Article   1

Landslide Field Mapping: IFFI-Restart Forms for Data Acquisition and Management for the Classification of Landslides in the Municipalities Affected by the 2016 Central Italy Earthquake

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Abstract: Over the last few decades, the approach to geological and geomorphological surveys has changed remarkably. The advent of digital tools has allowed significant advances in the acquisition and management of survey data. In this paper, we demonstrate the development and testing of a new and effective digital survey method that allows for the fast acquisition and collaborative storage and management of data and information. This method was tested in collaboration with five universities for the mapping and classification of landslides in 249 survey areas in Central Italy and, more precisely, in the municipalities affected by the 2016 Central Italy Earthquake. Geological and geomorphological surveys were carried out in the field with tablet PCs, GPS, and cameras. The survey project for collecting field data was based on the structure of the Italian Landslide Inventory (IFFI) and the Territorial Resilience Central Apennines Earthquake Reconstruction (ReSTART) projects. The structure of the database and input forms were implemented for these aims. Moreover, the data and information were retrieved and organised in detailed records useful to the administrative entities.

Keywords: Digital Geological Survey; Mobile GIS; Relational database; Geopackage; Landslide Inventory; Post-disaster management

1. Introduction

The reconstruction of the inhabited centres in the municipalities affected by the 2016 earthquake in Central Italy involves a series of studies and acquisition of geological knowledge of the territory, all of which is managed by the government commissioner in a system called ReSTART [1]. Within this system, numerous projects are carried out by institutions and universities for technical and planning purposes. Among them, a program agreement was activated between the commissioner for reconstruction and the Central Apennines River Basin District Authority (ABDAC), a public entity (recognised by national law since 2017) with technical–scientific competences and a detailed knowledge base of the geo-hydrological hazards and risks of the involved areas. This agreement also involved five universities of Central Italy (University of Camerino, Chieti, Perugia, Rome 'La Sapienza', Urbino 'Carlo Bo') in a project for the re-sizing and reclassification of landslides that mainly affect the inhabited centres, according to the schemes of the Hydrogeological Basin Plans (PAI: Piano d'Assetto Idrogeologico) regulated and managed by ABDAC.

PAI represents a fundamental tool for land-use planning through the application of land-use restrictions and regulations and may be changed periodically by the River Basin District Authorities based on new studies and surveys, the occurrence of new landslides and floods, realisation of mitigation measures, or requests by local authorities [2].

The landslide hazard zones of the River Basin Plans (PAI) include areas of potential 45
evolution of existing landslides and areas where new landslides may occur, in addition to 46
occurred landslides [2]. The Italian Landslide Inventory (IFFI Project) realised by the In- 47
stitute for Environmental Protection and Research (ISPRA)-Geological Survey of Italy 48
and the 21 Regions and self-governing Provinces [3–5] was the preliminary and key tool 49
used in the PAI for defining landslide hazard and risk assessment. The IFFI landslide 50
inventory is the most complete and detailed landslide database in Italy [2]. 51

In the framework of ReSTART activities, the ABDAC identified 1948 landslide and 52
239 survey areas (Figure 1), i.e., slope sectors delimited by morphological features such as 53
watersheds and drainage lines enclosing places with assets needing to be rebuilt (Figure 54
2). 55

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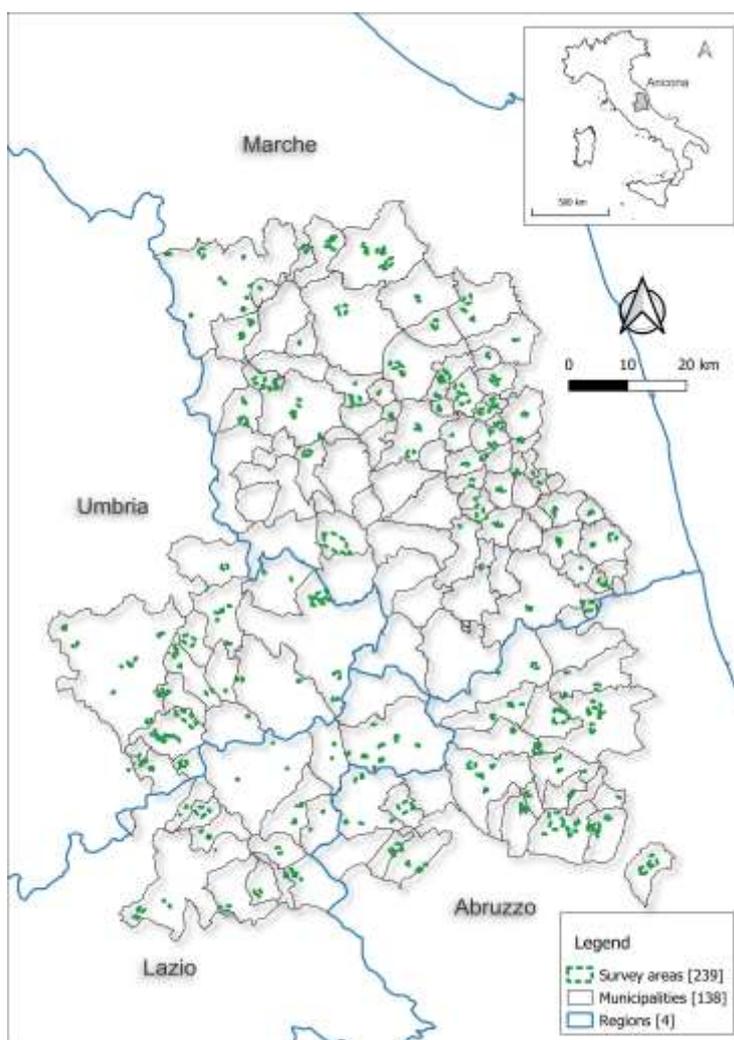
Figure 1. Geographical area including the 138 municipalities identified by the River Basin District 57
Authority for the recovery and reclassification of landslides occurring near the towns in the Region 58
sectors affected by the 2016 Central Italy earthquake. The green dashed lines represent the 239 59
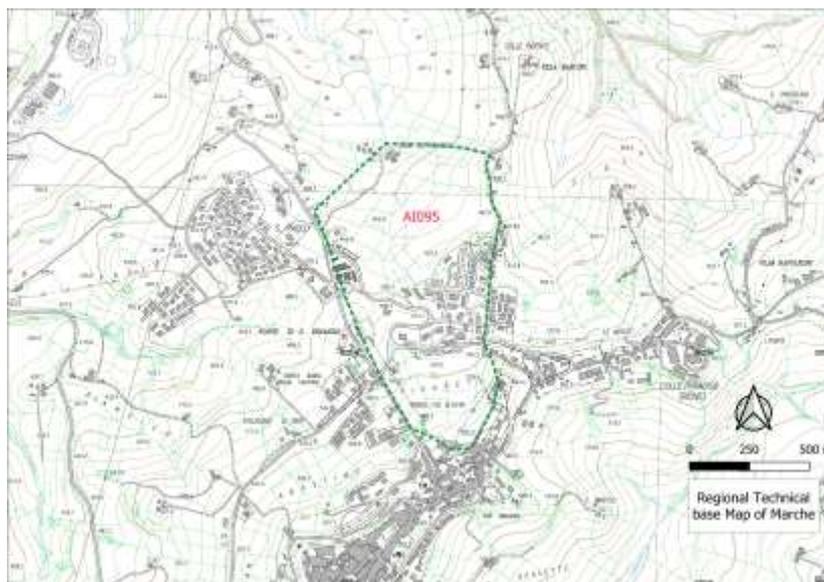survey areas. 60

Figure 2. Example of survey area as defined in Figure 1. The green dashed line bounds the area. Base map from the Regional Technical Cartography (C.T.R.) at the scale of 1:10.000 [6].

Geographically, the area includes 138 municipalities (Figure 1) belonging to the Provinces of Ancona, Macerata, Ascoli Piceno, Fermo, Perugia, Terni, Rieti, L'Aquila, Teramo, and Pescara in the four Regions involved (Abruzzo, Lazio, Marche, and Umbria). In these areas, the PAI regulations and classifications are distinct from each other in the plans of the Marche, the Tronto Basin, Abruzzo, the Tiber, and Umbria. They derive from the territorial analyses of the primary regional hydrographic basins of Central Italy that were conducted individually prior to the formal constitution of the ABDAC, which currently manages them jointly.

1.1. IFFI-ReSTART form

The need to adopt a common method and a scheme for all operators who work in the field and in the laboratory, while respecting the various regulations but with the aim of standardisation, led to the choice of data acquisition according to a well-defined form [7]. This form is related to a database management system (DBMS) here designed, implemented, and illustrated (see Appendix A), which was used within the university project for the re-sizing and reclassification of landslides.

The form, although assuming the definitions and fields of the IFFI Project [8,3,4], was redefined and integrated in some parts, both to standardise the different PAI and to adhere to the main purpose—the safe reconstruction of inhabited centres.

In the field, we acquired detectable data from direct observations and measurements or with ground- and/or drone-based photographic acquisitions. The form allowed acquiring relevant observations to facilitate interpretation of the field data.

The main advantage of this new tool is the standardisation of the field data collection, while guaranteeing a certain work speed and high data quality and providing storage that can be managed within a multi-platform database format and an open-source and free GIS program.

2. Methods

Before operating in the field, we acquired all the ancillary data and bibliographic documentation for the database and the photographic and satellite images for the identification and multi-temporal analysis of the phenomena under study and the neighbouring areas (defined in the project as the area of interest, AI).

The surveys were carried out through conventional geological and geomorphological methods with the aid of digital tools supporting a GIS field project [9]. 94 95

Therefore, while compass, hammer, binoculars and all the classic analogue instruments allowed the observation and measurement of geological data, the digital survey method developed during this project enabled acquiring and digitally storing the data directly in the field with the instruments that are described in Section 3. The digital survey method will be explained and discussed in terms of hardware and software in the following sections, and database development is covered in the Appendices A and B. 96 97 98 99 100 101

3. Hardware

The use of digital tools for field mapping is well-documented [10–12]. 103

In this project, tablet PCs (Windows Surface Pro 7) equipped with the Windows 10 operating system and an input pen (stylus) were used. Windows tablet PCs had more than adequate capabilities (CPU Intel® Core™ i5-1135G4; RAM 8 GB; 128 Gb Disk; screen size 12.3") to manage maps, images, and data used and/or collected on the ground. An adequate cover made the tablet more rugged and transportable (Figure 3). 104 105 106 107 108

The positioning was carried out with Garmin Glo receivers (available for GPS and GLONASS; update rate: 10 Hz; WAAS/EGNOS correction; accuracy: 3 metres; battery life: 13 hours) linked to the tablet via Bluetooth [13]. 109 110 111

For photograph acquisition, the tablet cameras and external digital cameras were used. 112 113

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Figure 3: Tablet PC Windows Surface Pro7 with accessories: Garmin GPS receiver, input pen/stylus, rugged cover with shoulder strap. 115 116

4. Software

The main GIS software used was QGIS (version 3.16) [14], which has been employed for years in field research. This GIS software was chosen for its ease and widespread use, as well as for the open-source approach that allows the customisation and creation of new tools suited for field work [15,9]. Some plug-ins such as BeePen [16] were used to write notes and draw with the stylus directly on the map, similar to the pen-on-paper system [15]. 118 119 120 121 122 123

QGIS is a professional, multi-platform Geographic Information System desktop application, the official project of the Open Source Geospatial Foundation [17]. 124 125

