Water and land management in the periurban catchment of São Paulo: a first conceptual framework

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Abstract *— A common representation of the interaction between urban expansion and water quality degradation in the periurban context of São Paulo Metropolitan Region has been elaborated to integrate different thematic knowledge. The model combines (1) a representation of spatial dynamics, land uses and their evolution, based on a basic spatial unit of one ha, that allow to composing various spatial management unit of hydrological(e.g catchment area) or social interest (e.g. legal zoning). The plot is also viewed as the support for a unique land cover, land occupation and urban infrastructure, including water and sanitation ones (2) a typology of actors, based on land ownership and residence place. This classification differenciates actor with direct action on land and water (either by direct take off the resources, effluents production, infrastructure development and management, or land use changes) and other groups of interests which include most of the stakeholders groups represented in the catchment committee. (4) An hydrological representation allowing to articulating spatial processes, water allocation and simplified quality processes in potable reservoir. This model provides a generic interpretation frame for the specific situation of the periurban catchment of the RMSP. It is being used to develop tools to support capacity building and strengthen local actors' participation in the catchment committee.*

1 - Introduction

The previous thematic studies have underlined the spatial and social heterogeneity of the peri-urban territory studies, the complexity of the impacted hydrosystem, the range of changes and transformation that affect the people and hydrosystem, the complex institutional framework. This development of these studies is relying on various different methodologies and conceptual basis. Some are clearly sites specific. Is this possible to integrate this different knowledge and representation? How to overcome thematic divides?

A common representation of the interaction has been elaborated by the Negowat Brazilian team. It was developed during sequences of workshops that gathered the different competences of the project. The discussion held were synthesized in a simplified UML representation that was use to represent the relationships between actors, between actors and the resources (management rules), and the impact of theses actions on pollution and water availability. The conceptual model proposed is structured around three main themes (1) representation of the spatial processes (land uses changes and dynamics), actors, their interactions and their actions on the resources (4) population and demographic dynamics (3) representation of the hydrological processes (water flows, water allocation between uses, and water organic pollution. This contribution aims to present and discuss this representation.

2 - Representation of the spatial dynamics, land uses and occupation

2.1 - The difficult choice of an adequate common spatial unit

Various space scales are relevant when dealing with land and water management in the periurban catchment of São Paulo (table 1): At household level (some 100 m²) families are using water for domestic needs, and some productive uses (for example urban agriculture activities), using different storage and distribution system. Irrigation is being developed in rural property: in the case of the irrigated horticultural system of the RMSP, the size of irrigated plots is varying between 1 and 10 ha with an average of 5 ha. For hydrological studies, and given the available information, the territory has to be divided in micro catchment with an area of some 10 km². The size of sub-catchments studied varies between 900 km² and 1980 km². The average municipal territory is 200 ha.

Table 1. The different spatial unit making sense in the catchment of the RMSP.

Plot size	Nb of elements	Types	Elementary surface
1ha	200	Housing unit in a urban area – low pattern (slums)**	50 / 60 m²
1 ha	80	Basic housing surface in consolidated urban*	125 m²
	10	Basic spatial unit for business areas*	1000 m²
	6,6	Basic spatial unit authorized in mix area*	1500 m²
	20	Basic spatial unit authorized in the surrounding of the reservoir*	500 m²
	2	Basic spatial unit in low density area (for tourism agriculture or week-end houses)*	5000 m²
1 to 5 ha	1	Average irrigated farm surface**	
30 ha	1	Average farm plantation surface**	

Source: Project of Specific Law of Guarapiranga (Anonymous, 2004)*, thematic studies and field work**

We have chosen to work at a basic spatial unit of 1 ha, representing a settlement of 100 houses or part of a farm property. This scale does not account for management processes at household level or biophysical processes at local level. Referring to wider management units such as municipal territories, land zoning or micro-catchment unit necessitates to aggregate plots to build the adequate spatial unit. The space representation may be thus viewed as a spatial raster grid of 1 ha plots.

2.2 - The basic spatial unit: a support for land cover,

Each 1 ha plot support is attributed a unique homogeneous land cover. This land cover can be obtained by satellite image analysis. Each land cover is characterized by the amount of organic pollution it generates (exportation coefficient), and possible economical variable (possible economic return, maintenance cost). Internal variability of land use within a plot is not considered except for urbanized land cover that is also characterized by a waterproof coefficient (waterproof surface such as concrete versus total surface).

