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URBAN DRAINAGE TRENDS – A PATHWAY TOWARDS MORE SUSTAINABLE SOLUTIONS
TENDENCIAS DE DRENAJE URBANO – UN CAMINO HACIA SOLUCIONES MÁS SOSTENIBLES

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Abstract

Urbanization is certainly one of the man made actions that most influences flood aggravation and generates higher environmental impacts. Land use and population growth are critical issues for great cities, which suffer from floods, in a spiral cycle where they are also agents for worsening floods, due to vegetation removal, imperviousness and flow retentions reduction. Traditional practices of urban drainage design focus on end-of-pipe solutions, in order to adapt the network to the generated flows. Urban flooding is still often treated as a direct result of excessive rain, without regard on the basin behavior as an interrelated and interdependent system. The traditional approach for drainage system design is being supplemented or replaced by systemic solutions, with distributed actions over the basin. This concept has been gaining importance in recent years, configuring an integrated approach and launching the basis for a sustainable urban drainage system design. The diversity related to the urban flooding process makes this phenomenon difficult to assess. The interaction between the drainage system and the urban landscape structures produces complex flow patterns. In this situation, mathematical models may become an important tool in assisting the design of integrated flood control projects. A case study developed in Rio de Janeiro State and supported by a hydrodynamic flow cell model, called MODCEL, illustrates this discussion.
Keywords: Urban Floods, Sustainable Urban Drainage, Mathematical Modeling, MODCEL

Resumen

La urbanización es sin duda una de las acciones del hombre que más ha influido en la agravación de las inundaciones, generando así mayores impactos ambientales. El uso de la tierra y el crecimiento poblacional son temas críticos para las grandes ciudades víctimas de inundaciones, en un espiral donde ellas también son agentes que empeoran las inundaciones debido a la eliminación de vegetación, la impermeabilidad y la reducción de las retenciones de flujos. Las prácticas tradicionales de diseño de drenaje urbano se centran en soluciones de final de tubería, con el fin de adaptar la red a los flujos generados. Las inundaciones urbanas siguen siendo tratadas a menudo como un resultado directo del exceso de lluvias, sin tener en cuenta el comportamiento de las cuencas en tanto sistema interrelacionado e interdependiente. El enfoque tradicional para el diseño del sistema de drenaje está siendo complementado o sustituido por soluciones sistémicas con acciones distribuidas a lo largo de la cuenca. Este concepto ha ido ganando importancia en los últimos años, configurando un enfoque integrado e inaugurando la base para el diseño de un sistema sostenible de drenaje urbano. La diversidad asociada al proceso de las inundaciones urbanas hace que este sea un fenómeno difícil de evaluar. La interacción entre el sistema de drenaje y las estructuras del paisaje urbano produce patrones de flujo complejos. Ante esta situación, los modelos matemáticos pueden convertirse en una herramienta importante para contribuir a la elaboración de proyectos integrados para el control de inundaciones. Un estudio de caso desarrollado en el Estado de Río de Janeiro y apoyado por un modelo hidrodinámico de simulación de cuencas, llamado MODCEL, ilustra esta discusión.
Palabras clave: Inundaciones urbanas, Drenaje urbano sostenible, Modelo matemático, MODCEL

1. INTRODUCTION

Water is essential to life and the cities depend on this resource to develop. Ancient cities grew near watercourses and the rivers, in particular, were responsible for water supply, soil fertilization after floods, irrigation, waste conveyance, fluvial transportation and defense against invaders. The development of cities along time, especially after the Industrial Revolution, suffered a great acceleration and the consequences for the industrial cities led to several infrastructure problems, diseases and environmental degradation.

Nowadays, several cities of developed countries tend to integrate and valorize rivers as a natural resource and part of the urban landscape, trying to join natural and built environments. In developing countries, however, rivers usually suffer urban and social pressures, with irregular occupation of their banks, acting as conveyors of waste waters and presenting a degraded environmental situation. Late and fast industrialization is not always accomplished with appropriate urban infrastructure. Most times, these cities turn their back to the rivers.

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Urbanization is certainly one of the man made processes that most influence the aggravation of floods, especially from the consequences related to changes in land use. This is one of the major problems in growing cities in present times. Therefore, the cities suffer from floods, in a spiral cycle in which they are also agents of floodsworsening. It is very difficult to discuss urban flood control, in a sustainable way, without discussing the city itself, the land use and the urban development.