Another application used in this field work was QField for QGIS [18]. It is a free software app released under the GNU Public License (GPL) and available for installation on devices such as tablets and smartphones to collect data on the ground. The QGIS QFieldSync plugin [18] allowed preparing and packaging the QGIS project and the asso- 126 127 128 129

ciated database system into a much lighter "portable" project file that could be opened   130
and used in QFied for QGIS. After the field work, the same plugin allowed synchronis-   131
ing the modification and updating of data with the database and the QGIS desktop pro-   132
ject file.   133

5. Database   134

A geographic relational database was developed to support the acquisition of land-   135
slide data in the field and their storage using tablet PCs, GPS, and open-source software.   136
The database was designed and implemented in the Geopackage format (Open Geospa-   137
tial Consortium). Geopackage is an open, standards-based, platform-independent, com-   138
pact native storage format using an SQLite database as container and the Geopackage   139
encoding standards defining the schema. Tables and fields in the Geopackage database   140
correspond to entities and attributes derived from the IFFI Project Italian landslide in-   141
ventory [4,5] and updated following the criteria adopted by the abovementioned Re-   142
START project. The entity–relationship schema of this database was fully developed   143
from scratch.   144

The database is named *restart.gpkg* and composed of spatial and non-spatial tables   145
with a series of lookup tables [19] storing fixed categorical and ordinal data values rep-   146
resenting classification standards of landslide-related information.   147

The database schema is synthetically shown in Figure 4 and is available with de-   148
tailed textual and graphic documentation in the Appendix A.   149

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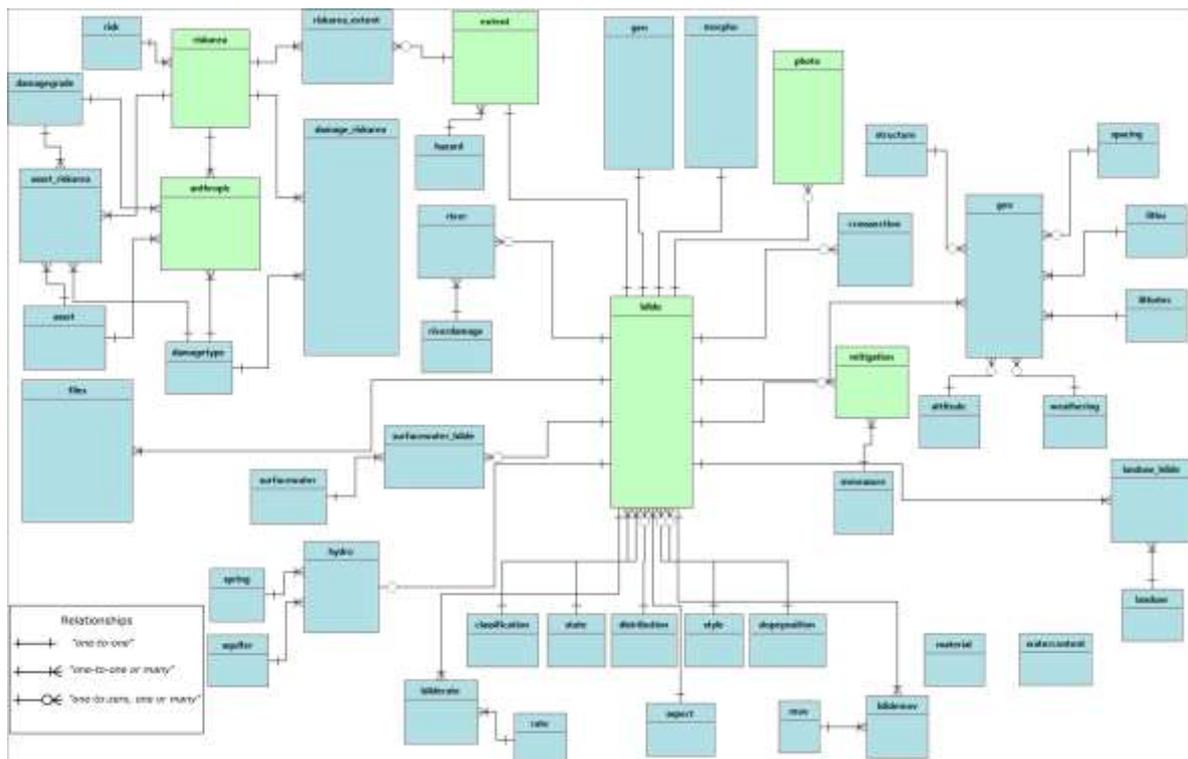
Figure 4. The *restart* database entity-relationship (E-R) diagram representing core spatial tables in   151
green, non-spatial association and lookup tables in blue, with listed fields and relationships be-   152
tween tables. A detailed explanation of all the tables fields and codes, and a better view of the   153
schema are available in the Appendix A (Figure A1).   154

The attributes of the *restart* database tables are linked to the fields in a series of forms   155
designed for use within the QGIS graphic interface; they, in turn, constitute the graphic   156
interface with the *restart.gpkg* geographic database. The forms allow the surveyor to   157
quickly record the data, ensuring proper entry and integrity.   158

The *restart* database is behind a GIS implemented with the QGIS software. The QGIS file project contains the forms configured for enabling the field data acquisition and storing it directly in the *restart* database. The form setting was based on the QGIS project file layer relations, based, in turn, on the database table relationships. The detailed form configuration and description of how they are used are also available in Appendix A.

6. QField for the field work

The *restart* database contains 91 tables. Many of these can store data obtained from bibliographic sources or from the subsequent processing and analysis of data previously acquired on the ground. As a result, there are too many entry forms for capturing data in the field and their use may be deferred for further laboratory work.

By using the QFieldSync plugin installed in the QGIS Desktop main project, it was possible to prepare and package the main QGIS project into a much lighter "portable" project file for *QField* to ease the acquisition of data in the field. The *QField* package created includes the project file and only the tables and features useful for field surveying that may be copied and used on a land-data collection device (Figure 5). The new *QField* project shows only the forms needed to collect the data observable in the field.
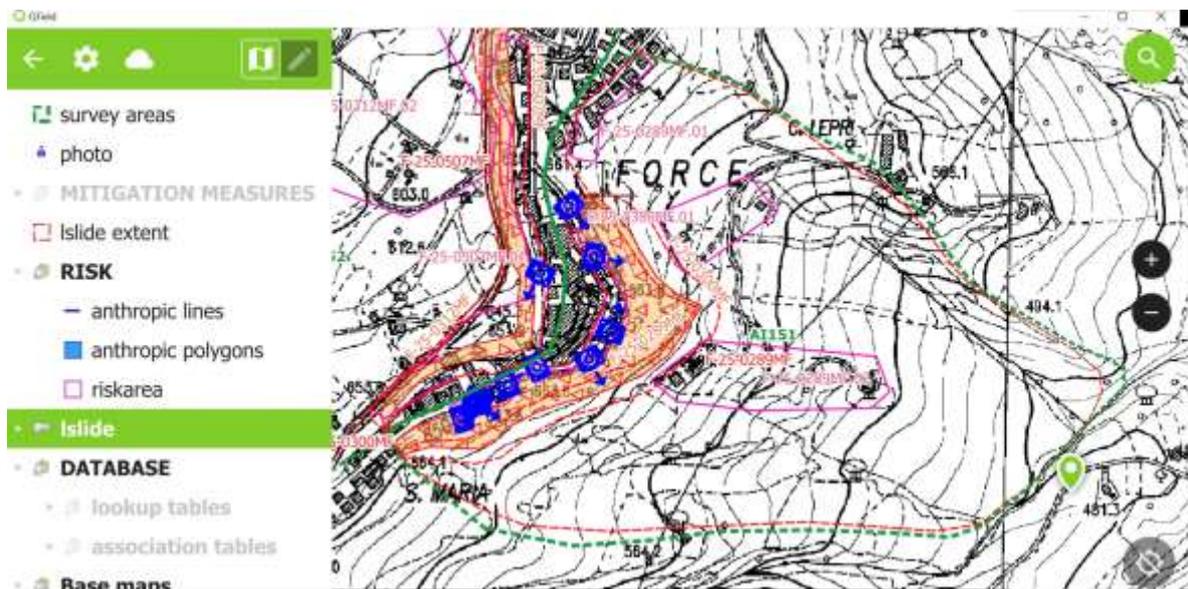
Figure 5. A survey area (bounded by the dashed green line) viewed in *QField* [18] with some features mapped and saved into the *restart* database with their attributes: two landslides (of light orange with red triangles), ten photographic shot points (marked by blue cameras), and other features explained in the *QField* left panel displaying the legend of the map with the main layers of the project.

After the digital survey in the field, the *QField* project package is copied from the device to the desktop computer where the QFieldSync plugin allows for synchronisation of the changes from the portable database tables to those in the main database.

The Chieti University survey group chose to work with the QField for QGIS version 1.X for Android on the Samsung Galaxy Tab Active Pro tablet as they assumed it was the fastest way of collecting field data [20].

To use the *QField* project, they organised the export according to the guided procedure from QGIS to QField, inserting the main layers/tables useful for data collection in the field.

The only information layers used were *lslide* and *photo*, and all other information useful for the population of the database was collected in the "digital field notebook".

The total compilation of the whole project, including the related database, was conducted in a second phase on the PC using QGIS Desktop.

7.1. Photo acquisition

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The PHOTOGRAPHIC DOCUMENTATION form page was set up to facilitate the rapid storage of the points representing the photographic shots taken in the field and of the other form attributes simultaneously with the point digitisation (Figure 6).

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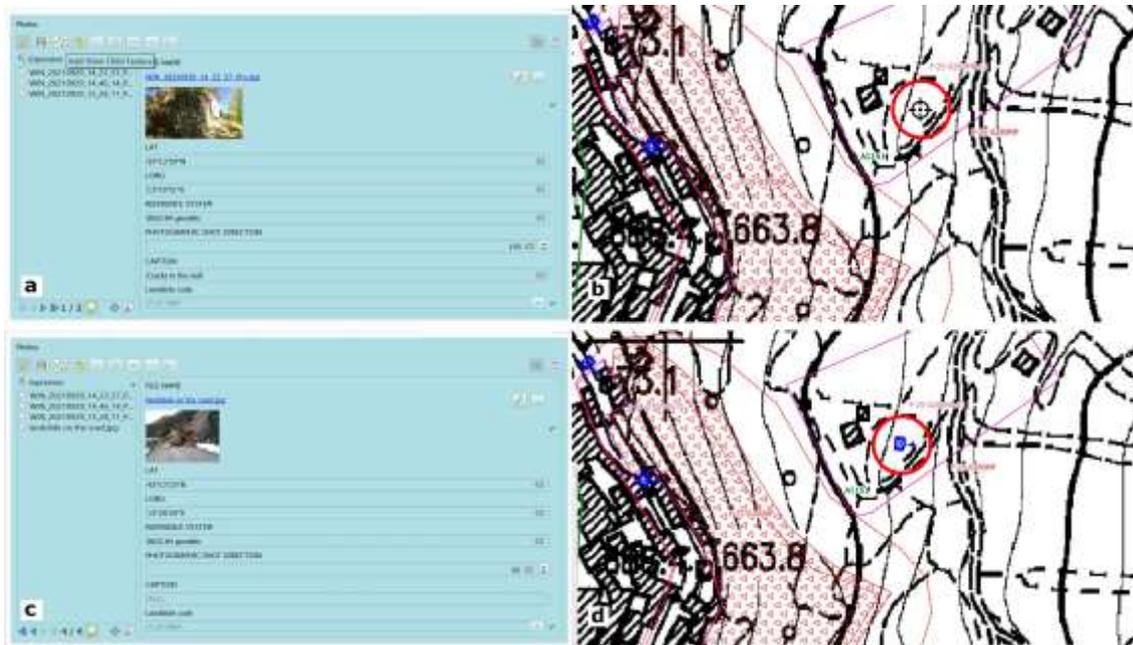
Figure 6. The four successive steps of photo acquisition simultaneous to the point digitisation: (**a**) After opening the form page and activating editing, click the Add Point button; (**b**) The view shifts to the map canvas and a target cursor appears (circled in red); (**c**) After clicking on the photographic shot point on the map, the view shifts again to the form view, allowing for loading the photo file using the browse button and filling in the other attributes boxes; (**d**) After saving the data, an oriented marker is displayed in the photographic shot point (circled in red).

