Modeling Legal Land Object for water bodies in the context of n-dimensional cadaster

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Key words: 4D Cadastre, Legal Land Objects, Mobile bounds.

SUMMARY

In the legal systems of many countries the delimitation of waterbodies is a problem that has led to different approaches. In general, its multidimensional character is recognized when delimited by the level at which the water arrives and by the morpho-hydrological variability of these elements of the landscape. In Argentina, publicly owned waterbodies have legal boundaries established by the "the maximum ordinary floods average level " (Riparian Line). The waterbodies thus delimited define a spatial unit subjected to alterations in the location or composition of those bounds, revealing the multitemporal question as a significant aspect. The variability of the fluvial bounds is recognized in the Argentine legal corpus, however, for the cadastral institutions it has always been difficult to register and it is a problem little treated in the international scientific literature. It is necessary to address the registration of waterbodies as Legal Land Objects (LLO) in four dimensions: 3D + time (4D). The general objective of this paper is to evaluate the rivers as LLO in the 4D Cadastre. The discussions in this paper analyze the need to implement multidimensional registers, considering the current legal and technical framework of the Argentine cadastre, reflecting on the fact that an adequate modeling of legal land multidimensional objects becomes a land management tool. The modeling of 4D-LLO is an open discussion that needs the analysis of the general theory of the cadastre, its meaning and purpose, as well as the approach of technological advances and multidisciplinary study approaches.

RESUMEN

En los sistemas jurídicos de muchos países la delimitación de los cuerpos de agua es un problema que puede ser analizado bajo distintos enfoques. En general, se reconoce su carácter multidimensional por su relación con la altura a la que llega el agua y por la variabilidad morfo-hidrológica de los elementos del paisaje. En Argentina, los cuerpos de agua de propiedad pública poseen límites jurídicos establecidos por el “promedio de las máximas crecidas ordinarias” (Línea de Ribera). Estos cuerpos así delimitados definen una unidad espacial cuyos límites están sometidos a alteraciones en la posición o composición, dando gran relevancia a la cuestión multitemporal. La variabilidad de los límites fluviales está reconocida en el marco jurídico argentino, sin embargo, para las instituciones catastrales siempre ha sido difícil registrarlo, siendo esta problemática poco tratada en la bibliografía internacional. En este contexto es necesario estudiar como registrar cuerpos de agua como Objetos Territoriales Legales (OTL) en cuatro dimensiones: 3D+tiempo (4D) siendo el objetivo general de este trabajo evaluar a los ríos como OTL dentro de un Catastro 4D. Los

análisis desarrollados permiten concluir sobre que es necesario modelar los OTL multidimensionales e implementar registros multidimensionales en Argentina, atendiendo el marco jurídico vigente, construyendo así una herramienta de gestión territorial. La modelación de OTL 4D es una discusión abierta que necesita del análisis de la teoría general del catastro, su sentido y finalidad, como así también el abordaje de los avances tecnológicos y los enfoques de estudio multidisciplinares.

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1. INTRODUCTION

In the legal systems of many countries the delimitation of waterbodies is a problem that has led to different approaches. In general, its multidimensional character is recognized when delimited by the level at which the water arrives and by the morpho-hydrological variability of these elements of the landscape. In Argentina, publicly owned waterbodies have legal boundaries established by the level (referred to a surface) that reaches the "the maximum ordinary floods average level". These boundaries, which in the legal lexical are called "riparian lines" (according to the Civil Code and National Constitution, 2015), contain a volume that has the characteristics of a Legal Land Object (LLO): that is, an object whose limits originate in a legal cause (FIG, 1998). The waterbodies thus delimited fit into the definition of 3D parcel since, according to Van Oosterom (2013), a 3D parcel is defined as a spatial unit in which one or more homogeneous rights, responsibilities or restrictions (RRR) are associated, and included in the cadastre. When alterations occur in the position or composition of those limits over time, the multi-temporal question comes into play as a significant aspect.

The riparian line and the restriction associated with it, the towpath, are homogeneous and unique RRR examples throughout the development of a navigable rivers or lakes. This aspect conducts to visualize the rivers inside the riparian line as three-dimensional parcels. As a consequence, considering the framework of the multi-purpose cadastre (Loch and Erba, 2007), waterbodies are presented as Legal Land Object (LLO) recordable and not as mere polygons that represent the projection of a terrain element.

Currently, this boundary is determined fundamentally under hydrological criteria, which are based on statistical calculation methodologies of registered hydrometric levels, which are permeable to changes in the parameters of river systems (Alberdi and Erba, 2016). These alterations are manifested in increases or decreases in water levels, pushing or contracting the lateral boundaries of the waterbodies. In turn, the morpho-dynamics of waterbodies can involve significant location changes of the boundaries. In this way, it is necessary to address the registration of rivers and lakes as territorial objects in four dimensions: 3D + time (4D).

