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WATER RESOURCES AND URBAN PLANNING: THE CASE OF A COASTAL AREA IN BRAZIL

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Abstract: Urban planning requires the integration of several disciplines, among them ones related to water resources. The impacts of urban development on those resources, and vice-versa, are well known, but some aspects have not been well characterized in literature. This research analyzes a case that shows interesting relationships between urban planning, its legislation, the evolution of urban occupation and several aspects of water resources: groundwater, surface water, drainage and saltwater intrusion. The research argues for integrated and dynamic planning, monitoring and directive enforcement of the urban processes, including environmental dimension and water resources. Advanced decision support techniques are suggested as tools for supporting this integrated approach.

Keywords: Water resource management; urban planning; coastal areas; urbanization processes; coastal plains; methods and techniques of urban planning

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INTRODUCTION

Brazil is a country with a long coast. Historically, the need for communication with the colonizing countries made the first urban towns appear mainly on the coast or in coastal neighborhoods. "The urban towns, established in the first centuries of the Brazilian settlements, were placed predominantly on the coast, because of economic, administrative and military reasons. Exceptions to this rule were the villages of the São Paulo plateaus. The economic system of the Colony, based on the international labor division, compelled the little urban towns to depend greatly on communications with the Metropolis. It was natural, therefore, that they be located in connection with efficient structures of communication which were guaranteed, preferentially, through fluvial and nautical routes, either for the exportation of products that were the economic base of colonial life, or for the obtaining of manufactured products" (Reis, 2000).

According to the same author, during the Spanish domain (1580–1640), when Iberian control was established on the entire coast, the villages and cities with small farms in plains or almost flat lands had become common, such as Cabo Frio, *João Pessoa*, Ubatuba, Parati, etc. The motivations for urban growth in coastal areas seem to have changed, but in reality there is still a great migration of people to those areas. It is happening for economic interests (in the case of big cities) or tourist or leisure interests (in the case of small coastal cities that periodically receive a large number of visitors or temporary inhabitants).

In Northeastern Brazil, the biggest cities are located on the coast, and aside from these, there are many small towns that sometimes receive a greater number of people during certain seasons of the year, due to the great search for leisure on the northeastern beaches. In these areas, many times, the urbanization process does not follow the environmental restrictions, such as estuary preservation or ocean dynamics. With urgency, and without much planning, authorities are trying to increase the water supply to meet the increasing demands, or the peaks of demand (in the case of tourist areas), and to facilitate the drainage of undesirable waters (pluvial, sewers, etc.). Braga & Ribeiro (2001) emphasize that, in general, there is not a concern for the impact on the water supply in its function of producing water and/or if this water is being used efficiently by society.

A common characteristic in these areas is the low topographical gradient that normally makes surface drainage difficult. Beside this, the high level of phreatic surface in rainy periods and the increasing imperviousness of the soil due to urbanization may cause floods. In this context, decisions for an effective water resource management in coastal areas must consider aspects inherent to the relationships between surface water and groundwater. For example, a controlled and monitored exploration of the aquifer, through water extraction from wells, could aid in surface drainage, as pumping in different locations along the area could help to lower the level of the phreatic surface and to minimize the occurrence of floods. However, these operations must be well managed, because exploration without rigorous control can lead to the scarcity of groundwater and the increase of saltwater intrusion.

Appropriate water management, seeking to reduce the surface runoff through the increase of soil infiltration, and, consequently, the refilling of the phreatic aquifer, represent an important practice to improve the usage of rainwater, minimizing flow peaks and reducing the deficit of water in dry periods (Pruski, 2001), besides minimizing the cost of the drainage.

Carmon *et al.* (1997) assume urban planning to be "water sensitive" if it considers the integrated water resource management (surface and ground water) in an urban environment. According to those authors, urban development must take into consideration the expected impacts on water quantity and quality of water sources (surface and underground) which will supply a determined area in the urbanization process and/or on the water used by this urban area (even if that water source is not geographically inside the city).

In this approach, Shamir and Carmon (1999) propose ways of increasing water infiltration (aquifer recharge) aiming to reduce surface runoff, which is a serious problem in very flat areas, such as the coast. Besides, some guidelines are suggested to help reduce the pollution of rainwater drainage that can enter the aquifer.