Five main types of land uses were differentiated: (figure 1).

1. Free water (for example reservoir).
2. Natural vegetation : Primary or secondary forest are not distinguished; Bushy vegetation is an intermediary vegetation stage between fallow and forest; The specific natural vegetation of wetlands area is identified.
3. Anthropic vegetation such as crop, fallow or pasture, wood plantation (pines or eucalyptus plantation). Three types of crop system are distinguished: irrigated horticultural crop, non irrigated annual crop, and covered crop system (corresponding to mushroom production, hydroponic gardening or intensive flower farming).
4. Business-like land cover with different water pollution risks - leisure compounds providing leisure activities for visitors, industrial areas with industrial activities, business/services areas with business or service warehouses and buildings, mining areas (for raw material extraction). This land cover type also includes areas for specific city infrastructure, more specifically two types of areas are stressed: water treatment station plant and garbage disposal area.
5. Housing areas differentiated by their urbanistic pattern such housing density and water proof coefficient. It includes various types of settlements (low income popular settlements, social housing project, high income closed compounds,) that are differentiated by their population capacity, and building mode (and costs). Slums are defined as dense non permanent type of housing, built by the dwellers and without any land rights (even occupation title). When land rights to the dweller are secured, we assumed that slums are upgraded in popular settlements. Housing types also included semi-rural district ("*chacaras*"district) and plots with week-end houses (1 or 2 by plot), as well consolidated urban district mixing housing uses and shops.

