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Spatial Data Management of Temporal Map Series for Cultural and Environmental Heritage *

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Abstract

This research focuses on the exploitation of real-time navigation of territory over time. This allows one to extract and compare multi-scale maps in order to verify spatial data management potentials of temporal map series. This paper discusses contributions to the knowledge, conservation, valorisation, awareness rising, and divulgence of cultural and environmental heritage at both regional and urban levels. The main aim is to promote the progressive involvement of historic maps within the planning processes, from the analysis to the governmental plan of addressing the territory, through sustainability projects and interventions. In addition, the systematic collection of temporal map series comparisons should contribute to a better knowledge of complex environmental sites of inland water basins and of the landscape in general, as well as of historic sites. In the former case, they could support the development of hydro-morphologic models and hydro-geologic risk analysis. In the latter, they could be integrated into conservation, restoration, and redevelopment projects. To fulfil these aims and to support a progressive adoption by different actors at a sustainable cost, an open-source geo-portal was developed following the geospatial community standards defined by Open Geospatial Consortium (OGC) and compliant with concepts of user-defined Web services. This is hosted by the Web platform available at www.atlantestoricolombardia.it ('Atl@nte dei Catasti Storici e delle carte Topografiche della Lombardia' - Atlas of historical cadastral and topographic maps of Lombardy) that is an ongoing project that aims to build up, collect, and manage historic georeferenced cadastral and current topographic maps of this

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region. In particular, some sets of maps covering areas along artificial and natural water axes are now accessible through an online geo-portal. These maps date back to the late 18th and 19th centuries. Cultural and environmental heritage needs to be analyzed using a case-by-case methodology. With regard to INSPIRE directive, these categories are supported by the 'protected sites' theme. The paper addresses the need for shared and standard approaches that need to be considered by the geospatial data community.

Keywords: Historic cartography, SDI, Web services, open-source geo-portal

1. INTRODUCTION

The rising need for distributed services when handling spatial-temporal data calls for developing standards in order to provide homogeneous metadata scenarios and promote data sharing at the international level via the Web. In particular, descriptive references are necessary so that multiple-content data can be proliferated, and a 'semantic web' approach can be improved. On the other hand, geo-processing methodologies and quantitative aspects like accuracy and reliability should be analysed so researchers are able to consider the geometric quality of historic maps generated using a process that is different from techniques currently used.

This information is necessary to help the user compare the physical transformation of the anthropogenic and natural environment over centuries, for example by exploiting the availability of old cadastral maps and historic cartography. The three spatial dimensions are therefore integrated by using a fourth, time. The resulting environment can then be referred to as a '4D Geodatabase'. Addressing the topic of past-current maps will facilitate the description of historic stratification of territory, perceived with continuity on a global scale, thanks to the geo-reconstructed mosaic of a large area with a high level of detail. The combined use of SDI to manage a temporal map series and Digital Terrain Models (DTMs) will strengthen the understanding of building settlements and of global synthesis, subjects that are usually poorly investigated. These subjects include water axes, ancient roads, and itineraries development, so it would be necessary to do an in-depth study, taking into consideration their relationships for centuries. Such an approach can help increase our understanding of the expansion of historical settlements along water axes, for example. In particular, river basins play a key role in supporting biodiversity and ecosystems. They are of great societal and economic importance as water resources but also because of activities that develop on their banks. Historic maps of the European river basin network can provide different representative analyses of complex and dynamic relationships, including both surface and groundwater interactions within catchments. These comparisons can lead to simulations of the relationships

between a river and groundwater in different scenarios of climatic conditions and provide information about their geo-morphologic features.

This paper discusses some considerations about the connection between the Spatial Data community and historical cartography that are a part of our cultural and environmental heritage, taking into consideration the EU INSPIRE directive and its terms of reference. Section 2 gives a brief overview of the state of the art of digital cartographic heritage in the international panorama. Section 3 illustrates the Web Map Services level accessing tools developed within the open source Atl@nte geo-portal site (www.atlantestoricolombardia.it), describing some of the main outcomes and difficulties encountered. Section 4 illustrates the main advantages of using historical heritage for land use planning and its decision-making processes at different levels. Section 5 discusses the obligatory importance of metadata to better understand and share information issue. Some further work still needs to be done in terms of implementing cartographic heritage with up-to-date information, as discussed in Section 6.

2. CARTOGRAPHIC HERITAGE WITHIN THE SDI COMMUNITY

2.1. State of the Art and International Overview

In recent decades an extended concept of cultural heritage has spread among the international scientific and institutional communities. This new concept provides not only a comprehension of historical buildings and construction, artefacts, archaeological settlements and documents, but also examines whole portions of territory, and its trails, traces, and changes over time. As defined by the World Heritage Convention (UNESCO, 1972) the term 'cultural landscapes' represents the 'combined works of nature and of man'. The landscape therefore should not be observed merely to study its geographic characteristics but as a container of natural and anthropogenic information with layers that are deposited over time. The studies of landscape stratigraphy need supporting historic information, a fact that justifies the promotion and diffusion of cartographic heritage in sectors other than art history. The European Landscape Convention established the necessity for European countries 'to integrate landscape into its regional and town planning policies and in its cultural, environmental, agricultural, social and economic policies, as well as in any other policies with possible direct or indirect impact on landscape' (Council of Europe, 2000). This policy focused on expressing 'general principles, strategies and guidelines that permit the taking of specific measures aimed at the protection, management and planning of landscapes'.

The ICA Commission on 'Digital Technologies in Cartographic Heritage'¹ states that 'Cartographic heritage is a component of the overall world's cultural heritage. It concerns specifically all the valuables which are or may be inherited from historic cartography and maps. It concerns also all the cartography heirs who are the receivers of the benefits offered by cartography, maps and mapmaking of the past. Cartographic heritage issues are thus addressed not only to experts but also to society and to the general public'. The Commission focuses on any specific information and communication technology (ICT) topic that interacts with the heritage of cartography and maps. It recognizes the rapid deployment of digital ICT relating to many issues connected to cartographic heritage. The digital approach to cartographic heritage is therefore defined as a meeting area that brings together two worlds dealing with cartography: the humanistic component involving learned and literate historians and the scientists and engineers of cartography concerned with everyday practice and cartographic technologies (Livieratos, 2006).