Nowadays, though decision-making processes in water resources have been more open and thus, more democratic than some time ago, their complexity increases with the insertion of so many levels of information, interests and ideologies. For example, ecological awareness and the crescent tendency of public participation are important characteristics and they demand changes of attitudes from official public managers.

Porto & Azevedo (1997) state that the sustainable development concept accepted universally nowadays demands strategic evaluation of the effects of the decisions, so that future generations are not harmed. Complex subjects, which some years ago were limited to technical spheres, need to be communicated and spread in accessible language to nonprofessionals, so as to establish communication channels that are appropriate for public participation (Souza Filho & Gouveia, 2001). In this sense, Porto & Azevedo (1997) state that the essence of the problem is in *how* to make right decisions about an area that is characterized by: "complexity, uncertainties of many kinds, the existence of conflicts, high investments, the need for long-term projection, constant changes through its lifespan, significant economical, social and environmental repercussions, and participation of heterogeneous groups in the decision making process".

COASTAL AREAS IN JOÃO PESSOA CITY

During the Cretaceous and Tertiary periods, an intense erosion phase in the northeastern region of Brazil caused the deposit of sediments, which created the formations that constitute the geological groups of Paraíba (Sandstone, Marls and Calcareous rocks) and Barreiras (Sandstone, Silt and Clays). These geological groups spread from the limits of the coastal belt, extending through the current continental platform. Sea level variations during the geological Quaternary period, resulting from intermittent glaciations and epeirogenesis movements, responded to the coastal erosion of the geological group Barreiras, originating the plains and coastal plateaus.

The plains and coastal plains correspond to countless portions of the Brazilian coast and usually these plains occupy very small areas. Generally, they are located at the mouth of rivers that flow into the sea, especially the smallest ones. They are very wide in the northern coastline and almost disappear in the southeastern coastline. Interspaced along the northeastern coast, these small plains are in areas of higher elevation, the barriers, which are also of sedimentary origin. These flat and low areas have been completely occupied by constructions.

The city of João Pessoa is located in the coastal zone of the State of Paraiba (**Fig. 1**). The city's area is of 210 km^2, and according to a population census taken by the Brazilian Institute of Geography and Statistics (IBGE) in 2000, it had 597 934 inhabitants, representing 15.3% of the total state population. Thus, it has the biggest population concentration of the State of Paraiba. The city presents a high urbanization rate and there is no rural zone. Non-occupied urban places correspond practically to preservation areas (portions of Atlantic forest, mangroves, Atlantic Coast restingas, lakes, dams, etc.) and recent allotments which still have not been occupied.

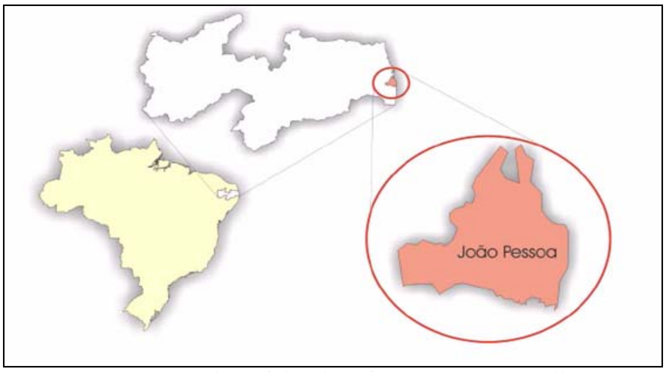

Fig. 1 Location of the city of João Pessoa, Brazil.

The João Pessoa coastline is extremely indented, forming inlets protected by reefs and interrupted in some places by river estuaries and wetlands, where there are mangrove swamps, which are under the constant influence of the tides (Nóbrega, 2002). The city has two predominant units of relief, the Low Coastal Tablelands (coastal plateaus) and the Coastal Plain (**Fig. 2**).

The elevated regions, corresponding to tablelands, are the largest extensions. They are sub-horizontal plateaus, with slight slopes in the direction of the coast. They appear drastically dissected in some sectors by the erosive cycle, creating steep slopes and strongly fitted valleys, with accentuated slopes at the heads. These plateaus extend to the coast, forming cliffs, which reach twenty or thirty meters of height. The sediments of the Beberibe geological formation and of the Barreiras group represent the elevated regions. Most of the city of João Pessoa, as well as its industrial district, are established on plateaus.