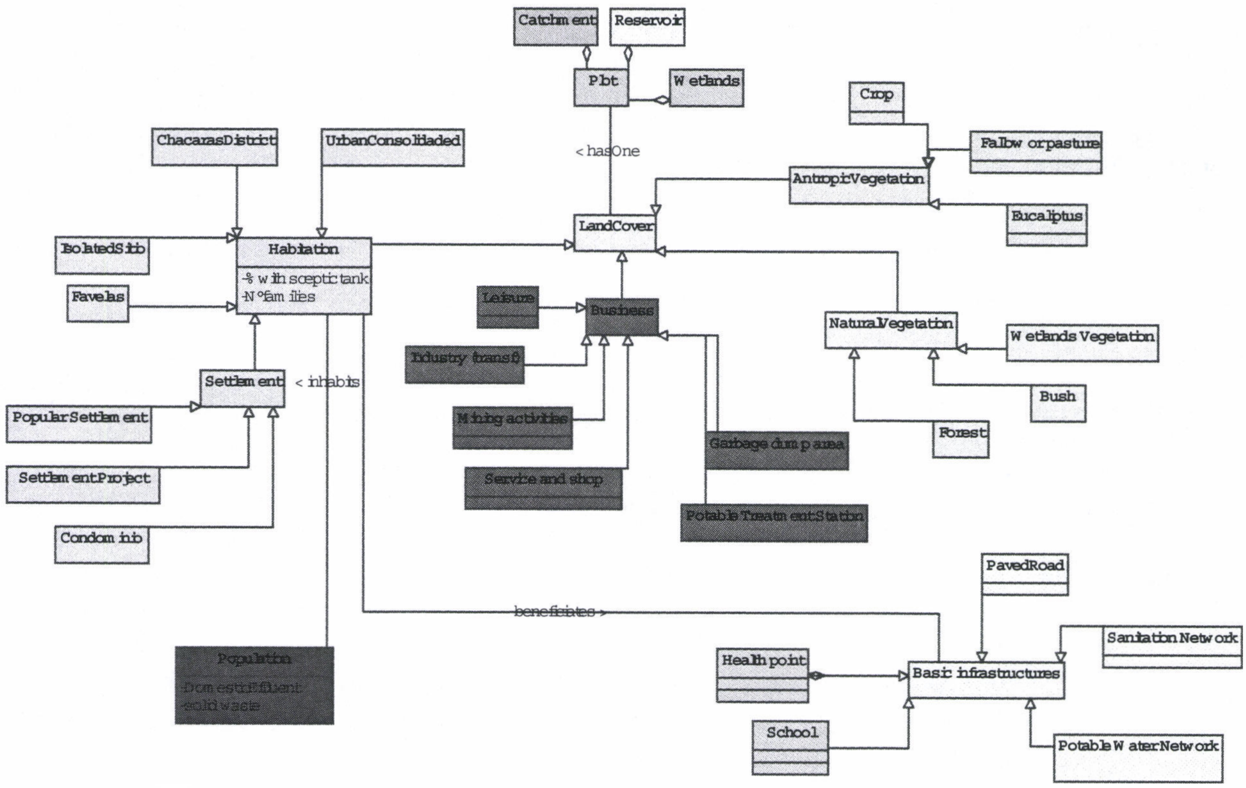


Figure 1 : Representation of the spatial land uses and spatial features

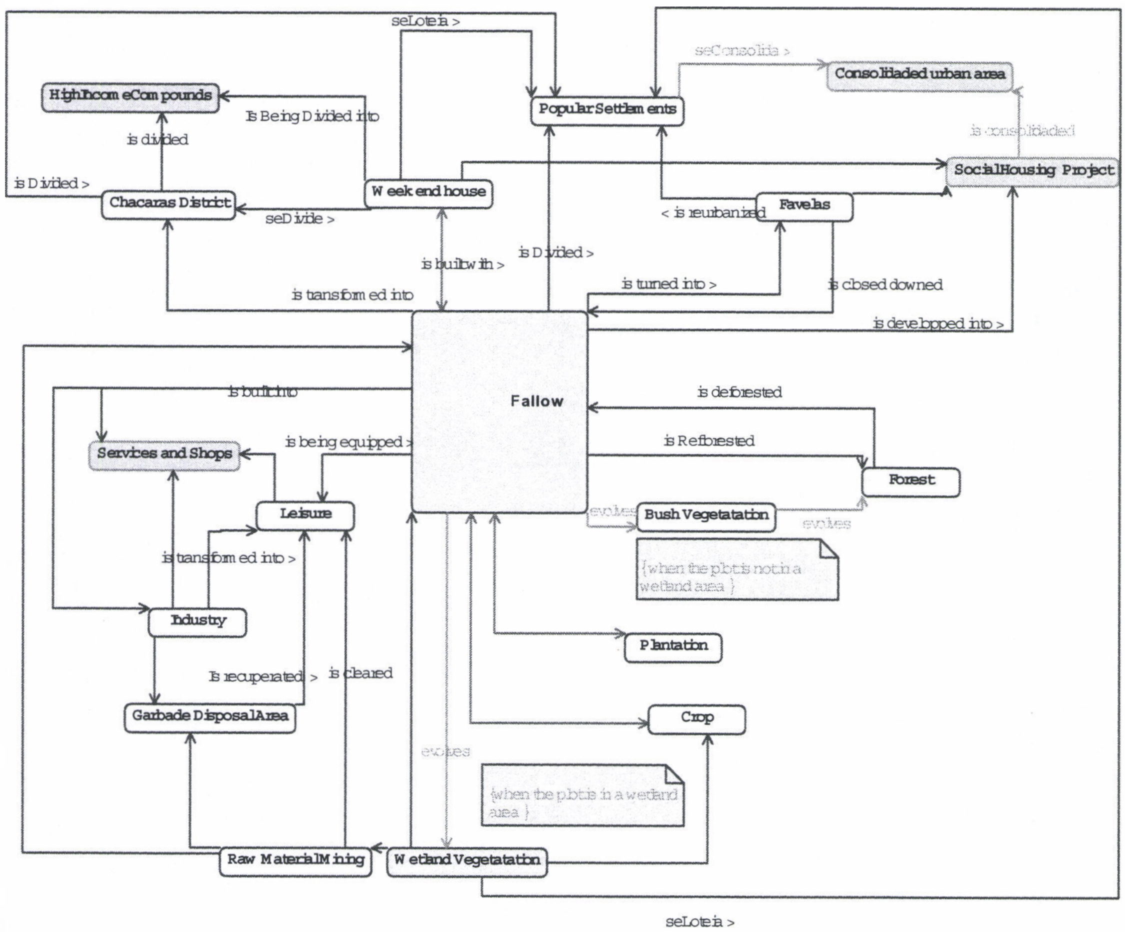


Figure 2: Land use dynamics.

The land cover evolution of a plot is presented in the figure 2. Between different stages of evolution, a plot necessary passes to by a fallow stage of land use. High income compounds, consolidated urban areas, popular settlements, service and shops areas do not evolve. Natural processes may drive some land use evolution - for example, an abandoned fallow area naturally evolves into a bushy plot and lately into a forested plot. However, most of the evolution processes result from human action such as plot division and building of housing schemes, or destruction of existing building. Theses changes suppose investments and may generate income.

