Land Use Policy 98 (2020) 104417

Contents lists available at ScienceDirect

Land Use Policy

journal homepage: www.elsevier.com/locate/landusepol

Modeling Legal Land Object for waterbodies in the context of 4D cadastre

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ABSTRACT

In the legal systems of several countries, the delimitation of water bodies is not a clearly solved problem. In most of the Civil Codes of Latin America, for example, the limits of properties are implicitly or explicitly described as vertical surfaces. However, water bodies boundaries have a 2D vision since there are named "riparian lines" –RL. In the international context there are some approaches that help to deal with rivers in a cadastral manner, there are even some standards, from which some basic concepts were extracted.

The general objective of this document is to develop a conceptual model of water bodies such as LLO with dynamic limits based on the legal definitions of riparian boundaries of the Argentine Law, to be registered in a future 4D cadastre system.

The results of this research, it is possible to conclude that there is a way to find an algorithm to automatize and describe the movement and the deformation of the dynamic boundaries with free and basic information and tools. In this context, it is also possible to conclude that water bodies can be described as 4D LLO. Its modeling is an open and necessary discussion that requires the analysis of the general theory of the cadastre, its meaning, and purpose, as well as the approach of technological advances and multidisciplinary studies.

Even when the LADM is not consolidated in Latin America, its multipurpose character creates conditions to push up the model along the region. Marine Cadastre and the Fluvial Cadastre renew the opportunities to consolidate the international standard.

1. Introduction

In the legal systems of several countries, the delimitation of waterbodies is not a clearly solved problem. In most of the Civil Codes of Latin America, the limits of properties are implicitly or explicitly described as vertical surfaces (Maldonado and Erba, 2012, De la Sala and Erba, 2012, Montero et al., 2012 and Salazar and Erba, 2012), however, the boundaries of waterbodies, widely called riparian lines - RL, are still described under a 2D vision.

The Argentinian RL and the restriction associated with it, the towpath, are homogeneous and unique Rights, Restrictions and Responsibilities - RRR examples throughout the water bodies like rivers and navigable lakes (Fig. 1).

The cadastral registration of natural elements defined by legal limits like in the Marine Cadastres, has only been addressed in recent years. Several countries with long coasts and large marine spaces, over which they exercise sovereignty and administrative powers, have shown interest in implementing the concepts related to the Marine Administration Domain Model. However, a common standard is still lacking and an accepted base model to specifically manage the Marine RRR and their spatial extensions. This need was already recognized by the permanent committee on GIS for Asia and the Pacific at the Congress for the Administration of the Marine Environment in Malaysia in 2004 and endorsed by the United Nations - UN Organization through the resolution of the 17th Conference for Asia and the Pacific in 2006 in Bangkok, Thailand (Alberdi et al., 2019). For the fluvial environment, there are several scientific papers describing the evolution of the definition of riparian boundaries towards the space perspective, however, no developments or proposals were found pointing the implementation of a Fluvial Cadastre. In a small territorial scale, some provinces in Argentina are regulating the need of the called "Waters Cadastre" and some papers are exposing it (Alberdi & Erba, 2019).

The cadastral registration of water bodies in Argentina is a problem because their boundaries are related to their natural behavior, which is known or registered, but not under a strict cadastral criterion. Thus, cadastres have registered them as public domain like empty spaces between private parcels adding restrictions over them, by representing their natural functioning, e.g. flooding. Even having laws that define how the legal boundary should be determined, there is not a clear definition of water bodies as Parcel of Legal Land Object (LLO).

In this context, cadastral institutions have difficulties to register water bodies, mainly due to conceptual inconsistency, legal deficiencies and budgetary constraints to implement more complex registration systems. This problem becomes more relevant when, for example, rivers

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https://doi.org/10.1016/j.landusepol.2019.104417
Received 18 April 2019; Received in revised form 16 November 2019; Accepted 5 December 2019
Available online 12 December 2019
0264-8377/

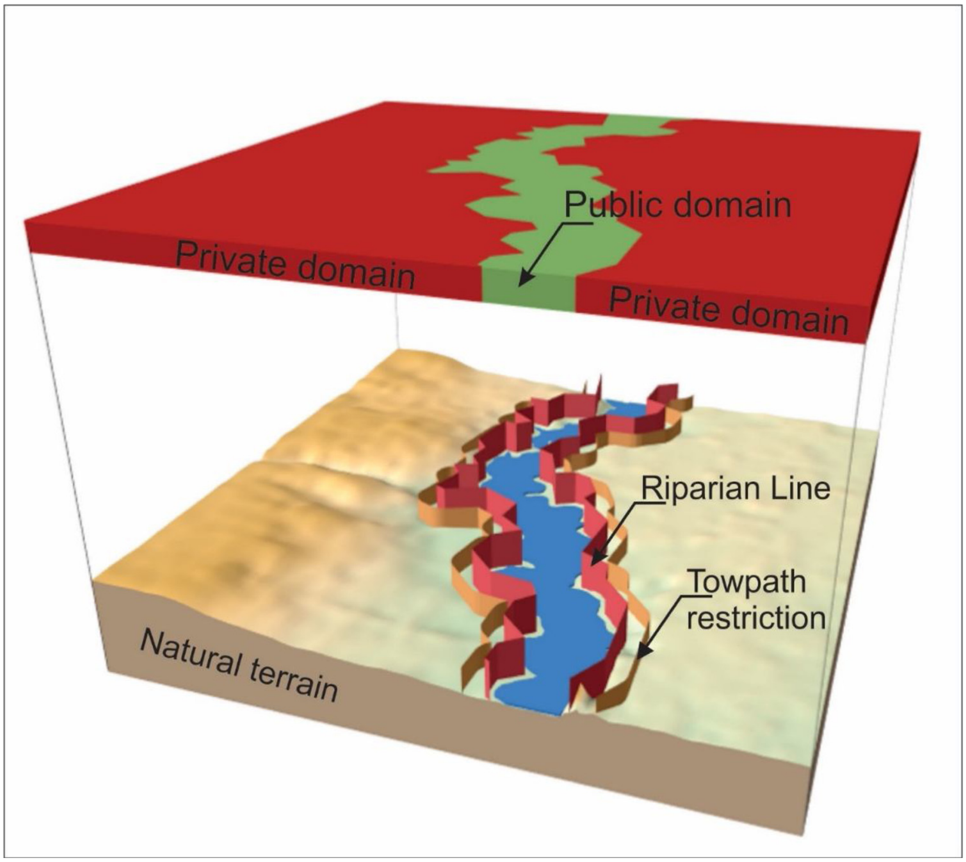


Fig. 1. Location of the Riparian Line and Tow Path.

constitute the boundaries between countries (Donaldson, 2011).

Demarcation and registration of waterbodies imply the transition between private and public domain involving natural resources with fragile ecosystems in many cases. In several countries, the boundaries of waterbodies are commonly determined by following hydrological criteria based on statistical methodologies that take into an account registered hydrometric levels, which are permeable to changes in the parameters of river systems (Alberdi & Erba, 2018). These alterations are observed in the water level: decreasing or increasing, expanding or constricting the boundaries and consequently the shape and the size of the water bodies.