In the city of João Pessoa, according to Silveira (1997), soil occupation, and the type of organization of urban space, obeyed the limitations imposed by two basic factors: the proximity of the coastal belt and the proximity of the Paraíba River riverbed, besides other restrictions, such as the nature of the soil and the topography. The natural drainage system is formed by small and medium-sized urban rivers that make the geographical boundary between nearby cities.

Paraíba River is the most important river in the city, because it drains around 40% of its area. The remainder of the city has its natural drainage carried out by other small rivers (**Fig. 3**). The banks of these rivers have been suffering landfills over time, the springs of the smallest rivers are being occupied by constructions, and the growth of canalization of streams can be observed. All these interventions have been happening without the appropriate analysis of the problems involved. This analysis should require a vision of the greater drainage and consider the watershed as a unified project.

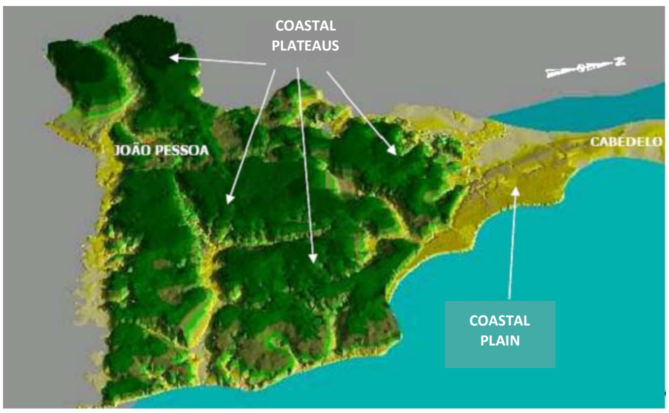

Fig. 2 Digital Elevation Model of the city of João Pessoa, Brazil (Rufino, 2004).

Fig. 3 City limits, location of Bessa district and the most important streams.

The city is developing in two main areas, the oldest urban network nearly always happening in the highest parts and the "new" city developing in lower areas, including the coastal plains. These coastal plain areas have low slopes and low quotas regarding the sea level. The area of study, known as "Bessa District", currently includes three districts (Aeroclube, Bessa and Jardim Oceania), according to the most recent official division of districts adopted by the city administration. It has an extension of 4.5 km in the north-south direction, varying in the east-west direction at about 1.8 km. In the west, it borders the BR-230 highway, in the east the Atlantic Ocean and in the north the river mouth of the old course of Jaguaribe River. Its area is 6.4 km² and its perimeter is 11.9 km (**Fig. 4**).

Fig. 4 Old district of Bessa (Bessa, Aeroclube, Jardim Oceania) and neighboring districts (color composition RGB from channels 5, 4 and 3; date of image: August 4, 2001, TM sensor, Landsat5 satellite).

URBAN EXPANSION

The urban drawing of João Pessoa resembles a "patchwork quilt" due to the restrictions of its geographical site and some tendencies of urban growth verified through its history. Silveira (2001) states that the space of João Pessoa city is marked by special characteristics from its natural landscape and these characteristics determine its change in space and time. Thus, the changes observed in Bessa district throughout the last three decades have a strong relationship with the natural characteristics of this area.

On the map presented in **Fig. 5**, some vectors of growth of the occupation of urban land in João Pessoa can be observed. The district of Bessa is located in one of these vectors - the northern vector - that indicates the urban consolidation of the Atlantic coast restinga between João Pessoa and the neighboring city of Cabedelo, with the occupation of the eastern edge of the BR-230 highway. According to Rocha (1996), it was in the period from 1977 to the middle 80's that the greatest modifications in the scenery of the restinga took place.

The intensification of the process of land allotment resulted in a great reduction of the vegetation covering the area. This devastation was caused by the opening of twenty-seven new land allotments, some dated as far back as the end of the 70's and others introduced in the beginning of the 80's. In parallel to the process of land allotment, an equally important fact occurred during this period: the acceleration of the construction process in the restinga. This can be noted by the surprising increase in the number of "certificates of occupancy" released between 1964 and 1995 (**Table 1**).