The variability of the fluvial boundaries, in addition, is recognized in the Argentine legal framework (Alberdi & Erba, 2016). However, for the cadastral institutions, it has always been difficult to register. Added to this, the cadastral registration of water bodies is a problem that has had little approach in the international scientific literature, highlighting the work on groundwater of Ghawana et al. (2010) and the promising modeling of Kitsakis & Papageorgaki (2017).

For all the above, the general objective of this paper is to evaluate the rivers as LLO in a 4D Cadastre context. One of the benefits that should be included in the 4D Cadastre is the prospect to record, not only the history of an LLO (Van Oosterom, 2006), but also the evolution of its boundaries. With it, the 4D Cadastre becomes a tool for land management. In this context, the particular objective of this paper is to contribute to the conceptual discussion for the LLO modeling for waterbodies in the Argentine legal context.

The discussions in this paper address the need to implement multidimensional registers, considering the current legal and technical framework of the Argentine cadastre, reflecting on the fact that an adequate modeling of multidimensional LLO becomes a public domain land management tool.

2. CONSIDERATIONS FOR THE 4D LEGAL LAND OBJECT

First of all, it is important to remember that an LLO is any "portion of territory in which homogeneous legal conditions exist within its boundaries" (FIG, 1998). When these homogeneous conditions have spatial delimitations (for example, the property right acquired for a flat of an apartment building), a three-dimensional LLO is configured. Consequently, following Alberdi & Erba (2016), a 4D parcel can be defined as dynamic LLO in space and time, by its legal conception. This concept can be extended to all LLO, particularly involving those which:

- naturally change their essential elements over time, modifying or even disappearing (e. g., adjacent parcels to the mobile riverbeds), and
- modifications were stipulated based on time lapses (e. g., superficial rights).

In the specific literature, much progress has been made in the definition of a 4D cadastre without reaching, however, final conclusions yet. At the moment, it can be understood as a broad concept that includes not only dynamics parcels, but also the appearance/extinction of restrictions, changes in the ownership of rights, just to mention some aspects of the LLO. It is a term in discussion that necessarily involves the time (t) variable in the multiple aspects that affect land order derived from the legal causes that origin it (Alberdi & Erba, 2016).
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" (Van Oosterom et al., 2006) is the only one that covers the dynamic boundaries. In this sense, the author points out that in parcels where one of the boundaries is related to natural physical events (such as river channels), there is a geospatial lifeline. In theoretical terms, this concept includes the recording of all the surveyed location reached by the object between two moments (Van Oosterom et al, 2006, citing Egenhofer, 2006), that is, a cadastral history. This register of locations is widely used in numerous and diverse disciplines: Mark (1998) cites as an example the search for movement patterns in animals.

This theorization is completed with the differentiation between linear times and branched times (Sass, 2013). Linear time are composed by a unique sequence of locations, while the branched time are structured so that the element can take a new position among several possible, after each location. The modeling of the temporal coordinates, therefore, must synthesize in some way that cadastral history, representing the tendency of the limits of the parcel movement (Figure 1).

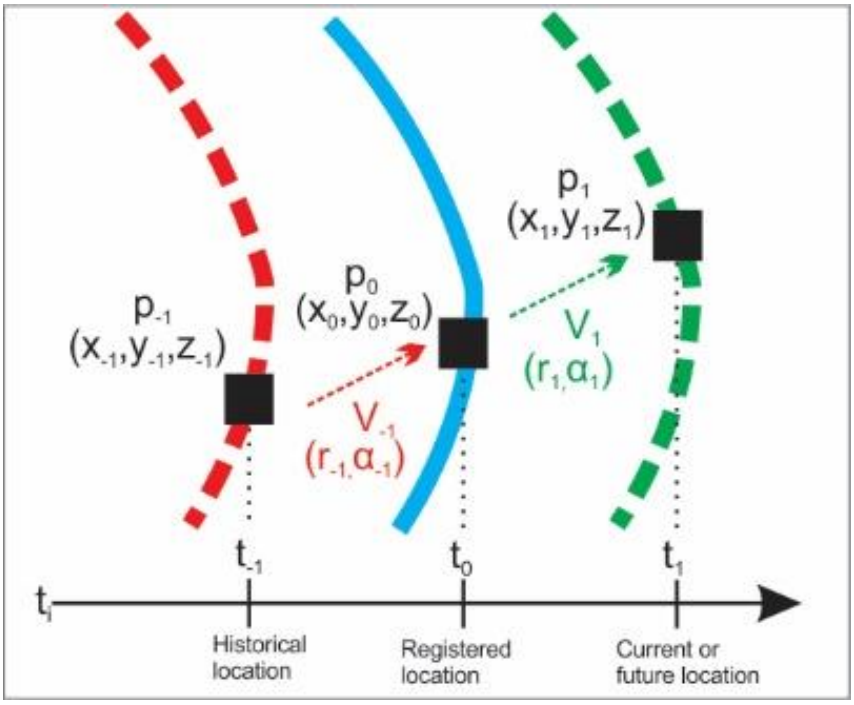

Figure 1. Mathematical modeling graphic interpretation of ideal linear time, applied to dynamic elements of the landscape