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By clicking on the top left Add point button, visible in Figure 6, the form disappears, giving way to the map view. After digitising the new photographic shot point, the form reappears to allow loading the previously saved photo's files and filling in the other requested parameters, such as the PHOTOGRAPHIC SHOT DIRECTION and the CAPTION. The LAT, LON, and REFERENCE SYSTEM field boxes, instead, will be automatically compiled by the action of database triggers executed when data are saved.

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A detailed description of the form setup and the associated table is available in the Appendix B.

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7.2. Other Data and Information

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In addition to acquiring "structured" data in tabular form through the survey sheet system illustrated above, customised with some plug-ins and other accessory programs, this mobile system makes it possible to acquire and manage usage information for final processing.

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The BeePen plug-in allows drawing notes directly on the map on the screen (Figure 7). Some quick corrections were made to the landslide and outcrop limits available from previous landslide cartography (IFFI, PAI, and regional geologic and geothematic cartography (CARG) [21] projects) or new acquisitions with indication/comment. These simple lines were digitised to a proper level.

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Another useful application is the Windows Journal, which can be freely downloaded and installed [22]. This app is used for field notes where text and sketches can be kept. Moreover, pictures and drawings in the app can be imported. The handwriting text

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can also be converted into digital text. All files can be saved in pdf format and georefer- 226
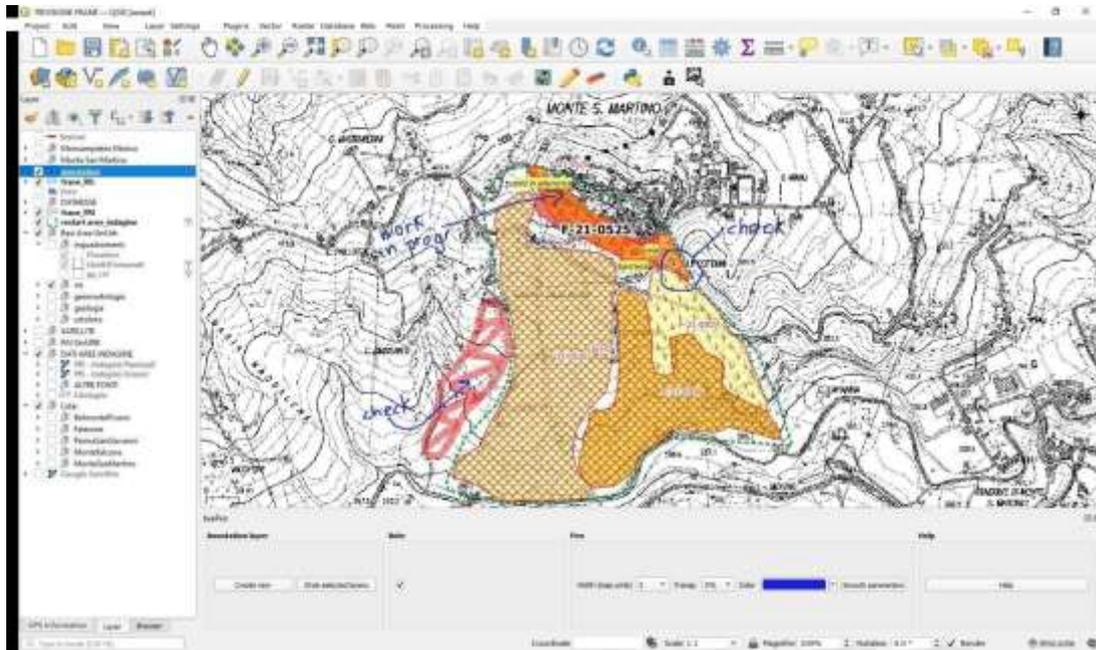enced by inserting them into a point layer of notes (Figure 8). 227

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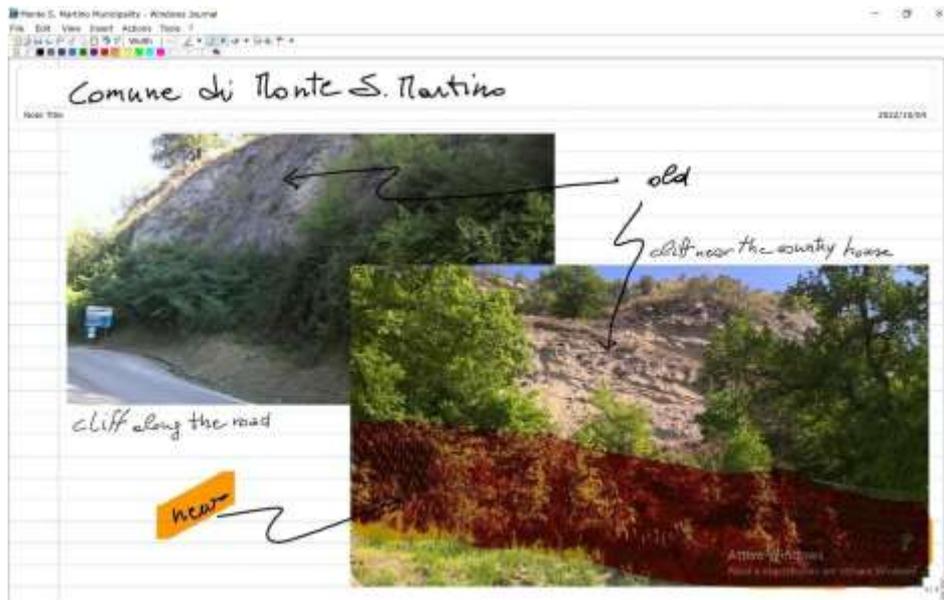**Figure 7**. BeePen plug-in (at the bottom) allows sketches and annotation on the map. 229

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Figure 8. Example of digital field notes using Windows Journal [22]. 231

8. Discussion

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The need to create a survey that could be used by different geologists and managed 233
in a simple and reliable way in the field and to organise data and information for easy 234
import and synthesis into the ABDAC database led to the creation of a dedicated GIS 235
project. 236

The database structure complicated the challenge of including data and information, 237
as well as maps, images and photos, sketches, and sections, that were manageable both 238
on the ground and indoors and in the end would lead to a synthesis providing a means to 239
analyse and produce the required reports. The Geopackage format best responded to 240

these needs because it was simple to use and allowed unifying data collected by different users in one database.

To improve the ease of management of the GIS project in the field, several data and information entry forms were created. Each of these windows had different characteristics and often benefited from lists of terms and standardised classifications.

Collecting the data of each survey group in an overall project was a key point of this project, and it was possible thanks to the QGIS project implemented and packaged in a portable version for QField and to the platform-independent, portable, and compact format of the Geopackage database that connected with the overall ABDAC database structure.

In addition to the data and information structured in the database, it was possible to use the tablet as a normal analogue campaign notebook in which to insert the observations that were useful for interpretations and processing but did not fit into the rigid structure of the IFFI-ReSTART card. Using the stylus both directly on the cartography ("Pen-on-map" surveying system) and on the pages of an annotation sheet (Windows Journal) maintained the traditional and proven surveying practices consolidated by decades of field practice.

The integration of field data with those already available or obtainable in the lab enabled creating a definitive database for PAI data that could be managed (and potentially increased or adapted to other functions) or consulted at various administrative levels (ABDAC, Regions, Provinces, Municipalities, professionals, and so on).

The accuracy of the GPS positioning was adequate. In fact, even if a cartographic antenna was used with an accuracy of the metric order, the reference base maps equalled those of the topographic map [6] at a scale of 1:10,000. At this scale (1 mm on the sheet equalled 10 m on the ground) the accuracy and precision of these instruments were largely sufficient.

The possibility of entering data into a GIS database directly in the field also reduced the possibility of errors in the subsequent phases of indoor so-called "digitisation", perhaps by a different operator [23]. For this purpose, GIS skills are no longer the prerogative of lab operators but also of field geologists.

Appendix A

The database was implemented in accordance with the *schema* shown in Figure A1, in which the tables named *lslide*, *photo*, *extent*, *riskarea*, *anthropic* and *mitigation* (green in the figure) are spatial tables. Their geometry type is "polygon" except for the *photo* table, the geometry type of which is the "point". The other tables (blue in the figure) are

non-spatial tables: 12 are association tables and 27 are lookup [19] or dictionary tables 293
(Figure A1). 294

The lookup tables store fixed categorical and ordinal data values representing clas- 295
sification standards of landslide-related information and are associated with the other 296
tables mainly by means of "one-to-zero, one or many" relationships (Figure A1). 297
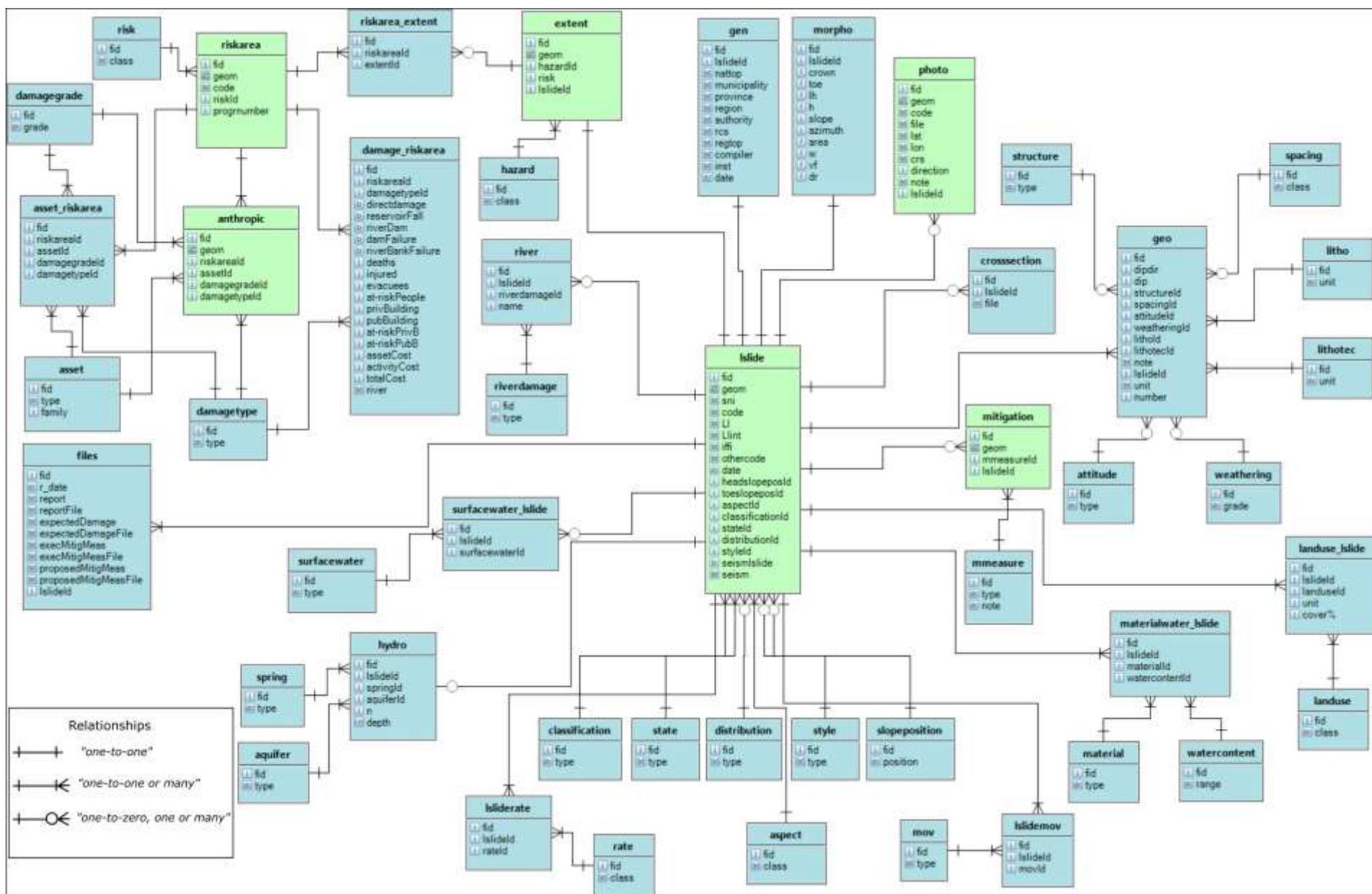
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Figure A1. The *restart* database entity-relationship (E-R) diagram representing core spatial tables in green, non-spatial association and lookup tables in blue, with listed fields and relationships between tables. The fields and the reasons for choosing the types of relationships between tables are illustrated below. The symbols of the types of relationships are described in the legend.