This fact is due to the increase in the number of secondary residences (residences that are used only a few times a year). Many of these properties belong to people that live in other cities of Paraiba State, such as in the city of Campina Grande. Since the early 70's, these people have gradually been acquiring properties at Bessa Beach and in other adjacent beaches to the north

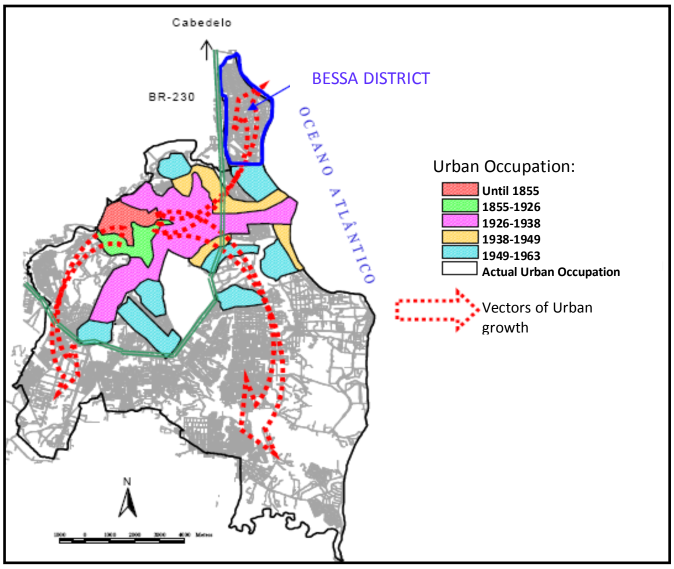

Fig. 5 Vectors of urban growth along the years.

Table 1. "Certificates of occupancy" released in the area of restinga in João Pessoa city (adapted from Rocha (1996))

Period	Number of "certificates of occupancy" emitted
1964 a 1970	16
1971 a 1977	131
1978 a 1985	360
1986 a 1991	1 724
1992 a 1995	1 934

(Formosa Beach, Camboinha Beach and Poço Beach). On the other hand, in the 80's, mainly at Bessa Beach, these residences were gradually turning into fixed residences, because they represented the option of living near the coast both for residents who already lived in João Pessoa city, as well as for new residents of the city (immigrants from other places in Paraíba or from other states).

Although presenting a substantial increase, the construction process in the district was initially limited to the first blocks of sea front. According to Rocha (1996), that can be explained by some urban equipment implanted in the district, such as the paving of main streets and the construction of pluvial galleries. Another impulse for this process was the introduction of running water supply in the end of 1991.

The accessibility to the area was also another important factor for this urban process. The facilities offered by a coastal road along the sea belt, connecting the *Bessa* district to *Intermares* and *Poço* districts (to the north), whose accesses until then had been only by BR-230 highway and by secondary roads, was an incentive to the real estate business sector. The urban expansion in this area practically devastated the existent restinga vegetation (**Fig. 6**), and this has been causing very strong geo-environmental changes, aside from serious problems of flooding, especially during the rainy season.

FLOODING: FREQUENT PROBLEMS

Bessa district, as well as other urban areas located in these coastal plains, has been suffering over time with a problem that brings very serious environmental, social and economical consequences: flooding. Occasionally, some streets from this district are completely covered by the water resulting from the deficiency of the pluvial drainage associated to the frequent outcrop of phreatic surface (**Fig. 6**). Bessa is the widest area of the coastal plain of João Pessoa; it is also the beginning of the restinga vegetation that forms the city of Cabedelo. Having almost two kilometers of width and being entirely flat, this district has a greater difficulty of drainage of pluvial and sewer waters than other coastal districts. Added to this is the fact that the phreatic surface is outcropping in the summer, and a great quantity of rainwater is accumulated in the winter and does not run off or permeate.

Nóbrega (2002) analyzes some of the causes of this flooding and insists that the land allotments in Bessa district were designed and launched into the market in

Fig. 6 Bessa district, Winter 2009.

their natural land status, with the idea of maximum usage of the area for city blocks and lots of land for building. During the project of these land allotments, small streams and seasonal ponds were not taken into consideration, because they only accumulate water in the rainy season. When the lots were sold, their owners filled in the small depressions in their properties. These were, in fact, the cited ponds and streams. They did this completely unaware of what those ponds and streams represented in the environmental set. Consequently, the natural flow of drainage of pluvial waters was interrupted, causing post-occupation flooding. A mosaic of aerial photos from 1976 (**Fig. 7**) shows the Bessa district when it still presented its natural characteristics, such as the preserved wetlands and coastal strands, although it was already possible to observe the outline of main streets. The aerial photos from 1998 (**Fig. 7**) show the intense occupation of the Bessa district, and comparing the two photos, which represents an interval of twenty-two years, it is visible that there was a massive occupation of the plain, totally disregarding natural drainage.