In ideal mathematical terms, the cadastral modeling must find a function f(p) that defines the vector V1 based on precedent records:

$$f(x_{-1},y_{-1},z_{-1},t_{-1})=V_1(r,\alpha) : (x_0,y_0,z_0,t_0) \bullet V_1(r,\alpha) = (x_1,y_1,z_1,t_1) \quad (1)$$

where: t refers to the moment of the data registration, and not to the temporal coordinate that is discussed below, which will be a function of V. On the other hand, the position p1 is illustrative and does not necessarily imply that between p0 and p1 there must be a topological type match (same number of segments, points, nodes, etc.). The way in which the cadastres record this variability, will depend on the objectives for which they are conceived, but it is understood that between the branched and the linear time there is a continuum in which a modeling will be more effective the closer the linear time is. When it succeeds in reducing to the minimum possible the uncertainty about future locations of a mobile element. So, for natural elements, it is well known that the only record of previous positions is not enough to model future locations. It requires additional information and interpretations that are not always can be modelled. The following topic presents the current situation of the Argentine cadastre and then discusses the possibilities of advancing in the previous postulates.

3. RIVERS REGISTRATION IN ARGENTINA

Formerly from the Roman law the legal notion on the rivers was crossed by the question of the common benefit. In this context -in which surface waters were fundamental for the development of the towns as a means of transport, supply for consumption and irrigation, and, at the same time, a latent risk for the populations located in their banks- they were included within the public domain. Since then, the hydrological and geomorphological dynamics of water bodies and in particular of rivers, with their flood and dryness regimes, which imply advantages and disadvantages for settlements, have been recognized. The limitation of the public domain of waters, due to these characteristics, has always been an under discussion matter that currently takes into account the hydrological statistics of the river, considering the boundary of the channel is the portion of land which is regularly or frequently flooded, in a "ordinary" form.

In the General Part of the CCyCN are mentioned as public property -among others- the waters that run through natural channels, delimited by the Riparian Line (RL) defined by the level that reach "the maximum ordinary floods average level "(Art. 235). It is the legal cause that limits the courses and natural waterbodies, compared to the real estate of the private domain. Once the RL is determined, the owner of a riparian parcel will know how far it reaches its property right on the side that borders the watercourse (Figure 2).

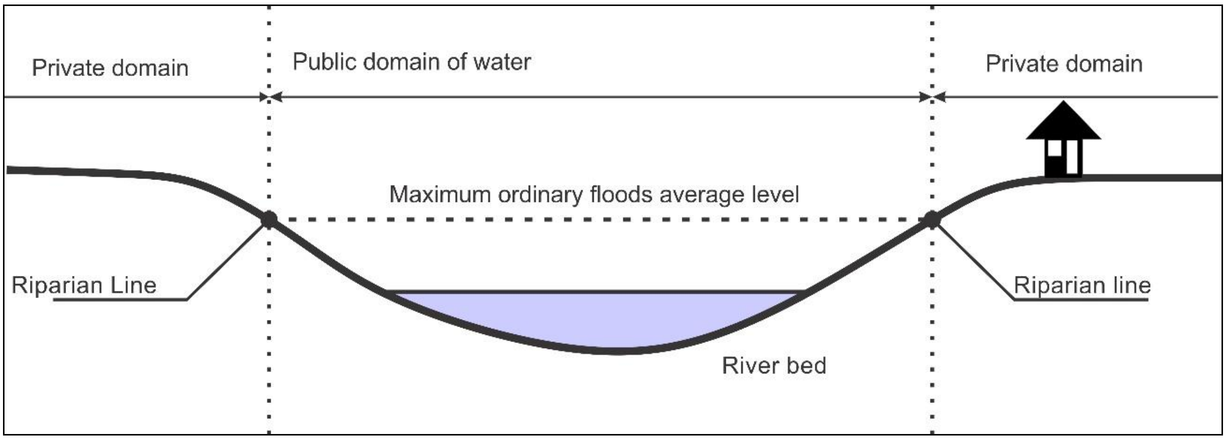

Figure 2. Location of the Riparian Line in relation to private and public domains