So, if the water bodies are delimited by the level reached by the water, the variability of river floods, and/or the morphological evolution of the landscape elements, the LLO or the parcel needs to be designed as multidimensional.

The proposals to model three-dimensional cadastral objects are abundant and well documented, and receive a constant update that can be seen at http://www.gdmc.nl/3DCadastres/literature. However, discussions about the temporal coordinate in the cadastral domain, commonly referred to as "4D cadastre," are less addressed and restricted to a conceptual approaches (van Oosterom et al., 2006; van Oosterom & Stoter, 2010) and possible applications in a handful of countries as well (e. g. Paixão et al., 2012; Siejka et al., 2014; Vučić et al., 2014). The most significant advances have been made in urban areas by analyzing for example, the case of utility networks (Döner et al., 2010). Specific literature, even with much progress, is still looking for a definition of a 4D cadastre without reaching a final conclusion yet, at least in Latin America.

The general objective of this document is to develop a conceptual model of water bodies such as LLO with dynamic limits based on the legal definitions of riparian boundaries of the Argentine Law, to be registered in a future 4D cadastral system.

The specific objectives are to propose a conceptual model based on a point cloud structure with coordinates varying over time, and to generate a model based on free access data to generate the cloud points with coordinates that represent the variability through time and space.

2. Towards a Fluvial Cadastre: background and conceptual framework

2.1. The variety of approaches to the same issue

Many definitions have been provided for thematic cadastres. In particular for water bodies information systems, the marine cadastre concepts can inspire the construction of a fluvial cadastre concept. As a first attempt, the Fluvial Cadastre (FC) could be define as "an information system that records, manages and visualizes the interests and the spatial (boundaries and limits) and non-spatial data (descriptive information about the legal status, stakeholders, natural resources) related to rivers".

As a cadastral model, FC has to describe and delimit parcels, identify public and private rights, as well as the restrictions over the parcels. As well as in land, FC does not only deal with parcels, it deals with entities related to the interests on land: the LLO.

A Fluvial Rights data model should provide a standard to write laws that facilitate the delimitation, registration, valuation and adjudication of fluvial property rights, the allocated interests, the resources that the interests refer to, and their 3D spatial extent.

A 3D parcel can be defined as a spatial unit in which one or more homogeneous RRR are associated and included in the cadastre (Van Oosterom, 2013). On the other, a LLO is any portion of territory in which homogeneous legal conditions exist within its boundaries (FIG, 1998).

Considering these definitions and as an anticipated conclusion, it is possible to assume that the conceptualization of the cadastral model of water bodies fits better in the 3D LLO definition. So, water bodies should be considered as LLO that should be recorded not as mere polygons in 2D, but as 3D bodies.

This discussion has had little focus on international scientific literature. Highlighting the work on concepts and methods related to groundwater by Ghawana et al. (2010), also the comprehensive work of Kitsakis and Papageorgaki (2017) and only a few examples of application in the cadastral context (for example, Dubnytska & Krelshteyn, 2018).

In the field of international standards, the "S-100: Universal Hydrographic Data Model" establishes numerous parameters and conditions for the registration of information referring to water bodies. However, sub-standard S-121 only refers to marine boundaries. On the river legal boundaries there is not yet a standard that serves as a basis for cadastral modeling. Even less, models of legal boundaries change over time.

In the area of territorial management of riparian areas, some authors have proposed the idea of a "fluvial space" (Ollero & Ibisate, 2012), also called "fluvial territory" (Ollero & Elso, 2007) or "room for the river" (Fokkens et al., 2007). Those researches were focused on flood-based boundaries, however, some strategies proposed by them can be adapted by cadastres for the LLO for water bodies modeling, basing their boundaries on hydrologic and morphologic behavior.

2.2. LADM for Fluvial Cadastre

Several authors worked on the development of a 3D Land Administration Domain Model (LADM), conceptualizing and classifying the marine entities and its relationships, exploring the adaptation of LADM to the marine environment. It is time to do the same with fluvial environments.

The LADM, approved as ISO 19152 provides a formal language for the description of existing systems, based on their similarities and differences. The implementation of the model in marine environments is a user requirement in LADM version A.

The common relationships that can be observed in land administration systems may also be modeled in the LADM through a package of party/person/organization data, RRR/legal/administrative data, and spatial unit (parcel) data (Kastrisios et al., 2017). A similar pattern can be applied in marine spaces and in fluvial spaces too.

The application of the LADM into the fluvial environment highlights the differences that may arise in the application of conceptual data models to different jurisdictions. The main issues refer to the decisions taken regarding how basic administrative units and any derivative spatial units are modeled. There are also differences relating to the linking or interfacing of land-based cadastres (that are based on existing standards) with new defined standards applicable to fluvial spaces (adapted from Griffith-Charles & Sutherland, 2014).

To identify the components of the Administrative Package, it is necessary to start analyzing the marine environment, fitting to the fluvial one. According to Ng'ang'a, 2006, property describes the resource, individual/s with an enforceable claim, and type of resource use claims. Moreover, boundaries of the public parcels owned by the state in the territorial river are not treated as a property and its boundaries are determined according to the use only (e.g., minerals, aquaculture among others). There is not usually a real estate market in river where parcels are subdivided and consolidated and sold off, nor a system designed to support this (Barry et al., 2003). This is because in rivers a different legal regime is shaped. In this environment the following types of RRR can be found (adapted from Athanasiou et al., 2016):

- State Interests: the state RRR are defined through the international Treaties (and bilateral agreements for states with rivers neighbors) and transposed into national legislation with laws;
- Public Rights: which refer mainly to the constitutional right of every citizen of the state having an unlimited/without obstacles access statewide (terrestrial and river space),
- Environmental RRR: refer to provisions that relate to the protection and conservation of water resources, places of preserved areas and cultural heritage, and
- Usage and Exploitation Rights: progressively functional rights tend to acquire a private nature, associated with individual stakeholders that coexist with the state rights.

About the Spatial Unit Package structure, Lemmen (2012) states that "… with some imagination, the laws (formal or informal) can be seen as parties; in fact, the laws allow people to have interests in "marine objects". The interests are RRR and the MarineObject corresponds with the SpatialUnit in LADM Version C.

Thus, it is expected that LADM can be used to marine space, so, it is possible to affirm that LADM can be used for fluvial space too. Fluvial Cadastre should attend the mobility of the boundaries, in this regard, two approaches to modeling dynamic aspects are proposed in Annex N of ISO 19152: the Event Based Modeling and the State Based Modeling (SBM). This paper adopts the SBM mainly because some authors are applying it with promising results (e. g. see, Sulistyawati et al., 2018). This vision links the dynamic aspects with explicit modeling, that is, each object is assigned at least two moments that determine the current or valid version. The specific attributes 'beginLifespanVersion' and 'endLifespanVersion' could describe a space path, in addition to the temporal one. In the following, it is analyzed how it could be carried out.