Statistics show that floods are the natural phenomenon that causes most damage and losses throughout the world. According to Freeman (1999), 60% of human life losses and 30% of economic losses caused by natural disasters are due to floods. Clarke and King (2004) show a map of disasters, related to floods, showing deaths and losses per continent. The numbers are impressive. In Asia, between 1992 and 2001, there were 50.034 deaths and losses of 105 billions of dollars. In America, there were 35.848 deaths and 31 billions of dollars in losses. In Europe, 32 billion dollars of losses were computed, with 1362 deaths. The number of great inundations is increasing exponentially along past centuries. According to a publication of the World Bank, (Jha et al., 2012), 178 million people were affected by floods in the year of 2010 and the total losses exceeded 40 billion dollars, in the same year. This increasing trend follows what is also happening with the world population and, more specifically, with the urban population. The built environment leads to the concentration of people and goods, increasing exposition and vulnerability, whilst helping to worsen floods. More and more people are becoming affected by flood events.

Flaws in urban drainage systems lead to the flooding of large areas. This situation interferes with the functioning of the entire city, affecting sanitation, housing, transport, public health, among others systems. This is an issue with technical, socio-economical, institutional and environmental connotations. The understanding of how urbanization affects the flooding process is a very important issue for proper planning and designing of urban drainage systems and flood control measures (when necessary). The urbanization of a watershed tends to promote the removal of the original vegetation cover, to occupy the riverine areas and the flood plains, and to increase imperviousness. Thus, larger volumes of water become available to flow more quickly and accumulate in low areas, often already occupied. When urbanization is not adequately planned nor controlled, more severe consequences appear. The cities grow and establish themselves as poles of attraction, receiving a migrant population, with illusions of a better life quality, but several times this population ends up in peripheral, impoverished and critical areas, conforming slums without infrastructure and sanitation. Figure 1, for example, shows a critical situation on Acari River Basin, in Rio de Janeiro city.

Figure 1: Scene from AcariRiver Basin, in Rio de Janeiro, Brazil. (Font: CityMunicipality – Rio-Águas, 2007)

Therefore, several challenges are faced by the urban drainage systems nowadays: population growth and fast urban development; uncontrolled land use and occupation; environmental degradation; excess of imperviousness and heat islands formation, due to local influence of urbanization, interfering with intense rainfall and increasing basin discharges; possible climate changes in a relative near future, increasing extreme rainfall events and the mean sea level. These problems need to be addressed adequately and technical solutions must evolve to face them. Engineering, Architecture, Urbanism, Environmental and Social Sciences must be considered in a multidisciplinary approach in order to meet sustainable standards for the urban development, integrating efforts towards practical solutions.

2. BRIEF HISTORY OF THE CITIES AND URBAN DRAINAGE EVOLUTION

It can be said that the main role as an agent of urbanization in ancient times was played by Rome. The Roman engineering stood out both in the context of buildings and monuments, as well as in fulfilling the needed infrastructure for a city to grow. Ferrari (1991) reports that in the fourth century AD Rome had more than 1 million inhabitants, 19 aqueducts able to supply the city with one million m³/day, sewerage system, paved streets, more than 45,000 buildings, some up to 8 floors, 80 palaces, and was protected by walls, in addition to a number of baths, theaters, amphitheaters, temples, and other monuments.

During the Roman era, significant advances were introduced in the design of urban drainage. Concerns about the urban flood mitigation and the need for lowlands drainage were very important to the city, settled on the riparian areas of the Tiber River, in a marsh region. To meet the needs of urban drainage, a complex network of open channels, landfills and underground pipes were built. This system was also used to transport sewerage from the housing areas (Burian and Edwards, 2002).

The fall of Rome led to the loss of importance of the cities and the urbanization process decayed during the Middle Ages. Europe has come to live in a state of almost permanent warfare. Concerns with sanitation deteriorated and the streets were used indiscriminately as the only means of disposal of wastewater and storm water runoff (Chocat et al., 2001).

The resumption of trade from the thirteenth century on was mainly a result of the recovery of the city importance. The Renaissance, on the fifteenth century, marks the movement to rescue knowledge of classical antiquity. Architecture and Urban Art converges to Urban Planning. At this time, also hydrology and hydraulics sciences began to develop faster.

Biswas (1970), in his book about the history of Hydrology, illustrates an interesting passage where Giovanni Fontana, studying the flood of the Tiber River in Rome, during Christmas 1598, pointed out several negative effects generated due to the lack of information from people who have settled their houses in marginal (and floodable) areas of the river and its tributaries. It is remarkable how this Fontana's observation could be repeated nowadays.