From the moment that it is presented as an average of certain levels previously occurred, the time variable is introduced in the definition. Many technical works have associated a recurrence of 2 years with the idea of ordinary floods in order to generate the RL based on mathematical hydrological models (e.g.: Hec-Ras). There are also methodologies for statistical analysis of hydrometric records at specific sites, especially when RL were determined at times when the models did not yet exist or were not easily accessible. In any case, the work was always based on the statistical treatment of a series of data not always available. In cases where it is determined, it has been generated for a specific moment and with the available data until then, constituting a fixed bound in time, related to hydrological levels or mathematical models. In many hydrologic studies it has been shown that rivers can modify their regimes to a wetter or drier one, so that the RL determined above would be over or underestimated. This situation is beginning to be understood, so that, for the province of

Santa Fe, the recently approved Provincial Water Law recognizes its art. 126 that "the Riparian Line is essentially mutable".

These deficiencies in the structural understanding of the riparian boundary have their cadastral consequences. In Argentina, the RL is not registered as a parcel, but as an element of the landscape. The boundary is fixed by the measurement survey that is made of the parcel which in its confection it must adopt the RL that has been calculated (in the few cases that exist). Thus, the "river" LLO is constituted by the succession of parcels bordering on the RL. In some provinces, the situation is more complex. In Santa Fe, for example, the river has been registered as a linear element of the landscape at a given time under a specific hydrological condition, which, together with the arbitrary updating of parcels by surveys, has generated conflicts in the database (Figure 3). Added to this, from the perspective of risk mitigation, the Province State incorporated its own legal ordering based on domain restrictions (Figure 4). Thus, it establishes that the natural channels are included in Area I, whose 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 LLO are the ones that were used in this paper for the critical analysis and the formulation of proposals of modeling of RL as 4D-LLO.

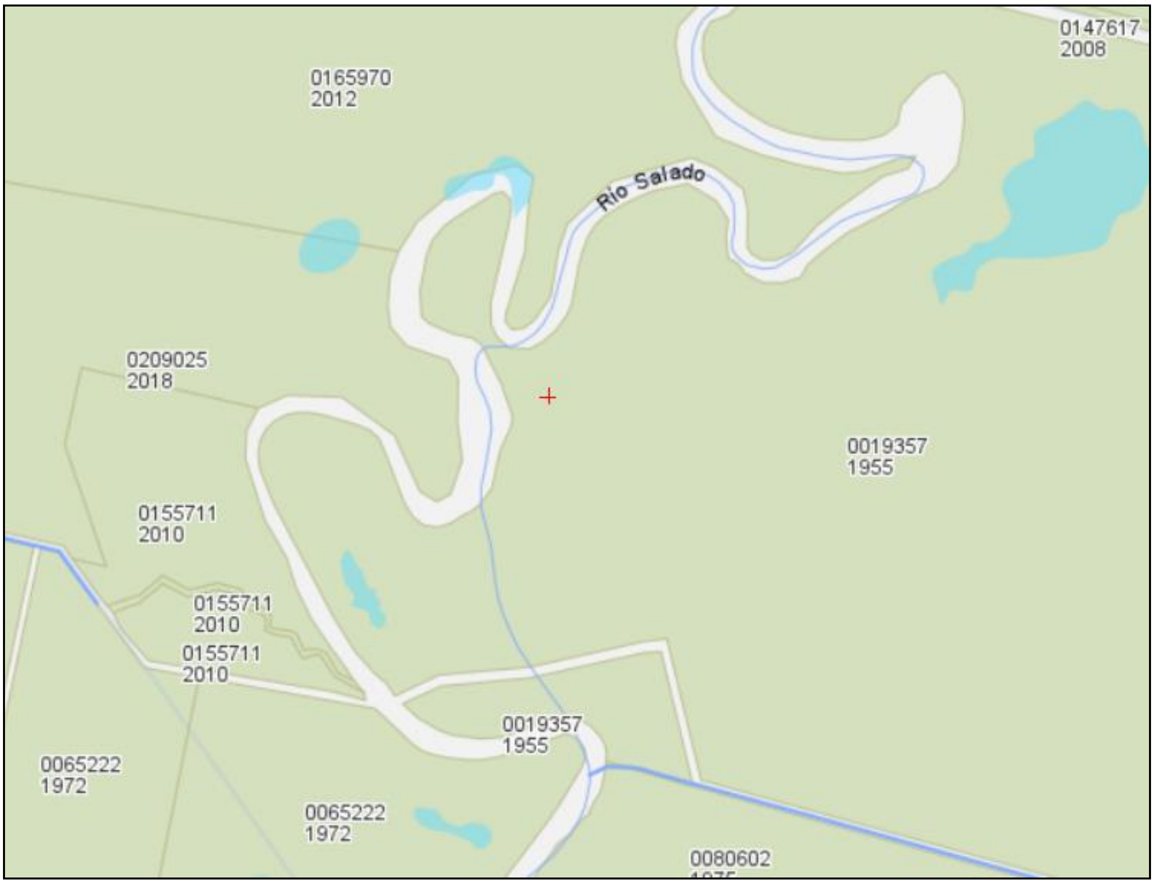

Figure 3. Cadastral inconsistencies between parcel boundaries and digitized channels. Source: Cadastre and Territorial Information Service, Santa Fe, Argentina