Nowadays, those who search for information about cartographic heritage must have prior knowledge about the cartographic data that is the basis for the search and familiarity with technological applications. Thanks to the ICT's progress, many geo-portals of historic maps have been developed in recent years (Moscicka and Marzec, 2010; Simon et al., 2010). On the other hand, a coordinated action following the publication of historical maps still does not exist. There have been sporadic initiatives by the National Archives or libraries or by funded projects. There is a rising need for a systematic instrument so that historic maps can be used not only in a comparative-semantic way but can also provide valuable data for third parties.

There are interesting examples on a national and international level. In Italy some remarkable examples are the project 'Topographia' developed by Hyperboea (Salvadori and Pialli, 2010) for the National Archives of Genoa, Italy (available at <http://www.hdue.it/AWasge/index.htm>), or the project 'DIVENIRE' for the National Archives of Venice, Italy (available at <http://www.archiviodistatovenezia.it/divenire/home.htm>). Another example is a digitalized map library provided by the Cartographic Institute of Catalonia that has great advantages for both internal and external users (Montaner and Roset, 2010). All of these projects respect the preservation, fruition and valorisation of cartographic heritage. Furthermore, they allow one to see maps' images in archival units and with detailed metadata descriptions. However, the maps included in these series are not georeferenced so they cannot be overlapped to provide up-to-date spatial data.

¹ In July 2005 a Working Group on 'Digital Technologies in Cartographic Heritage' was established inside the International Cartographic Association (ICA). In August 2007, the General Assembly of ICA promoted including the WG as part of the Commission under the same name (<http://xeee.web.auth.gr/ICA-Heritage/Commission/index.htm>).

Many cadastral map series are progressively georeferenced to support transformation analysis by local initiatives of the public administration and municipalities. The fact that many historical maps of areas, including river basins and lakes, are being digitalized gives witness to the utility of cartographic heritage for inland water comparison studies. These kinds of investigation always support analysis of land changes in the neighbourhood. An example is reported in Livieratos et al. (2009), where some historic maps of the Danube River are combined with imagery provided by Google. Other examples are reported in Bitelli et al. (2010), Brusa et al. (2010), Linsenbarth and Brzezinska-Klusek (2010).

Concerning the water theme, there is a need for a more sustainable management, especially in communities highly influenced by the presence of rivers and lakes, and there are innovative tools for surveying predictive modelling, as in the EU project Aware (<http://www.aware-eu.info/eng/home.htm>). A very practical follow-up to the use of historical maps can be observed in the case of river paths, lakes and coasts that are public property. The coastal zones are of a great strategic importance for the EU, so the INSPIRE directive together with Shared Environment Information System (SEIS) are identified as main tools to facilitate the information flow in these areas. Major attention focused on inland water and coastal zones should lead to a common juridical protocol capable of facilitating international cooperation, which is already foreseen for the Mediterranean area.

Changes in riverbeds, the presence of prehistoric riverbeds (paleoalvei), and transformations of the primary and secondary water paths are progressively being attended to through hydrology and morphology model development and the implementation of the Water Framework Directive². Recent studies on the biosphere reserve of the River Elbe landscape and habitat, carried out by the Freie Universität Berlin focused on the rediscovery of the secondary side canals. Through multispectral aerial images the study assessed the potential for reactivating and reconnecting them to the main network to mitigate flooding. Understanding the potential of these riparian aquatic systems is important to the large-scale improvement of the ecological status of bodies of water. To characterize selected habitat structures (especially at the micro-scale level concerning sediment, vegetation and morphology) information with a temporal and 3D spatial resolution will be obtained applying very high resolution remote sensing (VHRRS) techniques using Unmanned Aerial Vehicles (UAVs). A survey campaign can be constructively oriented by generating a geospatial temporal

² Directive 2000/60/EC of the European Parliament and of the Council establishing a framework for community action in the field of water policy, in short the EU Water Framework Directive.

map. Multispectral satellite images are used to detect the precious hidden networks to be restored so they can receive water in case of flooding runoff (Lüderitz, 2010). Detailed historic maps can be used in combination with multispectral images, extending the fourth dimension of a GeoDB into the past.

2.2. Necessity for Temporal Data Series and Data Sharing for Environmental Heritage Analysis

The problems of economic feasibility and sustainability of land policies indicate a necessity to study and assess possible connections between the enhancement of the environmental heritage and conservation aims. In order to predict the participation of private and public bodies, it is necessary to identify the incoming conditions, such as the investments in valorization and management and the maintenance of the territory in the future. This is a specific point that could be well supported by the information provided by historical maps.

The built environment can be divided into broad classes. A possible strategy for this classification might be based on historic, geographical, or morphological criteria. However it is almost impossible to think of the built environment as a global category since every monument, site or portion of landscape usually requires a tailored methodology. To provide standards and indications for such a variety of cases, a special heritage information system needs to be defined in accordance with European SDI community requirements. With regard to information, the main requirements at the European level are: (i) data harmonization, (ii) real data interoperability, and (iii) data availability and access.

INSPIRE directive recommends to develop spatial data sets and spatial data services as well as related metadata according to existing international standards and user requirements, with a particular focus on metadata validation. A major objective of the INSPIRE directive, is to set up a systematic method of coordination between data providers and users in order to gather information and knowledge at different levels. Since different data typologies and sets might exist, coordination and data harmonisation among EU member states is considered to be important. Before INSPIRE was established, there were many initiatives at Community³, national or regional levels, to collect, harmonise or organise the dissemination or use of spatial information. In fact, the directive was conceived to be a complementary tool to already-existing initiatives but also as a base that would generate a common ground for the work of many individuals and groups.

³ Those initiatives may be established by Community legislation like Commission Decision (2000) on the implementation of a European pollutant emission register (EPER) according to Council Directive 96/61/EC concerning integrated pollution prevention and control (IPPC) and Regulation of the European Parliament and of the Council (2003) concerning monitoring of forests and environmental interactions in the Community (Forest focus), in the framework of Community funded programmes (ex., Corine land cover, European Transport Policy Information System).

2.3. The Added Value of Georeferenced Cartographic Heritage

European regions like Lombardy and Catalonia have a very advanced SDI that is not merely 'product-driven' (first generation) but is based on a process-oriented approach that foresees major user involvement. After the analysis of the first- (9 European regions) and second-generation SDIs (Lombardy and Catalonia), in Craglia et al. (2010) the following benefits are summarized:

- positive cultural change in stakeholder organisations, greater willingness to cooperate and share resources;
- more coordinated initiatives at local level in data collection and reduction of duplication and costs;
- agreement on the common usage and maintenance of reference datasets;
- more evidence-based applications, particularly for land use planning and infrastructure planning and maintenance;
- time and cost reduction in finding and accessing data handled by other organisations; and
- improved shared understanding of problems and issues affecting the region among public agencies.

