Groundwater Management in Land Administration: A Spatio-temporal Perspective

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SUMMARY

Although the use of land and water is intertwined, specifics for groundwater management are not effectively dealt with in the laws and other institutional mechanisms related to land. Provisions for groundwater aspects in land management are there, but with a focus on the land itself. Land rights and restrictions are more or less static, lacking enough flexibility to incorporate the relatively short interval spatio-temporal dynamics of groundwater resources in the land management and regulation mechanisms. This leads to a gap between the scientific inputs and policy-decision making.

The paper suggests the adaptation of a spatial information science based approach to bridge the gap between the technical and administrative aspects of groundwater management. The land administration domain model (LADM) provides a basic set of elements capable of supporting the inclusion of basic groundwater modeling elements into land administration, making it possible to create a support system for the management of land and water. For this purpose, spatial and temporal dimensions under the legal-administrative and spatial unit components of the standard LADM model are reviewed.

The paper shows that the advancement of spatial technologies is capable of providing solutions for global issues such as groundwater resource management. As a first step towards implementation of these technologies, it is essential to include spatio-temporal dynamics properly in the standard data models. Increased knowledge of the behaviour of groundwater resources, supported by a technical system built on a land administration counterpart, could help improve greater sustainability in the use of such resources. Considering the specific arrangements of rights, parties and spatial units this could, if desired, also provide the base for a regulated private market in groundwater assets. Further research will be needed to fully operationalize and implement such data models, which ultimately could produce outputs at case study level which can help to formulate policies regarding natural resources more on the basis of technical inputs.

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1. INTRODUCTION

The characteristic dynamical aspects of groundwater management are not effectively dealt within the laws and other institutional mechanisms related to land. In most of the countries land and water rights are considered together. Provisions for groundwater aspects in land management are there but with a focus on the land itself. Land rights and constraints are more or less static lacking enough flexibility to incorporate the relatively short interval spatio-temporal dynamics of groundwater resources in the land management and regulation mechanisms. Almost absent, and only present in a suggestive manner, in the laws and regulations for land, and thus water, this creates a gap between the scientific inputs and policy-decision making.

The objective of this paper is to highlight the need of adopting a spatial science based approach to bridge the gap between the technical and administrative aspects of groundwater management considering the current scenario of the global water crisis and fast depleting groundwater resources. The land administration domain model (LADM) provides a basic set of elements capable of supporting the inclusion of groundwater dynamics into land administration, making it possible to create a support system for the management of land and water. For this purpose, spatial and temporal dimensions under the legal-administrative and spatial unit components of the standard LADM model are reviewed.

This paper is structured as follows: background (including groundwater resources and groundwater rights) in section 2; examples of groundwater regulations in section 3; spatial information science approach (including description of relevant concepts and models; and an indication how to bridge the gap between groundwater and land administration models) in section 4; use cases and instance level diagrams in section 5 and finally in section 6 conclusions and recommendations.

2. BACKGROUND

In the present era, the rapid development of civilization, with industrial growth in all the sectors, has dramatically increased the global demand of all kinds of resources. This unprecedented growth at global scale has put enormous pressure on the natural resources worldwide. To tackle this pressure, it requires a proper management and protection of these resources so that current economic growth should not lead to an era in the future of rapid decline in the development of human civilization (Greater Mekong Subregion Economic Cooperation Program, 2008).

2.1 Groundwater Resources

The use of groundwater revolutionized irrigation in many parts of the world, impacting the lives of millions of rural farmers. The rapid growth in groundwater irrigation has brought many benefits to the rural poor. However, the intensification of groundwater irrigation is also threatening the resource together with the lives, livelihoods and ecosystems dependent upon it (IWMI, 2005). In semi-arid areas groundwater resources are being depleted and degraded due to land use changes in aquifer recharge areas resulting in reduced seepage, with desiccation and salinisation of humid zones as the main agricultural production areas and habitats for dryland biodiversity. With these signals, the benefits with synergies and reduced overlap of integrated land-groundwater management interactions to sustain dryland eco-systems and adapt agricultural production to impacts of climatic change are increasingly recognized (Lee & Schaaf, 2006).

2.2 Rights to groundwater

In many countries, land and water rights are seen together. This means that the right over a piece of land gives the land owner largely a right to the water above and below the surface with some scope considering the independent nature of subsurface water flows. It is important to emphasize that European conceptions of water and water law have strongly influenced the development of formal water laws around the world, through the two principal European legal traditions: the civil law tradition and the common law tradition.

The civil law tradition Within the civil law tradition, by its turn in accordance with the basic principles of Roman law, groundwater is seen as the property of the owner of the land above it. This basic approach is reflected in article 552 of the French Civil Code. Although the code contains dispositions concerning the flow of surface waters, it does not elaborate on the flow of groundwater. For example, the related Portuguese Civil Code only restricts the extraction of ground water if it affects the supply of a public fountain (article 1396).

The common law tradition Although the conceptual approach taken by the common law tradition is slightly different, the effect is largely the same. The effect is that a land owner is entitled to sink a borehole or well on his land to intercept water percolating underneath his property, though the effect might be that it interferes with the supply of underground water to nearby springs. Yet at the same time, the owner of land, through which ground water flows, has no right or interest in it which enables him to maintain an action against another landowner whose actions interfere with the supply of water. In practice, however, as a result of the development and use of modern well drilling techniques and pumps, the approaches of the main legal traditions no longer offer a viable means of effectively regulating the use of groundwater, even though they continue to apply in a number of jurisdictions. A clear example of the inadequacies of traditional land-based approaches is provided by the experiences of their inability to prevent the depletion of aquifers, for example in Texas where groundwater provides about 60 percent of the water that is used each year particularly for irrigated agriculture and urban water supply (Hodgson, 2006).

International groundwater Law International law has so far only rarely taken account of groundwater. While surface water treaties are abound, groundwater is either nominally included in the scope of these instruments, mainly if it is "related" to surface waters, or it is not mentioned at all. Only few legal instruments contain groundwater specific provisions, and even fewer address groundwater exclusively (Burchi, 2005).

3. EXAMPLES OF GROUNDWATER REGULATIONS

We have reviewed the situation in different countries in different continents. We have tried to present the current scenario of groundwater demand and legal acts concerning it in these countries.