2.3. Moving boundaries. Considerations for multidimensional modeling

It is important to perceive that alterations in the position (natural displacement) or composition (by flooding fluctuations or built-by-man elements like dams) of the boundaries over time, generate multi-temporal issues that show up into the cadastral scene as a significant aspect. Since the morpho-dynamics of water bodies can produce location changes of the limits along the time, it is necessary to address the registration of rivers and lakes as 4D-LLO. In other words, when homogeneous conditions have spatial delimitations, a 3D-LLO arise, so, if 3D conditions vary, disappear, grow or suffer another kind of change along the time, a 4D LLO is configured. Consequently, the legal corpus must define a dynamic LLO in space and time to be registered.

This concept can be extended to all LLO, particularly those involving:

- naturally or influenced by man change in their essential elements over time, modifying or even disappearing (e. g., adjacent parcels to the mobile riverbeds).
- the contractually or legally stipulated modifications based on time lapses (e. g., superficial rights).

As a broad concept, 4D Cadastre includes not only parcels with dynamics boundaries, but also the appearance/extinction of restrictions, or the changes in the ownership of rights. It is a discussion that necessarily involves the time (t), variable in the multiple aspects that affect land order derived from the legal causes that originate it. Thus, Van Oosterom et al. (2006) postulated three cadastral time types: • Registry data update times;

- Times derived from legal events (e.g., creation or extinction of a parcel);
- Times derived from changes in property rights (e.g., timeshare rights, boundaries displacement, among others).
- The cadastral time that involves the "variations in the right over time" is the only one that covers the dynamic boundaries. In this sense, Egenhofer (apud van Oosterom, 2006) points out that in parcels where one of the limits is related to natural physical events

(such as river margin slipping), it should be named "geospatial lifeline". In theoretical terms, this concept includes the records of all registered locations reached by the boundaries between two or more moments, like a cadastral history. The register of locations as geospatial lifeline is widely used in numerous and diverse disciplines: Mark (1998) cites as an example of the search for movement patterns in animals.

This theorization is completed with the differentiation between linear and branched times (Sass, 2013). The first group consists of a unique sequence of locations, while the branched time is structured so that a point, from the initial location, could take a new position among several possible ones. The modeling of the temporal coordinates, therefore, must somehow synthesize the cadastral history, representing the tendency of the movement of boundaries of the LLO, following the dynamics of parcels and the updating (more frequent by intervention of the owners) in cadastral systems in Latin American countries.

3. River boundaries registrations in Argentina

Since the Roman law enactment, the legal notion on the rivers was crossed by the common benefit question. The surface waters were included within the public domain goods because they are essential for the populations development as a transportation means, consumption and irrigation supply and, at the same time, a latent risk for the population settlements near the flooding areas. The hydrological and geomorphological dynamics of water bodies, in particular the rivers with their flood and dryness regimes, have been generated advantages and disadvantages for settlements.

In Argentina, the General Part of the National Civil and Commercial Code (NC & CC, 2015) considers public domain "the waters that run through natural channels, delimited by the Riparian Line (RL) defined by the level that reached at the average maximum normal floods" (Art. 235). It is the legal issue that delimits natural water bodies, differentiating them from the private domain. Once the RL is determined, the owner of a riparian parcel will know how far its property right reaches the water bodies borders (Fig. 1).

From the moment it is presented as an average of certain levels previously occurred, the "time" variable is introduced in the definition. Historically, this legal boundary was always based on the statistical treatment of a (not always available) datasets. It is determined for a specific moment and with the available data at that time, constituting a fixed limit in time, and rarely or poorly incorporated into Argentinian cadastral databases.

Argentina does not have a centralized national cadastral institution. The National Constitution does not allow it, as it has been a faculty conferred to the provinces since the country became a republic in the 19th century. Consequently, each province has developed its own territorial information system, with its own laws, regulations, and interpretations of the national laws.

Province of Santa Fe has one of the most advanced in the country in cadastral matters. As a "fluvial province" Santa Fe needs to manage properly riverine areas, it is important to have cadastral boundaries representing the variety of fluvial systems and not a set of LLO for each aspect of rivers like flooding by a side, channels for others and so on.

The rivers have been registered as linear element of the landscape at a certain moment and under a specific hydrological condition. Furthermore, the problem affects to private domain: the private parcels riparian boundary are surveyed considering the apparent physical (but not legal) boundary, materialized by level of water at the date of the fieldwork. This situation generates conflicts in the databases (Fig. 2).

From the perspective of risk mitigation, the cadastre of Santa Fe incorporates its own legal ordering based on domain restrictions. The law establishes that the natural channels are included in Area I (Fig. 6) which boundaries result from the digitization of the areas flooded by the most recent biannual recurrence flood that could be detected in satellite images (INCOCIV, 2013). With the same methodology, Area II was stipulated for 10-years floods. These LLOs are used in this paper for the critical analysis and the formulation of modeling proposals of RL as 4D-LLOs.

4. Study area

The research briefly presented in this paper was developed in two study areas with different physical conditions (identified with circles in Fig. 3). They are located in flat relief, chosen because it exacerbates the complexity into the approach of dynamic limits of waterbodies. In this kind of areas, little changes on vertical levels of water imply big changes in the horizontal way (flooding). With this selection, dissimilar territorial scales were addressed and the hydro-geomorphological differences were highlighted.

The study area 1 (SA1) corresponds to a segment of 27 km located in the terminal area of the Salado River, in its confluence with the Paraná River. Salado River is the main watercourse of the Santa Fe province, it drains an area of 85,600 km^2 and it has an average flow of 159 m^3/s. It is a plain river with low slopes and large anthropogenic changes along its runoff, it corresponds mainly to the risk mitigation infrastructure.

The study area 2 (SA2) corresponds to a segment of 11 km of the stream "Arroyo del Medio", which materializes the administrative boundary between the provinces of Santa Fe and Buenos Aires (two of the largest, most populated and developed provinces in the country). It has a basin of 2035 km^2 and a flows rate of 9.4 m^3/s. The stream presents particular conditions as an embedded morphology where the erosive processes of margins and waterfalls predominate.

5. Methods and materials

5.1. Conceptual modeling

The way in which the cadastres record the variability of boundaries along the time will depend on their objectives. Since between the branched and the linear time there is a continuum, a modeling will be more effective the closer to the linear type.

On the other hand, since the elements of the landscape located around the boundaries change along the time, the whole boundary will not only be displaced but also deformed (Fig. 4). This process leads to the appearance or disappearance of new points.

For all these reasons, the dynamic of the process is hard to be mathematically modeled. This work proposes a conceptual linear time model based on the one-to-one correspondence of the data, that still requires development to become a mathematical model, especially in topological issues.

So, the hypothetical waterbodies' moving model could be represented through a vector V, which is a function of precedent records on each point of the RL [1].

$$((1))\ P_1 = P_0 + V_1(r,\alpha) : V_1(r,\alpha) = f(P_0,V_0,P_{-1}) \wedge P_0(x_0,y_0,z_0,t_0),\ P_{-1}(x_{-1},y_{-1},z_{-1},t_{-1})$$

where:

$\mathbf{V_0}$ is the movement vector from P_{-1} to P_0.

$\mathbf{V_1}$ is the movement vector from P_0 to P_1.

r is the distance of the displacement.

