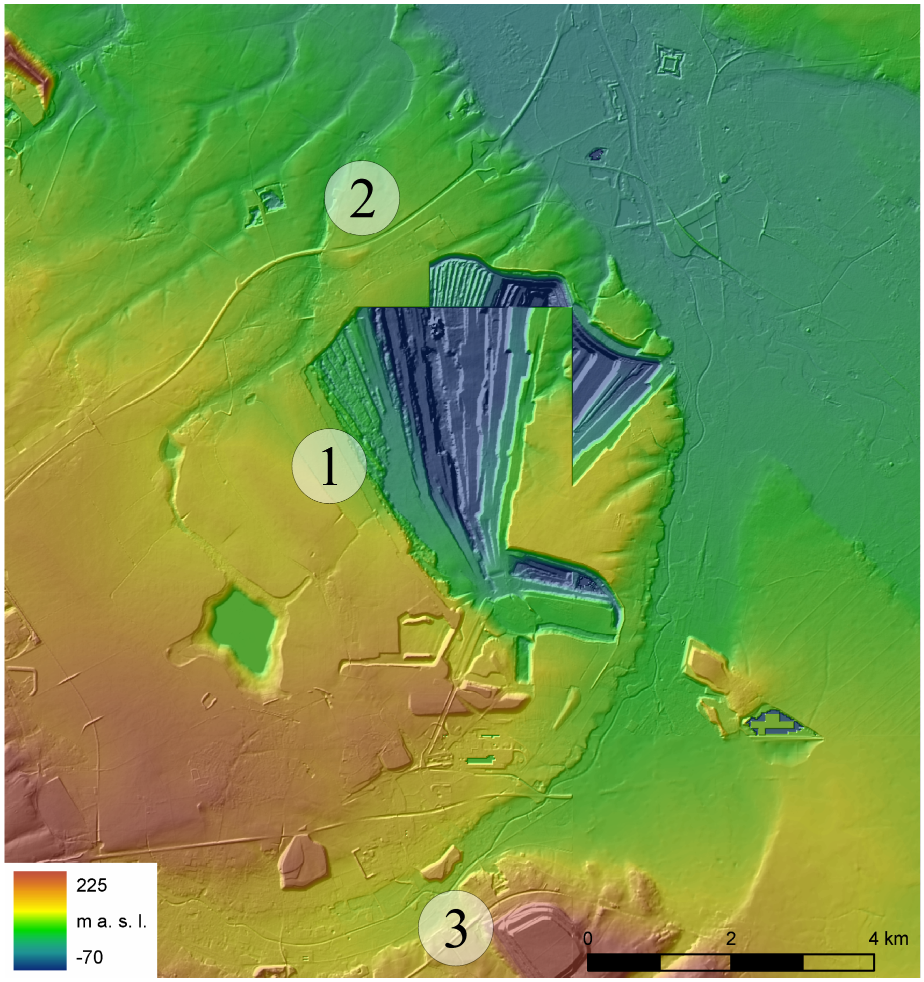

Figure 4 - Example of internal mismatch within the German DTM data in the vicinity of the city of Aachen: (1) Open cast mine Inden including an artificial break due to different dates of survey, (2) anthropogenous feature (highway)

For practical work on rivers with catchments between 10 to 100 km^2, a hydrological correct DTM with a grid cell size of 10 m or less would be desirable. Grids with larger cell sizes mask too many morphological features and are not appropriate for realistic estimates of morphometrical and hydrological parameters (for example, slope and channel networks). Based on the existing information, suitable data can be obtained only for part of the area under investigation (Table 1). Currently, several factors prevent a straight forward cross-border application of the DTM data: different geodetic reference systems and zero elevation as well as different data qualities, interpolation densities and poorly documented filtering techniques.

4.2 Topographical information systems and land cover data

Topographical information systems are of major interest for geo-ecological and hydrological analyses. Most of all, spatial land cover information, like the forested, agricultural or urban proportion of a landscape, represents a vital parameter of most hydrological, climatological and erosion models (Turner et al., 1995).

In Europe, cross-border land cover data have for some time been successfully compiled by the so called CORINE-Program, which provided raster data for most of the European continent based on analyses of satellite images from around 1990 (EEA, 1995) and around

2000 (Bossard et al., 2000). Landsat TM and ETM+ scenes, with a maximum resolution of 30 metres, have been used for these analyses. However, as this information has been aggregated to an even larger resolution of 100 m, it is not suitable for the scale used in this study. Furthermore, the classification accuracy of 85% (personal comment by M. Keil of the German Remote Sensing Data Center, DLR Oberpfaffenhofen, March 2005) is too low for answering typical questions pertaining to proper regional environmental management.

For more detailed studies, land cover information can be obtained from vector-based topographical information systems. This information is available for the three countries within the study area. Such systems are based on topographic and cadastral maps with scales ranging from 1:5000 to 1:50000. Unfortunately, the data are very expensive, even more so for a greater level of detail.

Here, the Top50Vector data were used for the territory of Belgium and the Netherlands, based on topographic maps 1:50000. The database architecture of these systems is similar to that of the more detailed Top10Vector systems. For Germany, the ATKIS system was used, and it is at a 1:5000 scale.

After re-projecting all data to a common reference system, the geometric shapes of the topographical elements were compared. It was found that there are only minor mismatches along the national borders, which can in part be assigned to different survey dates. The data used from the Netherlands and Germany were more up to date than those from Belgium and, as with the DTM data, the differential date of survey is recognisable within each data base. Again, the main errors occur in the areas with the highest land cover dynamics.

Although there is a general match of geometries along the borders, the data are not strictly comparable. Firstly, there are significant differences in the data base structures. The topographical information is separated into different numbers and types of layers. For instance, as far as the land cover and land use layer is concerned, the Belgian and the Dutch systems show only one layer whereas the ATKIS system contains several different layers; for example, land cover in urban areas, traffic and vegetated areas.