3.1 World tour

A groundwater management report by the Planning Commission of India (Planning Commission, 2007) is referenced here to summarize some examples. The Indian Easement Act 1882 links groundwater ownership to land ownership and this legal position has remained intact since then. The recent Kerala High court ruling in the Coca Cola case seems to indicate that the right is not unfettered and the extraction has to be within a reasonable limit. From previous discussions, it is clear that while the right to use ground water is to be governed by the ownership of the land above it, the extraction rights can and should be curbed by the State if the use of groundwater is considered “excessive”, which certainly covers situations involving sustained—and not just seasonal—decline in groundwater level.

Spain & Mexico reformed their water laws to make ground water a national property. However, their success in getting water rights of agricultural users registered has been insignificant. If Spain with 500,000 wells and Mexico with 90,000 wells find it difficult to enforce the new water law, the situation in India with 19 million wells can be imagined should they also declare ground water a government property. The US experience of buying out ground water rights and supplying surface water by trans-basin diversions has huge cost implications which India may not be able to afford. The strategy adopted by Oman of deftly combining demand side measures to control, protect and conserve water resources with supply side measures to augment the resources has the potential for successful replication in India.

In Alaska, a water right is a legal right to use surface or ground water under the Alaska Water Use Act (AS 46.15). When a water right is granted, it becomes appurtenant to the land where the water is being used for as long as the water is used. If the land is sold, the water right transfers with the land to the new owner, unless the Department of Natural Resources (DNR) approves its separation from the land (Division of Mining, Land and Water, Department of Natural Resources, Alaska).

The situation in China concerning groundwater seems to comply with riparian[2] rights doctrine to some extent, especial for rural region, allowing anyone who has the right to use land to get access to the groundwater to use it. The free occupancy system supports the legal basis for this action, since it regulates that drawing water for family use, livestock drinking, emergency use or 'few demands' for irrigation don't need permits. As stated above, seldom a specific Article could explains what the extent of "emergency use" and "few irrigation demands", and those regulations are difficult to take into action. This gives us a kind of misperception: the groundwater rights are attached to land use right. Due to this there is no other rational principle to restrict groundwater abuse, the way "groundwater rights adheres to the land use right" has become a kind of regulation established by usage (Tianduowa, 2009).

In the Netherlands the regulations related to groundwater roughly fall into two categories. First, related to the protection of the groundwater against pollution. This is rooted in the European groundwater directive (European Union, 2006) and does apply to all EU countries. Specific groundwater collection areas and (wider) groundwater protection areas exist, in which land use is partly restricted. These areas have not yet been included in the list of restrictions that needs to be mandatory registered via the Netherlands Cadastre (Wkpb, see Zevenbergen & De Jong 2002). Second, and more relevant in the context of this paper, related to the groundwater use. The permits for the use of groundwater are a matter for the provinces in the Netherlands (together with the water boards) according to article 11 of the Dutch Groundwater Law (Dutch government, 2009). Below a certain quantity no registration and permit is needed. Above this quantity registration with the provincial authorities is required and when above yet another quantity also a request for a permit is required. There are not a lot of spatial aspects in the regulations for the registration. However, on most of the forms from the provinces to apply for a permit some locational information is requested: addresses, xy-coordinates, and cadastral parcels.

The regulations in Portugal were studied by the authors, which focused on characterizing current institutions governing the use of groundwater in the country. Quantitative data on water volumes extraction, water quality and other measures is restricted to the Case Study example presented on following section. Deep aquifers containing water of hydro-mineral quality, be it drinking water or water for industrial uses, are considered to be a Geological Resource, and are thus regulated under the General Regime for Survey and Exploration of Geological Resources (Decree-Law 90/90). Decree-Law 226-A/2007 provides for a general procedure to allow private property owners and holders of concessions on Public Water Domain being able to request licenses and permits for the use of surface water or groundwater. Requests for exploration are examined by each Hydrological Region Authority, under supervision of the Waters National Institute (INAG[1]). Other agencies can be consulted during the process, although there are no explicit clauses concerning groundwater. It is explicit, however, that all efforts for surveying and extracting groundwater in a Public Domain shall be subject to licensing. At the end of the process, a Water Title is obtained, expressing the conditions and terms for the exploration. Although this law mainly concerns private use of surface waters in the Public Domain, it has a number of specific articles dedicated to groundwater (Article 41, 45, 46 etc.). As usual in this type of regulations, a number of sanctions are imposed. The contamination of groundwater through pollutant, for

[1] Abbreviation in Portuguese.
[2] Riparian rights doctrine is that any person who owns and occupies land on the bank of a natural stream acquires water use rights which are commonly known as "riparian rights" by virtue of the occupation of that land.

example, is being considered a very serious environmental infringement (Art. 81, 3f). All the legislation mentioned so far respect the water on the Public Domain (considering different types hereof) or at least inside protection areas in the vicinity of Public Domain. The waters (including groundwater) on private property that is not encumbered by any type of protection area or administrative servitude are regulated by dispositions of the Civil Code. Such dispositions follow (in general) the same lines referred above under the civil law tradition. Finally, the Civil Code has a number of dispositions concerning the joint use of water resources through co-ownership rights in water, but these mainly deal with surface (irrigation) waters. This common use has strong similarities with a regular (land) serving parcel.

3.2 A Case from Portugal - Impact of the New Lisbon Airport on the Tejo-Sado Aquifer

This major infrastructure has been foreseen as a required investment for the benefit of the whole of the Portuguese economy, since dictatorship. The first studies were conducted in the late sixties, but at the time they did not consider Environmental Impact Assessment (EIA), since this institution had yet to become a reality. The pressure for the rapid development of the New Airport of Lisbon has then pushed the government, following a lobby of concerned private associations, to ultimately change its preferred location in the Northern margin of Tejo River (at Ota) to the current location of the military training area of Alcochete (A Mansarda, 2007).