α is the spherical angle of the displacement.

$\mathbf{P_{-1}(x_{-1}, y_{-1}, z_{-1}, t_{-1})}$: is the position of a point registered previously on the cadastral records.

$\mathbf{P_0(x_0, y_0, z_0, t_0)}$: is the position of a point currently registered on the cadastral records.

$\mathbf{P_1(x_1, y_1, z_1, t_1)}$ is the position of a point in the future.

x is the easting coordinate

y is the northing coordinate

z is the vertical coordinate

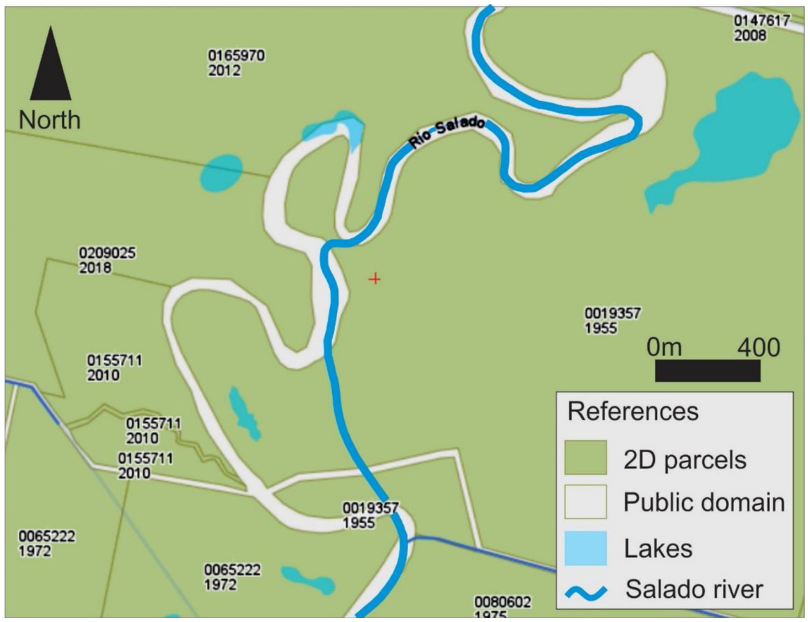


Fig. 2. Cadastral inconsistencies between parcel limits and digitized channels.
Source: Cadastre and Territorial Information Service, Santa Fe, Argentina.

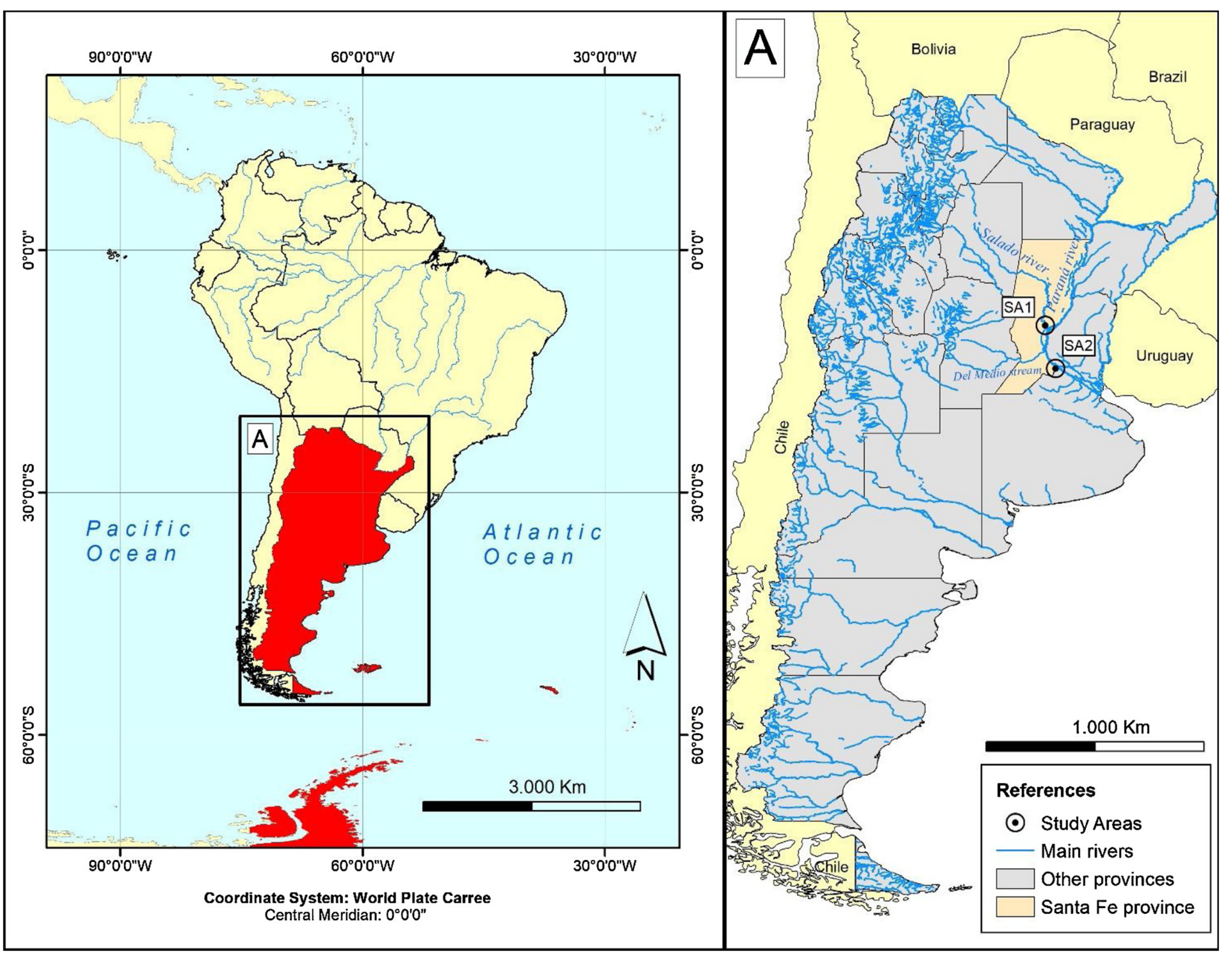


Fig. 3. Location of the study areas SA1 and SA2 in Argentina.