Secondly, the attribute names, as well as the number and names of land cover classes, are different. Again, the ATKIS system is very detailed showing about 90 land cover classes, while the other systems contain 38 (Belgium), and 29 classes (Netherlands).

Hence before further analyses can be carried out classes have to be aggregated according to an international legend. In our study, we reclassified the data taking the CORINE legend as a common basis. This was done by incorporating the CORINE class codes as foreign keys into each national information system. With this approach, the structures of the national databases remained largely unaltered. Moreover, the resulting data were detailed enough for studies on the scale relevant for regional environmental management. Figure 5 compares them to the CORINE2000 land cover data.

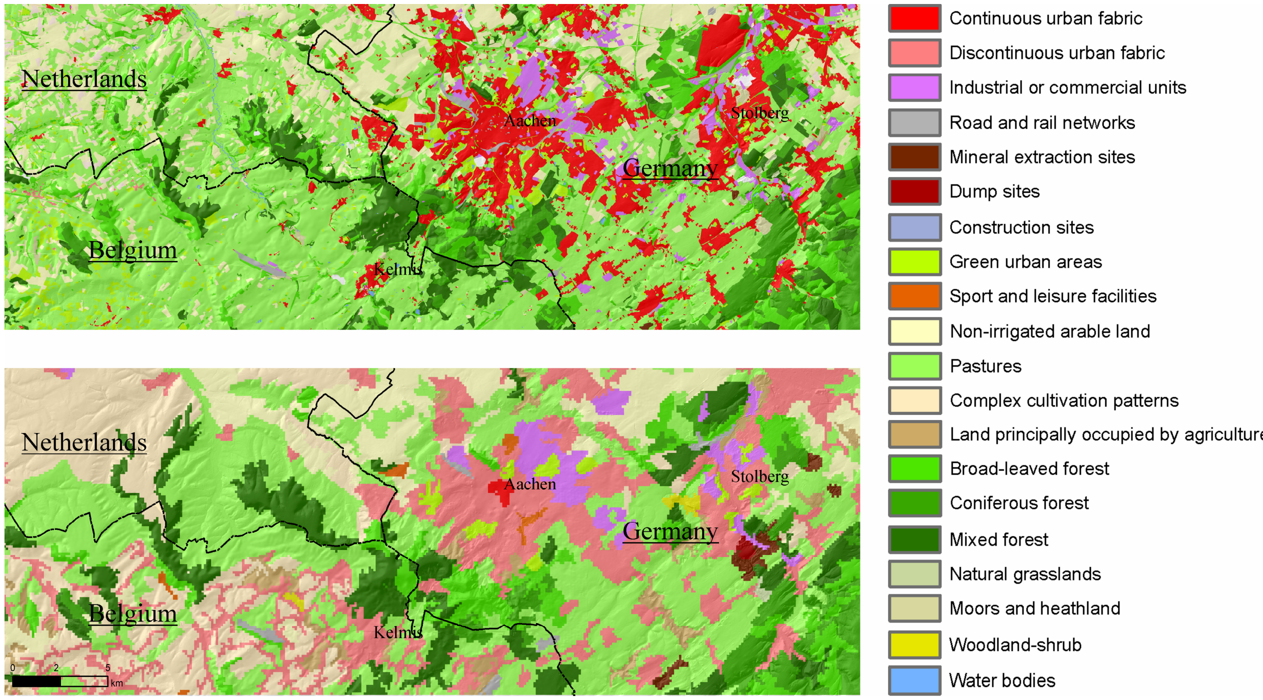

Figure 5 - Comparison of reclassified data from national topographic information systems (top) and CORINE2000 land cover data (bottom) for the area around the country triangle of Belgium, the Netherlands and Germany including the city of Aachen

4.3 Geological information systems

The nature of the geological underground influences many landscape functions such as groundwater recharge and landscape factors, soils, and relief (Bastian and Schreiber, 1999). Geological data are, therefore, very important considerations in environmental management.

Geological information systems are available at different scales. For instance, in the German part of the study area complete coverage can be obtained by using a vector system based on maps scaled at 1:100000. A system based on a 1:25000 scale has, currently, only a partial coverage. By contrast, in Belgian territory vector data are based on maps that are scaled at 1:40000 and which were surveyed around 1900, when some parts of eastern Belgium belonged to Germany and so were not mapped. The resulting gaps were filled by digitising the modern geological map at a scale of 1:25000. Finally, for the Dutch part of the study area, there is currently no vector-based system available. The relevant information was digitised from the "Geologische Kaart van Zuid-Limburg en omgeving" scaled at 1:50000.

Two thematic layers were produced from the national information systems as examples:

1. an overview of the geological age of the strata, and
2. an overview of the main lithological units.

Note that the geological data were processed using the two steps described above:

1. re-projection to a common geodetic reference system, and
2. matching of the attributes to a common legend.

The latter step is problematic because the geological strata are described in full text instead of as separate attributes. Moreover, the descriptions are given in national languages.

Therefore, in order to allow for cross-border data queries, new numerical codes were introduced for the type of rock (RTYPE_ID), texture (TEXT_ID), matrix (MAT_ID), and geological system (SYST_ID). These codes were extracted from the textual descriptions and inserted into a new data model (Figure 6). Due to many orthographic errors in the field entries, an automated extraction was impossible; manual work was necessary.