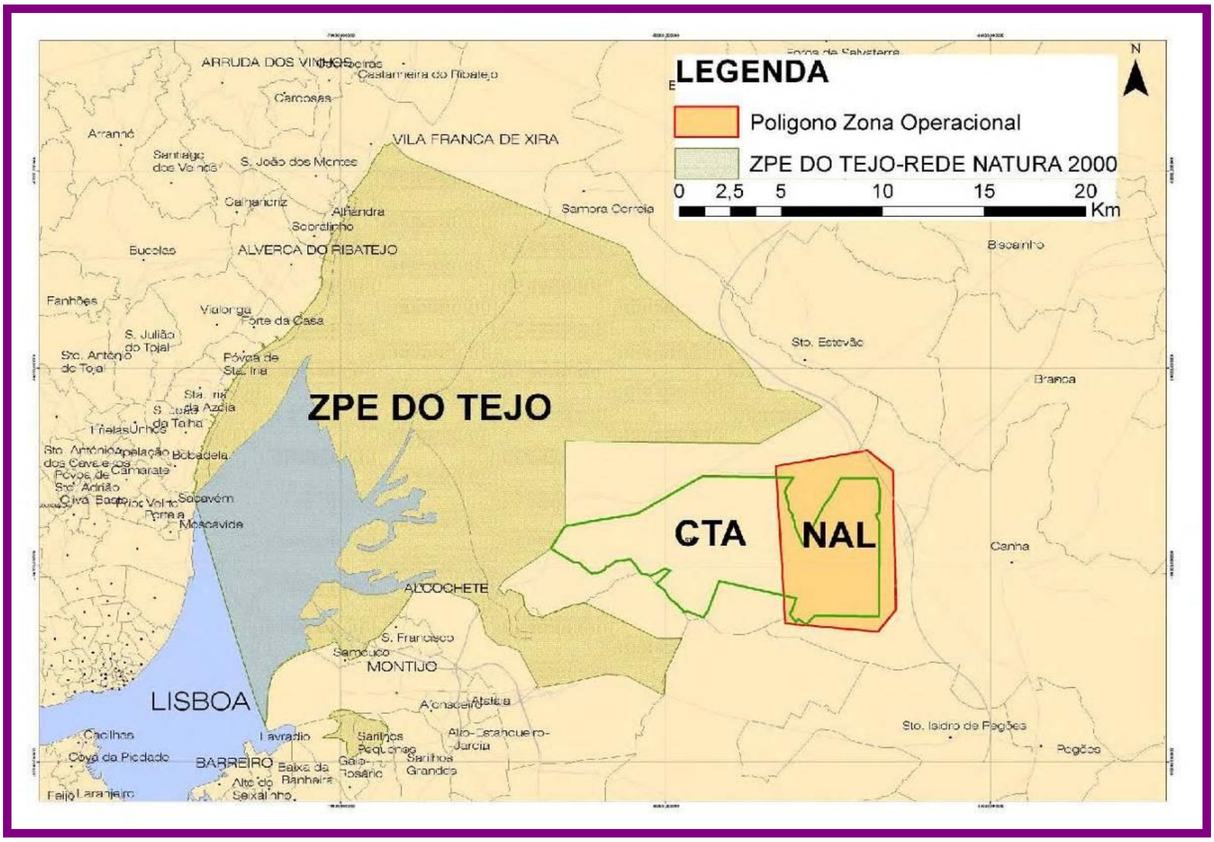


Figure 1: Map of the Airport zone in Portugal. ZPE: Special protection zone; CTA: Alcochete fire range; NAL: New airport of Lisbon (source: Veiga et al, 2006).

The initial area of the new airport will be 2400 Ha, but it is foreseen that the entire supporting infrastructure (namely the transportation network and the “airport city”) will eventually cover an area larger than 8000 Ha. Although this new location has been considered final, it is not supported so far with any integrated EIA study. The location of the New Lisbon Airport in Alcochete will affect the Southern margin of the Tejo-Sado aquifer, which is considered to be the largest in the Iberian Peninsula. Its average hydraulic potential is 0.25 hm^3 / year / Km^2. This aquifer contains water with good average quality for both human consumption and agricultural irrigation, which are its major current uses. The Tejo-Sado aquifer forms a complex, multi-layered aquifer, which is generally semi-confined, having a free, unconfined top layer that in some places is contaminated. The current situation seams sustainable, however, if the new urban developments are taken into consideration, together with the effects of the predicted climate change for the near future (Veiga et al, 2006), then the expected use of water will equal the total recharge, with a potential for over exploitation and gradual depletion on the long term. The picture can become even gloomier if the effects of the soil impermeability due to the construction of runways and the supporting facilities (including highways and railroads) are taken into account. It is estimated this can reduce the recharge with a further 10% of the current values, within the area. There are also concerns that quite a number of unregistered tube wells exist, for the purposes of agricultural irrigation. There is a lack of information concerning private use of water within the study area; existent information mainly reports on local government owned extraction facilities for public water distribution (LPN, 2008).

4. SPATIAL INFORMATION SCIENCE APPROACH

With the increasing scarcity of groundwater, more and more communities and governing bodies are going to set up regulatory measures through laws and institutional setups. However, this approach could not achieve the ultimate purpose of saving the groundwater just by viewing it as an isolated domain.

Making stringent laws and setting up user associations is an effective start to control the extraction of groundwater for different purposes. However, the different aspects of the water under the ground are generally hidden from the view of the user or the regulatory authority. This situation results in the half understood problem by the decision maker which confirms the notion that what is hidden from the direct view is seen by many as non-existent.

As stated earlier, land and water rights are considered together in most of the countries. Land administration, globally in general, defines the rights, restrictions and responsibilities of a party to a particular spatial unit in a particular time frame. The definitions of party, spatial units, time frame could vary under different regimes worldwide. However, we are not going into the details of these variations which could effect the implementation of the laws governing the land. We are also not trying to go into the intricacies of the different characteristics of geological layers as well as the behaviour of groundwater with different compositions in different depth zones.

However, touching all these issues, we want to state the need of an approach which can incorporate the results of technical details of groundwater dynamics into the regulations made concerning land management.

4.1 Spatial Information Science

With the advancement of GIS and Remote Sensing technologies, it has become possible to visualize more and more phenomena in three dimensions and to simulate the temporal patterns; e.g. using tools such as the Soil and Water Assessment tool from Texas Blackland Research Center. Popular GIS and CAD software like ESRI and Autodesk products provide such tools to visualize and to perform analysis in three dimensions. Three dimensional and temporal information analyses have a lot of potential in natural resources management considering the presence of these resources below, on and above surface. Most prominent examples can be given from geological explorations and water resources (DGI, 2009; Salvai-Benka, 2009).

It is essential to take the benefit of this science to formulate new regulations and laws considering the changing global scenario about these resources. The three dimensional analysis, based on process models, can help the decision makers to better understand the issues concerned.