As far as historic datasets are concerned, the following benefits can be added:

- amplifying the range of spatial data usage since information on the past landscape is important to both expert users and non-professionals;
- reducing real-life visits to the national archives because most of the public users can perform research on line (e.g., see the case of the Catalonia Map Library - Montaner and Roset, 2010); and
- cost reduction: since ancient maps exist as hard copy and their reproduction is usually done using photocopying techniques, the availability of a digital copy diminishes reproduction costs.

3. WEB MAP SERVICES FOR LAND HERITAGE: THE ATL@NTE GEO-PORTAL

3.1. Atl@nte Geo-portal: the Project

The Atl@nte platform of historical cadastres and topographic maps of the Lombardia region was conceived as a modern atlas with different levels of access. This is hosted by the Web platform available at www.atlantestoricolombardia.it ('Atl@nte dei Catasti Storici e delle carte Topografiche della Lombardia' - Atlas of historical cadastres and topographic maps of Lombardy). The research aims to contribute to the conservation,

enhancement and consciousness of cultural and environmental heritage through allowing one to browse maps of the territory over time. Open-source tools that allow extraction and comparison of multi-scale objects are being developed, following the geospatial community standards defined by the Open Geospatial Consortium - OGC (<http://www.opengeospatial.org/>) and the developing concept of user-defined Web-services.

Experts have estimated that the cartographic cadastral heritage amounts to 60,000-70,000 map sheets for each historical cadastral level of coverage (belonging to a period from the 18th to the 19th centuries) that is roughly estimated to total more than 250,000 sheet units, conserved in the Lombardy National Archives (Cadastrre of Maria Theresa of Austria, 1720-1750, Lombardo Veneto Cadastrre, 1850-1888, Cessato Catasto, 1886-1962) and in the Territorial Agency (Agenzia del Territorio - Cadastral administration that conserves the current cadastrre and the last historic cadastrre level, called 'Impianto al Vigente', edited in the period 1962-1994). This collection is one of the biggest in Europe. Summary data highlights the granularity level of the cadastrre local scale: it requires identifying a gradual and sustainable methodology to reconstruct the continuity of territory through creating a mosaic of sheets. The map patrimony made available to the Atl@nte by the National Archive of Milan amounts to 28,000 map units that corresponds with the map ensemble currently digitalised.

Atl@nte was established to publish and provide access to those maps in the form of geospatial services obtained from different sources and systems using compliant Web-GIS Web Map Services (WMS). With the support of a WMS server, the user can view and consult the information published by any other WMS compliant server (in the future, it could be the source server of other archives distributed in the provinces of Lombardy or other regions). OGC is the main reference on the subject of GIS interoperability articulated in different initiative phases, which mainly support the application developers for the integration of different geo-processing and location services (Lieberman, 2003): WMS, Web Feature Service (WFS), Web Coverage Service (WFS), and OGC Web Service Architecture.

The services provided by the platform range from a classical database query map catalogue allowing access to 28,000 maps to a geographical access. An intermediate level access is under development as described in Section 3.3. The main aim is to promote access to cartographic heritage and establish the habits of their use by developing spatial tools based on the affinity of the public users to analyze the landscape using maps and images, rather than using a basic database query access.

3.2. Competencies in the Field of Cultural Heritage: User Definition

In order to meet the above-mentioned objectives from the end-user's point of view, the Atl@nte map data consulting procedure is organised into several steps. These are implemented as services defined by the INSPIRE directive:

- discovery service: individuation and location of services or data sets of a particular interest or geographical region using metadata catalogues;
- view service: consultation and evaluation of sample data and detailed reports; delivery of specified data on coordinates and attributes, together with any relevant content of metadata; and
- download service: data download (or direct access) initiated by end-users for their own purposes.

The definition of a "user" in cultural heritage is, of course, all members of the society. However, some distinctions should be made among user profiles. They are here divided into two main categories: professionals or practitioner users and public users or guests. With reference to the Atl@nte platform:

- a professional user can operate within an interdisciplinary environment, is able to access the information and possibly change certain parameters (metadata). This category usually has the sub-categories administrator and collaborator;
- a public user can access the information from home through a standard Web interface that supports virtual navigation. A public user can be a citizen but this category also includes professionals, such as historians, architects, and researchers.

Atl@nte provides back-office and front-office functions because the needs of these two groups are very different and the dedicated content has to be properly tailored to each.

Employing the five use cases and actors' profiles (see Table 1) described by the INSPIRE directive for the category of Protected Sites, researchers have identified a first actor profile group for Atl@nte's purposes: within the field of cartographic heritage, these main groups can be further split up to better understand the exact needs of science branches involved in the process and arrive at solutions that would meet these requirements, improving the open spatial tools development and levels of interactive tools among users.