In relation to management and distribution of urban equipment in the area, it was only at the end of the 90's (after the entire urban expansion process was consolidated), that the first urban equipments were introduced. For example, the paving of the main streets between Bessa and the neighboring district (Poço), the expansion of a running water supply system, and the beginning of the construction of drainage canals in Bessa, were performed as a solution to the frequent problems of flooding in the area (Rocha, 1996).

While these interventions gave the necessary infrastructure for urbanization, they unleashed other problems for the users and residents of this district. The paving of some streets, for example, lifting up the level of the roads, left some residences in lower levels (**Fig. 8**).

In this case, there was a real need to elevate the street level; however, this fact caused some drainage problems in the neighboring areas, such as the


Fig. 7 Orthophotos mosaic of Bessa district (a) in the beginning of its urban expansion (1976), and (b) with its urbanization in consolidation phase (1998).


Fig. 8 Backup damming of natural draining caused by implantation of street networks in 2000. (Nóbrega, 2002)

accumulation of the surface drainage of rainwater, aside from contributing to the reduction of the infiltration area (Nóbrega, 2002). Furthermore, the increase of the level of some of the streets represented an onus for the residents, owners or tenants of the affected properties.

CANALIZATION OF RIVERS

Cavalheiro (1995), analyzing the environmental alterations caused by urbanization, emphasizes that in relation to hydrological aspects, the ideal ecological approach is for the waters to flow as slowly as possible, so that the biomass production is great. In the cities, it is ideal for the waters to arrive rapidly to drain in great speed. Frequently, to solve problems connected with floods, municipal administrations make canals or rectify the streams and rivers that cross their cities, and very often they use the old streambeds, or the edges of the created canals, when they are introducing road systems.

This attempt to ease the drainage of undesirable waters in urban areas by waterproofing canals solves some flooding problems, but on other hand, it has brought serious environmental and landscape problems. Tucci (2001) reports that this type of solution follows a pattern of solving only a section of the watershed, without predicting the consequences for the whole watershed, nor for different horizons of urban occupation. The canalization of critical reaches of streams merely transfers flooding from one place to another downstream in the watershed. In the study area, parts of existing rivers are already canalized (**Fig. 9**). From a geo-environmental approach, these engineering projects caused the disappearance of fauna and flora species, which were present around the edges of these drains. Significant alterations in groundwater flow have also already been observed.

Observing the natural elements of the landscape of this area, one can notice that there are close relationships between water and relief, soil, climate and vegetation. The vegetation interferes directly in the water behavior, for the retention of water in the ground is proportional to its vegetation mass. The elimination of vegetation, when it is removed from protected spring areas for canalization, reduces ground protection. The permeated water increases the levels of phreatic surface, many times making them emerge. Besides, there is a high rate of evaporation, which is a normal characteristic of coastal areas, and a high level of precipitation in the area (approximately 1700 mm/year) concentrated mainly during four months of the year: April, May, June and July (70%). The flat relief and the predominance of sandy soils make this area become sensitive to flooding due to the level of the phreatic surface, which is superficial and elevated (Rocha, 1996; Vieira *et al*., 2001).

SURFACE DRAINAGE AND GROUNDWATER

In coastal regions, as those analyzed, the study of phreatic aquifer behavior is very important to supply subsidies for surface drainage designs. It can indicate the best configuration for the outline of the drainage channels, considering the interference level they would have.

In Bessa district, the design of surface drainage did not contemplate hydro-geological aspects. In other words, for example, it did not consider the influence of the drainage channel construction on the phreatic aquifer, and vice-versa. The official state institution responsible for the environmental control, worried that such a construction could cause an undesirable elevation of the levels of the phreatic aquifer, demanded that relevant investigations be performed. According to the project, the collected waters are directed toward the channels (**Fig. 10**): (i) Channel 1: is launched into


Fig. 9 Sections of canalized rivers in Bessa (Nóbrega, 2002).

Fig. 10 Main drainage channels in Bessa district.

Channel 4; (ii) Channel 2 is launched into Channel 4; (iii) Channel 3 is launched into a wetland; (iv) Channel 4 is launched into both the Jaguaribe River and the old Jaguaribe mouth in Intermares Beach. The point of division is near the launching of Channel 2. The water coming from Channels 1 and 2 flows toward Jaguaribe River (Nóbrega, 2002).