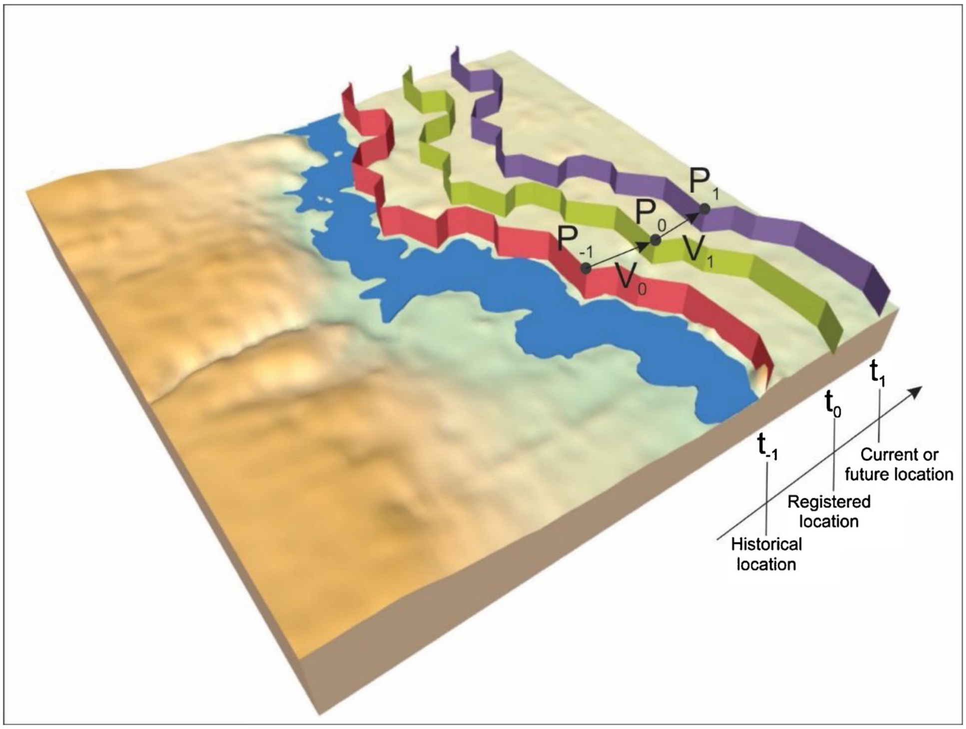


Fig. 4. Displacement of the boundaries along the time (three-dimensional conceptual representation).

t is the date of the data registration on cadastre database.

V_1 identification implies a lot of analysis of multi-layers of information that materialize the mobility of the boundaries like changes in the runoff regime, morphological variations, among others.

To analyze this theory of dynamic boundaries behavior, it was built a strategy to work with primary data, toward to produce maps and information to conclude.

5.2. Data based modeling

The methodology used in this study was inspired by the classic fluvial evaluation based on historical river records. Several authors have proposed different approaches to delimit or demarcate historical positions of the channel (e. g. Rapp & Abbe, 2003), as well as the extent of flooding (Ollero et al., 2015). These approaches are commonly based on the available cartographic information, so, this paper proposes a workflow conceptually similar, but adjusted to the availability of information in the Santa Fe province (Fig. 5). All data were integrated into the 3D QGIS environment. In fact, a database was designed to be easily implemented by the cadastral institutions, using open data and free software for storage, processing and analysis even with basic knowledge in remote sensing, cartography and GIS.

With this methodology and tools, complex limits could be registered with non-expensive software or hardware for government institutions.

The boundaries of the Salado River that define SA1 was mapped by INCOCIV (2013) using polylines for the 2D representation. Since the definition of the limits of Area I has a high degree of coincidence with the definition of RL, there were used as boundaries of this LLO waterbody (Fig. 6, upper left).

On the SA2, only one of the boundaries of Arroyo del Medio stream corresponding to the Santa Fe margin was represented (Fig. 6, lower left). This is because the other margin belongs to the province of Buenos Aires which has a different definition and cadastral registry criteria.

The digital elevation model called "MDE-Ar" elaborated by the National Geographic Institute of Argentina was adopted as a vertical reference to build the 3D LLO in SA1 and SA2. The surface was generated in raster format (Fig. 6, right). The model has 30 m of spatial resolution and 2.46 m of height error (IGN, 2016), referred to the national geoid Geoide-Ar16.

For the analysis of the SA1, the hydrometric height values were taken at the gauge station located on a bridge of the provincial Road 70. The analysis of the SA2 was developed with the hydrometric height values of a gauge station located on "La Emilia" town.

In both cases, the maximum values came from the beginning of the '90 s, after those years, both series presents discontinuity. Graphic 1 was elaborated to show the linear trend of the data in order to analyze annual floods behavior.

Flooded areas in the SA1 were delimited on satellite images taken close to or even during the most important flood peaks (Table 1). The bands compositions that highlight the boundaries between land and water were processed, drawing a polyline in order to have vector information. These polylines allowed to identify the territorial impact of the hydrological variability of the river. Furthermore, geomorphological studies that describe the functional limits of the river and characterize the land uses, were used to reinforce the analysis (Ramonell & Amsler, 2005).

The evolution of the boundaries on SA2 was identified on aerial photos taken in 1996 which were set up in a georeferenced mosaic and compared with a satellite image of 2018. The digitization of stream margins was performed in both moments to calculate rates of displacement.

6. Results

On SA1, the hydrology of the Salado River presents irregularity on the flood levels. On Graphic 1 (left), dashed line shows an increase trend of the maximum hydrometric levels. As regard the hydrometric level corresponding to the current LLO (“calculated RL” in graph 1), it can be seen that in the last 7 years, the maximum annual values have been equal or exceeded the level of ordinary maximum flooding, compared to what happened at the beginning of the period, when the levels appear mostly below and only extraordinary values are above (e.g. flooding in 2003).

Comparing the increasing trend with the stable RL, it is evident the

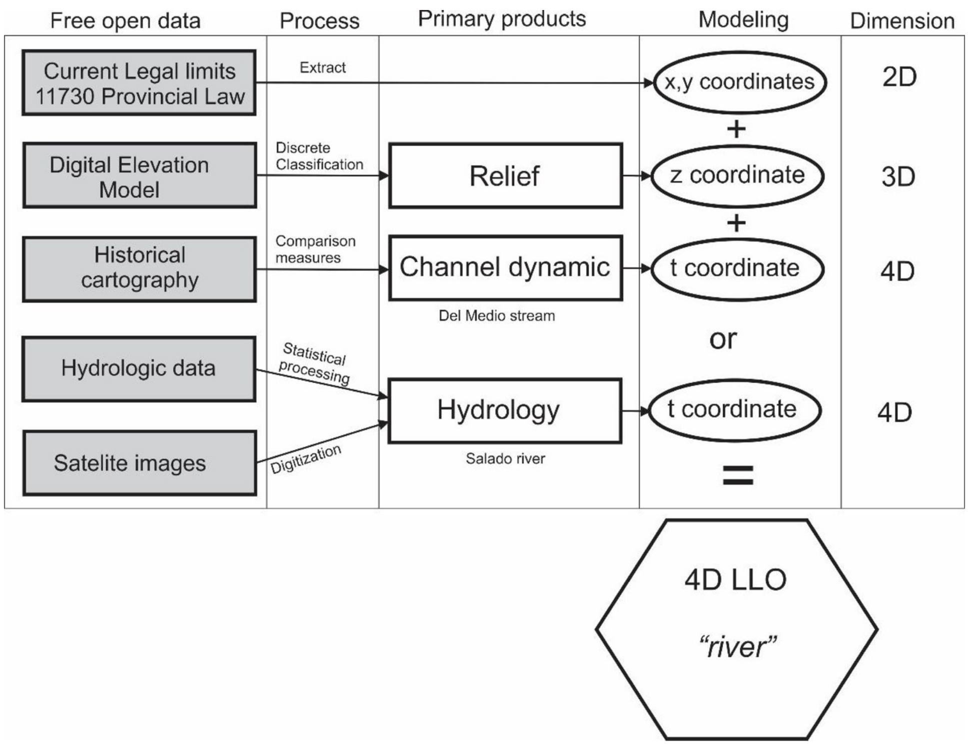


Fig. 5. Data processing workflow to delineate water bodies as 4D LLO.

need to validate the position of the RL over time.