The Indian planning commission report recommends for the Indian example that the effectiveness of groundwater management (including artificial recharge) could be substantially improved through the application of advanced tools such as remote sensing, Geographical Information Systems (GIS), integrated within information technology systems. The use of these tools can help in making the ground water management plan more accurate, holistic and efficient.

4.2 Conceptual Diagram – Current Scenario

After describing the present scenario in the above mentioned case studies, we have conceptualized the present groundwater management in the form of a Semantic diagram.

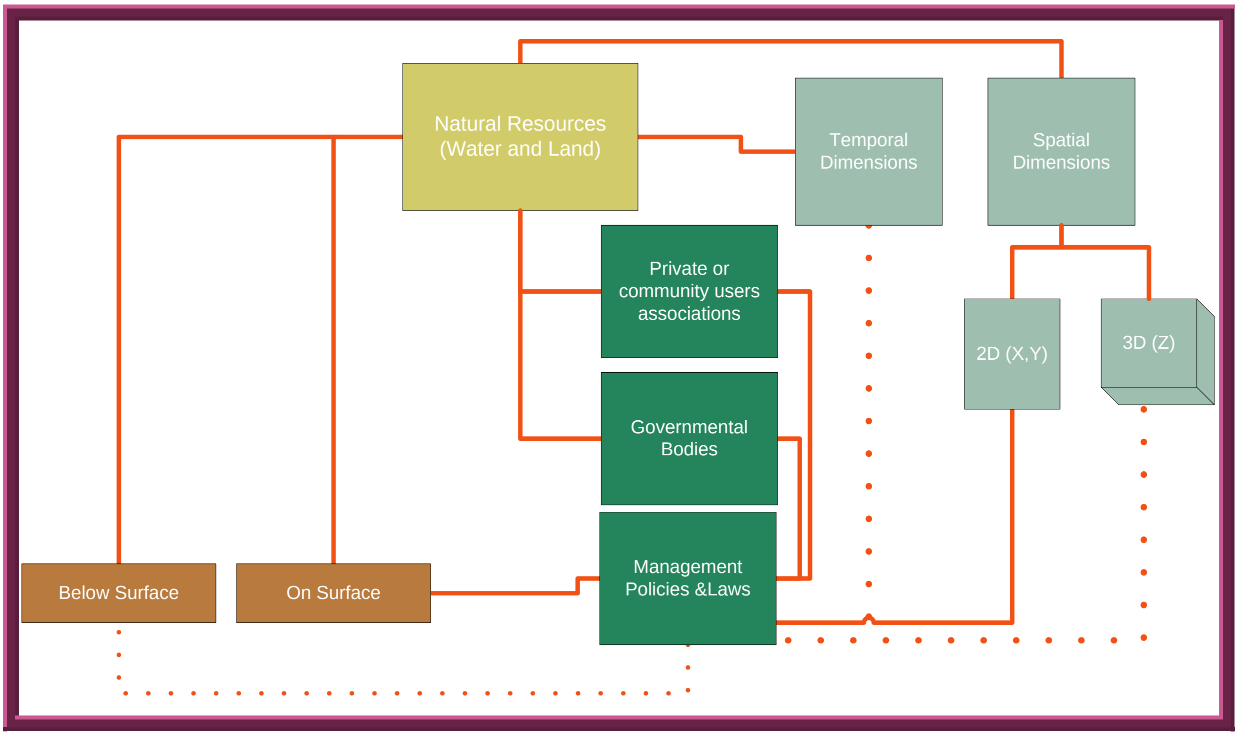


Figure 2: Conceptual representation of current policies & laws regarding natural resources (note: dotted lines represent weaker links)

The conceptual diagram shows that the natural resources (water and land) on and below surface are managed by users associations and governmental bodies through policies and legal acts. These natural resources have their spatial and temporal dimensions. But the policies and legal acts only consider the X, Y dimensions of these resources in a strong manner while the consideration about the Z dimension is present only in a suggestive manner. The same is true for the temporal dimension which is often ignored. Further, the policies and laws address the on-surface usage in an evident manner but the below surface issues are tackled with less stringent measures that are also difficult to enforce. The reason behind this could be given as the absence of proper information related to these resources their functioning and usages.

4.3 Land Administration Domain Model

Land administration is a large field; the focus of the LADM standard is on the part of land administration that is concerned with the *spatial objects (in land or water) and related property rights (restrictions and responsibilities)*, and the *spatial (geometrical, topological) components* thereof.

The LADM provides a *reference model* which will serve at least two important goals: (1) avoiding reinventing, and re-implementing the same functionality, over and over again, but providing an extensible basis for the development, and refinement of efficient, and effective land administration system development, based on a Model Driven Architecture (MDA), and (2) enabling involved parties, both within one country, and between different countries, to communicate, based on the shared vocabulary (that is, an *ontology*), implied by the model.

The second goal is important for creating standardized information services in an international context, where land administration domain *semantics* have to be shared between regions, or countries, in order to enable the necessary translations. Important conditions during the design of the model were: it should cover the common aspects of land administration all over the world, should be based on the conceptual framework of Cadastre 2014 (Kaufmann & Steudler, 1998), should follow ISO standards, and at the same time the model should be as simple as possible, in order to be useful in practice.

The LADM contains classes for parties, RRR's (rights, restrictions, and responsibilities), spatial units (for example parcels or apartments), and basic property units (collections of spatial units with the same RRR's, in LADM terminology: LAUnit); see figure 3, which is also showing the packages with the names of the other classes involved. The data could be maintained by different organizations. The model might be implemented through a distributed set of (geo-) information systems, each supporting the maintenance activities and the information supply of parts of the registered data sets, represented in the model, hereby using parts of the model. The model might also be implemented by one, or more maintenance organizations, operating at national, regional, or local level. This underlines the relevance of the model: different organizations have their own responsibilities in data maintenance, and supply, but can communicate on the basis of standardized formal, administrative and technical updating processes. The LADM core consists of *four* classes:

1. Class LA_Party: an instance of Party associates to zero or more (*) instances of a subclass of LA_RRR.
2. Class LA_RRR (where RRR stands for Right, Restriction, and Responsibility): an instance of a subclass of LA_RRR associates to zero or one (0..1) instances of LA_Party, and to exactly one (1) instance of LA_LAUnit.
3. Class LA_LAUnit; an instance of LA_LAUnit associates to one or more (1..*) instances of a subclass of LA_RRR.
4. Class LA_SpatialUnit: an instance of LA_SpatialUnit associates to zero or more (1..*) instances of LA_LAUnit. It should be noted that normally a LA_SpatailUnit does not belong to more than one LA_LAUnit, but there are some exceptions; e.g. in Norway it can belong to several LA_LAUnits.