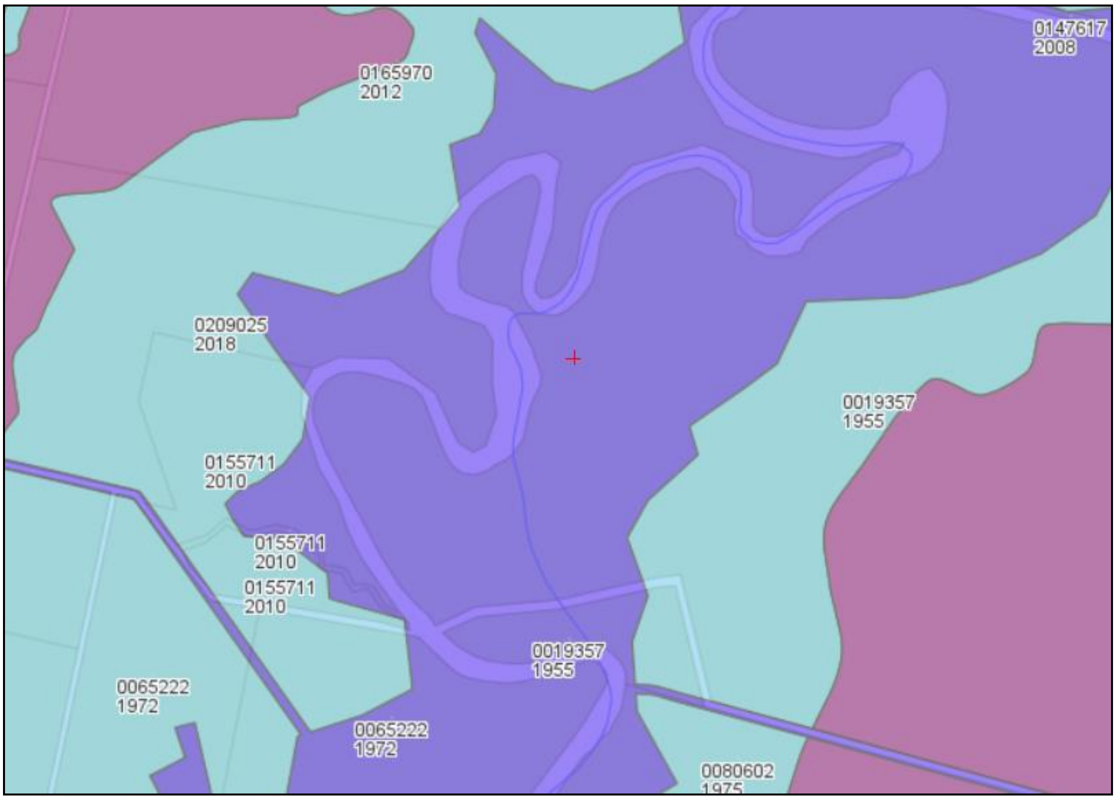

Figure 4. Cartographic representation of the Provincial Law Nº 11.730. In dark blue, the 2-years flood areas, in light blue, the10-years flood areas and in violet, the area with no water surplus on the soil. Source: Cadastre and Territorial Information Service, Santa Fe, Argentina

4. MATERIALS AND METHODS

A segment of the Salado River (Santa Fe province, Argentina) was selected as a study area given the register existence, the accessibility for field works, and the flat relieve where the boundaries of the rivers are more sensitive. The cadastral layer of fluvial limits area I, elaborated by INCOCIV (2013) was used as a registered river polygon, due to the similarity with the definition of RL. This vector layer was crossed with "MDE-Ar" elevation surfaces (IGN, 2016) to add the z coordinate to the object and thus build the three-dimensional LLO. The vector V1 was sought through the analysis of different layers of information that materialize the mobility of the boundaries, both by changes in the runoff regime (greater or lesser flow) and by morphological variations resulting from the channel natural dynamics. The information layers considered are comprised of: a) the geomorphological map of the area (Ramonell & Amsler, 2005), the hydrometric records of the stations near the stretch and the satellite images of the most important river floods, for the study of bounds' hydrological stability; b) aerial photographs of the year 1983 as a contrast to current satellite images for the evaluation of land use changes; and finally c), National Geographic Institute (IGN, in Spanish) topographic maps based on surveys of the 1940s, base for the morphometric position changes of the channel analysis. All the material was integrated into a GIS on which an entity constituted by the 3 spatial variables was obtained, together with the 4th dimension as a secondary characteristic whose cadastral modeling is deeply analyzed in the discussions section. Figure 5 shows the information layers used and the maps obtained.