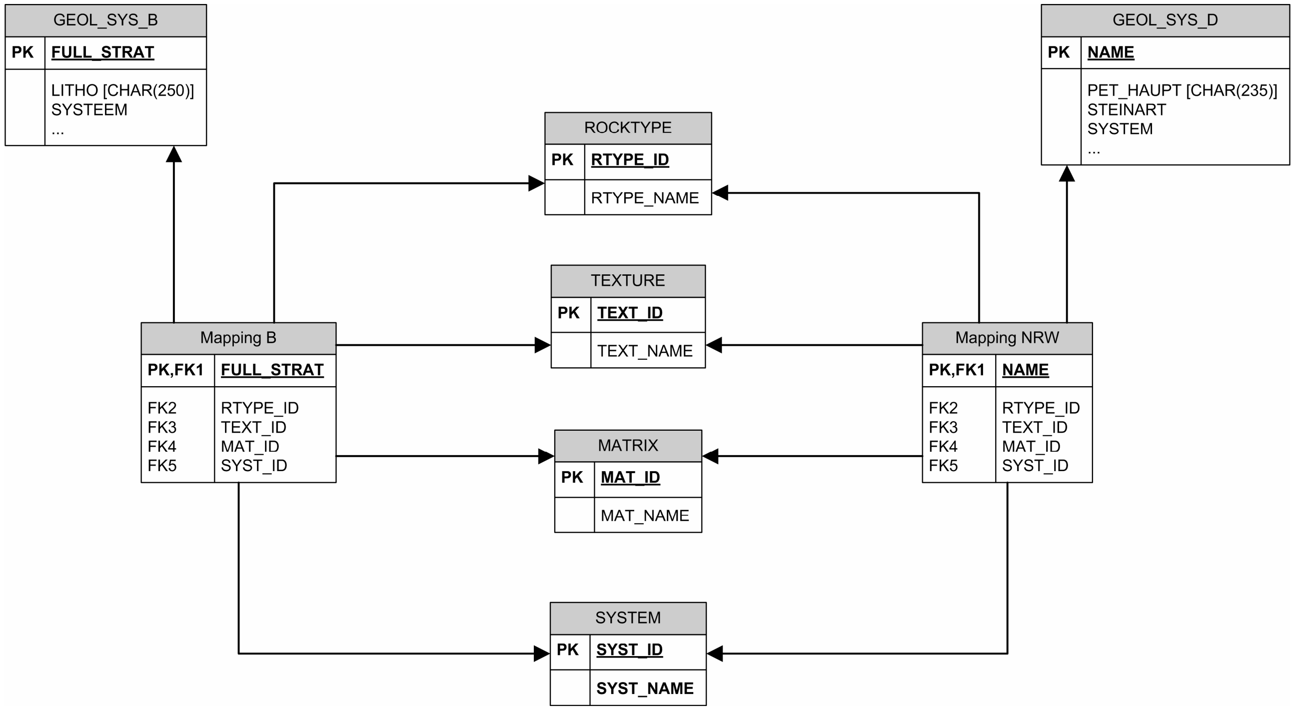

Figure 6 - Refined data model of a cross-border geological Information system: The mapping tables match the primary keys converting from national attribute tables to common attributes, which were either extracted from descriptions or translated from other fields given in national languages

The resulting overviews (Figure 7 and Figure 8) show a relatively good compliance of the different data bases, except for the south-western (Wallonian) part.

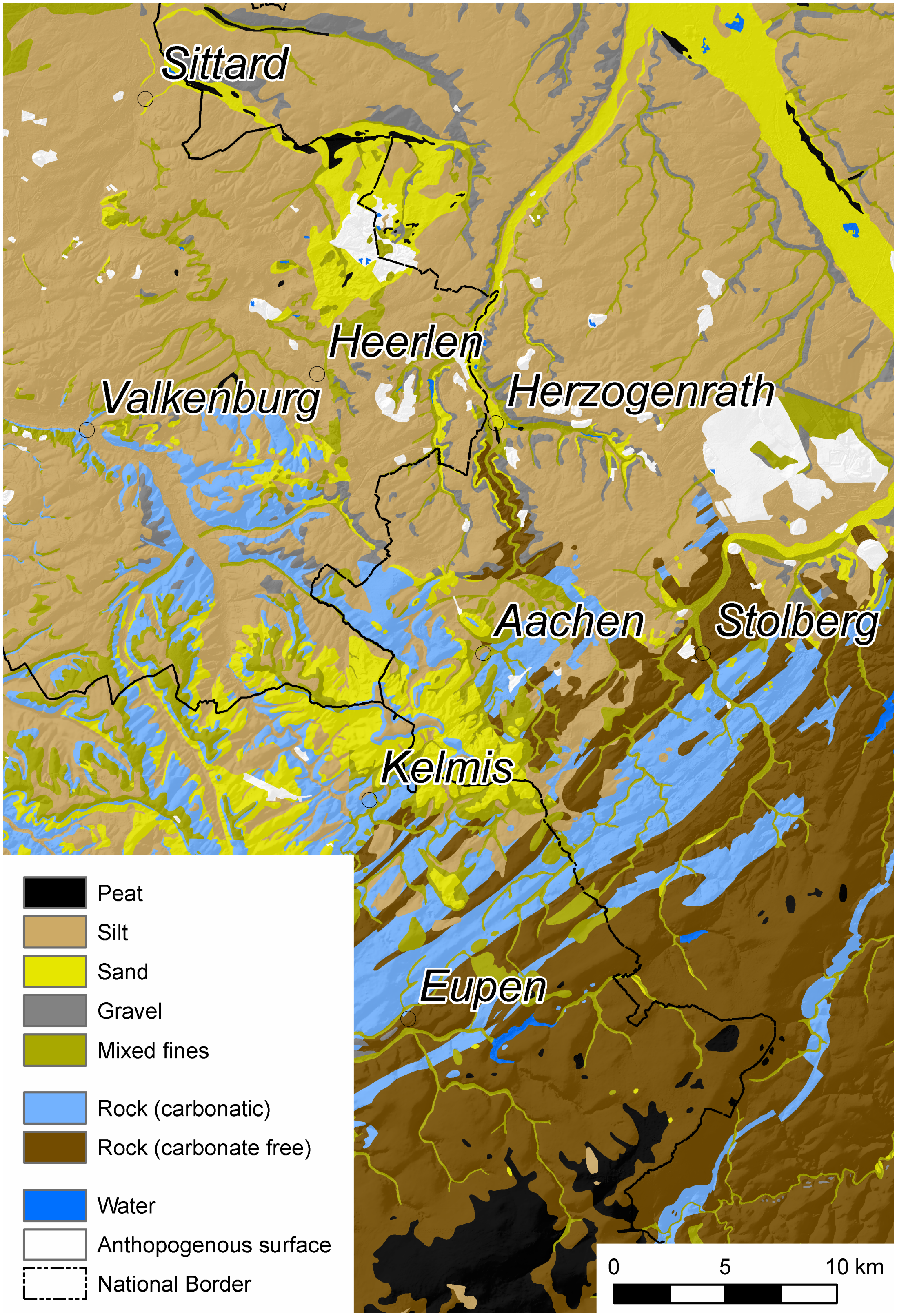

Figure 7 - Main lithological units in the country triangle of Belgium, the Netherlands and Germany compiled from different national geological information systems