A topographic profile traced perpendicular to the Salado river shows a step relief configuration, demonstrating the existence of fluvial bands according to flood levels. Since the RL is determined over the lowest step, by superimposing the digitalization of the flooded areas at different annual flood peaks, it was possible to observe the trend of these last episodes to reach higher topographic steps of the floodplain.

With the "z" values extracted of the DEM was created a block and the

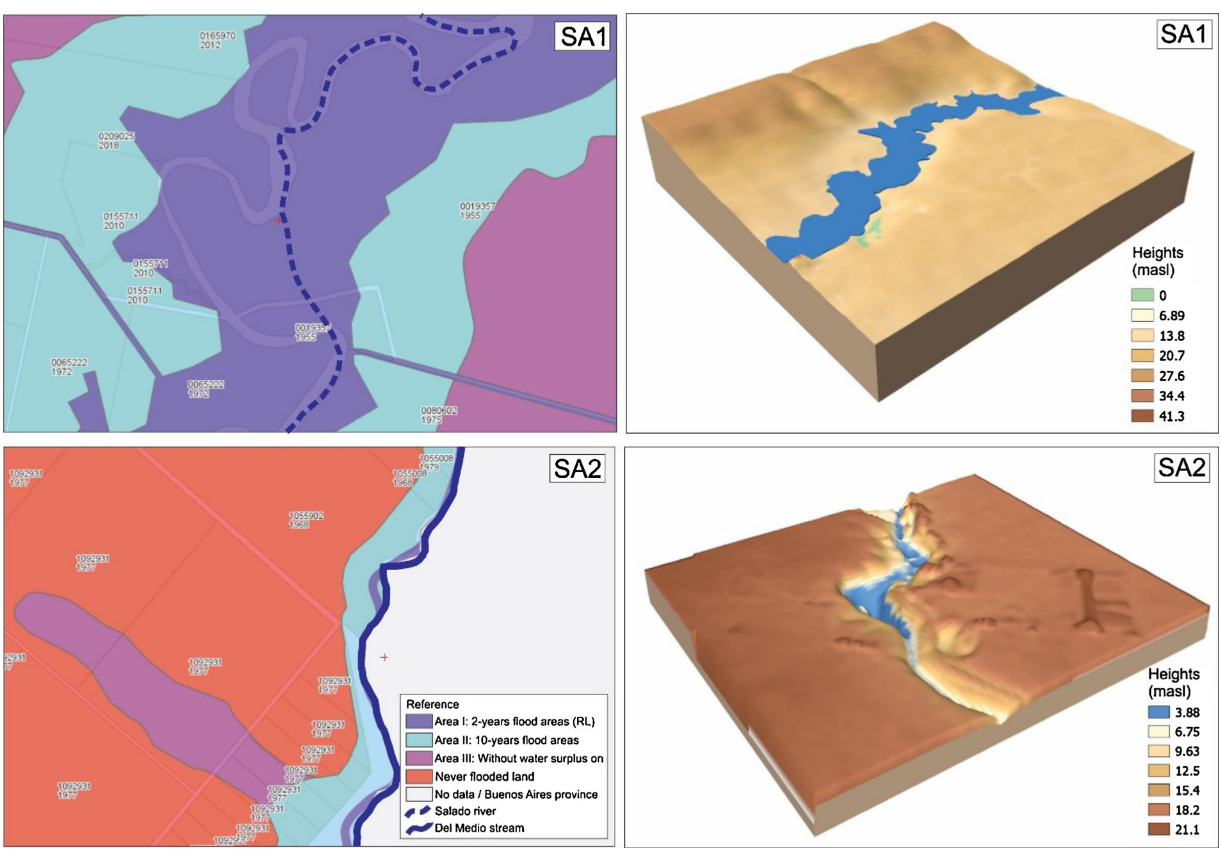
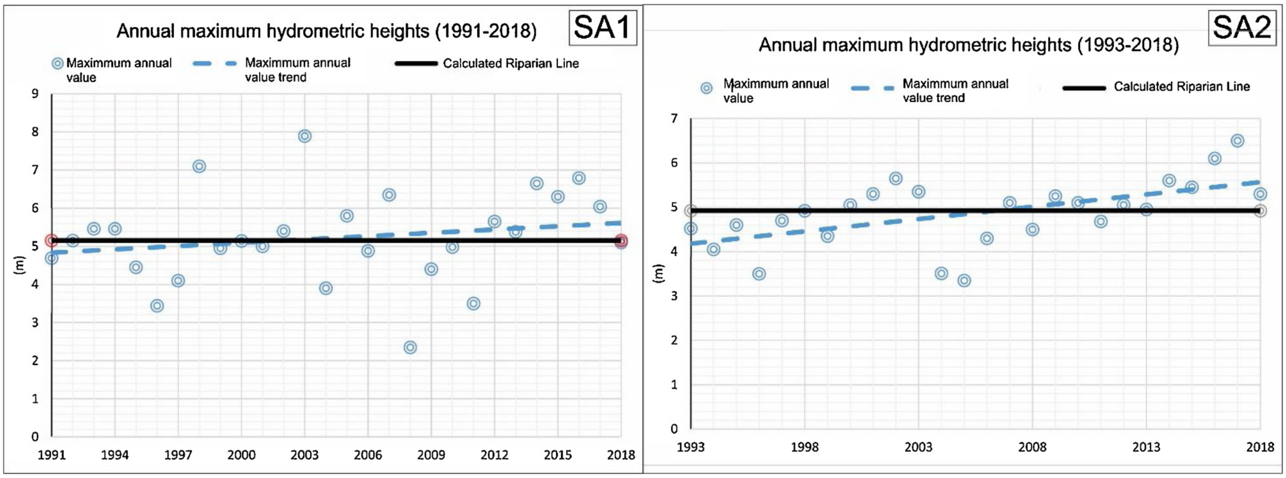


Fig. 6. Upper left: SA1 flood areas. Lower left: SA2 flood areas. Upper right: relief on SA1 DEM. Lower right: relief on SA2.



Graphic 1. Left: SA1 Hydrologic trend. Right: SA2 Hydrologic trend.

limits corresponding to the existing LLO. On the other hand, those that coincide with the last major floods. A three-dimensional belt was obtained which represents the oscillating floods (it can be seen in graph 1).

The "pressures out" process of the current legal limits, imposes the need to update them periodically and monitor them constantly. In the case of the Salado river the temporal variable will be conditioned by the increase in flood levels which should be monitored at least annually (Fig. 7).

On SA2, the Del Medio stream was determined as LLO only to the stream bed, not including the surrounding flood areas because this waterbody does not have floodplain (Fig. 6, lower right). It is an incised channel that has high ravines in the margins that keep the channel confined, although they are reached by some floods.