The studies performed (UFPB/ATECEL, 1999) included the survey of the lithology of the phreatic aquifer and measurements of the groundwater level in different periods of tides (the measurements taken in the morning, with low tide, were repeated in the afternoon, with high tide). Tests of permeability for the determination of hydraulic parameters, to quantify the natural drainage of phreatic surface, etc., were also performed.

Some conclusions were obtained from these studies (UFPB/ATECEL, 1999; Vieira *et al.*, 2001): two situations, extreme and opposite, could be expected from the relationship between the channels and groundwater in Bessa. One of them would be the functioning of the canal as an artificial barrier interposed to the natural flow of groundwater, which would cause the elevation of phreatic level. This elevation would begin near the channel walls, and would be propagated by the great extension of the aquifer, completely altering its natural form.

In this case, the channel, although taking the drained surface waters away, would contribute to the formation of flooded zones, with marshy characteristics, due to the overflowing of the aquifer, supersaturated by the elevation of its level. The peaks of surface runoff would also be exacerbated by the impossibility of infiltration of rainwater into the aquifer, whose phreatic level was previously elevated, aside from other ecological and economical consequences of this situation.

Another situation expected from the relationship between channels and aquifer would be opposed to the previous one, i.e. that the channels would work like perfect groundwater drains, contributing to the reduction of the phreatic surface level around them, and all along the aquifer area. The consequences would also be opposed to the previous situation, and would favor the general drainage of the district, improving its habitability conditions. On the other hand, the border vegetation which depended on the high levels of the phreatic near the brooks and low areas would have a tendency of disappearing.

In the present case, according to the studies performed, *none of these extreme situations happened*. The newly built channels do not work satisfactorily as groundwater drains; neither have they worked as waterproof barriers. The groundwater flow can reach the channels, in reasonable quantities, through the expansion joints in the walls and bottom of the channels. In fact, this situation is caused by the fact that these channels were not designed to function as groundwater drains. Their expansion joints were planned to be release conduits of sub-pressure, and the channel itself as pluvial waters drains.

Thus, these studies concluded that, in the dependence of an appropriate and efficient operation, channels can accomplish this function of groundwater drainage, with its expected beneficial consequences. However, the lack of regular maintenance on the channels can lead to opposite consequences, since in the long run, there will be a natural tendency of the draining expansion joints to become obstructed by cementation or growth of vegetation. Worse than that, the obstruction of the channel by debris can create real internal barriers, which would immediately elevate water level in its interior, and in some areas cause an inversion of the flow, making the channel feed the aquifer.

The studies also showed that the aquifer is quite sensitive to human interventions. This was determined by the extension of the reductions from the phreatic aquifer, provoked by wells pumping in some points of the district, visible on all the maps of groundwater flow networks. The wells even interfere in the draining function of some of the channels built. This condition is particularly advantageous for *reducing* phreatic levels with the objective of improving the drainage conditions in the district.

In the future, if tendencies to permanent elevations of phreatic surface are perceived, the most viable solution, according to these studies, is the construction of groundwater collector drains located crossing the channels, with spacing and dimensions properly designed for the wanted effects of reduction. It is still possible to expect that the surface draining system itself and the waterproofing of infiltration areas caused by the quick urbanization process of the district will contribute to the reduction of the recharge rates of phreatic surface by rainfall, influencing the groundwater drainage.

LEGAL ASPECTS

For an analysis of the legal aspects inherent to a water resource management process in an urban environment, it is necessary to observe both the laws that govern urban planning, and the laws that are specifically related to the environmental aspects and water resources. Thus, this analysis includes the federal, state and municipal instances, since, in the last decades, the legal competence of deciding on some environmental and town planning aspects was attributed to state and local authorities. **Table 2** summarizes the regulations related to the case reported in this paper.

The matters that concern urban planning on a federal level are governed by Law #6766 from December 19, 1979. In a general way, this law regulated the proceedings inherent to urban planning, including the establishing in its 1st Article, Only Paragraph, that the States, the Federal District and the Cities could establish complementary principles related to their urban land use planning to adapt this Law to regional and local peculiarities. In this law, some basic demands are established for the permission of a land allotment. It seems that these requirements were not observed in the case of Bessa district.