2.3 - The plot: support for infrastructure and population occupation

The plots also support some basic infrastructures that are simplified into 5 main types.

- Elementary infrastructure, such as school and health center.
- Individual water infrastructure such as wells or septic tanks.
- Network infrastructures: (1) potable water network (2) sanitation network (3) paved road. Also not strictly speaking an infrastructure, the organization for domestic garbage collect and disposal was also included in this category.
- Network infrastructure is or not connected to a main network (adductor, main road, etc) and/or treatment station (for potable water / sanitation) or specific individual infrastructure (well to provide raw water). Some of these facilities (treatment station, garbage area disposal) can also be represented as a type of land use which allows connecting them with the hydrological system.

Development of urban water services is linked with public health, and at settlement level, each urbanized area is characterized by a specific health indicator which is infantile diarrhea.

Population is viewed as group of families occupying a plot, more specifically plot with an housing land cover. The family group size defines the population density of a plot. Each population group provides a certain amount domestic effluent and solid waste depending of the size of the group and their "income" level. Their impact on water pollution depends on the available sanitation infrastructure at plot level.

2.4 - Different territorial management unit

Each plot (the basic spatial unit) is characterized by its geo-morphological characteristics (hilly slope, high slope, flooding plain area) which defines its potentiality and risks for different types of land use. For example, irrigated agriculture is not possible in plots with a high slop, while mining activities for raw materials are only available in plots of the flooding plain. For human settlements, two area of risk are considered: flooding plain (risk of inundation) and high slope areas. Flood plain areas are conflictive areas because of their various possible uses: farming, raw material extraction, urbanization, flood control area or de-pollution service.

Sets of plots also define micro-catchment area whose run-off provides water for the reservoirs, themselves formed by an aggregation of "water"plots. Plots may be also aggregated in different social management unit such as zones of municipality planning or catchment planning, or actors property. These social management units are managed by a specific actor.

3 -Representation of actors and social processes

3.1 - Actors with direct action on land and water resources

Actors with direct action are actors whose activities and daily decisions are directly affecting the resources (either by depletion of the water resources, pollution of water resources, changes of land use).

1. The framework distinguishes 5 types of direct actors
2. Mayors, elected to manage a municipal territory and urban services to the population. They are particularly interested in municipal population welfare, especially public health.
3. Water service firms (that can be a water municipal service)
4. Local managers of the hydrological systems especially the reservoirs
5. Non local dwellers, with land property in the area studied
6. Local dwellers, than can be organized (district organization, farmers) or not.

Socio-economic agents can be characterized by various different ways such as their main activity (example farmers, business man), income level, size of the family. We have chosen to characterize them by their residence and ownership link to the land_(table 2). We thus assume that local dwellers (agent whose permanent residence is situated in his property) is embedded in a local social network that strengthen their relation with other local actors, difficult their moving out of the area and sometimes land use changes. This is more specifically the case of small family farmers and local urban dwellers (group of families in this framework).

Table 2: Typology of actors with direct action on the resources

	Local dwellers (in its property)	**Non resident in the plot**
Owner of a (set) of plot(s)	Family farmer / small scale farmer (family living in a local settlement) representative of a settlement and local dwellers (	Owner of a week end house Owner of land with a business strategy or "a land reserve" strategy
Non owner (with a contract with local owner)	Tenant (housing)	Visitor or tourist

Non local dwellers with land property in the catchment are differentiated by 3 main strategies: (1) week end house owners sporadically living in the catchment, (2) owners with business strategy willing and able to develop business activities from its land property (3) owners whose land property is merely viewed as a "land reserve". Decision-making related to land use can be delegated to a local tenant, a non owner that beneficiates from a tenure contract either for house or land cultivation.

Actors interact with the resources (land and water) in different ways : (1) *land owner* are linked to a set of plot by *an ownership link.* They are able to change plot land cover by making appropriate investment, depending of their main strategy, interests and social links. In this periurban area, ownership right is legally recognized or not (legal title or occupation title) as land market studies indicate it (Bueno A.K.S, in this report) (2) *The water service firms* are in charge of the development of water (potable water / infrastructure and the management of the treatment station. They are linked to the mayor by a specific contractual relationship (service contract or part of the municipal services) (3) *Mayors* are responsible for the development of transport infrastructure (road), garbage collection and disposal and sometimes of the development of local or isolated water infrastructure. (4) *District/settlement representatives* represent a group of families inhabiting an housing areas. Their interests and relationships types with the mayor depend on the type of settlement represented and the income level of the group of families (5) *Reservoir managers* control water allocation from the reservoirs.