The *lslide* table stores only the information regarding the landslide bodies, already censused or newly identified, and the polygon geometry representing both the landslide detachment zone and the zone of accumulation (Figure A2). 309 310 311
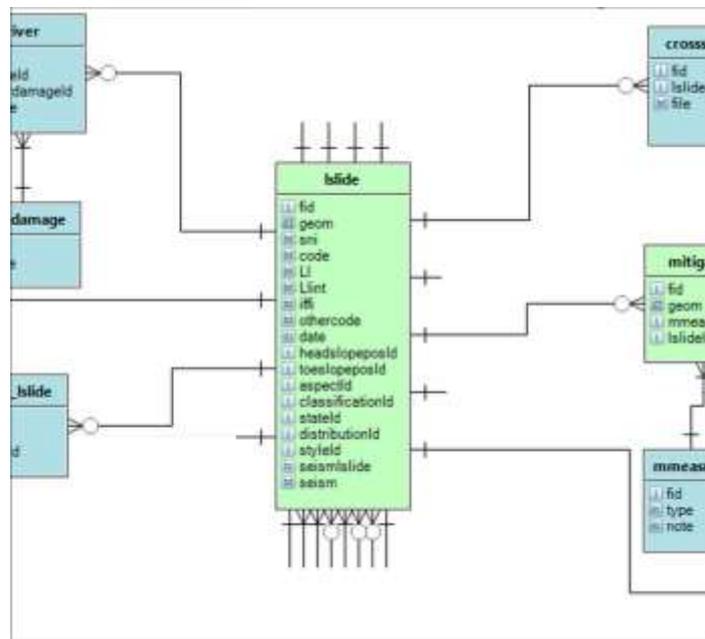
Figure A2. The *lslide* entity with fields representing data about landslide coding and labelling, position on the slope, activity, and eventual spatial relation with already censused landslides. For the black line symbols see the *Relationships* legend in Figure A1. 313 314 315

The *extent* table is a spatial table storing a polygonal geometry representing the potential enlargement of the landslide, which may coincide with the current one or be mapped by the surveyor as larger than the landslide assuming its maximum expansion area. This table is associated with the *lslide* table by means of a "one-to-one" relationship (Figure A3) and is an intermediate table between the *lslide* table and *hazard* table, because the latter contains the four hazard levels to be assigned to the landslide extent polygon as required by the ReSTART project standards. The *extent* table is also associated with the *riskarea_extent* table by means of "one-to-zero, one or many" relationship (Figure A3). The *riskarea_extent* table is an intermediate table between the *extent* table and the *riskarea* table. The latter stores the polygons of the risk areas possibly enclosed by the landslide extension area. Each polygon of the *extent* table can enclose any, one or more risk areas. A *riskarea* table polygon encloses the asset features already mapped in the official cartography. The lookup *risk* table provides the classes of risk to assign to each risk area. The greater risk class between those assigned to the risk areas will be associated with each polygon of the *extent* table. 316 317 318 319 320 321 322 323 324 325 326 327 328 329 330
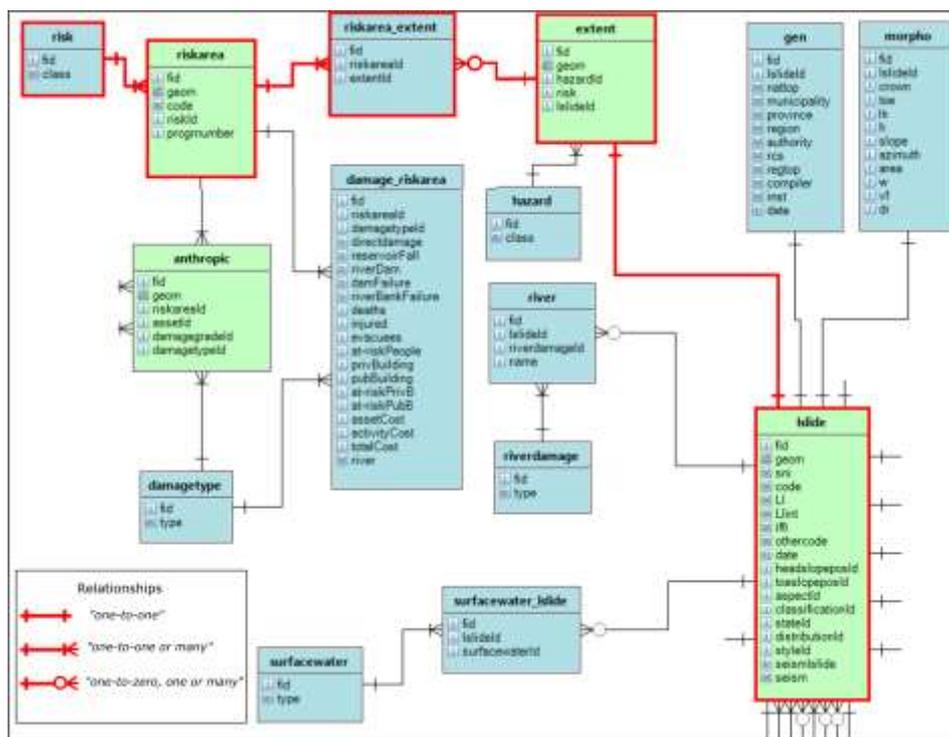
Figure A3. Relationships between the *lslide* table and the *extent* table, and between the latter and the *riskarea* table through the *riskarea_extent* intermediate table. The red line symbols represent the type of relationship as described in the legend.

The *asset_riskarea* table is another intermediate table between the *riskarea* on the one hand and the *damagetype*, *damagegrade*, and *asset* tables on the other, allowing the association of the types of assets involved in the landslide and the type and grade of damage with the risk area enclosing the assets (Figure A4). In addition, the *anthropic* table is an intermediate spatial table with the same role as the *asset_riskarea* (Figure A5). The latter table stores data relative to assets already mapped in the risk areas; the *anthropic* table instead allows the surveyor to map new polygons or linestrings representing asset features not yet mapped, as well as to record the relative types of assets and the type and grade of damage (Figure A5). In the *damage_riskarea* table, instead, it is possible to store information on the different types of damage induced by landslides in each risk area and the related costs (Figure A4). The spatial *riskarea* table is associated with this table by means of a "one-to-one or many" relationship.
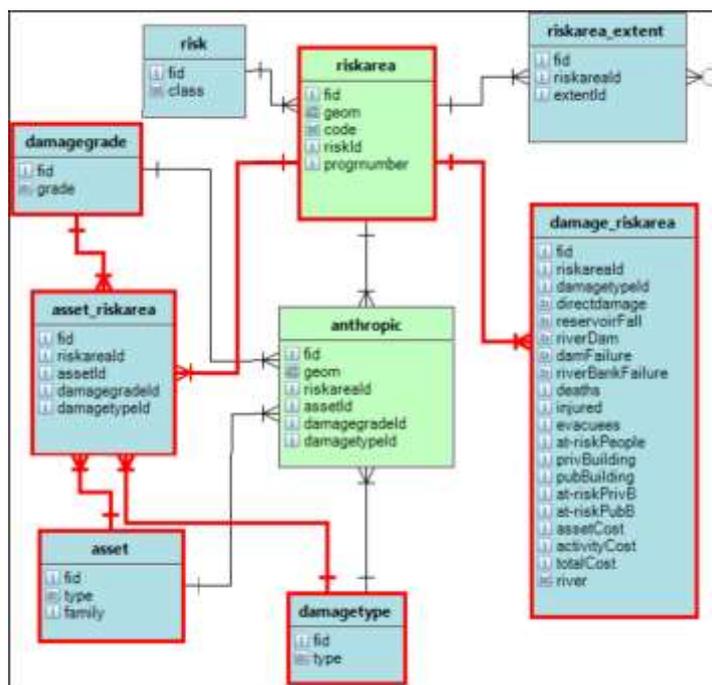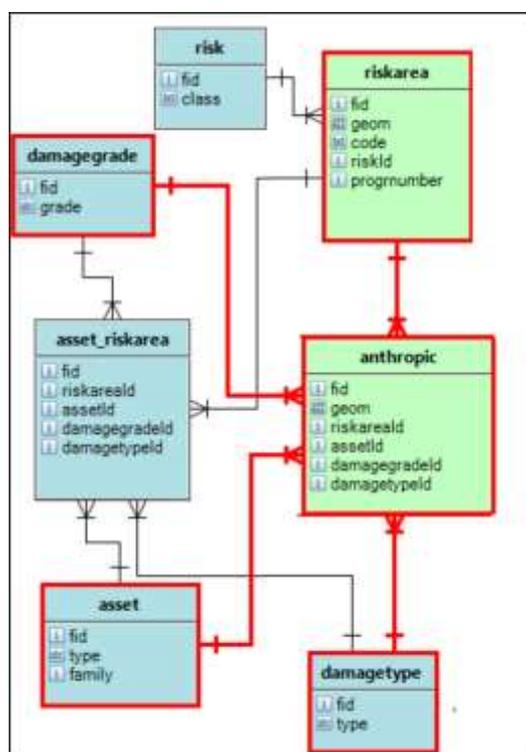
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Figure A4. Relationships between the *riskarea* table that stores the risk area polygons and all the   348
entities providing details about damage types, damage grades, assets and people affected by the   349
landslide. The *asset_riskarea* table allows for storing damages relative to assets already mapped in   350
the official cartography. For the red line symbols see the legend in Figure A3.   351