Table 1: Interpretation of Use Cases and Actors' Profiles

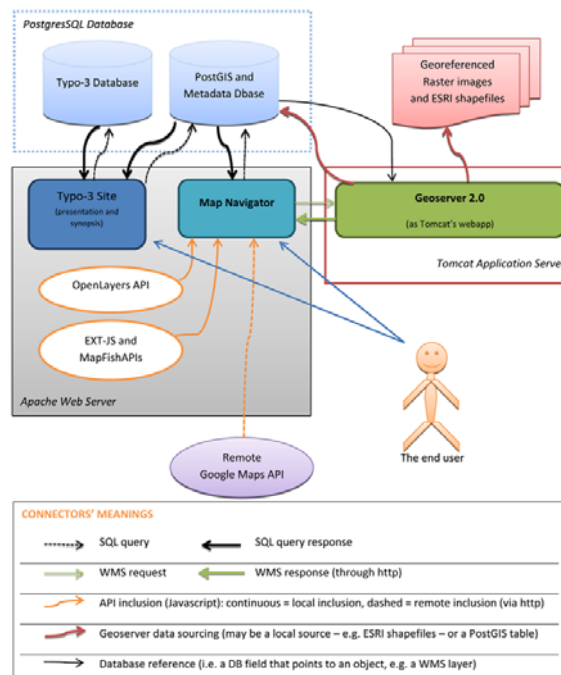
Use cases	Actors profile	User	Atlante Project
Generating EU Protected Sites spatial data report	Europe-wide, including Natura 2000 sites; expert user/regional government including Eu Commission and Eu Environment Agency	Bodies and institutes involved in CH protection and documentation	Atl@s Spatial Data layer definition, WMS and SDI architecture are constantly shared and evaluated under the supervision of Ministero per i Beni e le Attività Culturali, (Ministry of Cultural Heritage and Activities, IT), local and regional superintendents for CH. Collaboration with International Research Centres is being defined for the following year (2011), in order to identify matrix content and make a deeper analysis of the thematic reading level of landscape heritage through historic georeferenced maps.
Naively query and view Protected Sites	Local, regional and Europe-wide; non-expert/public user	Visitor/ Student/ Virtual tourist	Visitor/student can already access the distributed WMS. Virtual tourist level will be exploited in the next year in collaboration with other research centres following UNESCO requirements with local municipalities.
Expertly query, view and analyse Protected Sites	Local, regional, cross-border; to support environmental impact assessment and decision making	Architects /planners involved in conservation projects; PAs; local authorities; Regional authorities.	Atl@nte provides <i>View service</i> of historic map data allowing PA institutions, mainly local municipalities in Lombardy, to constrain professionals' systematic use of historic maps in the overall design processes (mainly architects and planners involved in conservation and urban and territorial planning)
Download protected sites data	Expert / semi-expert user	Professional in the field	At the moment, consultation is done physically in the National Archives (here ASMi). Download service, under development, will be activated by the end of the project (definition of administrative and legal terms provided by the Ministry of Cultural Heritage). It will support researchers in the field, universities, archivists and the public at large, but also professionals and architects involved in urban, landscape, local, and global planning and in design processes, by contributing to limit time and costs at a sustainable level, widening the user base.
Provide PT data according to EU legal obligations and data flows	EU member state	National authorities and PAs	Local authorities, Lombardy Region, national authorities and administrators (level to be defined)

Source: INSPIRE Data Specifications on Protected Sites

3.3 Geo-database of Historical Maps Developed within Atl@nte

The geographic functionalities developed within the geoportal Atl@nte allow the users to manage a database of all the raster georeferenced images, tiled and published as WMSs, as explained in the logical scheme of the Geo-database application (see Fig. 1).

Figure 1: A Logical Schema of the Geo-database Application



The Geo-portal is divided in three access steps (Table 2), developed using a Geoserver. This task is implemented in an OGC standard compliant open source that ensures the interoperability with other systems. The first-level access is made using map catalogue functionalities, a simple database query with classic high-resolution visualisation of the 28,000 map units.

The second-level access is based on the spatial data generated on the georeferenced maps. Although they may have been generated in different periods using diverse methodologies, maps that have a 'metric measurable content' (as in the case of 2D map representations) are directly comparable to current maps through the geo-referencing process. This fact allows someone to relate the current state of the art with the historic assets, browsing along multiple time layers of land. A great part of the research done to date has been dedicated

to refining a methodology for geo-referencing the blocks of maps belonging to the same chronological series (Brumana et al., 2009).

Some tests are on-going using typical photogrammetric algorithms of independent model aerial triangulation (Kraus, 2008) based on the measurement of persistent features like buildings or other objects within the ancient and current maps (control points) and points along the borders (tie points) which are common in adjacent sheets. The algorithm and control parameter definition, shared by members of the international scientific community, permitted people to conserve the precious qualitative-quantitative contents of the maps (Brumana et al., 2010).

Table 2: Atlante Geo-Portal: Data Access Available Tools Using Different Levels

Basic level: Map Catalogue. DB query access	Map catalogue of 28,000 non-georeferenced map units, belonging to the cadastral collections and cartographical historic maps of ASMi can be accessed through the WMS application.
Georeferenced level: GeoWebMap A. Territorial-regional georeferenced map level (chorographic, others) B. Large scale and urban georeferenced map level	Access to the series of historic maps georeferenced to current cartographic coordinates (in Italy: Gauss-Boaga projection for large scale maps and UTM-WGS84 projection for the territorial maps) and to the related information structured in the GeoDb, built up to manage the georeferenced spatial data level.
Map Processing Service accessed by querying the DB through the georeferenced chorographic layer	ESRI SHP [®] files extracted from old regional chorographic census boundaries are used to support interactive user functions, i.e., to query the DB built upon the 28,000 non-georeferenced map units.
Semantic content: thematic axis level	Thematic content development on course within the DB, will strengthen the valorisation and analysis of the potential SDI of temporal map series and related current and historic layered ESRI SHP [®] files. Data like Toponyms and Hydronyms of ancient roads, river basin modifications, and inhabited areas can be derived from the Geo-database, supporting cultural dissemination of chosen themes.

Once the registration process has been completed, the maps are published as a service in the online geo-portal. The metric content of the maps becomes an immediate instrument for strengthening the understanding of the land by a large

number of citizens and users as they compare them with the territory in which they live.

For this purpose, the potentials of georeferencing chorographic maps were analysed. These particular kinds of maps were established to provide an overall presentation to the cadastral officers. Their purpose was to control different territorial divisions in addition to the geographic purposes. The maps are, however, very rich in descriptive geographic content, such as hydrographic and topographic items (Fig. 2). Chorographic maps are considered to be a perfect link between the Lombardo-Veneto cadastral maps (belonging to the first cadastre surveyed within a geodetic reference) of the municipalities on a large local scale (1:2,000) and the topographic maps (1:84,600). In particular, through those chorographic maps that provide a synthetic view, it is possible to transfer knowledge to the people about the unique history of artificial river networks that made the territory navigable. Covering canals and parts of rivers was not only a great cultural loss but it is also the reason for many disruptions today (i.e. flooding of the Seveso and Lambro Rivers in the urban area of Milan).

As shown in Figure 2, the mosaic reconstructs the territorial continuity, allowing a user to compare modifications of the administrative boundaries in Lombardy as they occurred over time. Indeed, the availability of areas corresponding to different municipalities in the old cadastral maps (called 'Unità Censuarie'), enable a geocoding process in which each cadastral sheet is identified by an attribute that links it to the municipality it belonged to in the past (Fig. 3).