The Industrial Revolution marked a profound change in society, causing an increase in goods availability and services provision, associated with the effect of technical and economic transformations, increasing cities' attraction. In parallel, the Liberalism stimulated the reduction of public intervention in all sectors of social life, including urban controls, believing that the necessary adjustments would be provided by society. The consequences were critical to the cities - the urban growth occurred quickly and disorderly.

In this context, poor sanitation became a critical issue to urban life. Plagues easily spread bringing death in a large scale. Streets were used to convey both rainwater and wastewater. Urban floods began to increase in magnitude and frequency, what worsened sanitation problems, spreading contaminated waters over large areas. As a consequence, the role of urban drainage has become crucial in the life of cities. To face this problem, drainage systems were designed to fast convey and safely dispose storm waters. At this time, a hygienist phase took place in the drainage development, pointing directly towards improving flow conductance aiming to control water related diseases. This became the main objective of urban drainage systems until a few decades ago.

In developing countries, the late industrialization induced an even faster urban development and population growth, mainly on the second half of the twentieth century. Thus, the expected situation of buildings and structures designed properly, in a city governed by an urban development plan, referred only to a portion of the population. Another part had no formal access to the city services and had to organize on their own, in precarious and irregular conditions, with all the negative consequences of these agglomerations. Poverty and lack of infrastructure led to urban chaos. The formation of an irregular city near to the regular one has forced to reconsider the development of modern urbanism.

From the perspective of urban flood problems, considering this rapid urban growth over the last two centuries, it became difficult to simply propose drainage network corrections, such as canalizations, rectifications or pipe enlargement. Canalizations could not account for all urban flooding problems and, in fact, this approach tended to transfer problems to downstream areas, rather than to solve them. Engineering became aware that the existing infrastructure was being overloaded. Project solutions focused on the consequences of the urbanization process, that is, the runoff continuous increasing and this concept could not stand alone anymore. Increasing conveyance indefinitely was not the needed answer to this problem. Source control, acting on flood causes, using storage and infiltration measures, emerged as a new technical option in the 1970s (Andoh and Iwugo, 2002). An integrated approach, considering the river basin as the unit of work, became the basis for a sustainable urban drainage system design and several concepts were developed in this context, gaining importance along time.

3. URBAN DRAINAGE TRADITIONAL DESIGN

Traditional practices of urban drainage design are based on canalization works in order to adapt the system to receive and convey the new generated and concentrated runoff. This approach equates the undesirable consequences of the process, which are the greater and faster discharges produced by the built environment.

The urban drainage system comprises two main subsystems: micro-drainage and macro-drainage. Micro-drainage is the system of conducts constructed for receiving and conveying the storm water that flows from the urban surfaces (building roofs, lots, streets, squares, etc). The micro-drainage system is essentially defined by the layout of the streets in urban areas. The macro-drainage, by its side, is intended to receive and provide the final discharge of the surface runoff taken by the micro-drainage net. Macro-drainage corresponds to the main drainage network, consisting of rivers and complementary works, such as artificial canals, storm water galleries, dikes and other constructed structures.

In general terms, the urban drainage system design comprises the following steps:

- Subdivision of the area into sub-basins.
- Design of the network integrating urban patterns and natural flow paths, trying to match with topographic conditions.
- Definition of the design rainfall, considering a time of recurrence, depending on the safety desired for the project, and a time of duration, associated with the concentration time of each sub-basin considered – calculation is made step by step, as the sub-basins are summed to compose greater areas;
- Determination of design discharges through the Rational Method, for example, or another hydrological method, if convenient.
- Hydraulic design of each drainage network reach, using Manning or Chèzy formulas, to conduct the maximum discharge found in the previous topic. Sometimes, in the macro-drainage context, the channel design considers a maximum discharge produced by the watershed that contributes to the stretch of canal that is being calculated. Then, with this flow, the channel is calculated through backwater formulas, considering steady varied flow. Figure 2 shows a schematic view of micro and macro-drainage calculation.