3.2 - Actors with indirect action of land and water resources

All the interactions are being developed within a given specific institutional context (set of rules including legislation). State organisms (State Ministry of Environment for example) are in charge of the definition and implementation of this regulation. They are supported by agent in charge of the monitoring and enforcement of the law (CETESB, state or municipal inspectors).

To be complete, this framework should include other groups of interests such as environmental NGO, or agents from corporation linked to building and urbanizing activities - architects, engineers – In the context of the RMSP, their actions on the land and water resources are often indirect, executors in the development of infrastructure or settlement, trainers responsible for information and/or capacity building of local stakeholders. However studies have underlined the prominent role of corporation in urban water management in the context of European cities, as the main prescriber of technological solution (essential to diffuse water saving technologies) (Pahl-Wostl, 2002).

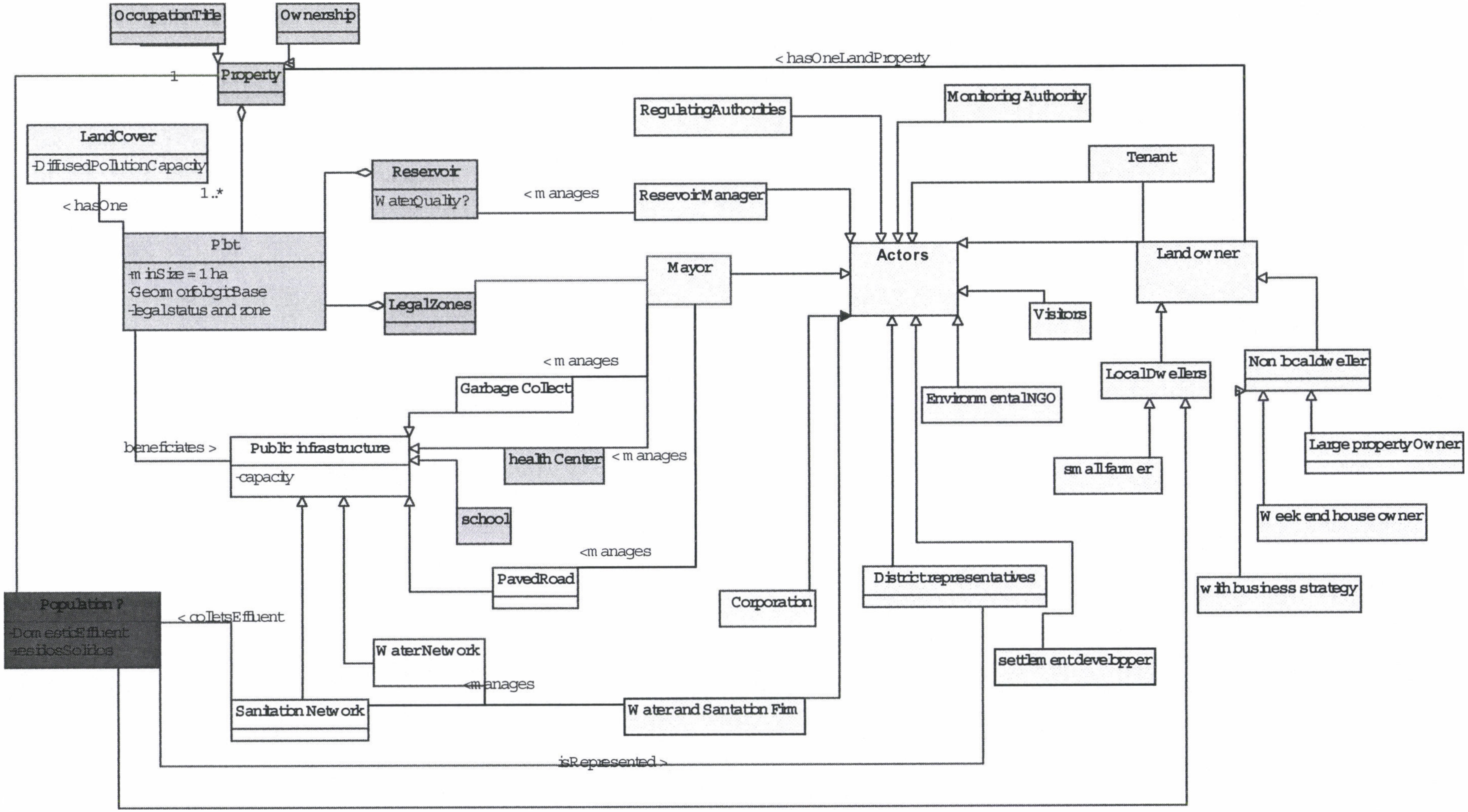
3.3 - Local dwellers dynamic

Urban population in this catchment may be very important (various thoursand of people) and the periurban population is still growing. Three different forces are responsible for the population growth :

1. District internal growth
2. Urban migration from the center of the city
3. A reduced flow of hinterland migration for either urban dwelling or local farming activities.

The different processes have still to be quantified.

Figure 3 : Interaction between actors and resources.



3.4 - Interaction between actors

Actors are interconnected by different types of relationships:
1. contractual link (municipality with water firm, tenant with land owner)
2. consumers-providers links which rely on a tariff payment against a service (water firm with connected urban dweller);
3. users– service link relying on a tax payment against the implementation and maintenance of public services (municipality with local dwellers);
4. a representation links (district representative with district population, elected mayor with local dwellers);
5. dependency links (low income district representative with mayor – Barban V. and al in this report);
6. administrative link (business-like landowner submitting a business project or housing project to be approved by the municipality);
7. socio-economic relationship (between landowner – local dwellers and visitors) with job providing or good offer or between landowners or landowners and population (land market processes);
8. information diffusion and capacity building (district representative and the water firm, or municipality in case of project development, Environmental NGO and local dwellers);