Table 2. List of laws to support urban planning in João Pessoa

Year	Law	Level	Description
1965	#4771	Federal	*It will be considered of* ***constant preservation:*** *the forests and any other forms of natural vegetation situated:* ***in the Atlantic Coastal restingas****, as support for dunes or stabilizers for mangroves*
1975	#2102	Municipal	*Municipal Code of Urbanism*
1979	#2699	Municipal	*Zoning of land use was established and the use allowed for each zone was defined, as well as* ***rates and restrictions of occupation***
1979	#6766	Federal	*Land allotment* ***will not be allowed in marshy lands and lands subject to floods, before taking the steps to guarantee waters drainage; in lands where geological conditions do not make construction advisable***
1981	#4335	State	*It was established* ***COPAM and SUDEMA***
1990		Municipal	*Organic Law of João Pessoa*
1992	#3 e #4	Municipal	*Statutory Plan of João Pessoa*

Law #4771 from September 15, 1965, that established the new Forest Code, when it deals with forest preservation, set some guidelines that are applied to processes of urbanization, like that in this case. This law received a new edition through the Law #7803 from July 18, 1989. As to inspection, this law rules that the Union, directly through its specific executive agency, or in accordance with the States and Cities, will be responsible for the inspection of norms applied by the Forest Code (Law #4771). This way, it is possible to create essential services and, in the urban areas, the inspection is of the competence of the cities themselves, and the Union acting as a supplement.

The State legislation only began to include these matters as of 1981 with the promulgation of the State Law #4335, which gives COPAM (Council of Environmental Protection, established through this Law) and SUDEMA (Supervision of Environment Administration) the preventive, supervisory and repressive tasks in defense of natural resources. In accordance with this Law, COPAM, as a supervisory agency, and SUDEMA, as an executive agency, must stimulate the cities to adopt measures that rationalize urban development and expansion “within limits that guarantee the maintenance of essential ecological conditions” for public welfare (8th Article, § V).

As stated previously, most of the land allotments in the study area were approved and released at the end of the 70’s and all during the 80’s. The official administration of João Pessoa, aiming to restrict the indiscriminate use of urban land, prepared the Municipal Code of Urbanism in 1974. This code was ruled by Municipal Law #2102 of December 31, 1975.

The Urbanism Code establishes that for the approval of a street plan or a land allotment, at least some services are considered for recognition and acceptance of the urbanization land by the city administration. Among these are the implementations of networks of surface pluvial water drainage, including curbs and gutters, groundwater networks of pluvial water drainage, sewer drainage systems. These are the responsibility of the concessionary agency of these services and others (Article 111).

Subsequently this code suffered modifications with Law #2699 of November 7, 1979. Through the article 168, a zoning of land use was established and the use allowed for each zone was defined, as well as rates and restrictions of occupation. Among these, four special preservation zones were created, among which the corresponding area of the old valley of the Jaguaribe River is included, and the wetland formed by its mouth, the marshland located in the south-west portion of the area, which over the years has been a target of constant aggressions.

The local urbanism code reinforced what was already established by Federal law about land use (Law #6766/79), establishing in its article 91 that **marshy**

lands or lands subject to floods would not be allowed to be made into roads or allotted before **the necessary services of filling with land and drainage** were performed by the interested people. Beginning at the fact that this code was already in use at the end of the 70's, and that it seems not to have been considered for the liberation of the land allotments in the area of Bessa, it is possible to say that real estate interests prevailed over the damages, which can still be quantified in the current days. In 1990, the Organic Law of the city of João Pessoa was promulgated, which, in its articles 152 and 240, demands that the city have an Urban Statutory Plan. According to this Law, the Statutory Plan must be a document of guidelines that will direct the growth and the development of the city of João Pessoa up to the year 2010, undergoing periodic revisions every five years (article 240).

Supplementary Laws #3 (12/1992) and #4 (04/1993) established the Statutory Plan of João Pessoa city. This Plan is characterized by a set of guidelines for the planning, control and use of urban space, land allotment and land occupation, circulation, environmental protection, economical and social policies of development, as well as the necessary instruments for the implementation of these policies.

In its 4th article, the Statutory Plan considers the demand for the ordainment and management of urban space, according to the rule by Federal and State Constitutions and by the Organic Law for João Pessoa city. Specifically on the sea front, the Statutory Plan establishes restrictions of occupation, such as the maximum height of the constructions situated in a belt of 500 meters along the coast (article 25), besides updating the zoning established by the Urbanism Code. In this zoning, the portions of territory located both in urban and in rural areas, in which the social interest of preservation, maintenance and recuperation of landscape, environmental, historical and cultural characteristics impose specific and differentiated standards for land use and occupation, are considered special zones of constant preservation (article 39). The area of this study is included in one of these zones.