This approach greatly simplifies the real situation. In the design context, it may not be serious, once all the calculations follow a certain pre-defined order and the effects are accumulated. However, discharges in a drainage system are, in fact, unsteady. In a situa-

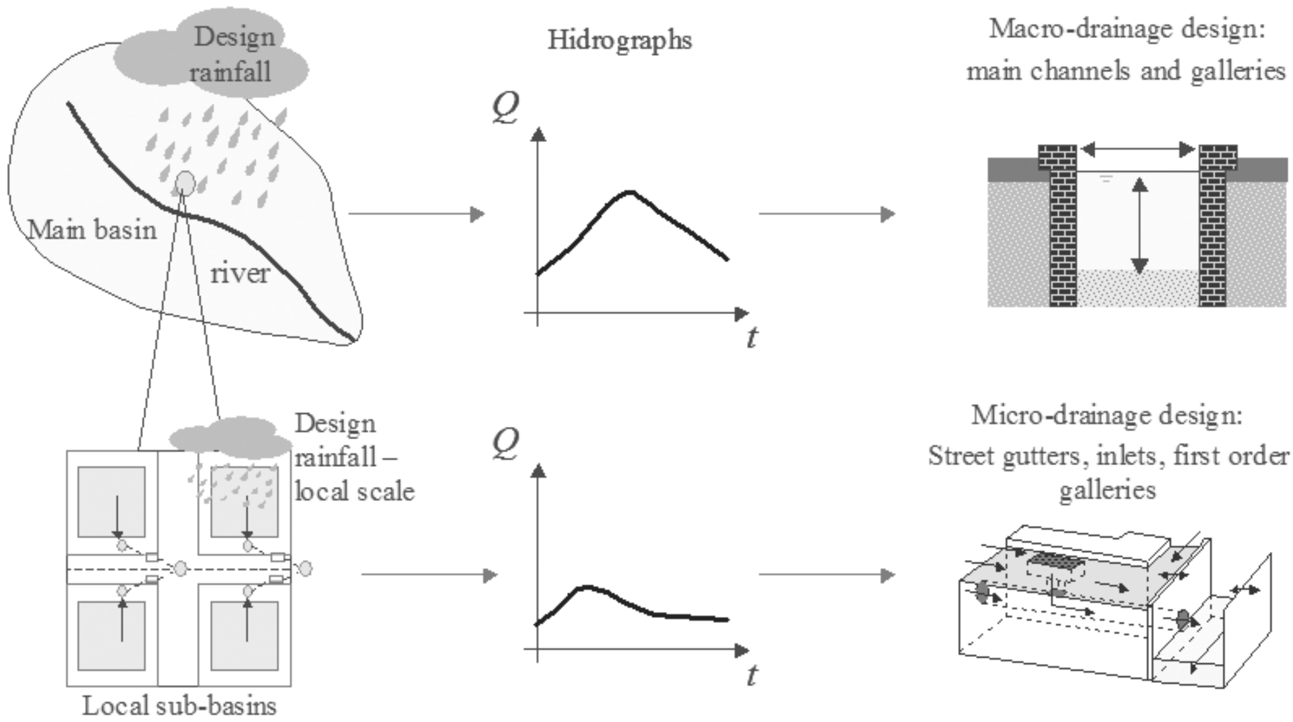

Figure 2: Schematic view of micro and macro-drainage calculation

tion of flood occurrence (drainage system failure), for example, with the project already implemented, it is not recommended to work in such a simplified form. Diagnosis is something that needs a systemic approach. The combination of effects in time and space becomes crucial for the assessment of flow conditions. Besides, closed conduits introduce an even more complex element, when the system fails. Under this condition, the design discharge is surpassed and flow under pressure may occur, replacing the basic hydraulic laws of free surface flow, which has guided the original project.

4. URBAN DRAINAGE DESIGN TRENDS

The traditional approach for drainage system design is being supplemented or replaced by newer concepts that seek for systemic solutions, with distributed actions over the basin, trying to recover flow patterns similar to those prior to urbanization. It is important to emphasize the necessity of systemic solutions, regarding the basin as the basic design reference.

These newer concepts, with little differences, highlight the necessity to reduce impacts over the urban water cycle, recovering (as close as possible) natural functions. Among these concepts, some are detached below as frequent references on urban flood control:

- Best Management Practices (BMP) –concept developed from the 1970's, working on the runoff generation control, regarding aspects of quantity and quality (AMEC, 2001). In Brazil, a similar concept was formalized more recently, considering the introduction of compensatory techniques to account for urbanization effects over flow patterns and urban water cycle (Baptista et al. ,2005)
- Low impact Development (LID) -in the 1980s, this concept appeared as an alternative for the urban water management, trying to recover the natural characteristics of the water cycle. The LID concept proposes the use of techniques that may be able to increase the local capacity of interception, infiltration and evaporation of the rainwaters, also increasing the opportunities for storage and slow the runoff generated by urbanization, in order to make it as similar as possible to the natural behavior (Walsh and Pomeroy, 2012; Ahiablame et al. 2012).
- Sustainable Urban Drainage Systems (SUDS) – this concept integrates aspects of flood control and urban design. Drainage systems can be developed to improve urban design, managing environmental risks and enhancing built environment. SUDS objectives account both for reducing quantity and quality problems and maximizing amenities and biodiversity opportunities (CIRIA, 2007)
- Water Sensitive Urban Design (WSUDS): this concept may be defined as an interdisciplinary cooperation involving water management, urban design and landscape architecture, combining water management tools and urban design approach and facilitating synergiesfor the ecological, economic, social and cultural sustainability (Langenbach et al. , 2008). WSUDS is related with a framework of physical sciences, social–economic sciences, community values and legal and institutional aspects (Wong, 2006).