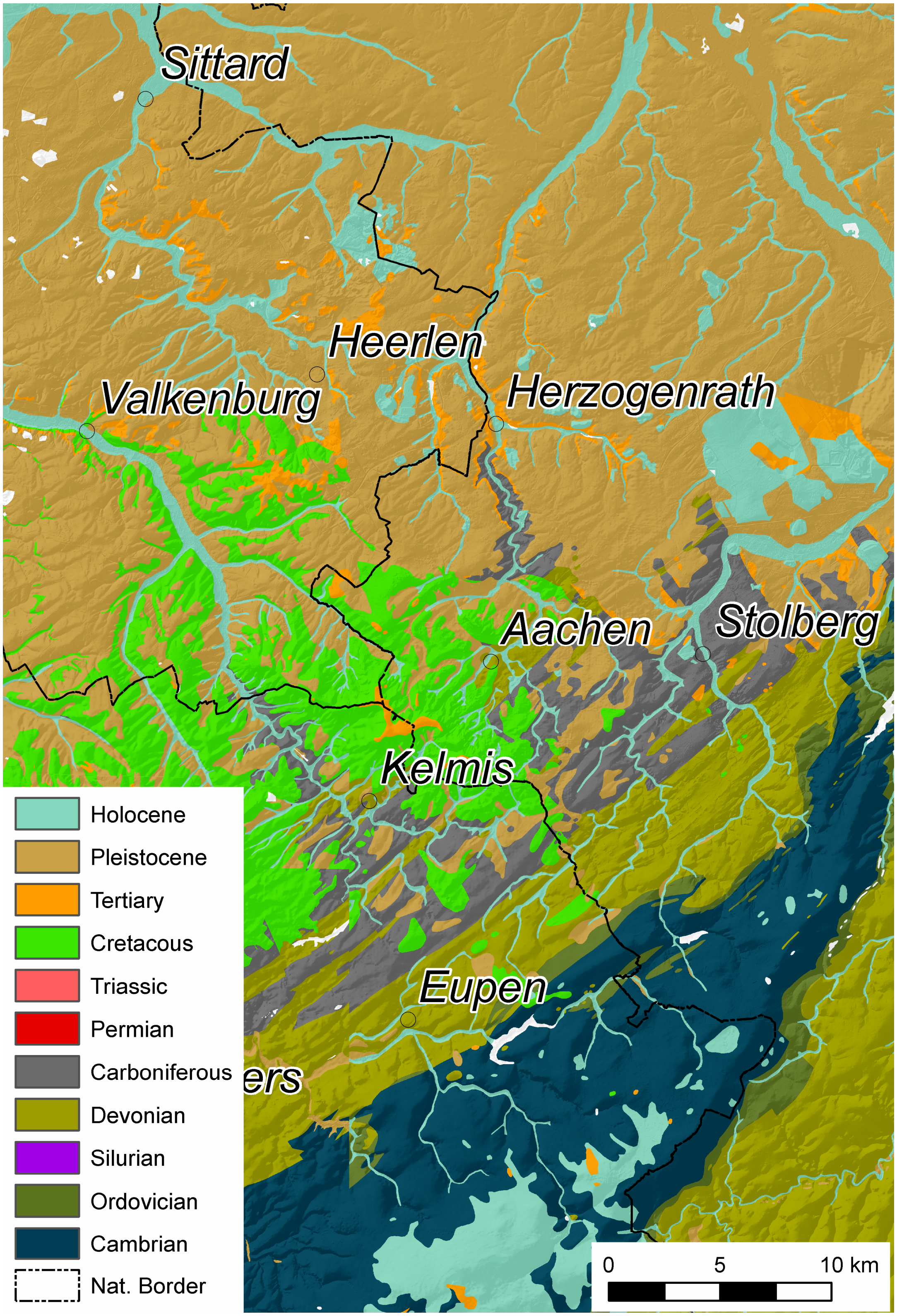

Figure 8 - Overview of the geological ages of the strata in the country triangle of Belgium, the Netherlands and Germany compiled from different national geological information systems

However, a deeper investigation confirms the existence of major inconsistencies (Figure 9).there are artificial faults, especially along the German-Belgian border and the Quaternary strata are underrepresented in the Belgian data.