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Figure A5. Relationships between the *riskarea* table that stores the risk areas polygons and the en-   353
tities providing details about damage types, damage grades and assets not yet mapped. The new   354
linestrings or polygons representing new assets may be digitised and stored by the surveyor in the   355
anthropic table, which has an extra geometry type field compared to the *asset_riskarea* table. For the   356
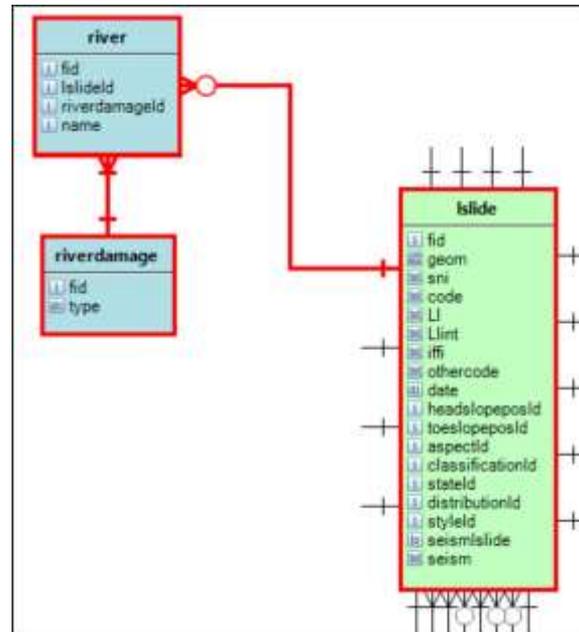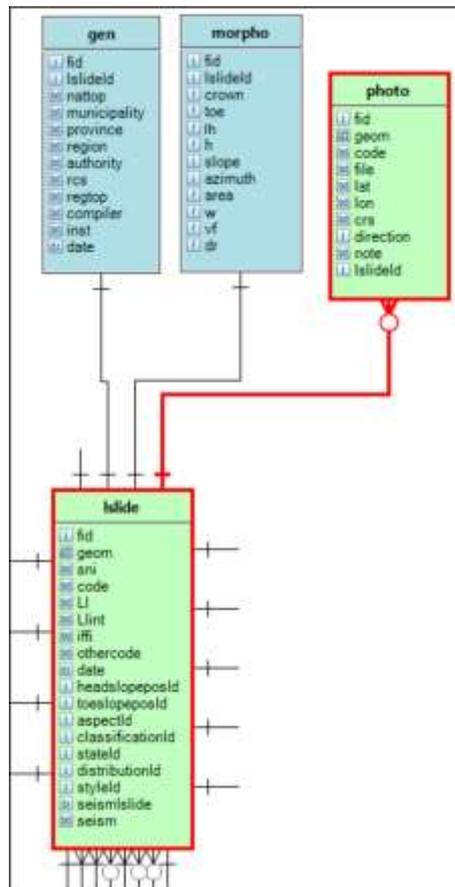red line symbols see the legend in Figure A3.   357

The database can also store the information relative to the type of damage eventu- 358
ally induced by landslides to a river course by means of the "one to zero, one or many" 359
relationship between the *lslide* table and the *river* intermediate table (Figure A6), because 360
a landslide can affect or potentially affect one or more river course. The *riverdamage* 361
lookup table provides the list of damage types to assign to the *river* table (Figure A6). 362

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Figure A6. The relationship between the *lslide* table and the *river* table is "one-to-zero, one or 364
many", because a landslide may not have affected any river course or may have affected one or 365
more river courses. For the red line symbols see the legend in Figure A3. 366

The photographic documentation is stored in the *photo* table associated with *lslide* 367
by means of "one-to-zero, one or many" relationship (Figure A7). Each individual land- 368
slide can be documented by one or more photographic images. In this table, geometry 369
type data and the point coordinates are also stored. 370

Figure A7. "One-to-zero, one or many" relationship between the *lslide* table and the *photo* table. For the red line symbols see the legend in Figure A3.

The *lslide* table is the spatial table storing the polygonal geometry of the landslide and containing a set of foreign keys pointing to lookup table attributes characterising landslides regarding the classification of the kinematics, state, distribution, style, and position on the slope (Figure A8).
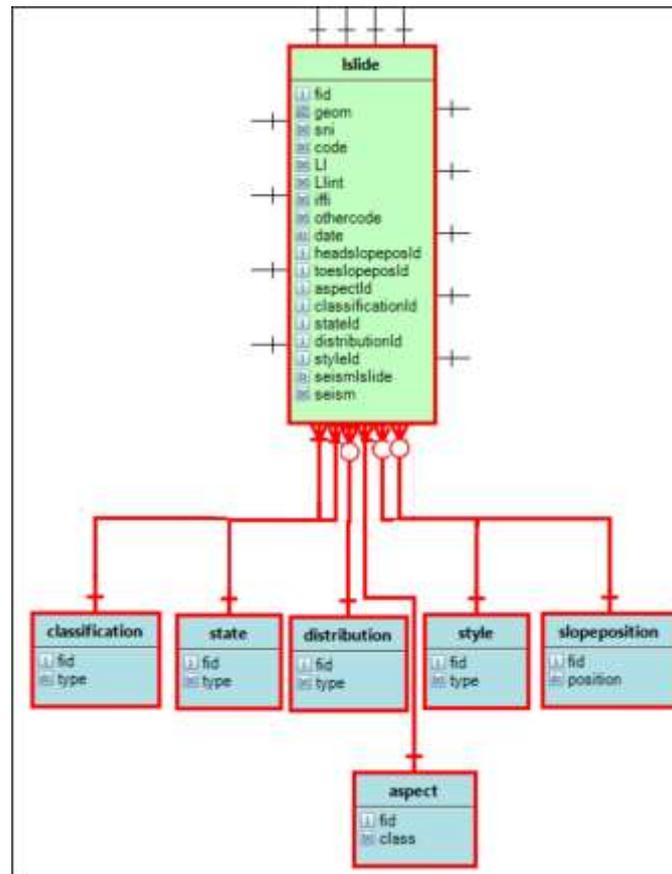
Figure A8. The *lslide* entity (the green entity) shows the *LI*, *LIint*, *iffi* fields for storing identification codes of already censused landslides from other inventories that will eventually be overlayed by the new landslide polygon. Below the field *date*, the other fields are foreign keys referencing lookup tables (blue entities) providing landslide position relative to the slope (*headslopeposId* and *toeslopeposId* for the landslide head and toe, respectively); landslide aspect (*aspectId*); type of landslide movement (*classificationId*); state, distribution and style defining the landslide activity (*stateId*, *distributionId*, *styleId*, respectively). *seismlslide* is the field to be filled with *true* or *false* if the landslide is earthquake-induced or not. *seism* is the field for the earthquake date value. For the red line symbols see the legend in Figure A3.

The *lslide* table is associated with the *gen* and *morpho* tables by means of a "one-to-one" relationship, and with the *geo* table by means of a "one-to-one or many" relationship. In the *gen* table general information about the geographical and adminis-trative location of each landslide is stored. In the *morpho* table, instead, the values of the main morphometric parameters of each landslide can be registered (Figure A9).
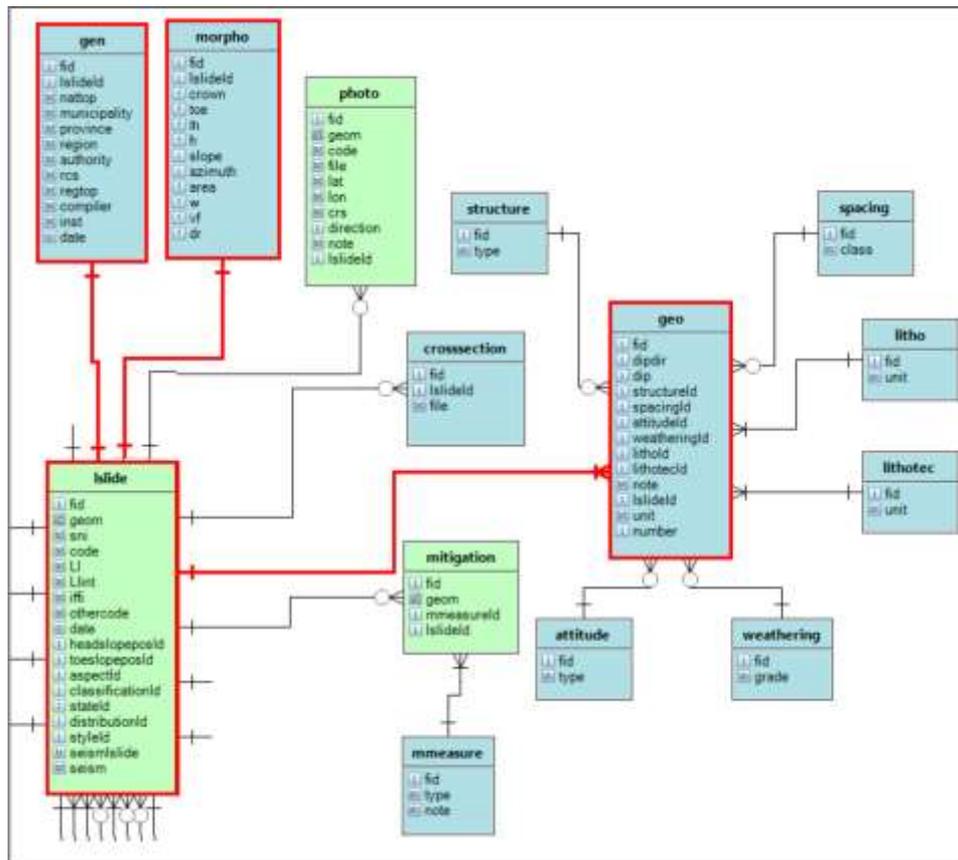
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Figure A9. The *gen* table may store only one record of geographic and administrative location data 394
relative to one landslide (see the *gen* table fields below *fid* and *lslideId*): *nattop*, the main toponym; 395
municipality, *province* and *region*, the administrative units where the landslide occurs; *authority*, the 396
River Basin Authority; *rcs*, regional cartography reference; *compiler*, the surveyor name and *inst*, 397
their institutional affiliation; *date*, the date of the landslide survey. Similarly, a landslide may have 398
only one record of morphometric data (see the *morpho* table fields below *fid* and *lslideId*): the *crown* 399
and *toe* elevations; *lh*, the horizontal length; *h*, the difference in height; *slope*, the slope angle; the 400
azimuth of landslide movement; the landslide total *area*; *w*, width and *vf*, final volume of the dis- 401
placed mass; *dr*, the depth of the rupture surface. The relationship between the *lslide* table and the 402
geo table is "one-to-one or many" because a landslide may have displaced material from one or 403
more lithostratigraphic units (see the Figure A10 caption). For the red line symbols see the legend 404
in Figure A3. 405

One or more lithological and lithotechnical types (retrievable from the *litho* and 406
lithotec tables, respectively) and one or more lithostratigraphic units can be affected by 407
the same landslide; thus, one or more records of the *geo* child table can be associated 408
with one record of the *lslide* parent table. The attributes of the *geo* table are mainly for- 409
eign keys pointing to the primary keys of six lookup tables, allowing the association of 410
values of the compositional, physical, and mechanical characteristics with each geologi- 411
cal unit affected by the landslide (the lookup tables are *litho*, *lithotec*, *structure*, *spacing*, *at-* 412
titude, *weathering*; see Figure A10). 413