The Lombardo-Veneto cadastral map ensemble chronicles these ancient boundaries, allowing a user to read changes along the borders and rivers shared by different municipalities. In addition, it is possible to analyse the complex history of urban aggregations that took place. This geographic service supplies full access to georeferenced maps. For the non-georeferenced cadastral maps (that are the major part of the materials available), the use of chorographic maps allows the user to jump from a geographic vector file representing an area of interest to the map extraction. The use of a database query based on the classical alphabetic keys, usually more difficult for the public at large, can then be avoided. This chorographic spatial data layer is used to generate a Web Processing Service (WPS) to extract and navigate more than 28,000 map units of the three historical cadastral series, from 18th to 20th centuries.

Figure 2: (top left) A Mosaic of the 10 Chorographic Georeferenced Maps Cut to Borders. (top right) Geo-portal Tools Allow the Addition of Current Cartographic Layers, such as the Hydrographic Network and Administrative Borders of Municipalities and Provinces. (Bottom Left) Chorographic Map of Valtellina Province with Persistent Boundaries related to Perimeters of Current Municipalities along the Adda River. (Bottom Right) Transformations in the City of Milan with the Current Aggregation of Old Sections

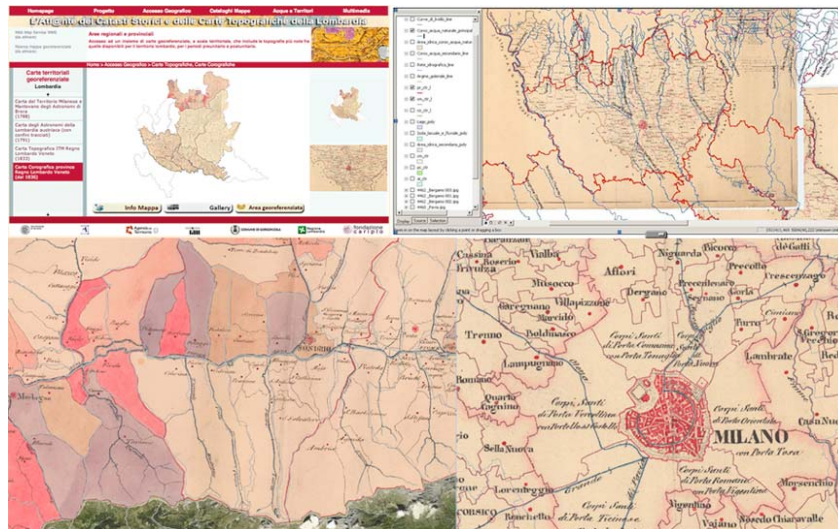


Figure 3: (Left) Extraction of Map Sheets Belonging to Ancient Municipalities' Extensions in the 19th Century, through a Vector File. (Far Left) Classified with respect to the Name of Census Parcel Units, using a WPS Tool. (Right) Direct Comparison to the Current Vector File in the Geographic Navigation



4. TEMPORAL ANALYSIS OF THE CHANGES OVER TIME

4.1. Cartographic Heritage as an Additional Spatial Data Layer of the INSPIRE Themes

As defined by the UNESCO (1972) World Heritage Convention, the term cultural heritage refers to sites, groups of buildings, or monuments with a 'historical,

artistic, aesthetic, scientific, ethnological, or anthropological [...] outstanding universal value' while natural (environmental) heritage is described as the 'natural features consisting of physical and biological formations or groups of such formations, which are of outstanding universal value from the aesthetic or scientific point of view'. The progressive extension of the concept of cultural heritage into the environmental domain calls for defining methodologies to better investigate larger portions of territory and landscape that are recognized as being characterized by a stratified and complex history and values. The use of historic maps can provide an important contribution when addressing safeguarding policies and maintenance interventions regarding historic cultural traces and vulnerable landscapes.

The cartographic heritage is a special form of heritage as it contains artistic elements but also valuable geo-spatial information that allows one to consider territorial, environmental, geographic, and political changes that occurred in the past. It consists of important documents that define a precious dimension of space and time potentially useful when related to the current state of the art. Obviously, it cannot substitute for an in situ analysis of landscape and site material traces, but it can become a powerful complementary instrument for decoding and conserving traces that are sometimes imperceptible or disaggregated.

Historical cartography can be employed when one is dealing with archaeological heritage, which is usually a very time-consuming process. Integrating the historic information with contemporary technologies like remote sensing satellite images can bring about interesting results, both for archaeological and other overall landscape analysis (Agosto et al., 2003).

Historic cartography can be helpful in the complex phase of recognising ancient signs that are a resistant matrix imprinted on the territory, especially if they are correlated to current spatial information such as remote sensing data (i.e., infrared thermal or multispectral images). Integrating the historic information with these contemporary technologies can provide interesting results both for archaeological and other overall landscape analysis. Historic maps can be systematically used to address in situ analysis for better-focused maintenance, such as cleaning operations, vegetation mitigation, detritus removal along ancient dykes, or as support for those participating in archaeological digs and investigations. Finding information about any precious information about pre-existing settlements, monuments, or sites can reduce the time and cost of archaeological research and limit destructive analyses. The knowledge of changes over time is of great importance to support territorial analysis and planning processes, built environment transformations, and discovering and restoring the viability and water network infrastructure. Historic maps can be an information layer that complements other spatial themes.

4.2. Historical Spatial Data Potentialities in Temporal Analysis of the Built Environment

Historical maps are currently exploited because of their potential for temporal analysis of the built environment. The lack of easy access to cartographic documents limits the systematic diffusion of their use outside the small community of historians, map experts, and geographers. Moreover, having to go to the National Archives that conserve the greater part of the historic map collection represents a further obstacle to spreading information about the cartographic heritage.

The experience gained through the setup of Atl@nte geo-portal demonstrated how the availability of historical cartographic data in structured Geo-databases on the Web can be an important opportunity to spread cartographic heritage among a wider public. This could result in improving the global knowledge about the manmade environment over time. The cartographic heritage might become an instrument to support the public administration at different levels in the decision-making process, in the interpretation of permanencies and mutations related to the land, and in the assessment of sustainable interventions (Bartoněk, 2010). Moreover, this tool could be of great help for academics but also for tourism and social and economic development. In addition, ordinary citizens could gain access to such heritage from their homes.