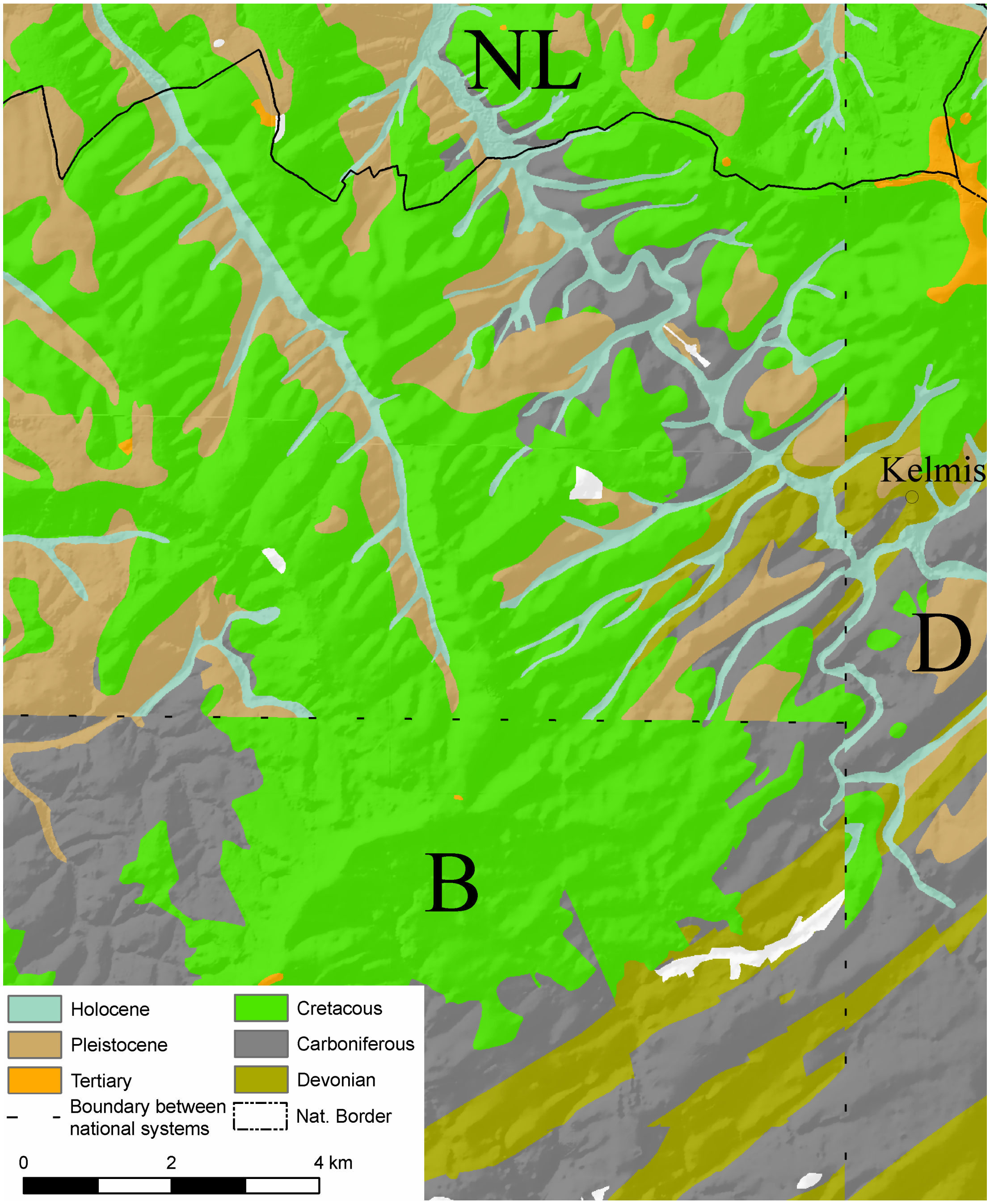

Figure 9 - Artificial 'faults' along the boundaries of national geological information systems

The first and more serious problem is due to the fact that the geological strata in the three countries are assigned to national bio- and litho stratigraphies, which do not fit in detail. This is especially true for the Devonian and Carboniferous strata between Germany and Belgium. Different subdivisions of these systems prevent cross-border compilation of the data. Such fundamental inconsistencies cannot be handled by data management strategies. Clearly, co-operation networks like the International Commission on Stratigraphy (ICS) have to be involved and new surveys may be necessary.

The second problem may be explained by different prioritisation of geological features in the three countries. Obviously, during early geological surveys Quaternary covers played a minor role in Belgium (Wallonia) compared to Germany and the Netherlands. The problem appears to be less serious because information about the Quaternary cover layers can mostly be obtained from the new Wallonian soil information system, as discussed below.

4.4 Soil information systems

The pedosphere is the boundary layer between the atmosphere and the lithosphere, the hydrosphere and the biosphere. It is an area of complex interaction between these environmental subsystems (Bastian & Schreiber, 1999). High quality soil data are, therefore, desirable for ecological analyses.

Soil information systems are available from national or private authorities from all countries investigated here. They were generated by vectorisation of soil maps scaled at 1:50000 for the Netherlands and Germany and at 1:20000 for Belgium. Whereas he data bases of the Belgian and the Dutch systems were filled using the information in the alphanumerical soil codes of their legends, the German data base contains additional information from bore hole data.

Note that while the information systems from Belgium and the Netherlands are confined to the national borders of the respective countries, the system from Germany stretches far beyond the border. Hence after re-projection of the data to a common reference system, the shapes of the soil zones can be compared in the overlapping areas. Generally, such comparison reveals severe mismatches between the systems (Figure 10).