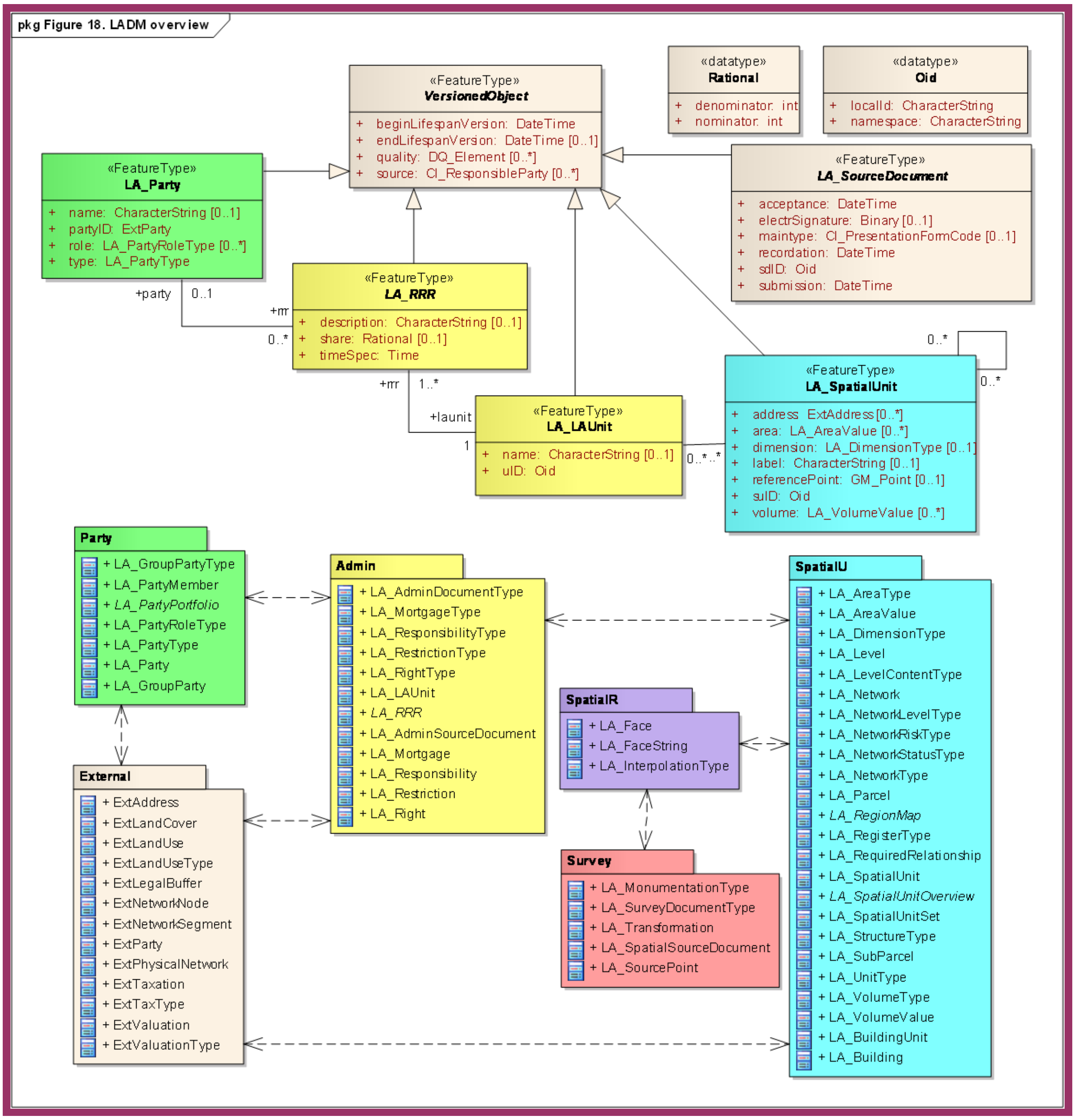


Figure 3: LADM Core Model Representation and involved packages (from ISO/TC211, 2009)

LADM supports temporal aspects of LA_Party, LA_RRR, and LA_LAUnit. They all inherit temporal attributes from class VersionedObject. The Class LA_RRR is an abstract class (it has no instances). It has an attribute called "timeSpec" which is defined as operational use of a right in time. This attribute is capable of handling different temporal representations, such as reoccurring patterns (every week-end, every summer, etc.). This means for example that a party can hold a right to use an apartment each year in March, as usual in a time sharing right. Or a group of pastoralists has the right to cross a field each summer. The meaning of each of the following classes is briefly described next:

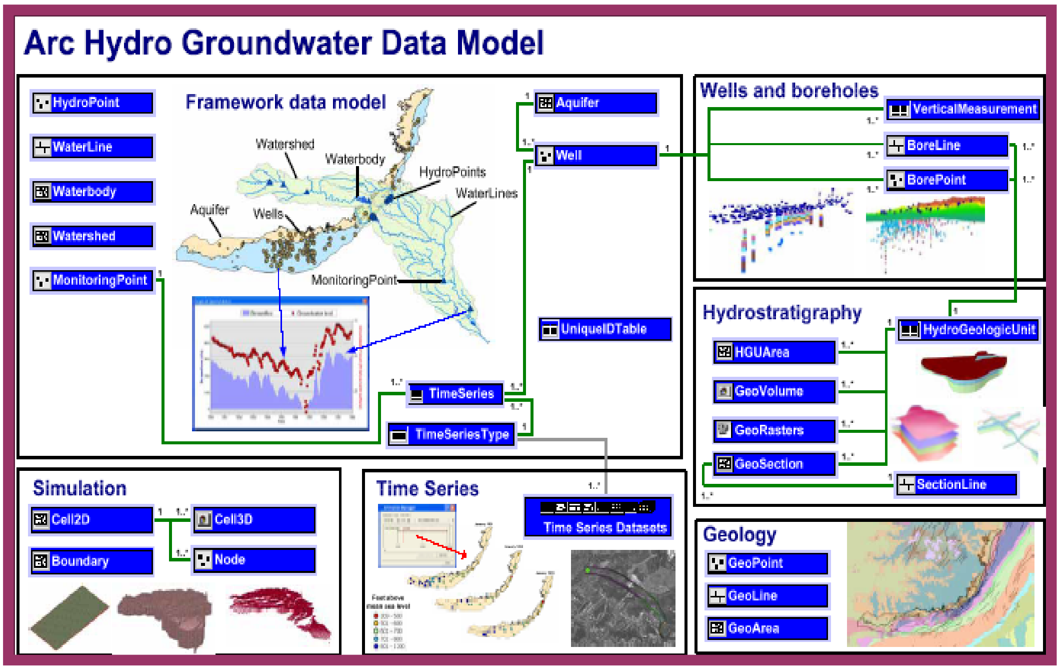
- Class LA_Right (subclass of LA_RRR): grants powers to a Party, entitling it to do something related to the parcel (or parcels) of land covered by such right.
- Class LA_Restriction (subclass of LA_RRR : refrains a Party holding a right to exert the granted powers in full.
- Class LA_Responsibility (subclass of LA_RRR): usually results directly from the grant of a right, and demands that the right holder actively does something in relation to the land he owns.
- Class LA_SpatialUnit: based on (UN/ECE, 2004; WG-CPI, 2006), is a single area of land, or more specifically a volume of space, under a homogeneous, and unique right (e.g. a property right, or land use right). By unique is meant that a right is held by one or several parties (e.g. owners, or users) for the whole spatial unit. By homogeneous is meant that a right (e.g. right of ownership, use, social tenure, lease, or mortgage) affects the whole spatial unit, with the exception that specific rights may affect only part of the spatial unit (e.g. an encumbrance). In such a case, the spatial extent of that specific right could be left unspecified, or otherwise it will correspond to a new spatial unit. The LA_SpatialUnit is a subclass of LA_VersionedObject. A LA_SpatialUnit is associated with LA_LAUnit.

Spatial units are refined into three main categories: land (2D)/space (3D), buildings, and networks. Land (2D)/space (3D) spatial units may originate from different registrations. The different types of land (2D)/space (3D) spatial units include: topological spatial units, unstructured line spatial units, reference point spatial units, text based spatial units and mixed representations (2D and 3D) spatial units.

4.4 Groundwater Data Model

The following figure 4 (a, b) shows a groundwater data model of the popular commercial GIS software company ESRI. The model considers the spatial (2D & 3D) and temporal dimensions also of the groundwater datasets. It includes the surface and subsurface features including watershed boundaries, surface water bodies, wells and boreholes, geological features. The simulation generates multipatch texture classes for 3D Cells.

(a)



(b)

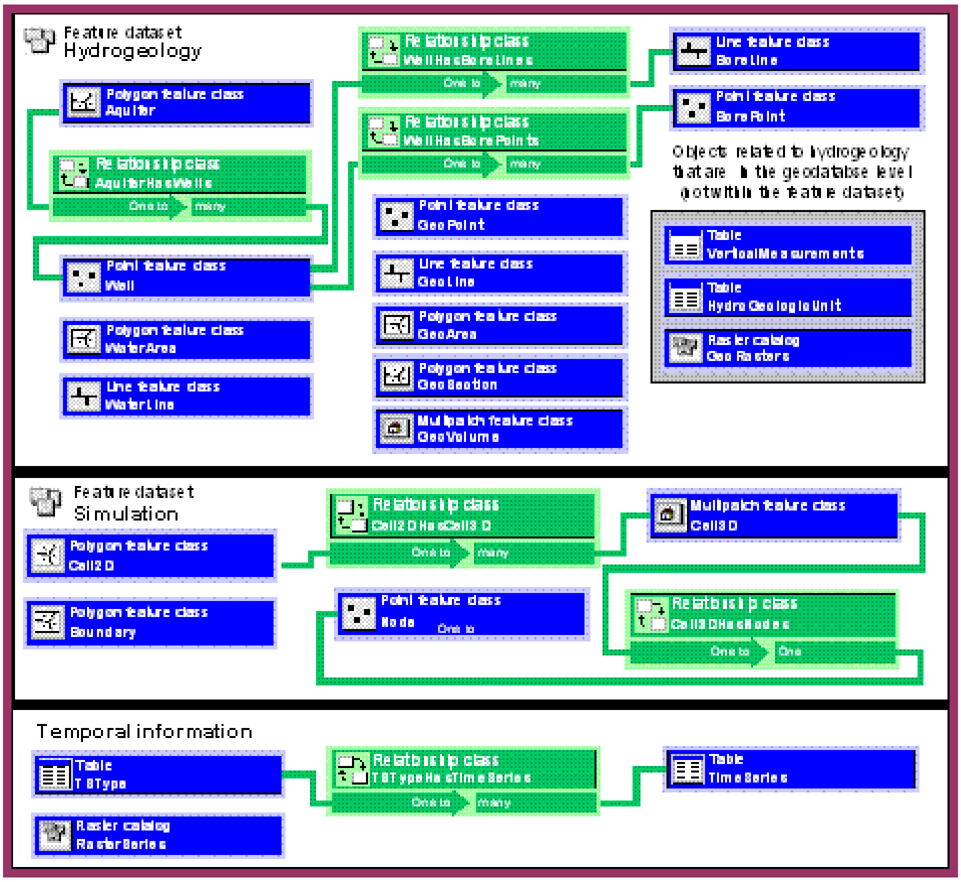


Figure 4: ArcHydro Groundwater Data Model

The data model design outlines three components for the data model: Hydrogeology, Simulation, and Temporal information. The Hydrogeology dataset includes representations of two-dimensional features such as wells and aquifer outlines, and three-dimensional classes to describe hydrostratigraphy, solid volumes, and cross sections. Temporal information is represented with the ArcHydro tabular structures such as TimeSeries and TSType (TimeSeries Type) tables. The RasterSeries raster catalog represents gridded temporal information (Figure 4 a & b).

Rather than trying to anticipate all the different types of groundwater data that can potentially be stored in a geodatabase, the focus is on describing ground water information in terms of raw field data and conceptual representations of the primary features in a hydrogeology system. This allows the data model to be used as a tool for archiving and sharing groundwater data for a wide variety of applications. The importance of three-dimensional GIS in the characterization of the subsurface has been widely emphasized. An effort is made to include three dimensional features (i.e. solids, cross sections) as much as possible to reflect the nature of hydrogeology systems.