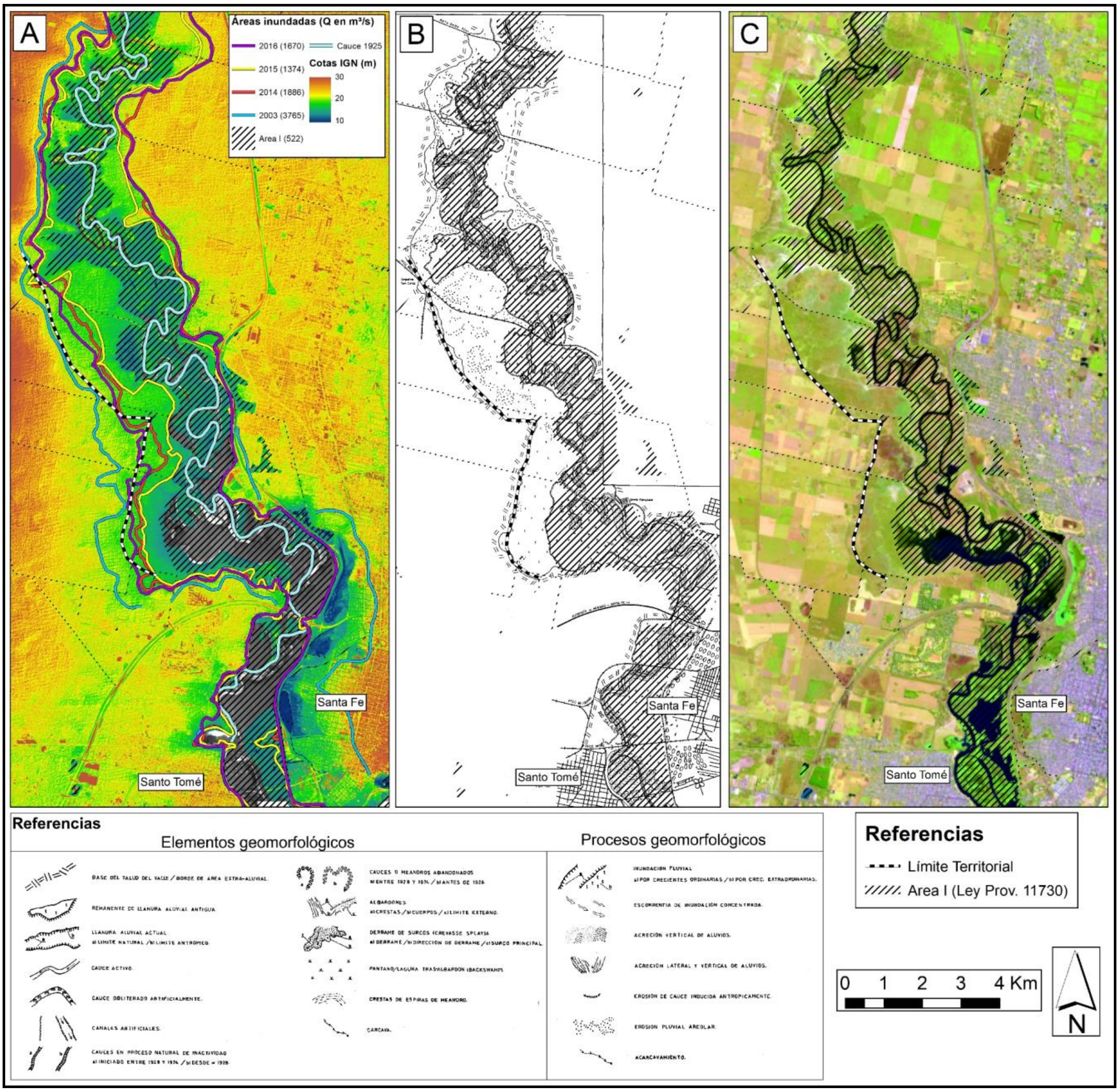

Figure 5. Base information maps used in the GIS. A) Scope of the floods of the Salado River over the MDE-Ar; B) Geomorphological map (Ramonell y Amsler, 2005); C) Landsat 8 image RGB band composition

5. 3D AND 4D-LLO

The proposals for modeling three-dimensional cadastral objects are abundant and well documented. However, as the aim of this paper is to deepen discussions about the temporal coordinate, for the spatial coordinate a simple model was considered based on the simple incorporation of a height level value referred to a known and controlled surface level. For this, the MDE-Ar was used, a digital elevation model corrected with the national altimetric network. Although the discussion on its relevance in absolute terms for the cadastral registry is pending matter, the homogeneity in the quality and precision of the data allow its use in this modeling exercise.