9. social relationships (between neighbour).

4 - Representation of the hydrological processes

The figure 4 represents the articulation between the spatial representation of the catchment with different land uses and the hydrological representation, based on a traditional arc-nodes representation. Aggregation of plots allows to represent biophysical territories such as catchment areas, or geomorphologic areas (wetlands areas, hilly areas or high slopes areas), with their different potential for land cover such as urbanization or farming activities.

The water systems is represented through a ordered sequences of nodes: storage nodes (divided into dam nodes and wetland nodes, as the manager is considering wetlands are a specific type of reservoir), contribution nodes (giving water to the system that can be divided in catchment and effluent treatment station) and demand nodes or consumption nodes that can be divided into potable water treatment, consumptive demand node (industry, irrigation) or pumping station.

This representation permits to represent each structuring hydraulic elements of the system through two types of representation: (1) as an hydraulic node (2) as a spatial representation (made of a plot or an aggregation of plots). Thus changes of land use at plot level will be able to be transformed into changes in water demand (new irrigation demand for example) or in pollution runoff. The representation of water quality has still to be detailed. Quality processes will include (i) diffused pollution processes resulting from run-off aggregated at catchment level depending of land uses, population density and sanitation infrastructure (2) pollution evolution in the reservoirs (3) risk of alga blooms depending of climatic conditions and eutrophication processes in the reservoirs

5 - Discussion: consequences for catchment management

5.1 - A generic representation of the periurban catchment of the RMSP

This framework underlines the different levels of management of land and water in a periurban catchment. It stresses the intrinsic integration of land market processes, land uses, infrastructure and urban services, and the evolution of water availability and quality in the periphery of São Paulo. Thus, a special attention has been given to articulation nodes between the different layers. For example, each hydrological unit (a reservoir, a catchment) is represented in the same time as a spatial element and an hydrological element. Actors interact on land use on their "property", a spatial unit defined by a land ownership title that links plots with a specific actor. Water Infrastructure is linking actors with the water resources, and specific actors are in charge of infrastructure development and management (maintenance, tariff collection).