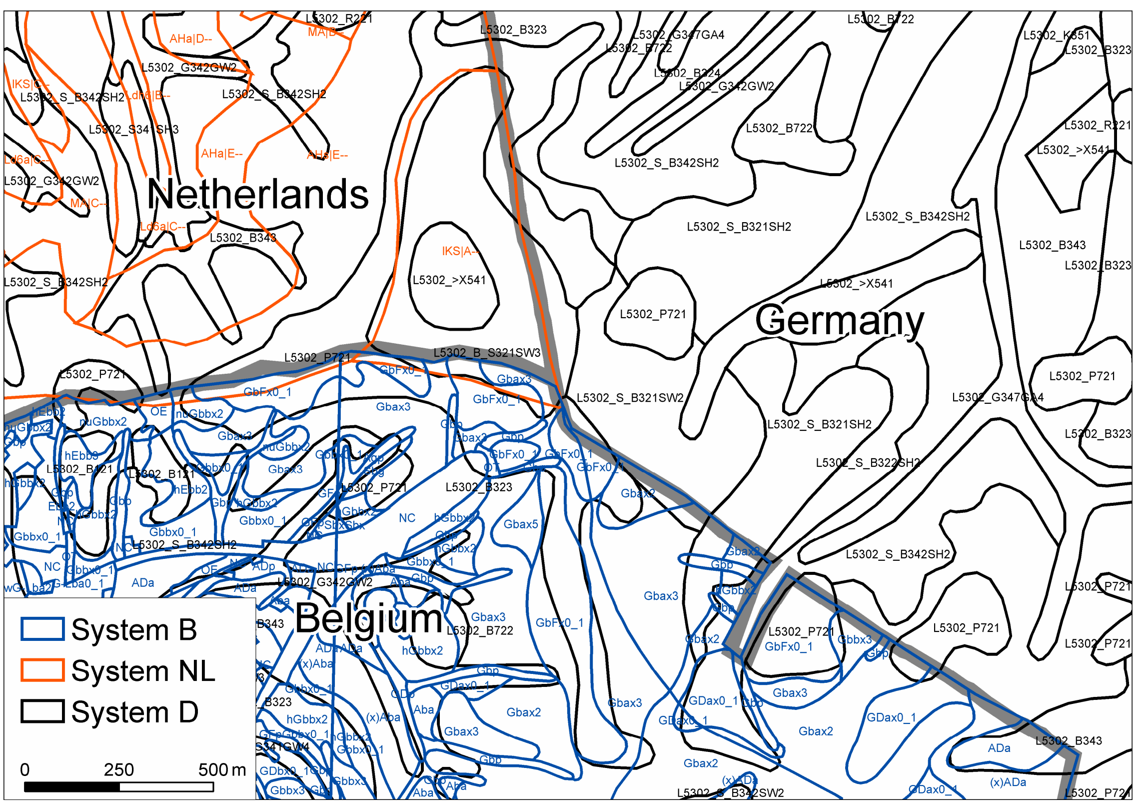

Figure 10 - Comparison of the shape of soil zones in the country triangle of Belgium, the Netherlands and Germany compiled from different national soil information systems

As expected from the scale of the original paper soil maps, the Belgian system shows more geometric details than the other systems do (Table 2). These mismatches can be explained mainly by the different soil typologies applied in Belgium, the Netherlands and Germany. The first two countries use an effective classification scheme, which separates soil zones by physicochemical properties, whereas the German classification scheme is generic and based on soil development identified by diagnostic horizons.

System	Subset	number of shapes	number of soil types
NL	NL	16	16
B	B	280	41
D	NL	39	16
	B	45	18

Table 2 - Comparison of characteristics of the Dutch and the Belgian soil information systems in test areas overlapped by the German system: The size of the area is ~4,6 km^2 in both countries

Also, the data bases show major differences. The translated attribute names are given in Table 3, and although the data bases hold a wealth of physicochemical soil parameters there are only few which are present in more than one database. Even in the case of comparable parameters, cross-border queries are hampered by differences in data coding and data types. Parameters are given as textual descriptions, as numeric or textual codes or as quantitative values.

Field	D	B	NL
Soiltype	Code (Text)	Code (Text)	Code (Text)
Field capacity	Value		
Air capacity	Value		
Potential cation exchange capacity	Value		
Erodibility	Code (Number)		
Saturated water conductivity	Value		
Capillary ascendancy of groundwater	Value		
Water budget (classified)	Code (Text)	Code (Text)	
Suitability of soil for decentral infiltration	Code (Text)		
Groundwater depth	Value		
Number of layer	Value		Value
Thickness of layer	Value		Value
Percent stones	Value		
Percent sand	Value		
Percent loam			Value
Percent silt (D: 'Schluff')	Value		Value
Percent clay	Value		Value
Percent peat	Value		
Percent humus	Value		Value
Percent carbonate	Value		Value
Texture (classified)	Code (Text)	Description	
Profile development		Description	
Grain size of sands			Value
Density			Value
pH-value			Value
Fe_2O_3 content			Value
C/N ratio			Value
Soil value (classified)	Code (Number)		
Substrate		Description	Code (Number)
Utilisation			Code (Text)

Table 3 - Comparison of database attributes of national soil information systems for Belgium, the Netherlands and Germany

Another important difference between the information systems lies in the differentiation of soil profiles. The Dutch system shows separate information for different soil horizons, with information based on standard profiles for each soil type, which are matched to a standard depth of 1.2 m and are applied for the whole area of the Netherlands. By contrast, the profiles in the German system are applied only to the areas of the former map sheets and these show a variable depth. Finally, the Belgian system does not provide any detailed information on profile differentiation and although there are hints on the differentiation in the textual descriptions like "above" or "under" and some indication on soil development, an evaluation of single soil horizons is not possible. Therefore, comparable cross-border information on textures for specific soil depth or horizons can not be obtained with available database-management tools.

To further investigate integration of national soil data, we tried to compile a cross-border layer of soil texture as an example. This information is principally available from all three data bases (Table 3). Unfortunately, the data types differ. While the systems from Germany and the Netherlands give percentages of the rock, sand (Germany only), silt and clay fraction, the Belgian texture data are pre-classified according to the Belgian classification scheme. Therefore, for the compilation of the soil layer, we tried to make the national data comparable by re-classifying them according to a common classification scheme (Boden, 1994).

The resulting cross-border layer of soil texture shows enormous discrepancies (Figure 11). The boundaries between the information systems are clearly detectable and along the boundary between Germany and the Netherlands, where non-classified numerical data meet, mismatches are much less pronounced. However, a closer look at the systems in the overlapping areas shows that the number of shapes and soil types is not comparable.