For the temporal coordinate (t) the Egenhofer proposal was followed, 2006, constructing the geolifeline of positions occupied by the LLO prior to the present. The vector of the 4th coordinate was obtained from the processing of the different information layers mentioned, considering the layer obtanied by INCOCIV (2013) as initial position t-1 of the geolifeline. First, if we consider the hydrograph of maximum river flow values in the area, we observe that the regime trend is to increase flows (Figure 6), which forces us to consider that what has been obtained some time may be lost validity in the future.

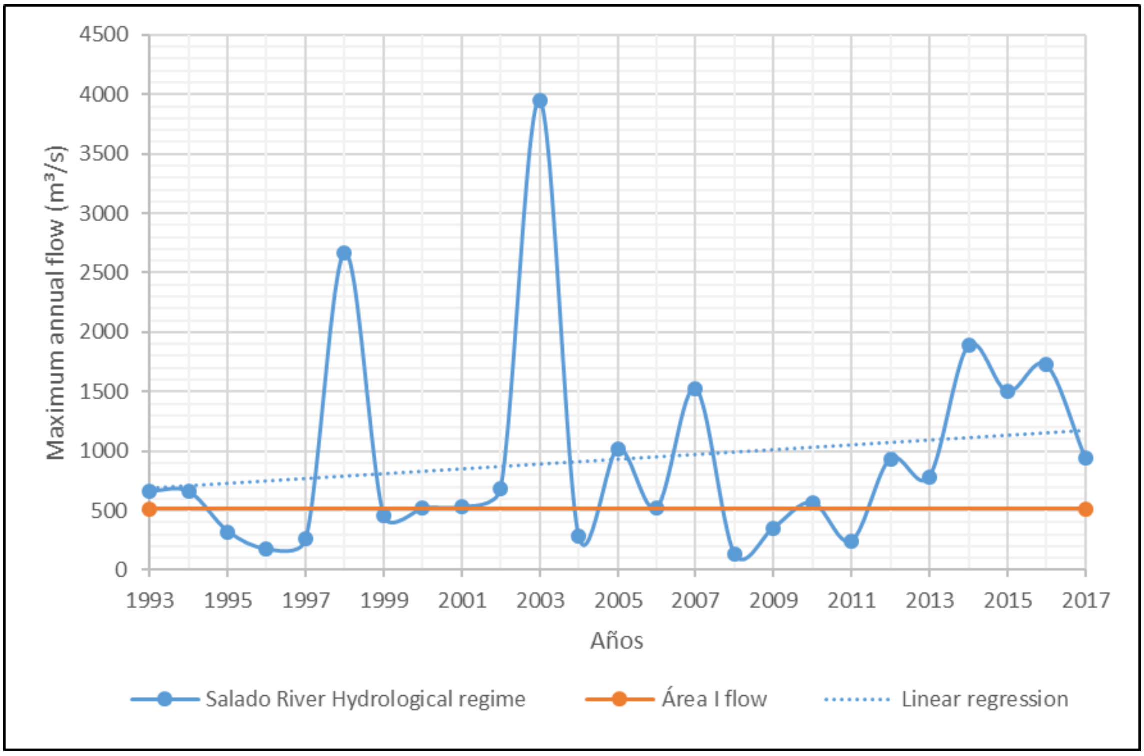

Figure 6. Maximum annual flows of the Salado River in 25 years (1993-2017)

Specifically, what emerges from the graph of the figure and art. 126 of the Provincial Water Law of Santa Fe is that at least the hydrological dynamics must be translated into cadastres. When the spatial expression of some of the indicated flows is analyzed, it is verified that the vector V1 will have orientation and magnitude from the t-1 towards the outermost flood polygons, "pushing" the boundary of the river and affecting the bordering parcels. The mathematical processing to achieve a three-dimensional polygonal that synthesizes this trend exceeds the scope of this work, but the state of the art of the multitemporal GIS confirms this task can be solved through a Geospatial Event Model (Siabato et al., 2018), assuming in this case the fluvial limits as the objects and the floods as the events. In addition, the geomorphological map confirms that the possibly flooded area is similar to the one shown by the flood reach lines, which adds weight to the expansive tendency of the limit. If land uses are analyzed, item C of Figure 5 shows that the rural use of the parcels is limited coincidentally with the two previous maps, adding data to the expiration of the bound defined until 2013.