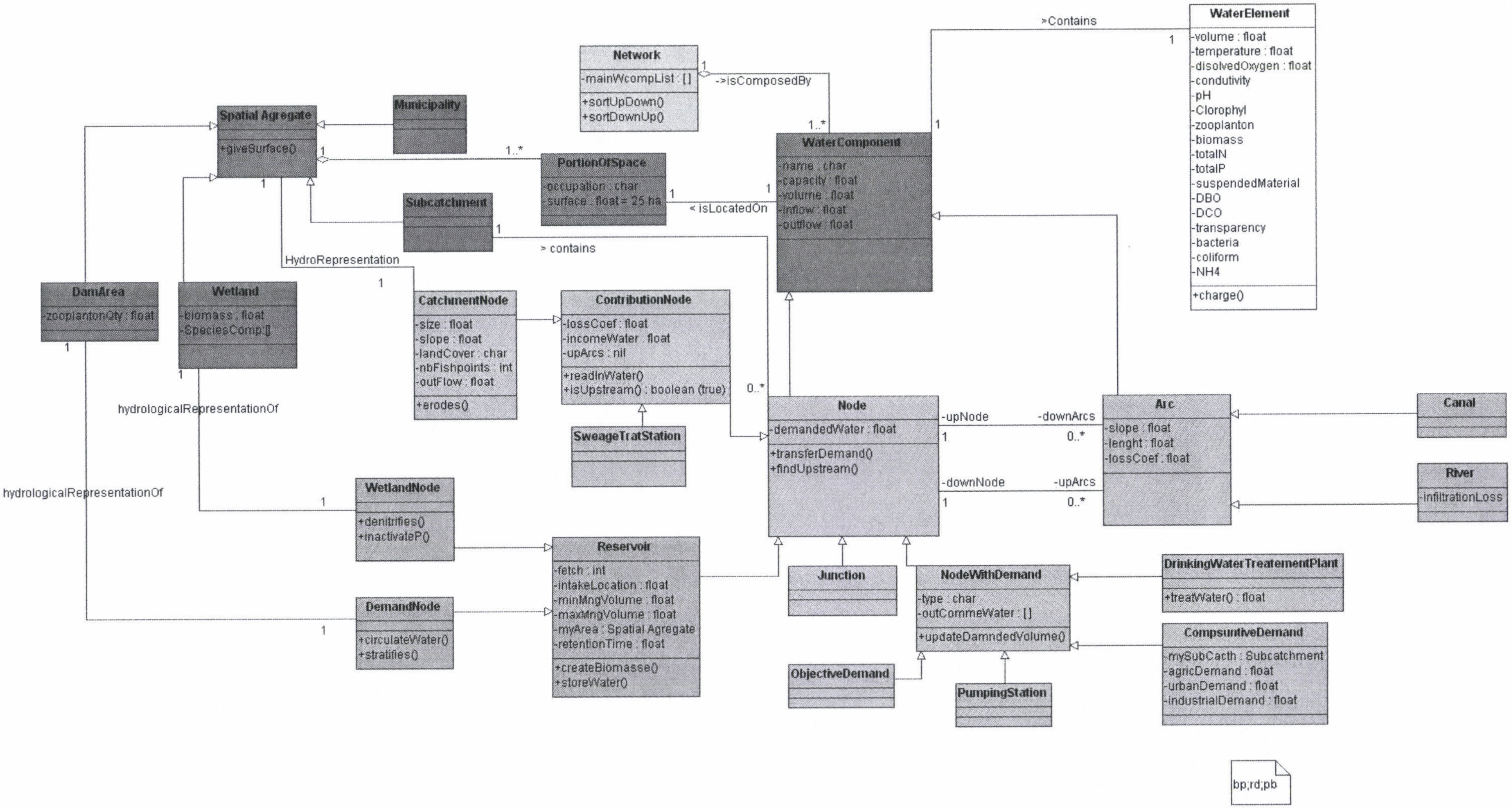


Figure 3: Representation of an periurban hydrological system (Brazil case study).

But this generic framework refers to a very specific situation: the head periurban catchment of a mega-city with a very centralized water service organization, and little variability of water uses at household level, and weak organization of periurban civil society. It significance in other periurban area such as the Bolivian case studied have to be discussed.

5.2 - Consequences for the catchment discussion bodies

The framework underlines the central role of municipalities in catchment management. Because of its role in land planning and territorial management and their ability to coordinate and amplify local preservation initiates, they should act as in interface between the water services firm, the catchment management authorities and local actors. Strengthening the local social, economical and environmental role of periurban agriculture to overcome the simplified representation of a competing and polluting use also supposes the integration of agriculture in the urban project (Fleury, 2004), not only a sectorial project at catchment level. However along with local community representation, municipality participation in the catchment negotiation processes remain insufficient (Jacobi and al, this report; (Neder, 2000)..