4.5 LADM and ArcHydro Groundwater Data Model – Bridging the Gap

Under the current situation where most of the countries laws consider land and water rights together, we focused on the temporal and spatial Z-dimension in LADM itself.

It is essential to include the temporal changes in spatial location and quantity of the groundwater. As stated above, the LADM provides such scope under the 'TimeSpec' element of the abstract class LA_RRR under the Legal and Administrative component. This expansion of the temporal aspect will provide the required flexibility in defining the rights, responsibilities and restrictions about the resource usages of a party according to the temporal variations on a more scientific basis. Land issues, when joined with the groundwater spatial changes in a time frame, could be seen with a new perspective.

According to related research, reported in (Doner et al., 2008), the ideal solution would be to consider a 4D Spatial Unit where a space-time topology assures full consistency. However, the current technical solutions are based on 3D spatial attributes and separate temporal attributes. Additional constrains are needed to obtain consistency.

To highlight this importance of the temporal dimension in the Legal and Administrative component, it is equally essential to include the spatial Z-dimension in the spatial units component of LADM. Inclusion of this dimension will provide opportunity to see the dynamic changes occurring seasonally in groundwater quantity and quality at different depths. Once the 3D movement of groundwater could be understood and incorporated in the spatial unit component, expansion of the temporal aspect in the Legal and Administrative component of LADM will be more easy and flexible. The spatial unit in LADM is clearly defined, with the specific rights which may affect only part of the spatial unit identified, through shares. In our case, it could be a shared right over the groundwater aquifer spread beneath several land parcels. These land parcels could have distinct unique rights over the whole spatial unit on the surface. Further, the refined definition gives land (2D)/space (3D) as one of the categories of spatial unit (Refer to figure 6).

Figure 5 represents a simulated spatio-temporal output of surface and sub-surface features from an ArcHydro groundwater simulation model. Further, this output will be converted in the required format and spatio-temporal resolution to be included in the legal-administrative and spatial components of LADM. What will be the mechanism to achieve this compatible format is presently not explored by the current authors. Specific to the groundwater simulation models is that they provide predictions, which are quite different in nature that the registration type of information normally included in the LADM.

The same system architecture is envisaged in (Doner et al., 2008), which deals with utilities instead of groundwater, but where the same arrangement applies: "*The ideal solution could be to take advantage of SII*[3] *to share spatial information of utilities maintained by organizations responsible for the operation of the network while registering legal space of these physical objects in the land administration.*"

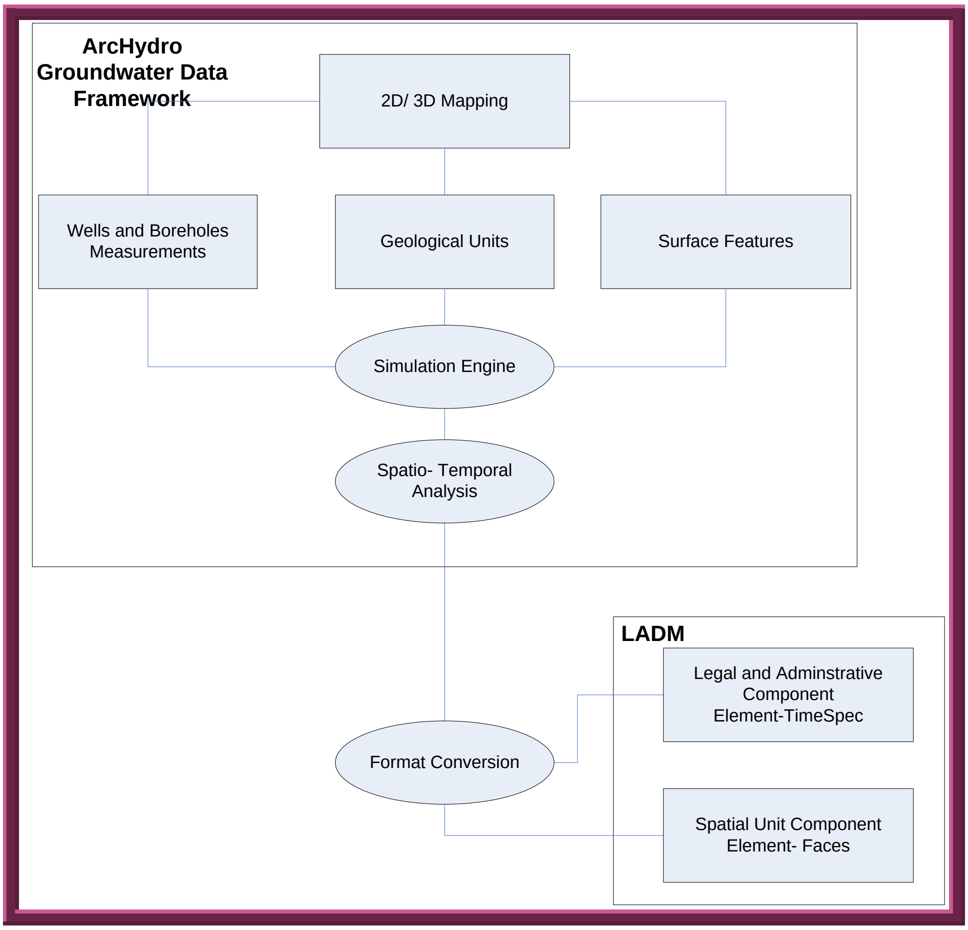


Figure 5: Technical to Administrative Groundwater Modelling

5. USE CASES

Using a more elaborate classification of Rights as an RRR class specialization, presented in (Paasch, 2005), it is possible to model a number of groundwater use scenarios, corresponding to situations which can be found globally. A number of Use Cases is presented below, from were the second one was selected for a more detailed representation using an Instance Level diagram. The LADM is the sole source for the presented modelling.