Considering these ravines as boundaries, as currently, the margins stability is the controller of its temporal validity. So, the study of lateral migration processes (mainly by erosion) defines the limit displacement vector.

For the determination of the temporal coordinate (t) in the Del Medio stream, Egenhofer (2006) proposal was followed, constructing the geolifeline of positions occupied by the margins in the past. The vector of the 4th coordinate can be obtained by processing the different information layers mentioned, considering as the initial position of the geolifeline t_{-1} the one surveyed in 1996 and as t_0 the situation in 2018 (Fig. 8). By calculating recoil rates it is possible to assign magnitudes to the vectors that will determine the position of t_1, assuming that the direction is always perpendicular to the tangent of the origin line.

7. Discussions

Analyzing the spatial expression of the flows in SA1, it is verified that the vector V_1 will have a different orientation and magnitude from the positions originally registered as t_{-1} for each point of the boundary of the water body.

In the Salado River (SA1), the movements tend to be towards higher flood positions, expanding the river boundary and the size of the LLO, affecting the adjacent private parcels. The boundary dynamics respond to behavior related to probability because, each level of flood that is added to the RL calculation increases or decreases the RL position. In other words, in the SA1 the flood dynamics is conditioning the limits in the Salado River, adjusting to the conceptualization of RL in the NC & CC (2015), but in 4D (3D + time).

In the area of the Del Medio stream, the channel erosion processes predominate over the flood dynamics, the boundaries are determined by following the physical movement. Its process is not statistical, it is factual. So, the concept of RL in the NC&CC is not applicable, but technically possible. The law needs to be changed in order to allow the cadastres to register these situations.

Considering that between both cases there are many differences, the conceptual approach [1] can be applied. The result is an entity composed by nodes with four coordinates representing the current and the future position, based on historical information (even though other kinds of information also can be included in order to improve the method). The nodes could be represented as:

$$((2))\ P_0 = x_0,y_0,z_0,T_0 : T_0 = V(r_1,\alpha 1) \text{ for a certain moment}$$

where:

T is de temporal coordinate

$\mathbf{V_1}$ is the movement vector from p0 to p1.

$\mathbf{r_1}$ is the magnitude (distance) of the displacement.

$\boldsymbol{\alpha_1}$ is the angle (spherical direction) of the displacement.

In this context, P_0 becomes a part of a waterbody 4D LLO, influencing the neighboring parcels. In SA1 it is already happening: the restriction resulting from this conceptual approach [2] impacts the land management, the real estate and market agents because of the high degree of correspondence with the risk areas. In fact, the conceptual

Table 1
List of satellite images used.

Satellite images				Hydrological information		
Segment	Platform	Scene date	Date of flood peak	Station	Image water height (meters)	Peak flood height (meters)
Salado river	Landsat 7	1/5/2003	29/4/2003	Prov. Route 70	7,78	7,89
	Landsat 5	18/4/2007	31/3/2007		4,00	6,35
	Landsat 7	13/4/2014			6,65	
	Landsat 8	7/3/2015	6/3/2015		6,15	6,30
		26/4/2016			6,75	

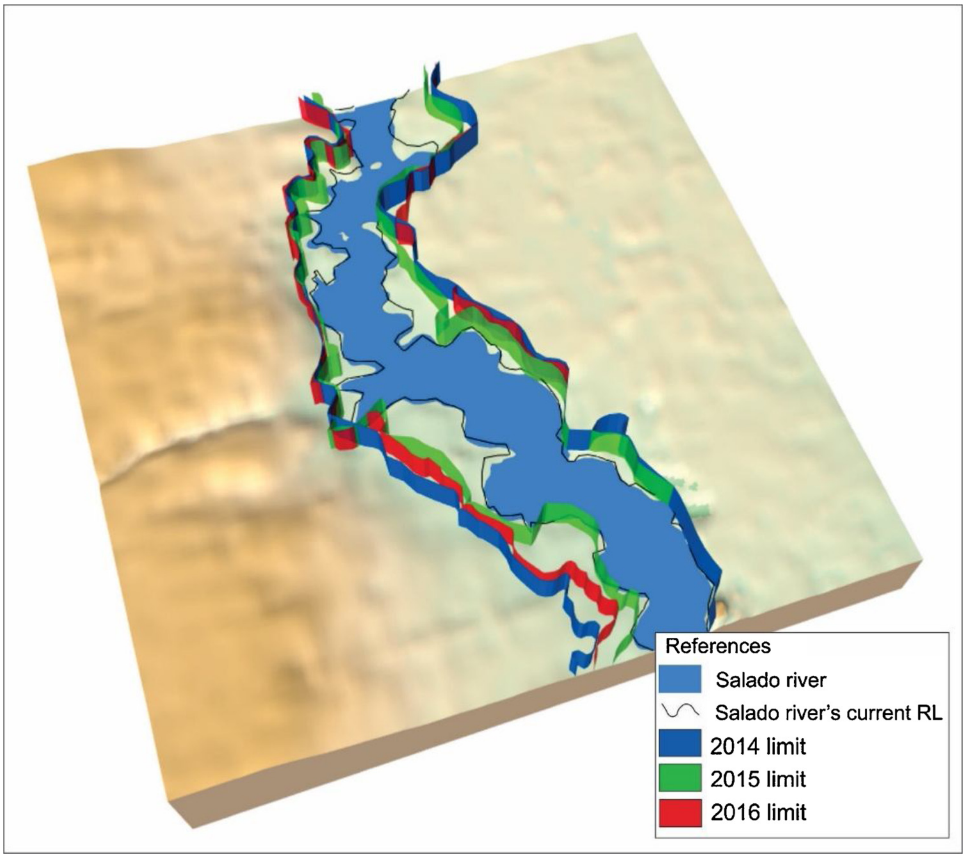


Fig. 7. Representation of the 4D LLO on SA1.