In a mega-city such as São Paulo, the articulation between municipalities within the same catchment is also determinant (Toledo Silva, 2003). There is no real integrated regional policy related to metropolitan management and co-ordination. Metropolitan management relies on the juxtaposition of various sectorial policies (transportation housing health, security) at the best defined at metropolitan levels (such as the transportation policy), and most of the case at municipal level. The water management model, that combines a regional objectives, a delocalised and participative implementation is even proposed as model for metropolitan management policy (Refinetti Martins, 2003). Different tools included in the legislation are aiming at facilitating the coordination between municipalities. The financial compensation between municipality is proposed in the Revised Law of Catchment Spring *(Lei de Proteção e Recuperação dos Mananciais*). This economic tool aims to orient financial transfer between economically developed municipalities with high demand in potable water toward municipalities specialised in water production and pollution control, which is incompatible with a high economical and industrial development pattern. While defined in the revised law, this compensation remains very vague and work have to be done to make this mechanism operational. Other tool includes the definition of pollutant charge norme at global level, that leave to the responsibility of the municipality such as the specific law of Guarapiranga proposed.

The framework divides actors and group of interests into two main groups: actors with direct action on land and water resources and actors with indirect action. It stresses the role and place of local actors which are actually badly represented in the discussion body (catchment committee) at sub-catchment level: these local actors are first viewed as land owners and resident and secondly as domestic water users. This stresses their main concerns which are securing land and housing conditions and household welfare. Local health and educational conditions, violence control, securing land title thus appear interesting terms of negotiation with local communities in the pursuit of better water preservation. Facilitating the participation of these local communities, taking into account their own priorities is a way to improve the functioning of catchment committee. It supposes the development t of specific tools to allow this less informed actors (or their representatives) to have access to information, as well to express their specific knowledge even if partial, local and non scientific. In the French Local Water Commission, the representatives argued that economical, political and cultural problems were more difficult two solve than the problem linked to the lack of scientific knowledge. Thus, more than scientific studies, members of this committee were eager for adequate board tabs, allowing to clearly present the information necessary for decision making (Latour and Le-Bourhis, 1995; Le Gal *et al.*, 2000). Such a need proved also to be useful in other collective and participative management bodies such as collective irrigated schemes (Le Gal et al., 2000).

5.3 - Some limits of the framework proposed

The framework results in an effort to organize the periurban landscape and actors in various categories. If the retained basic unit of one ha seems to adequate to discuss catchment and municipal planning, it does not allow for social action and urban intervention that deal with much lower scale : householdes, housing schemes etc As any typology, this structure, especially the boundaries between types, number of types, definition can be discussed. It results from a compromise between the complexity of the reality and the necessity to organize our representation and simplify it in order to permit action. Other typology can be been provided. Thus Nemczynowizc propose to differentiate mega-city landscape in four units (city center, existing organized suburbs, new organized suburbs, existing squatters area, unorganized new squatter area) where different type of waste water treatment options are relevant (Niemczynowicz, 1996).

The framework is being developed to support discussion and negotiation around two main issues: tensions between urban expansion and degradation of water policy and the place of agriculture in an urbanizing catchment. Thus, various important issues of periurban management are not taken into account in this model: for example drainage and flooding, which are strongly related to land use changes, land occupation solid waste collection. Another important issue not dealt with in this framework is the relationships individual infrastructure and management (septic tank, wells, pumping), subterranean resources, and superficial resources and public water access. Neither is waste water reuse, which is not organized in the periurban catchment even if various discussions are being held to institutionalize at federal and state level at least. Even if not acknowledged as such irrigators are however using diluted effluents for irrigation.

6. Conclusion

The framework was developed to facilitate knowledge and thematic integration in a multidisciplinary team. It permitted to propose a generic framework to account for catchment management for water availability and quality preservation in the context of the periurban area of a mega-city. The model, result from a compromise between the complexity of reality and a necessity to simplify and organize the information, to provide a generic interpretation frame that can be discussed and modified if necessary for action.

At this stage of development, this model provide only for a static representation of the periurban situation. Representation and discussion of possible evolution supposes to be able to build scenarios, accounting for evolution of strategy of land uses changes, infrastructure development and /or relationship between actors. We propose to use the framework to develop different tools that could support discussion processes. The tools are view as a way to materialize this representation, and discuss it and explore scenarios by simulation. Work with actors is necessary to adapt the framework to the specific situation studied. As thus, it can be used as a guideline to develop the specific tools.

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