414
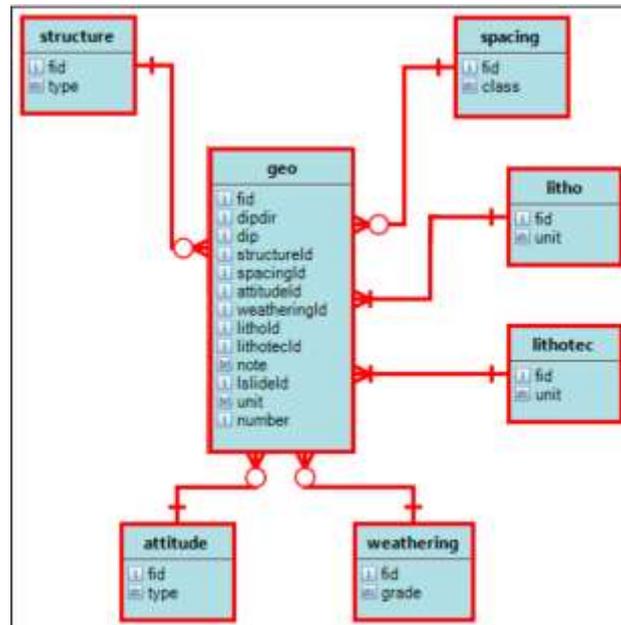
Figure A10. Each record in the *geo* table represents the attributes of a single lithostratigraphic unit 415
affected by the landslide. The fields below *fid* are: *dipdir*, the dip direction values average of a set of 416
discontinuities; *dip*, the dip angle values average of the same set of discontinuities. The fields below 417
are the foreign keys referencing lookup tables that provide classification descriptors in accordance 418
with the International Society for Rock Mechanics Standards (ISRM) [24]. These describe the 419
structure of the rock mass and the nature of its discontinuities: structure of the rock (*structureId*), 420
mean distance between adjacent discontinuities (*spacingId*), bedding attitude (*attitudeId*), degree of 421
alteration (*weatheringId*). The other two foreign key fields are *lithoId*, referencing the *litho* table; and 422
lithotecId, referencing the *lithotec* table. The stored values are in accordance with a classification 423
based on field criteria [24–26]. For the red line symbols see the legend in Figure A3. 424

    The *materialWater_lslide* table has three foreign keys referring to the primary keys of 425
the *lslide* table, the *material* table and the *watercontent* table. This table allows the associa- 426
tion of the material and the water content with a landslide by means of a "one-to-one or 427
many" relationship (Figure A11). 428
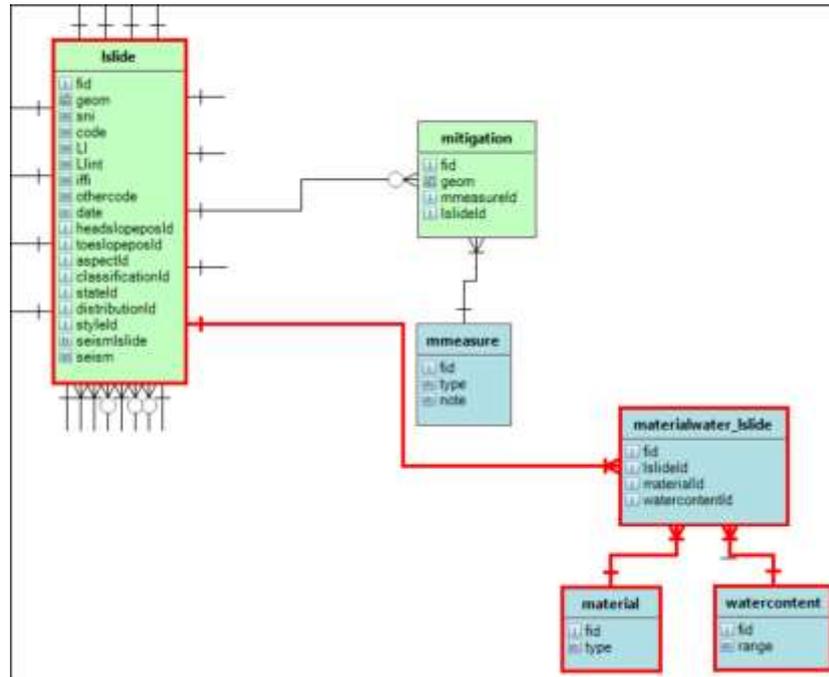
Figure A11. The *materialwater_lslide* table intermediate between the landslide polygon table (*lslide*) and the lookup tables *material* and *watercontent* containing classification values in accordance with [27] and [28]. For the red line symbols see the legend in Figure A3.

The *lslideId* foreign key of the *lslidemov* intermediate table points to the primary key of the *lslide* table establishing the "one-to-one or many" relationship from the *lslide* parent table to the *lslidemov* child table, thus allowing the association of the types of movement with a landslide. This is because one or more types of movement, retrievable from the lookup table *mov*, can characterise a landslide, particularly if it is a complex one. The *lslidemov* child table is associated with the *mov* parent table by means of a "one-to-one or many" relationship (Figure A12). Identical relationships are established between the *lsliderate* intermediate child table and the *lslide* parent table, and between the *lsliderate* table and *rate* parent table. One or more classes of the rate of movement of a landslide, retrievable from the lookup table *rate*, can characterise the different types of movement of a complex landslide (Figure A12).
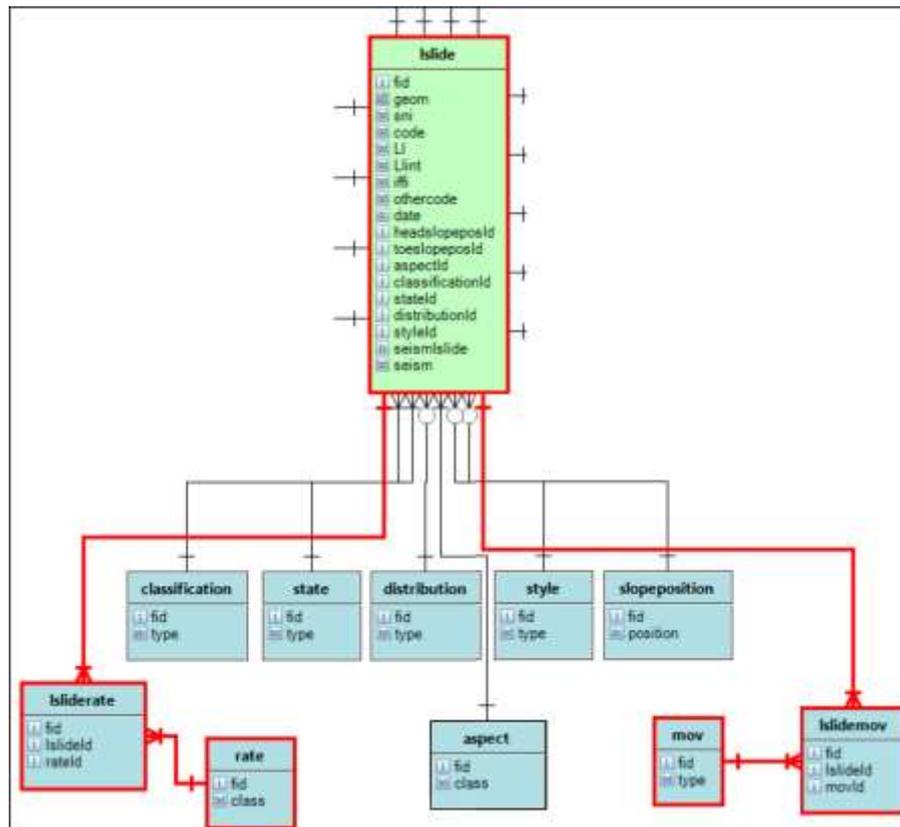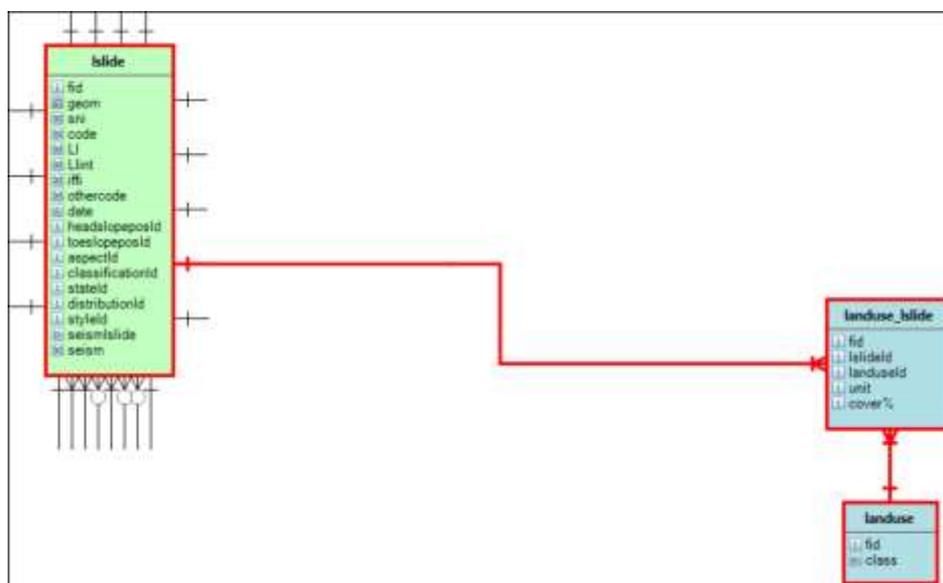
Figure A12. Relationships between the landslide polygon table and the intermediate tables *lsliderate*   445
and *lslidemov* allowing for association of rate and type of movement whose values are in accord-   446
ance with [28]. For the red line symbols see the legend in Figure A3.   447

The *lslide* table is also associated with the *lslidelanduse* intermediate table by means   448
of a "one-to-one or many" relationship, because one or more land-use units can be af-   449
fected by the same landslide; thus, one or more records of the *lslidelanduse* table can cor-   450
respond to one record of the *lslide* parent table (Figure A13). Another foreign key in the   451
lslidelanduse table (*landuseId*) points to the primary key of the *landuse* lookup table and   452
stores the unique 'id' of the land-use class involved in the landslide (Figure A13).   453


454

Figure A13. Relationship between the landslide polygons of the *lslide* table and the *lslidelanduse* ta- 455
ble allowing for association of one or more land-use units affected by the landslide with the latter. 456
For the red line symbols see the legend in Figure A3. 457

The *lslide* table is also associated with the *mitigation* table by means of a 458
"one-to-zero, one or many" relationship (Figure A14). The *mitigation* table is an interme- 459
diate spatial table between the *lslide* table and the *mmeasure*. This table allows the sur- 460
veyor to use the mapping polygons or linestrings representing mitigation features not 461
mapped. The *mmeasure* parent table is a lookup table storing a list of mitigation methods 462
that can be associated with the landslides through the *mitigation* child table (Figure A14). 463

464
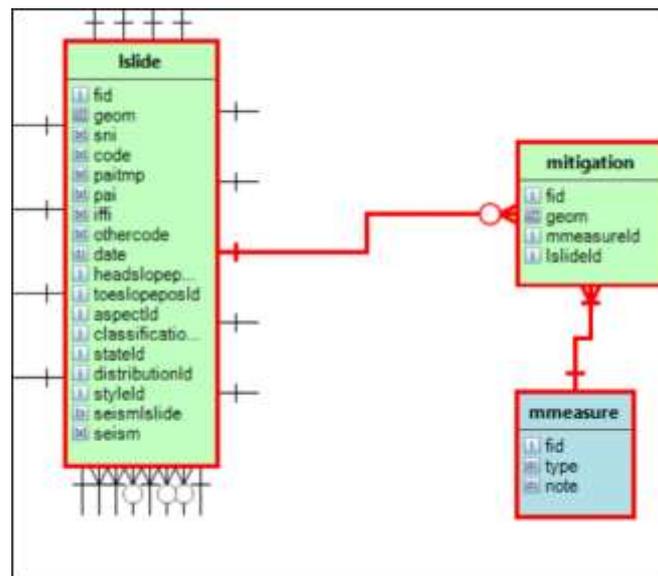
Figure A14. The "one-to-zero, one or many" relationship between the *lslide* table and the *mitigation* 465
table can occur when there are one or more mitigation works for a landslide or none. For the red 466
line symbols see the legend in Figure A3. 467