5.1 Overview

Private use of groundwater for a certain recurring pattern (time share in water use): A number of individual parties have a non-overlapping time-share to extract groundwater from a certain well (or wells) located on a given parcel (Paasch: Personal Rights);

Private shared use of a collective resource: This could also be called a "serving groundwater parcel". Corresponding individual shares should be defined, according the areas of adjoining or superimposing private properties (Paasch: Common Rights). This can accommodate water users associations;

Private groundwater extraction lease: Lease of water extraction equipment to a private owner of a land parcel by a specialized water instruments firm (Paasch: Personal (contract) Rights);

Public use of groundwater for a certain recurring pattern (time share in water use): A Permit is issued in a certain area for public use of a groundwater deposit for a certain period (especially for drinking purposes);

Public use of private groundwater for a limited time period (extending requisition to water rights): Use of groundwater resource under private land parcels for a public resource such as construction of a dam.

5.2 Instance level representation

An Aquifer (groundwater volume) is modelled as a 'Serving Parcel', which is underneath the served (surface) land parcels. Here each party will own a share which could be proportional to the volume of the aquifer delineated by the surface parcel boundaries and /or the temporally divided right delineated again by the surface parcel.

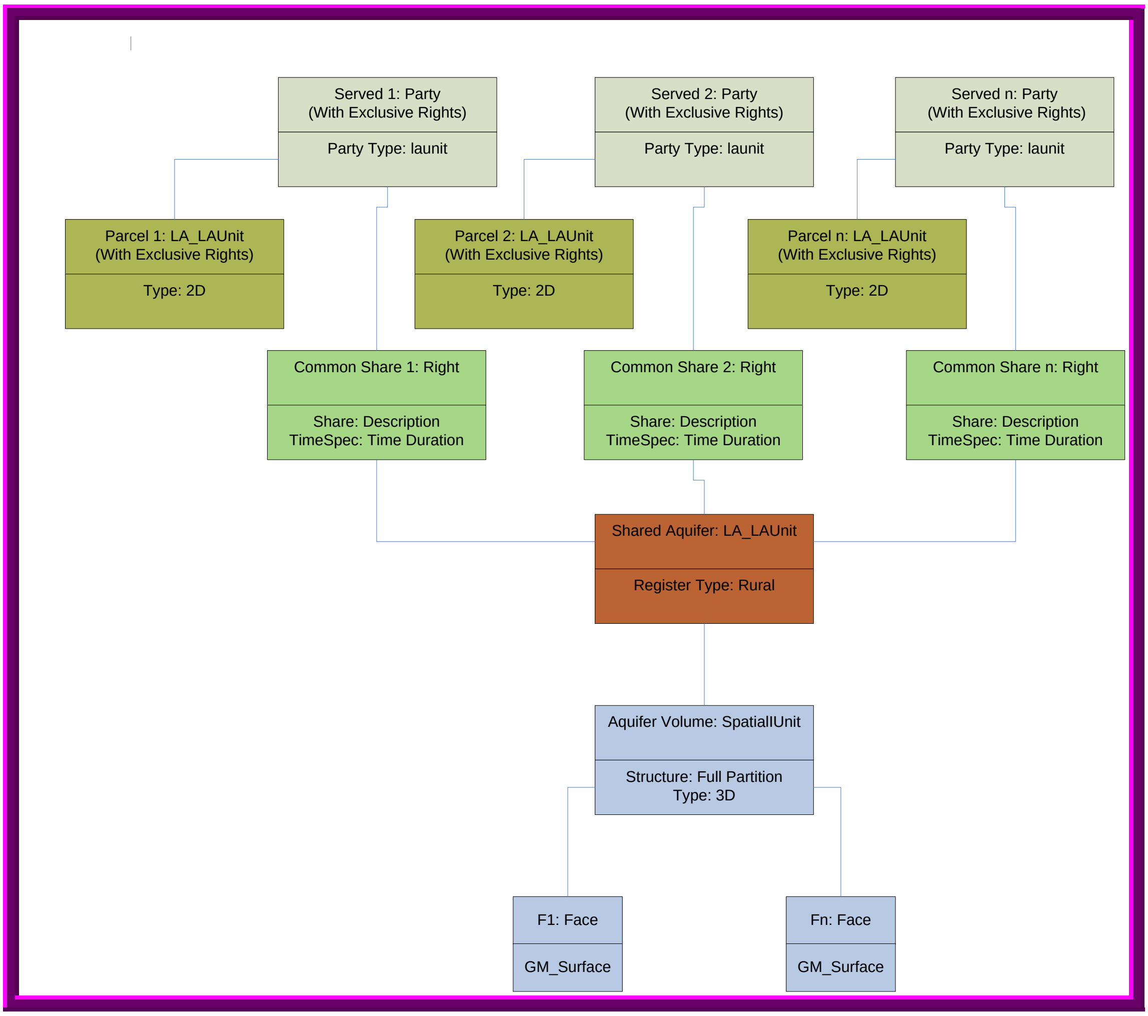


Figure 6: Instance Level for a "groundwater serving parcel"

All the different spatial units are recorded on the same type of registry, of the rural type, once all these units are under private rights which should be registered. The spatial units representing the ground parcels (Parcel1 … Parcel n) use a 2D representation and so they use different geometric classes (not shown in the Figure 6) as the one used to represent the groundwater aquifer, which is called Face and uses the GML generic type of GM_Surface. The aquifer is treated as a (closed) solid containing water, which is of course just an initial approximation. It is fair to state that in this example not so much attention is paid to the dynamic/temporal aspects (predictions based on simulations). Also the flow of groundwater is ignored in this initial attempt. As stated earlier true 3D spatial features with dynamic behaviour might require a 4D approach (Doner et al, 2008).

6. CONCLUSION AND RECOMMENDATIONS

We conclude that the advancement of spatial science based technologies is capable of providing solutions for the global issues such as groundwater resources. As a first step towards implementation of these technologies, it is essential to include spatio-temporal dynamics properly in the standard data models. Increased knowledge on the behaviour of groundwater resources, supported by a technical system built on a land administration counterpart, could help improve greater sustainability in the use of such resources. Considering the specific arrangements of rights, parties and spatial units could also provide the base for a regulated private market on groundwater assets. Future research on this topic should focus on a number of issues, namely the specification of use cases reflecting concrete situations in diverse countries, represented under a common framework using UML Use Cases, Activity and State Machine diagrams, related to LADM. From such studies, a general Groundwater Rights profile (Legal component) could be derived, as well as an Aquifer Spatial Profile (Spatial component).

The applications of such data models can thus produce outputs at case study levels which can help to formulate policies regarding natural resources more on the basis of technical inputs.

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