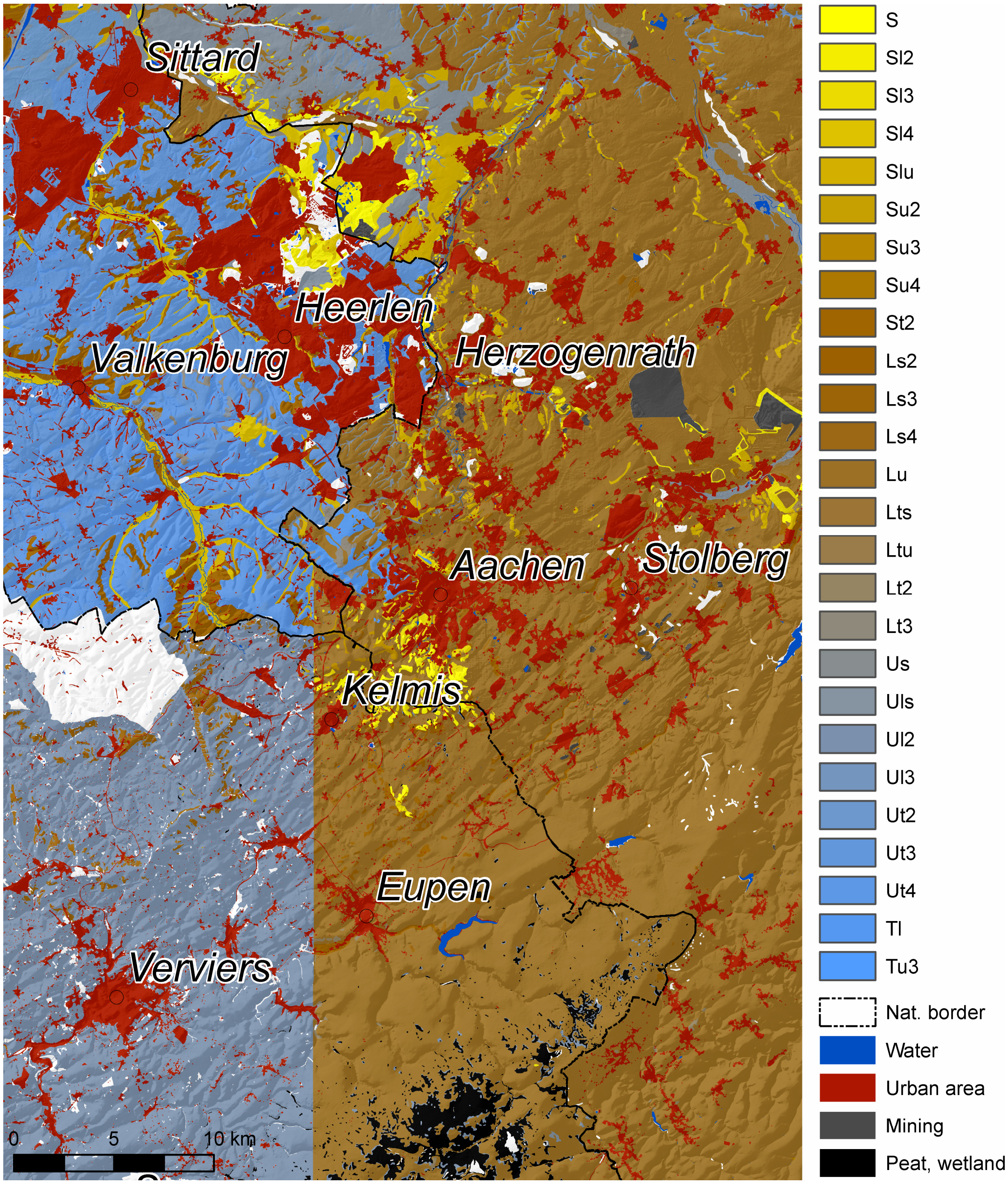

Figure 11 - Soil textures in the country triangle of Belgium, the Netherlands and Germany compiled from different national soil information systems (re-) classified according to AG Boden (1994): The texture classes are ordered with decreasing grain size from yellow (sands) to brown (loams) and blue (stilts and clays). No-data areas either belong to built-up/industrial area or to another information system (e.g. the Flemish enclave of Voeren)

5. Discussion and conclusions

The GIS data bases analyzed here have proven to be an essential source of information in many geoecological studies within Belgium, the Netherlands and Germany (Blümel et al., 2003; Bogena et al., 2006). However, cross-border applications of the data are currently hampered by different inconsistencies within and between the data bases. Such inconsistencies can be assigned to the categories summarised in Table 4.

Category	Subcategory	Example, explanation
errors	Data entry errors	wrong typing during
	Geometrical errors	wrong / weak georeferecing or digitizing
database specific differences	different data formats or data models	different fields, data types and tables
	different timing and update of survey	features of different years are mapped together
	different classification procedures	subjective (field) or objective (laboratory) measures, different aggregation levels
	different quality criteria	smooth curves vs. rough curves
	different geostatistical procedures	interpolation and filter techniques
country specific differences	national geodetic reference systems	in the area under investigation: Belge Lambert 72, Rijksdriehoeckstelsel, Gauß-Krüger Zone 2
	different reference data	different zero heights
	national languages	national field names
	country specific classification schemes	national typologies and stratigraphies
	country specific priorities	missing or under represented features (e.g. contour lines of height in the Netherlands)

Table 4 - Comparison of database attributes of national soil information systems for Belgium, the Netherlands and Germany: Categories of inconsistencies and incompatibilities observed

Inaccuracies, such as incorrect typing during data entry, cause problems when querying the data. When primary keys are affected, the attribute look-up fails and so the query gives "no data" areas as results. When typing errors occur in attribute fields, a query based on unique values will cause duplicate results for identical features. Currently, these errors have to be corrected with time consuming manual work.

Even though in the information systems used here, geometrical errors were negligible, such errors can occur due to wrong geo-referencing or imprecise digitising. Currently, no general quality criteria exist, for example, standards for the spacing of vertices in arcs within a meso-scale GIS. Moreover, support systems based on user feedback and update services are generally missing. The result is that rectification of detected errors is prohibited and erroneous data has been distributed over many years. Hence both international quality standards for GIS data, and regular data updates based on user feedback would significantly improve data compatibility and quality.

Most inconsistencies result from database or country specific characteristics (cf. Table 4), and Inconsistencies of these categories are mostly systematic. However, this does not always imply simple solutions. Though re-projections of geodetic reference systems and translations of field names are easy in principle, they cause some difficulties in practice.

As far as the different national reference systems are concerned, the European Union has already proposed a common system (ETRS 89). yet this system is not yet commonly applied, and most national data providers continue to use their own systems. Re-projection still has to be done by the user, and it can be quite time consuming depending on the file size, file number, file type and computer facilities.