The development of geographic tools can improve one's ability to consult thousands of historic maps once they have been registered to national mapping grids and made into mosaics. Examples of cadastral map series available across Europe, generated with different methodologies and technologies over the last three centuries, can add value to the citizenry's consciousness of the history of our territories.

The experiences described here were carried out in recent years as focused case studies. Their results demonstrate that geospatial information and instruments like geo-portal can be used to improve temporal analysis of landscape changes and those of its anthropogenic traces, consenting their analysis among various maps' features, at different levels. In all of them it was necessary to attempt integration with the INSPIRE directive.

A. Historical Site Transformation

Almost all European cities lie in areas where there were previous settlements. The 'protected sites' in the list of spatial data themes (Annex I of INSPIRE) reflects a great awareness of the EU community that there is a need for a spatial description of its environmental and cultural heritage. The directive as a

bureaucratic instrument will be very significant to launch further initiatives that will lead to an overview of the heritage distribution with a geographic reference.

Figure 4 illustrates a case study of the research carried out on a small historical site (Cantù, Lombardy). Here an apparent lack of ancient traces is evident from the analysis of the land as it is today. Cross-relating georeferenced historic cadastral maps with on-site data acquisition allowed researchers to highlight permanencies and changes over the past centuries (arches, porches, masonry brick-block stratigraphic units, etc.). For example, the system of fortifications, wall perimeters, primary and secondary roads, the network of staircases, and the generation and transformation of neighbourhoods have been underlined (Brumana and Prandi, 2006).

Figure 4: Small Historical Site within The Town of Cantù, Lombardy (Italy). Historical Geo-Database Made it Possible to Highlight Some Important Permanencies Related to On-Site Data Collection: Building Blocks and Transformation Levels (Above), Ancient Stairs Network, Wall Perimeters (Below)



B. Thematic Axis: 'Water and territory'.

A specific objective of the Atl@nte project is to contribute to the enhancement of thematic subjects registered within the historical maps, such as the theme water and built environment. The mosaics of ancient maps reconstructed along the river

beds allow a researcher to observe the territory with a synthesis that has not been thoroughly investigated until now. The Lombardy has an extraordinary feature in that its long-lasting hydraulic infrastructure still exists. It provided commercial paths during the past centuries and has strongly influenced the economy of the region (Fig. 5). The articulated network of rivers, lakes, natural elements, artificial canals, and other manmade artefacts like ditches and fountains deserves to be rediscovered and protected.

Within the Atl@nte geo-portal several navigation paths on 'Water and Territory' topics were developed, such as 'agriculture', 'historical buildings', 'parks and gardens', 'river boundaries', 'archaeological traces', and 'hill and mountain landscapes', in order to highlight precious characteristics of landscape, panoramic views, and the built environment, all of which needs to be protected.

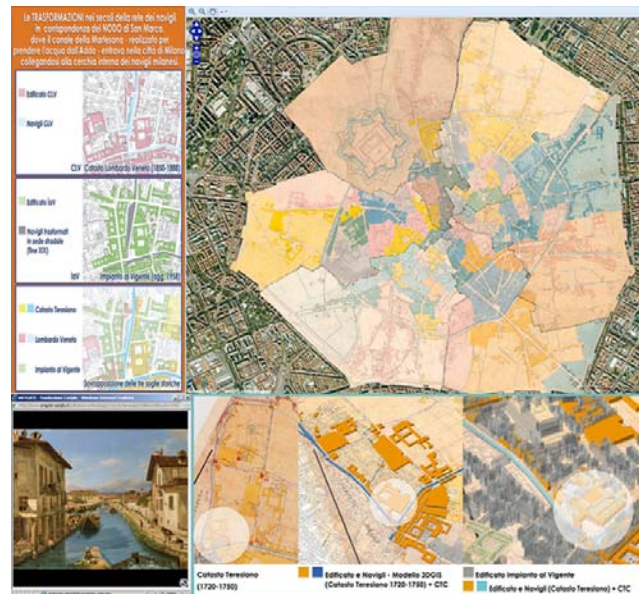
Figure 5: Above, a Digital Map of the Martesana Canal. Made in the 15th Century to Connect the Adda River and Milan, It passes through the Lambro and Seveso Rivers. The Temporal Series Shows Different Scales in relation to Current Maps of Regional and Local Large Cadastral Scales. Below, Territorial Analysis as a Contribution to Rediscovery of Secondary Canals Network Made to Bring Water to the Agricultural Sites. Some of Them are being Progressively Cleaned and Repaired Using The Georeferenced Maps



Analysing the content of the historical maps could be of a particular interest under the INSPIRE theme 'hydrology' as it offers a spatial/temporal overview of changes in water paths in the Lombardy territory over a period of a few centuries. In this case, the integration of small-scale historical chorographic maps (Fig. 6) in

the SDI contributed to raising the consciousness of both citizens and public administration and disseminating information about the history of the hydraulic network (Oreni et al., 2010).

Figure 6: Transformation of the Canals Network in Milan during the Last Three Centuries: Historic Georeferenced Maps Overlapped with Global Imagery. Below, a Detail of the Connection Node between the Martesana Canal and the Internal Network



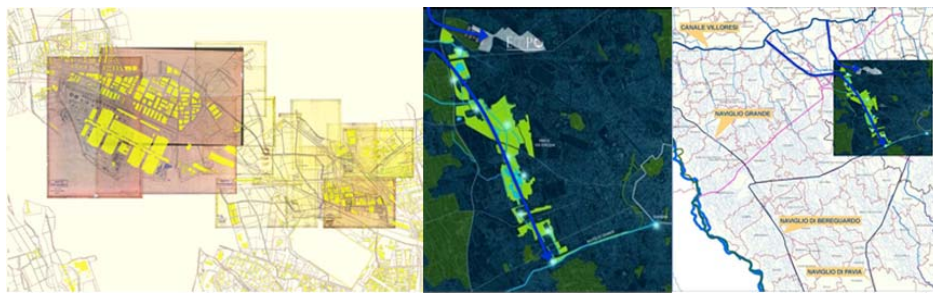
The published chorographic maps include the Maps of the Astronomers of Brera Observatory (39 sheets at scale 1:1000) and the Maps of 'Corpi Santi' (map copies from 18th century made on Teresian Maps from the 17th century), illustrating the urban structure before the canals were covered in the late 20th century.