The *crosssection* table stores any cross-section crossing the landslide body. The *lslide* 468
table is associated with this table by means of a "one-to-zero, one or many" relationship 469
because one or more representative cross-sections can be drawn for the investigated 470
landslide, or no cross-section may be available (Figure A15). The *file* field of the *crosssec-* 471
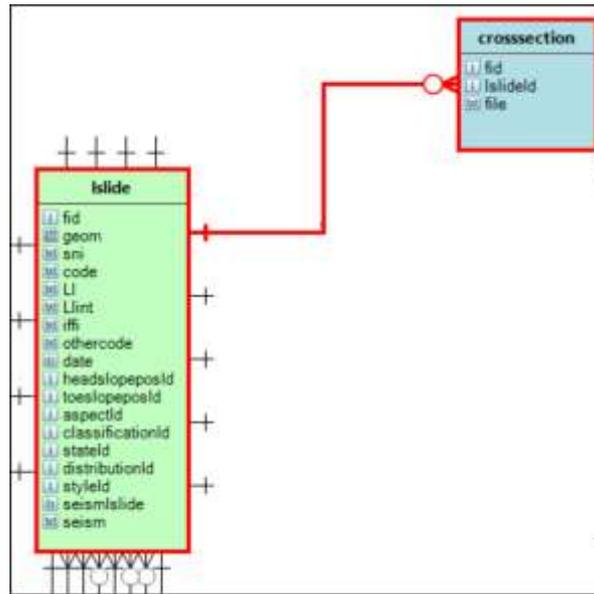*tion* table stores the path and name of the file of the cross-section graphic representa- 472
tions. 473

474

Figure A15. The "one-to-zero, one or many" relationship between the *lslide* table and the *crosssec-* 475
tion table. For the red line symbols, see the legend in Figure A3.   476

The *surfacewater_lslide* intermediate table shows the same relationship types as the 477
mitigation table, with the *lslide* table on the one hand and the *surfacewater* table on the 478
other (Figure A16). The table allows the surveyor to associate the surface water content 479
with the landslide.   480

Regarding the groundwater, the *hydro* table is an intermediate table that allows the 481
association of information about the absence or presence of springs and their type of 482
distribution retrieved from the *spring* table. The *hydro* table also allows the recording of 483
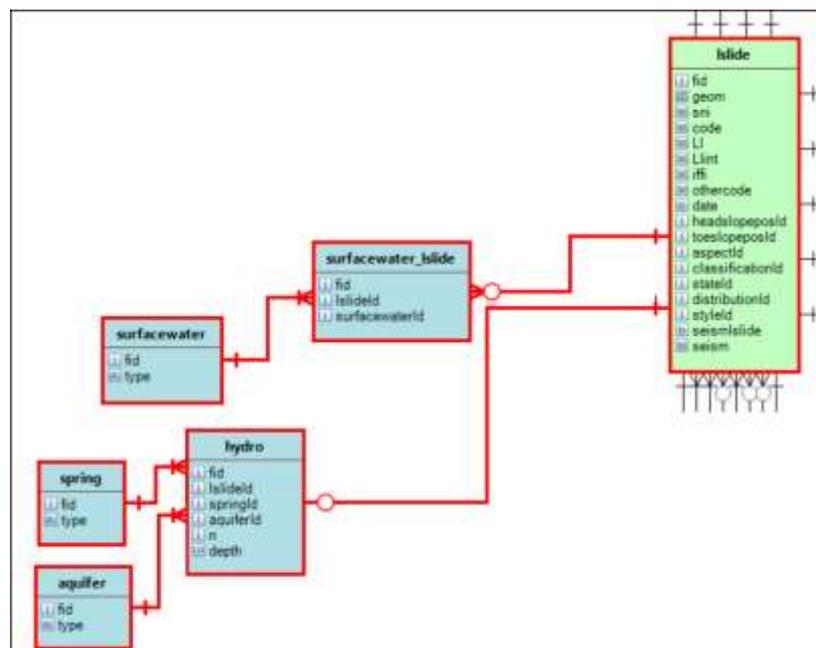information on the type of aquifer (confined, unconfined), if present.   484

485

Figure A16. Relationships between the *lslide* table and the intermediate tables allowing for associa- 486
tion of surface water types, springs, and types of aquifer values, if present, with a landslide area. 487
For the red line symbols see the legend in Figure A3.   488

Last, a table named *files* stores textual descriptions and/or paths and names of files   489
containing a brief report on the landslide, the expected damages, and the existing and   490
proposed mitigation measures (Figure A17). The "one-to-one or many" relationship be-   491
tween the *lslide* table and the *file* table represents the need to store in the database at least   492
one report, albeit short, relating to the landslide observed.   493

494
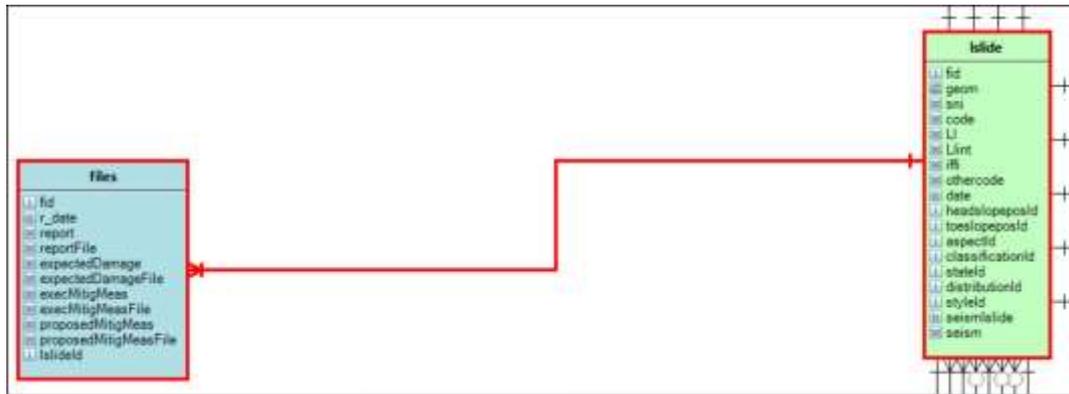
Figure A17. "One-to-one or many" relationship between the *lslide* table and the *file* table requiring   495
the recording of at least one report on the landslide investigated. For the red line symbols see the   496
legend in Figure A3.   497

Appendix B   498

One main form was configured for the purpose of expediting the acquisition of data   499
in the field and storing it directly in the *restart* database. The form is a multi-pages form   500
accessible through 11 tabs (Figure B1).   501

502

Figure B1. Multi-page data acquisition form accessible from the tabs visible at the top. Tab headers,   503
not all visible in this figure, are aliases of the main database tables. The tab headers are: 1. POSI-   504

TION and ACTIVITY; 2. GENERAL INFORMATION; 3. MORPHOMETRY; 4. GEOLOGY; 5. LANDUSE; 6. MOVEMENT; 7. MATERIAL and WATER; 8. HYDROGEOLOGY; 9. PHOTO-GRAPHIC DOCUMENTATION; 10. REPRESENTATIVE CROSS-SECTION; 11. NOTES. The background colour of each form page is the same as those adopted in the previous figures of the E-R diagram tables: green for the form pages linked to the spatial tables and blue for the form pages linked to the non-spatial tables. The figure shows three-quarters of the first form page named "POSITION and ACTIVITY". The remaining part of the first form page is visible in Figure B2.

The first form page named "POSITION and ACTIVITY" is used to record the landslide identification data and the main landslide attributes surveyed and recorded (Figure B1).

After digitising each landslide polygon, the form window opens and field boxes are autocompleted. The "LABEL" field is automatically filled based on the autocompletion rules coded in the database triggers.

The autocompletion of the label value depends on the eventual intersection of the digitised polygon with one or more landslides already present in the PAI inventory and pre-loaded as layers into the QGIS project file. In this case, the surveyor chooses the pre-existing landslide label to change and deletes all others. Then, the autocompletion rules store in the LABEL field the value composed of the label chosen and the surveyor's initials. In the event of digitising a new landslide polygon not intersecting with any pre-existing one, the autocompletion rules store the label value composed of the local administrative unit code, the surveyor's initials, and the progressive number. Thus, the landslide label displays a new unique landslide identifier code.

The other identification data are represented by the field boxes:

- "Name of the surveyor", the field containing the surveyor's name;
- "Progressive number", to be filled only in the event of digitising a new landslide polygon not intersecting with any pre-existing one. Otherwise, it is left empty;
- "IFFI", the field automatically filled with the univocal landslide identifiers from the national inventory (Inventory of Landslide Phenomena in Italy, IFFI) only when digitising a new landslide polygon intersecting with one or more pre-existing *IFFI* inventory landslide polygons pre-loaded into the QGIS project file as a layer;
- "Other", the field provided to store a label or identifying code of the landslide reported in a scientific publication.

Scrolling down, fields describing the landslide slope position (relative to landslide head, toe, and aspect), the activity (including landslide state, distribution, style) and the main type of movement are completed, along with whether the landslide is earthquake-induced or not:

- "HEAD", "TOE", "Aspect", "STATE", "DISTRIBUTION", "STYLE" and "CLASSIFICATION" are attributes whose values are selected from the respective drop-down lists present in the form (Figures B1 and B2). The fields are linked to the attributes of the database's lookup tables (*slopeposition*, *aspect*, *state*, *distribution*, *style*, *classification*) containing the codes of the geological/technical data representing the descriptors of landslide position, movement, and activity following [28–30];
- "earthquake-induced", the field storing a Boolean data type: the *true* value means that the landslide is earthquake-induced, the *false* value that it is not. The default value is set on *false* (Figure B2);
- "earthquake date", the field storing the value of the earthquake date time (Figure B2).

Figure B2. The remaining quarter of the first form page named "POSITION and ACTIVITY" from   554
Figure B1 with the other field boxes described in the text.   555

The second form page, named "GENERAL INFORMATION", contains the attrib-   556
utes relative to the location of the landslide, the date of the inspection, and the survey-   557
or's name (Figure B3).   558

559

Figure B3. The second form page named "GENERAL INFORMATION" showing the landslide   560
code on the left and the field boxes on the right storing the unique values attributed to that land-   561
slide.   562

The "MORPHOMETRY" form page is used to record the values of the landslide mor-   563
phometric parameters within the following fields (Figure B4):   564

- "CROWN ELEVATION", the field storing the elevation of the non-displaced mate-   565
rial at the highest parts of the landslide main scarp expressed as metres above sea   566
level;   567
- "TOE ELEVATION", the field storing the elevation of the lower margin of the dis-   568
placed material of a landslide expressed as metres above sea level;   569
- "HORIZONTAL LENGTH", the field storing the distance from crown to tip of the   570
landslide measured on the topographic map;   571
- "HEIGHT", the field storing the elevation difference between the highest point of   572
the crown and the lower point of the toe measured in metres;   573
- "SLOPE", the field storing the slope angle in degrees.   574

Figure B4. The third form page named "MORPHOMETRY" showing the field boxes filled with the unique morphometric attribute values relative to the landslide, which is labelled by the code on the left.

In the "GEOLOGY" form page the fields to be compiled hold the attributes of the *geo* association table and of six lookup tables providing the list of compositional, physical, and mechanical parameters associated with the geological units affected by the landslide (Figure B5). The fields to be filled are:

- "UNIT", the field containing the lithostratigraphic unit extended name whose values are selected from a drop-down list provided by the *lithostratigraphy* lookup table;
- "UNIT NUMBER", the field storing the numbering of the lithostratigraphic units affected by the landslide, increasing from the head to the toe of the landslide;
- "DESCRIPTION", this field is used to record a short description of the outcropping lithological unit;
- The tag "Discontinuities" includes six fields relative to a series of parameters describing the attitude, structural, and mechanical characteristics of the involved rocks, where observable:
  1. "DIP DIRECTION", the integer field storing the average of the immersion azimuth of a discontinuities set;
  2. "DIP", the integer field storing the average dip of the line of steepest inclination of the discontinuities set;
  3. "STRUCTURE" and "DISCONTINUITIES ATTITUDE", the attributes whose values are selected from their respective drop-down lists. The fields are linked to the attributes of the database's *structure* and *attitude* lookup tables. The *structure* table contains the descriptor values of the main generic aspects of the rock. The *attitude* table contains the different bedding-slope relationship types [24];

4. "SPACING" stores the spacing of adjacent discontinuities defined in accordance with the ISRM standards [24]. The class's value is selected from a drop-down list;
5. "WEATHERING" stores the weathering grade whose values express the degree of alteration in accordance with the ISRM standards [24] and are selected from a drop-down list.