The result of the model is an entity whose nodes are composed of four coordinates that represent the current position and the future trend (Figure 7), although historical information could also be included. Mathematically, it is described as:

$$P_0 = x_0,y_0,z_0,t_0 : t_0 = V(r_1,\alpha_1) \text{ for specific time (2)}$$

where r is the magnitude and α the displacement direction. In this way, P0 becomes an LLO with influence on the neighboring parcels, as occurs in the facts recognized by legislation, by land managers and by real estate agents. In fact, the affectation resulting from this modeling has a high degree of correspondence with what the specialists mapped as a flooded area.

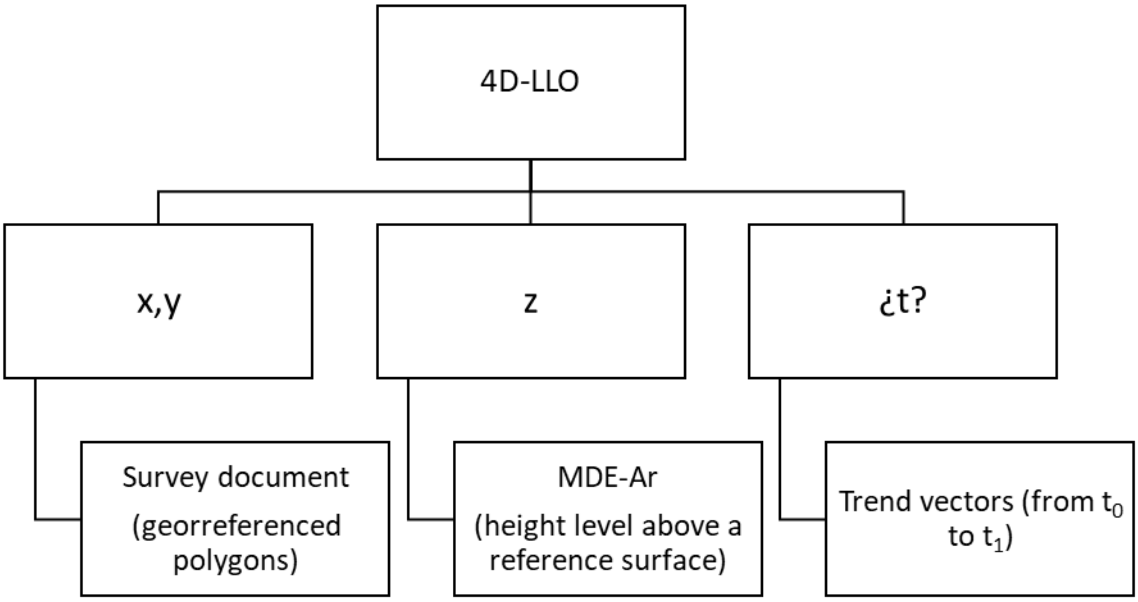

Figure 7- Conceptual schema of an 4D-LLO component that can be registered in the Argentine legal cadastral structure

6. DISCUSSIONS

The conceptual and practical modeling of the entities to be registered by the cadastres should not be an abstract discussion. The local legislations and the governmental interests configure the guiding axes of the cadastral institutions and the aims that they pursue. In this sense, the definition of LLO can be modeled according to the available technology that allows to measure and represent it, but if it does not behave in turn as a transformation tool or land management, it can become a great technological deployment with little use. In Argentina - and particularly among surveyor engineers- there are many discussions about the mobility or expiration of the limits, but the cadastral inconsistencies that some LLO show, verify that cadastres are not static (or at least do not depend only on the parcel dynamics).

The specific literature has advanced in relation to the incorporation of temporal variability in the cadastral elements. In fact, in Annex N of the International Standard ISO 19512, possible approaches are suggested for the historical and dynamic issue of the registered entities, for which there is already another ISO Standard that defines the terms of reference (ISO 19108). 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 Multipurpose Cadastre is a context that allows those approaches, but the current situation of Latin American cadastres has not yet been adapted to the territorial needs of its population.

7. CONCLUSIONS

It was observed that the LLO are dynamic and, in some cases, strongly conditioned by how they are legally and technically defined. When the dynamics of the object is manifested in its spatial cadastral elements -that is, in its x, y, z coordinates- the multitemporal registration is relevant because it allows to administrate the variability. The 4D cadastre exceeds a historical registry system and become a land management tool, in which not only the parcels boundaries are taken into account, but also their consequences in the legal and economic aspects.

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.

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BIOGRAPHICAL NOTES

Ramiro Alberdi is graduated in Surveying Engineering from National University of Litoral (Santa Fe, Argentina) and he currently researches on river legal boundaries and 3D/4D Cadastres, especially in the Paraná River context.

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