In addition, the translation of field names is time consuming also. A simple solution could be an "attribute mapping service", which matches field names of different databases for different themes. Figure 12 shows a schematic data model of such a mapping system. Based on available metadata, these tables could help to "internationalise" national GIS databases without the need of modifying their content or structure. The idea is to include an additional attribute to the metadata which allows fields belonging to the same thematic layer to be found, regardless of the language of the fieldname. Note however that a prerequisite for such an approach is the presence of identical attributes and comparable cardinal scales.

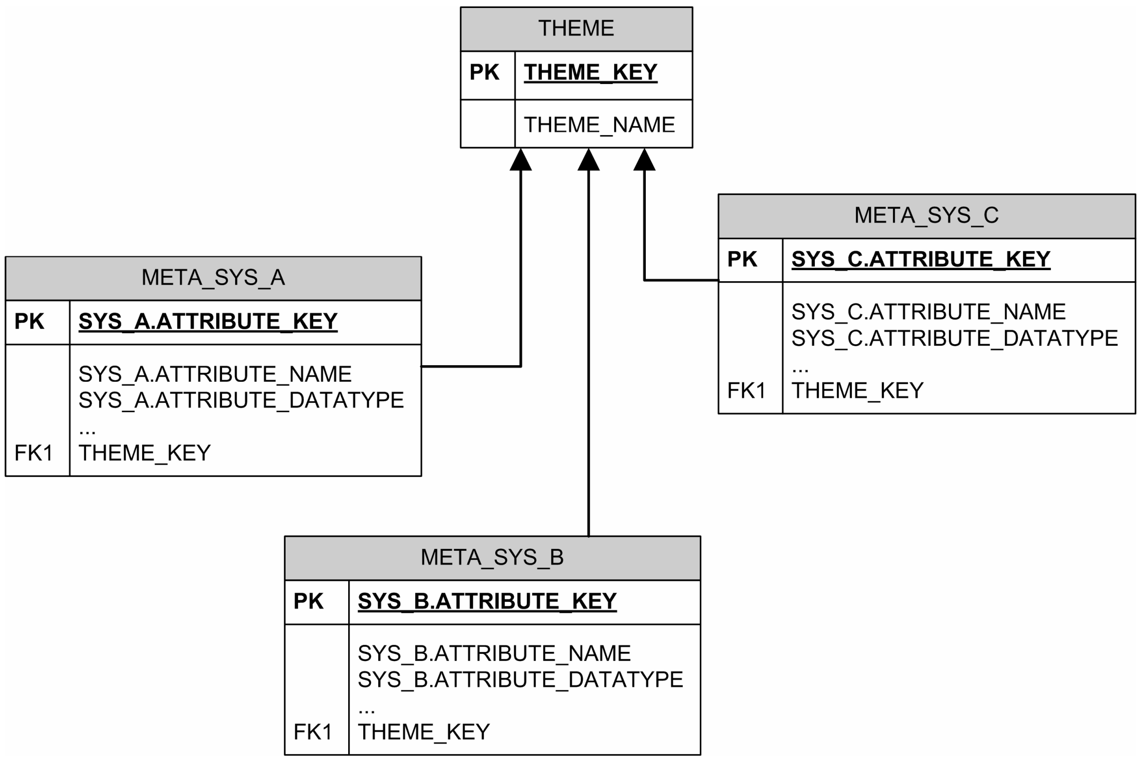

Figure 12 - Simplified metadata model supporting theme based attribute mapping capability

Some inconsistencies, like the country specific classification schemes, can only be addressed with long term strategies. National soil typologies as well as bio- and litho-stratigraphies cannot simply be matched into international soil typologies by data management solutions. This is because national classification schemes that have been used for many decades first have to be matched.

This task requires joint initiatives of international commissions like the International Commission on Stratigraphy. Only then, can a re-analysis of the existing GIS data be sustainable. However, in some cases, new field surveys might be necessary.

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Appendix: Data Sources and license numbers

Digital terrain data:

DGM5 NRW: Digitale Daten des Landes Nordrhein-Westfalen, © Topographische Karten, Landesvermessungsamt NRW; Verwertung im Auftrag des Landesumweltamtes NRW.

AHN, Limburg: © Basis-gegevens: Rijkswaterstaat, Directie Limburg.

DTM 1:10000/1:50000, Wallonie: Origine de l'information MRW.DGRNE.

Topographical information and land cover data:

Corine Land Cover (CLC90): © EEA, Copenhagen, 12/2000.

Corine Land Cover (CLC2000): Belgium: NGI, 2004; Netherlands: Alterra, 2003; Germany: Umweltbundesamt, DLR-DFD 2004.

Top50Vector Netherlands: © Basisgegevens: Rijkswaterstaat, Directie Limburg.

Top50v-GIS Belgium: © Institut géographique national - IGN - Top50v-GIS.

20 m Raster data of Wallonia: Plan d'occupation du sol, Ministère de la Région Wallonne, Conférence Permanente du Développement Territorial, 1999.

ATKIS Germany: Digitale Daten des Landes Nordrhein-Westfalen, © Topographische Karten, Landesvermessungsamt NRW; Verwertung im Auftrag des Landesumweltamtes NRW.

Geological data:

Belgium (Wallonia): GIS - Geological Maps of Belgium at scale 1/40000: Version 1.1. Contract no 2003/DCCartgeol/06

Netherlands (Limburg): Ways-of-Water team.

Germany (Northrhine Westfalia): Informationssystem GK100, Geowissenschaftliche Daten: Geologischer Dienst NRW, Krefeld, _12/2002

Soil data:

Belgium (Wallonia): Ministère de la région wallonne, Direction générale de l'agiculture et la Faculté Universitaire des Sciences Agronomiques de Gembloux, 2004, Projet de Cartographie Numérique des Sols de Wallonie, IRSIA.

Netherlands (Limburg): Database No. 133.03 - Soil data. © Alterra.

Germany (Northrhine Westfalia): Informationssystem BK50, Geowissenschaftliche Daten: Geologischer Dienst NRW, Krefeld, _12/2002.