Two last fields contribute to the complete description of the unit: "LITHOLOGY" and "LITHOTECHNIC UNIT", whose values are selected from their respective drop-down lists. In this case, the fields are linked to the attributes in the database's lookup tables containing the descriptors of lithological and geological/technical units [3].

Figure B5. The fourth form page named "GEOLOGY" composed of three group boxes: one at the top with the first three fields describing the geological units, in the middle with the tag "Discontinuities", and below the last two fields completing the description of the units.

The fields of the "LANDUSE" form page (Figure B6) are linked to the *lslidelanduse* table's fields *unit*, *landuseId*, *cover%*, and *lslideId*, which are displayed on the form page as:

- "Unit NUMBER" to enter the numbering of the land-use units affected by the landslide;
- "LANDUSE CLASS" to record the land-use class name whose value is chosen from the drop-down list linked to the *landuse* lookup table containing the Corine Land Cover land-use classification [31];
- "COVER %" to enter the percentage of the relative areas covered by the different land-use unit types observed;
- The "Landslide code" field is automatically filled owing to the relationship between the *lslide* table and the *lslidelanduse* table by means of the *lslideId* foreign key field.

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Figure B6. The fifth form page named "LANDUSE" that allows storage of the characteristics of up   630
to three land-use units, the maximum number of land-use classes recordable based on the Re-   631
START project standards.   632

The "MOVEMENT" form page is composed of two internal sections: *Movement* and *Rate*   633
(Figure B7).   634

- The *Movement* section displays the field "TYPE OF MOVEMENT" corresponding to   635
  the *mov* database table from which one or more types of landslide movement are   636
  selected [27,28], especially in the event of a complex landslide (Figure B7). The   637
  movement types from this field allow better specifying the type of movement with   638
  respect to the value recorded in the above "CLASSIFICATION" field of the first   639
  form page;   640
- The *Rate* section consists of a field named "RATE" corresponding to the *rate* data-   641
  base table. From this field a descriptor of the movement rate is selected from a   642
  drop-down list based on the glossary used by [28] (Figure B7).   643

644

Figure B7. The sixth form page named "MOVEMENT" split into two sections: on the left, the *Movement* section for storing one or more types of movement retrievable from the drop-down menu; on the right, the *Rate* section in which to store one or more rate classes also retrievable from a drop-down menu.

Also in the "MATERIAL and WATER" form page are two internal fields displayed as "MATERIAL" and "WATER CONTENT", which are drop-down menus listing descriptor values derived from [27,28] (Figure B8).

- "MATERIAL", the field describing the type of material before involvement in the landslide;
- "WATER CONTENT", the field describing the moisture conditions of the material before the occurrence of the landslide movement.

Figure B8. The seventh form page named "MATERIAL and WATER" with the two drop-down menus allowing selection of the type of material involved in the landslide and of the water content, retrievable from the *mov* and *watercontent* tables, respectively.

The form page "HYDROGEOLOGY" allows storing information, if available, related to the surface water and groundwater of the landslide area by means of two separate internal sections: *Surface water* and *Springs and aquifer* (Figure B9). Descriptor values are selected from drop-down lists, then stored in the *surfacewater_lslide* and *hydro* association tables, respectively.

- "CATEGORY" is a drop-down list linked to the *surfacewater* lookup table from which to select a descriptor of the absence/presence and behaviour of the surface water;
- "SPRINGS" and "SPRING NUMBER" are drop-down menus from which to select the option if springs are absent and the type of distribution, and the number of existing springs;
- "AQUIFER", the field with a drop-down list to select and then store the type of aquifer: confined or unconfined;
- "AQUIFER DEPTH (m)", the known or inferred aquifer depth below the landslide.

Figure B9. The eighth form page named "HYDROGEOLOGY" vertically split into two sections: the
upper section in which to store a surface water category from the *Category* drop-down menu; the
lower section in which to store the four attributes relative to the presence, number, and distribution
of springs and types of aquifers, as described in the text.

The ninth form page ("PHOTOGRAPHIC DOCUMENTATION") is used to enter
the information regarding the images depicting the landslide features, the structures that
have suffered landslide-induced damages, and the adopted mitigation measures (Figure
B10). The data related to the images are stored in the "restart" database's *photo* table.
This table is associated with the *lslide* table using a foreign key in accordance with
"one-to-many" relationships for which each landslide is associated with one or more
images (see Section 7.1).

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Figure B10. The ninth form page named "PHOTOGRAPHIC DOCUMENTATION" from which to   690
activate the point digitising mode by means of the top left *Add point* button and to load the images   691
relative to the investigated landslide by means of the top right *browse* button.   692

The *photo* table is a spatial table, and an *Add point* button on the form page allows digit-   693
ising a new geometry point representing the photographic shot point (the button with   694
the three points in Figure B10). Once the point is drawn, the attributes dialogue box   695
opens showing the *LAT*, *LON*, and *REFERENCE SYSTEM* fields, which will be filled by   696
the action of triggers executed when data are saved. The triggers are defined on the *photo*   697
table and stored in the database as *photo_coords_ins* and *photo_crs_ins*.   698

Before saving, is necessary to: 699

- Load an image file with the *Browse* button aligned with "FILE NAME" from the   700
  folder where the file was previously saved. This action stores the file name and path   701
  in the *photo* table *file* corresponding field and displays the file name on the page. A   702
  QGIS "Photo" widget is used, which allows the image to be previewed on the same   703
  form page (Figure B10). The *file* field represented by the alias "FILE NAME" is con-   704
  strained to unique, so duplicate entries are avoided;   705
- Store in the "PHOTOGRAPHIC SHOT DIRECTION" field the azimuth of the pho-   706
  tography direction. The field corresponds to the *photo* table's *direction* field;   707
- Compile the field "CAPTION" with a brief description of the image subject;   708
- The "Landslide code" field is automatically filled by means of the relationship be-   709
  tween the *lslide* table and the *photo* table.   710

"REPRESENTATIVE CROSS-SECTION" is the form page allowing the loading and storing of the images of one or more cross-sections relative to the selected landslide (Figure B11).

- By means of the *Browse* button in the "FILE NAME" field, an image file may be loaded from the folder where it was previously saved. The action stores the file name and path in the *crosssection* table *file* field and displays the file name under *FILE NAME* on the page. A QGIS "Attachment" widget is used, which allows the image to be previewed on the same form page (Figure B11). The *file* field, alias "FILE NAME", is constrained to unique, so duplicate entries are avoided;
- The "Landslide code" field is automatically filled by means of the relationship between the *lslide* table and the *crosssection* table.
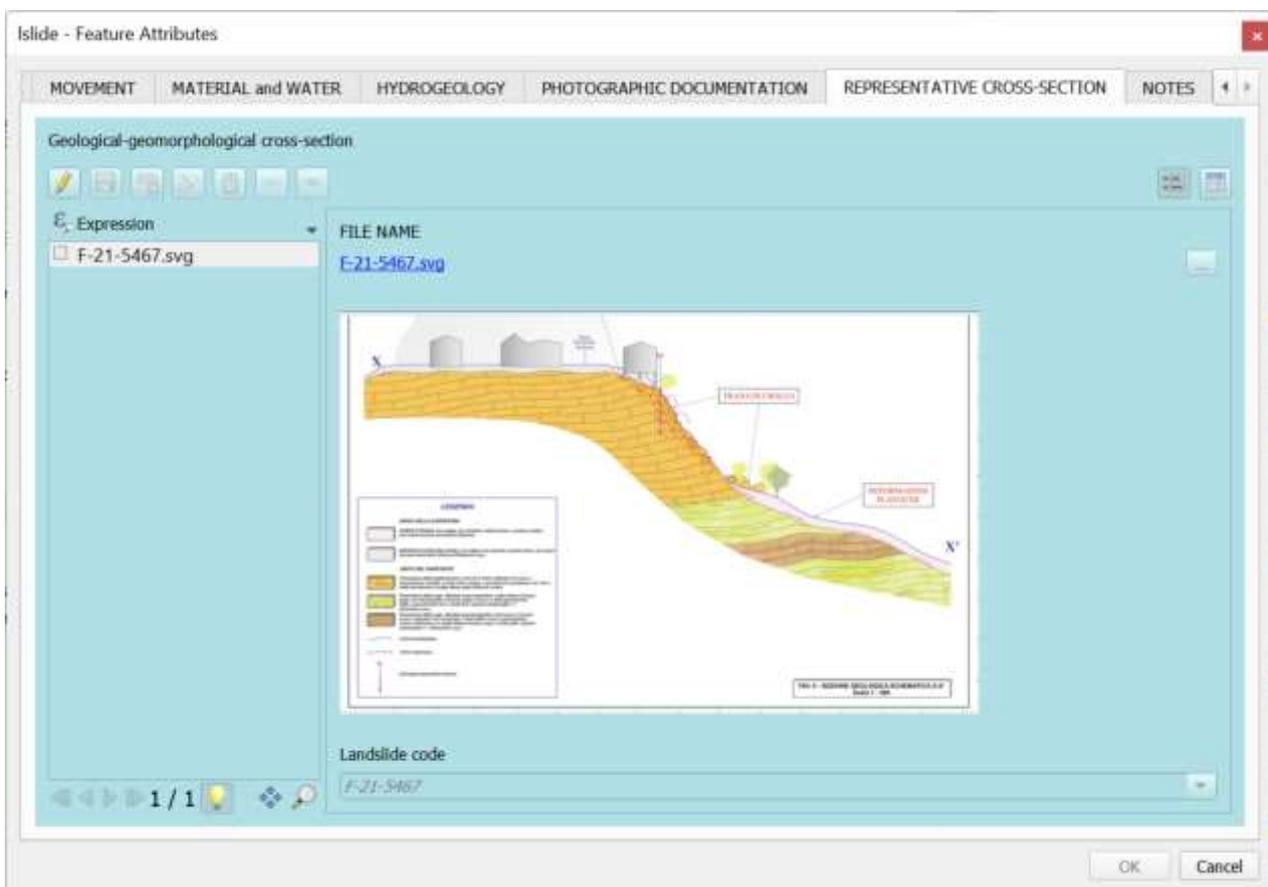
Figure B11. The tenth form page named "REPRESENTATIVE CROSS-SECTION" for loading one or more images of geological–geomorphological cross-sections by means of the top right *Browse* button. *Landslide code* is automatically recorded.

The last form page is "NOTES". It is composed of four tags allowing for storing different types of reports: reports on expected damages, reports on executed and proposed mitigation measures, and landslide analysis reports (Figure B12).

Each tag is composed of:

- "Registration date of the report", a field for recording the report date in the database;
- "SUMMARY REPORT", a multi-line field for recording a synthetic report of the analysed landslide. In each tag, the summary report covers the topic in the header;

- "REPORT FILE", a field for saving the report file name and path in the database   735
and creating a link to open it directly from the form.   736

737

Figure B12. The eleventh form page named "NOTES" and composed of four tags, each of which   738
stores one of the report types required by the ReSTART project, as indicated by the tag headers.   739

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