The revision of the Statutory Plan of João Pessoa is in the execution phase and the administration staff is preparing additional modules. One of these modules will pertain exclusively to the design and control of surface drainage. Currently, there is not a draft text of this module available, thus, this analysis is limited to the available guidelines in the referred and present legislation.

CONCLUSIONS

Urban planning is understood in this research as being a multi-disciplinary science project: in a rational and organized way, the distribution and adaptation of physical space has the objective of providing and maintaining worthy conditions of life to all the involved persons. In this sense, this planning has also to consider hydrological variables, in order to avoid problems like the ones that were identified through the developed case study.

Disorganized (badly planned) urban occupation causes changes in the physical characteristics of the watersheds and, consequently, of the entire hydrological cycle of a region. The relationship between natural and built environments is interactive and, when any of these parts suffers impacts, whether an environmental, structural, social or economical impact, the effects will also occur in other urban segments.

Through this text, urban planning impacts on water resources, and vice-versa, were shown and characterized in Bessa district and adjacent places: urban planning, its disciplinary legislation, the real and effective evolution of urban occupation, and their relationships with several aspects of water resources, such as groundwater, surface waters, their drainage and saline intrusion. Some important observations were:

(a) External factors (such as migration from other cities) had an important role in the urban occupation process;

(b) Although there were legal mechanisms to prevent a disorganized and predatory occupation of the water resources of the area, these were not used at that time by management agencies;

(c) The deviation of the Jaguaribe River was a consequence of quick and disorganized urban growth, and also stimulated a greater occupation of the surrounding areas of the river and, because of this, the whole fauna and flora estuarine was decimated.

The current legislation – through the Laws, Codes and referred Plans – already supplies the necessary criteria and guidelines to offer habitability conditions in terms of urban infrastructure, as well as predicting preservation measures that can still be adopted for the conservation of referred special zones (including the studied area). For the effective fulfillment of this legislation, integrated and dynamic monitoring and inspection of urban processes, including the environmental dimension and, within it, water resources, are necessary. For these actions to be efficient and viable, they need appropriate tools, like integrated systems of information (Maniezzo *et al.*, 1998) and numerical models of simulation of urban and environmental processes for the creation of management sceneries (Pettit & Pullar, 1999).

Urban planning guidelines could be established from the simulated sceneries (landscapes) using decision-making support tools. These guidelines for urban land occupation and water resource exploration could help supply the great demand caused by this occupation (for example, the concentration of demand in a place can be good to control the phreatic level: a stimulus to vertical constructions and visualization of the best scenery). The possibilities of a legal formalization of these guidelines can be investigated for inclusion in the Statutory Urban Plan of João Pessoa, since it is still in the research and consolidation phase, mainly regarding the module that deals specifically with urban drainage.

As examples to the appropriate aquifer management, which has a great influence on surface drainage, on saline intrusion and on the resulting urban problems (traffic of persons and vehicles, floods, damages to public and private properties, etc.), it can be suggested that, in the period without rains, squares and gardens be watered with phreatic water. This action could help to maintain the low levels of phreatic surface, waiting for the infiltration of the rains, and avoiding or minimizing the floods. Naturally, the operation of wells to maintain low levels of groundwater will demand the prediction of surface water and groundwater flow behavior and technical follow-up of their effects.

Thus, computer simulations might help minimize social and economical impacts caused by frequent floods in Bessa district, through the optimization of groundwater usage under some previously established conditions (Green, 1996). These suggestions of "non-structural" measures indicate a tendency in the search for management solutions for urban environments. The "structural" measures are those that require the construction of structures to obtain control of the runoff and quality of waters, such as the construction of dams or channels, the construction of water treatment stations etc. The "non-structural" measures are programs or activities that do not require the construction of structures, such as land occupation zoning, regulations against waste, etc. In areas with a high density of occupation, for example, although solving some problems, intervention through great engineering infrastructure projects can cause discomfort to the public in many aspects, such as expropriations, alterations in the traffic, etc.

Finally, joint interventions in macro and micro surface drainage of the district, besides a more rigorous control of land usage, might complement the efforts performed by this research, in the way of promoting an intelligent and integrated water management in this urban coastal environment.

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