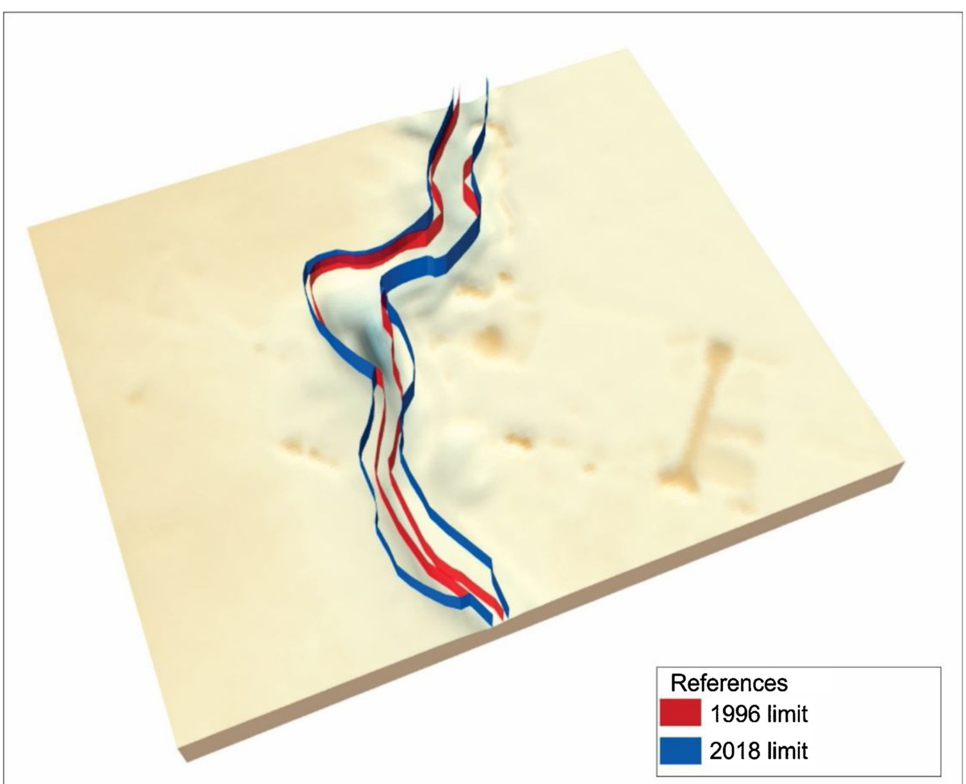
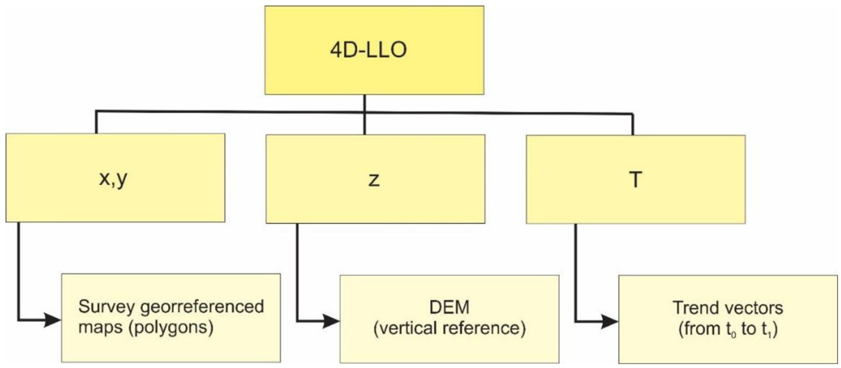


Fig. 8. Representation of the 4D LLO on SA2.



Graphic 2. Conceptual schema for water bodies 4D LLO delimitation and registration on a cadastral structure.

and practical modeling of the LLO to be registered by the cadastres should not be an abstract discussion. However, it is important to mention that for the model be completed, it is necessary to investigate the evolution of topological relationships between nodes. This aspect has not been addressed in this research but it is understood that it plays a fundamental role in definitive modeling.

Local legislation and the governmental interests configure the guiding axes of the cadastral institutions and the aims that they pursue. In this sense, as shown here, LLO can be modeled according to the available technology that allows measurements and representations the LLO based on the landscape behavior. It could turn into a transformation tool or land management representing faithfully.

The specific literature has advanced regarding the incorporation of temporal variability in the cadastral elements. Annex N of the ISO 19.512 (ISO, 2012) suggests the entities registration to track the history and dynamics, while ISO 19.108 (ISO, 2002) defines the terms of reference.

Since the normative reference to IHO S121 (Marine Limits and Boundaries) is based on the LADM principles, included in the revised version of ISO 19152 (Lemmen et al., 2019), it is important to ask whether it is possible to include a specific package for fluvial object modeling in a future revised version, based on, for example, the S-100 standards.

In this context, the 'beginLifespanVersion' and 'endLifespanVersion' attributes can be a first approach to model the trend vector in a VersionedObject class for a LADM-based LLO. The results of this paper show how to simply could be to register the two moments that, together, represent a pathway of a 4D LLO

If the existence of dynamic LLO is recognized, the registration models should aim to describe them, but also to understand them in a useful sense for land planning, for the regulation generation, and not as a mere file of entities. The theoretical framework of the Latin American Multipurpose Cadastre model (Erba & Piumetto, 2016) allows those approaches, but the current situation of the cadastres along the region has not yet been adapted to the territorial needs of the society.

The methods to implement these models exceed the scope of this work, but the state of the art of multi-temporal GIS confirms that this task can be solved through a Geospatial Event Model (Siabato et al., 2018), assuming, in this case, the fluvial limits like objects and floods or erosion processes like events.

8. Conclusions and recommendations

Based on the analysis of two different cases, it was observed that the LLO are dynamic and sometimes strongly conditioned by how they are legally and technically defined. The conceptualization of the cadastral model of water bodies fits best in the 3D LLO definition. So, water bodies should be considered as LLO that should be recorded not as mere polygons in 2D, but as 3D bodies.

When the dynamics of the object is manifested on its 3D cadastral coordinates, the multitemporal registration (4D) is relevant because it allows to administrate the variability. Thus, a 4D cadastre exceeds a historical registry system and become a land management tool in which not only the parcels and LLO boundaries are taken into account, but also their consequences in the legal and economic aspects.

For cases like the SA1, the proposed theoretic mathematical model allows gradually incorporate values of areas of annual floods updating the statistics that define the fluvial limit for a certain moment (in the case study, the limits defined by law 11,730). Meanwhile, for situations like the SA2, it can be designed a tool based on an erosion rate.

In both cases, by establishing a threshold or tolerance for change, time-based automated monitoring and limits updating can be established. Considering Figs. 7 and 8 and the results of this research, it is possible to conclude that there is a way to find an algorithm to automatize and describe the movement and the deformation of the dynamic boundaries with free and basic information and tools. In this context, it is also possible to conclude that waterbodies can be described as 4D LLO for registration following the conceptual schema presented in Graphic 2 .

The 4D-LLO modeling is an open and necessary discussion that requires the analysis of the general theory of the cadastre, its meaning and purpose, as well as the approach of technological advances and multidisciplinary studies. The Time plays an important role as the fourth dimension in cadastral systems. In the fluvial environment, most activities can co-exist in time and space and can move over time and space. Therefore, the registration of the fourth dimension will capture the temporary nature of many particular rights.

Even when the LADM is still arising in Latin America, its multipurpose character creates conditions to push up the model along the region. In November 2018, during the International Workshop LALA LADM, in Quito, Ecuador, Latin America Land Administration Network - LALAN was established. Representatives from seven Latin American countries were present at the workshop. The network was established with the objectives of perform activities that can support capacity development and sharing knowledge in both fit-for-purpose and responsible land administration within the Latin America Land Administration Network of education institutions (Todorovski et al., 2019).

This recent movement creates a new opportunity for the region move forward on the LADM implementation, in which the Fluvial Cadastre would have its own space. Marine Cadastre and the Fluvial Cadastre renew the opportunities to consolidate the international standard.

CRediT authorship contribution statement

Ramiro Alberdi: Investigation, Conceptualization, Methodology, Data curation, Writing - original draft. **Diego A. Erba:** Project administration, Conceptualization, Supervision, Validation, Writing - review & editing.

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