Georeferenced maps at a territorial-regional and a cadastral-local scale can be further integrated with space data and information from other sources like multi-spectral satellite images, airborne and UAV photogrammetry, mobile-mapping vehicles, laser scans, in particular for identifying and analysing water courses. In this way, new scenarios for retrieving geospatial knowledge of territory can be provided in order to address regional planning and local municipalities' actions on the built environment.

C. Agriculture versus Agricultures

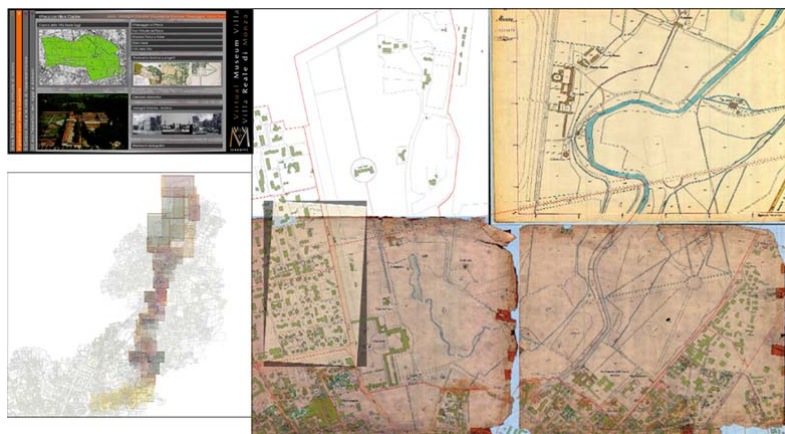
The forthcoming Expo2015 in Milan is entitled 'Feeding the Planet, Energy for Life'. A display of the existing water network has been planned in the Expo area in order to focus attention on 'water and agriculture' as energy life sources that can be supported by historical temporal spatial data analysis (Fig. 7).

Figure 7: Milan Expo 2015 Area is Planned for a Water and Agriculture Network Valorisation as Feeding Energy Life Sources (Right). Temporal Reconstruction of Territory, Sites and Water Basin can Support Planning (Left)



Some studies on the rediscovery and conservation of ancient cultures to safeguard bio-diversity are ongoing, exploiting the parcel attributes registered in Maria Theresa's and Lombardo-Veneto's cadastral maps (Fig. 8).

Figure 8. Georeferenced Temporal Data about Lambro River Crossing in the Park of Villa Reale in Monza (Lombardy) Showing Plant Species in Parcels along the River among Windmills and Farmsteads, Distinctive for Rural Landscape (Details of Ongoing Process)



This information can be an instrument to support analysis and new plantings of ancient species. The 'land use' and 'land cover' analysis can support agricultural terrains for species and biodiversity studies. In the case of the Park of the Villa Reale in Monza (Lombardy), the historical layer of Teresa's maps gives important evidence concerning 'villas of delight' that lie near the water paths (Figs. 6 and 8), a project showing the vocation of agriculture by Archduke Ferdinand of Austria.

5. INTEROPERABILITY AND SDI METADATA FOR HISTORIC CARTOGRAPHY DATA SETS

5.1. Interoperability

To fully appreciate the cartography heritage information, it is necessary to clearly understand all the phases of the mapmaking process and the richness of their qualitative and descriptive contents. A great importance should be given to metadata creation as they are crucial for tracing, recognising and employing the right dataset that will correspond today to any given point of a certain case study.

The interoperability issue is one of the pillars of the INSPIRE directive. In order to have interoperable data of historic maps, it is important to provide a common background on data description shared across Europe and possibly use a common language for their development. In this way, the metadata definition would be compliant with the bureaucratic requirements of the directive on the one hand and fulfil the necessities of the scientific community on the other. This aspect is of particular interest for more reasons: firstly, today the producers of maps follow the SDI while historic map libraries still function as bearers of content standards (Montaner, 2009). In fact, this dichotomy is the reason that there are two different approaches to metadata creation with no common methodology as far as objects of cartographic heritage are concerned. Therefore, a universal definition strategy would be useful in the processes of digitalization, storage, and management of this kind of heritage. Moreover, it could set bases for the correct insertion of historical georeferenced information into the current SDI at regional, trans-regional, or international levels.

Data processing is becoming more and more automatic. Consequently, very careful and high-quality work with metadata is required to record data sources and production parameters (Dawes et al., 2008). This care will also assure:

- resource discovery;
- organizing electronic resources;
- interoperability;

- digital identification; and
- archiving and preservation.

Service-oriented applications involving geospatial data are possible also because the geospatial community, supported by the OGC, has proposed specific interface descriptions. While the philosophy and principles remain intact, the main difference resides in the descriptive languages used.

The creation of metadata, however, is essential for three main reasons, which are related to three major benefits (FGDC, 2000; Nogueras-Iso et al., 2005), and are reported in Table 3.

Table 3: Synthesis of Main Reasons for Metadata Creation and their Major Benefits

Need for metadata	Major benefits
Organization and maintenance of investment in a particular data organization	The completion of metadata descriptions of contents and the accuracy of a geospatial dataset will encourage the reuse of data.
Information for data catalogues and clearinghouses	GIS requires menu themes for data, and it is not always possible to provide the most appropriate ones.
Information to aid data transfer	The metadata should accompany any data set transfer in order to facilitate the organizational requirements.

Source: (FGDC, 2000)

Cartographic heritage is very often accompanied by other documents (drawings, historic photographs, and other media contents) that foresee dealing with Digital Asset Management (DAM), Media Asset Management (MAM) and metadata. Questions arise when it comes to their management and storage as they contain both geo-political content-based and artistic-based elements with historic value (Jobst, 2008). Creating an exhaustive metadata for the cartographic heritage has to include both aspects: geographic content expressed using SDI characteristics (ISO19115) and historical-artistic value expressed via library contents standards (MARC21). Coordinated guidelines on an international level could contribute to overcoming these gaps. Of course, one of the main properties that a metadata must have is to be updatable. When it comes to storing geospatial time-based data, a common standard is still not defined. At the moment, an encoding standard developed for the purpose of expressing the geographic features is Geography Markup Language (GML) based on XML (Lake, 2004).

5.2. Metadata Standards related to the INSPIRE Directive

A geographic information metadata standard is ISO 19115 that defines contents, spatial-temporal purchases, data quality, access, and rights to the use of geographic information and associated services. The committee responsible for this standard is a technical committee formed within ISO. Its work is closely related to the efforts of the OGC: the two organizations have a working arrangement that often results in identical or nearly-identical standards, often adopted by both.

As far as the INSPIRE directive is concerned, the national transposition procedure was to be completed by May 2009 in all member states⁴. The legislation framework is of great importance for single national bodies (research centres, public authorities) as the INSPIRE directive sets up bureaucratic but no semantic rules. Specifications on translation into practice have to be provided, a task to be implemented by single governments. In Italy, it is the responsibility of the Ministry of Environment, and the legal act⁵ (published in March 2010) regarding the INSPIRE transposition is already in force. It should help to set-up the national metadata construction methodology compliant with INSPIRE and to avoid a double transposition for authorities. In Italy, metadata standards are to be developed by Centro Nazionale per l'Informatica nella Pubblica Amministrazione (CNIPA - www.cnipa.gov.it), a public body governing the process of developing the use of information systems and technologies among national-regional-local public administrations. CNIPA is currently expecting the Ministry of Environment to proceed with developing standards that are compliant with INSPIRE and hence provide rules for all public bodies that manage geospatial data.

5.3. Creating Metadata for Historic Maps within Atl@nte

A database of historic maps created in Atl@nte geo-portal will also provide all the information for the metadata description. Given the large number of sheets that make up a single map series (e.g. 39 sheets of maps that make up the 'Astronomi di Brera' map, 1807), some large categories of map properties have been setup. In fact, some of the fields contain the original source name, the name of the georeferenced file, the code of the sheet within a set, its raster specification, the Italian National Institute of Statistics (ISTAT) identifier, the fluvial axis the map refers to (see 'Water' thematic axis), the current province, and so on (<http://www.istat.it/>).

⁴ As of January 2011, all 27 member states have taken measures to develop their indications on which national initiatives could rely, although they still need to be checked for conformity and comprehensiveness

⁵ Decreto legislativo, number: 32; Official Journal: Gazzetta Ufficiale della Repubblica Italiana, number: 56, Reference: (MNE(2010)51912; information source: <http://eur-lex.europa.eu/LexUriServ/LexUriServ.do?uri=CELEX:72007L0002:EN:NOT>

Metadata profiles for some chorographic maps were developed while more consistent analysis will be carried out as the project progresses. Some of the first considerations regarding metadata elements, as prescribed by the Metadata Implementation Rules of INSPIRE are the following:

- 'Identification': as cartographic heritage has both geographic and artistic contents, its position should be correlated with archive databases based on librarian logic (matching DAM, MAM and metadata);
- 'Geographic Location': (1) chorographic maps were originally produced with no coordinate references, and their content might involve portions that today belong to different regions and states (i.e., if georeferenced in different countries, the same map will have different mapping grids); (2) historical large-scale cadastral maps in Atl@nte are georeferenced within Gauss-Boaga – I fuse (EPSG: 3003), and the territorial ones within UTM-WGS84/ETRF89 – fuse 32 (EPSG: 32632). The use of global imagery for comparison purposes causes problems for the reference system because these orthophotos and maps use the Spherical Mercator projection with geocentric coordinates (EPSG: 900913) and cannot be re-screened. As it is impossible to visualise maps with non-homogeneous systems of reference at the same level, the system (here Geoserver) automatically re-projects maps in geocentric coordinates. All this information needs to be underlined within metadata; and
- 'Spatial resolution' is not a compulsory element for common spatial data, but for historic maps this information should be mandatory: all maps are first produced on paper and are digitalized at a later stage. This process implies map precision and accuracy parameters that can be different from the original map (e.g., if maps are digitalized at low resolution) need to be underlined within metadata.

The limits encountered in metadata definition do not indicate that historic maps cannot be used or compared to the current cartographic products. Nevertheless, they emphasise that some implementation will have to be considered when it comes to cartographic heritage in order to fulfil all the SDI requirements.

6. CONCLUSIONS

In recent years, the spatial data community has acknowledged a strong need for geographic information sharing. As described in this paper, cartographic heritage can be a powerful instrument to improve sustainable territorial and urban development in the future. Great follow-ups are expected in contributing to raise the awareness of landscape and environment, which are the main sources of a country's welfare, culture, historical memory, and identity that need to be transmitted to future generations.

A better comprehension of territory and its natural and anthropogenic characteristics can lead to a more sustainable way of planning and improving territorial government facilities with citizen acknowledgement and participation. Strong support from the technological point of view is needed, either in terms of visualisation media or virtual environments as a communication tool (Kibria, 2009), and there should be distributed Web services that provide geographic contents, which could otherwise be difficult to access and consult. Hence, there is a necessity for a historic spatial data description and for precise indications related to metadata construction, implementation, and maintenance. Metadata could help create a better resource diffusion, understanding, and usage. The power of this communication tool should be available to all and written in a commonly comprehensive language.

Atl@nte Historic SDI (HSDI) has been structured to support functions at different map level scales (territorial and urban) by developing WMS and WPS within an open-source portal to support a spatial use for both georeferenced and not yet georeferenced maps. This structure allows saving time and costs for easy access to the historical maps by different users, now almost exclusively used by the experts. To speed up the expected arrival of such spatial data set availability, experts must focus on research regarding automatic tools used in the registration process. At the same time, the HSDI standard definition has to be strengthened through debates and projects within the scientific community, in order to support the growth of a 'self made portal' of spatially referenced historic maps and to avoid an unsatisfactory level of rigorous methodologies of spatial data generation and management. HSDI related to developing WMS/WPS tools within an open-source geoportal can be easily replicated with low energy and cost dispersions for public administrations and document archives, allowing a satisfactory level of access and customization of tools and guaranteeing a maximum knowledge diffusion.

From this point of view, HSDI should be intended not merely as a technical instrument but as a metric, semantic and qualitative tool that can improve thematic content recognition and knowledge transfer. As far as Atl@nte is concerned, this process will develop in two directions. On the one hand, a collaboration with UNESCO Chair Centre of KU Leuven is being defined in order to delineate a template of thematic contents and elaborate further on the thematic reading of landscape heritage, using historic georeferenced maps. On the other, improving the integration of historic cartography with new data sources (multi-spectral satellite images, airborne and UAV photogrammetry, mobile-mapping vehicles, laser scans) is proceeding. Particular emphasis will be given to 4D multi-temporal spatial data generation in the case of river water boundaries and riparian areas to support rediscovery of side canals and re-connection through sustainable interventions to address risks of mitigation and flooding.

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