New urban subdivisions must consider the challenge of developing urban areas without changing natural hydrological patterns (Souza et al., 2005). Storage and infiltration measures are considered together in integrated design solutions (Souza et al., 2012). Moreover, these new trends add concerns of water quality control, as well as enhance rainwater as a resource to be exploited in an integrated approach for sustainable management of urban stormwaters.

Besides, the possibility of combining flood control measures with urban landscape interventions, capable to add value to urban spaces (figure 3), with multiple functions, is becoming an interesting option from the point of view of revitalizing degraded areas, as well as the optimization of available resources and public investments.

5. MATHEMATICAL MODELING TO SUPPORT THE SYSTEMIC APPROACH TRENDS AND NEEDS

The occurrence of floods, with channel overflowing and surcharging of storm galleries, makes urban landscape structures start to work in order to supplement the network that failed. Streets begin to act as channels and these flows may gain independent paths. Transpositions may occur from a sub-basin to another, changing the patterns expected on the original drainage system project. Overflowing discharges may pass through several drowned inlets until they find the chance to return to the network. Flooded squares and public spaces start to act as reservoirs, damping flows and also changing drainage patterns originally planned. This situation happens in an undesirable way, once houses may be flooded in this process and several losses may occur. Eventually, lack of maintenance of micro-drainage can cause flooding, with harmful consequences, even when macrodrainage still presents capacity of flow.

The diversity related to the urban flooding process makes this phenomenon difficult to assess. The possibilities of effect combinations in space and time are not trivial. The interaction between the drainage system and urban landscape structures, which eventually acquire hydraulic functions, in a complementary way, produces an unpredictable drainage network, distinct from the one that was originally designed. Flow patterns developed on this new complex sys-

Figure 3: Examples of multifunctional landscapes – a detention basin in Santiago–Chile and a retention basin in La Rochelle-France. (Font: authors' personal collection, 2009).

tem is not known in advance. Thus, it is not possible to simply accumulate effects or compose a step by step calculation. Local solutions can lead to undesirable effects, with the simple transfer of problems. Apparently good solutions for different places may combine negatively effects due to temporal composition of the hydrographs generated. Sometimes, different interventions just overlay concurrent results. On the other hand, it is possible to generate better results, with extra benefits, when proposing adequate combinations of measures capable to join efforts in the desired direction.

In this situation, mathematical models may be able to assist in the design of integrated flood control projects, because of the possibility of conducting a systematic evaluation of the basin. The observation of different project arrangements can be simulated in various scenarios of combined interventions and future development hypothesis.

Many models, with different characteristics, may be cited, in order to illustrate the discussion on how to treat flood problems. Among these models, some free options are the SWMM - Storm Water Management Model, developed by the United States Environmental Protection Agency (EPA), mainly used for storm drains design, and the Hydrologic Modeling System (HEC-HMS), developed by US Army Corps of Engineers (USACE), which focuses on rivers or major drainage design. Presently, there are several alternatives of 1D-2D modelling, which seem to be the most promising alternative in this field (Leandro et al., 2009, Simões et al., 2011, Castellarin et al., 2011). A quasi 2D model, developed in the Federal University of Rio de Janeiro (UFRJ), charcterized by being a free and academic model, is MODCEL, which will be briefly presented here and then used in a case study, with the aim of demonstrate how critical an uncontrolled urban development may be, and alsocomparing an urban drainage traditional design with new trends in urban flood projects.

MODCEL

MODCEL (Mascarenhas and Miguez, 2002) is a hydrodynamic model based on the concept of flow cells (Zanobetti et al., 1970), capable to represent the urban basin in an integrated way, by building a network of compartments covering the entire surface. Each cell performs a rainfall-runoff transformation process and the connections among cells compose a network responsible for representing flow patterns. The mass conservation principle is applied for all cells and hydraulic laws are written for all flow relations. The several hydraulic laws are taken in a one dimensional way, although the space modelling creates a pseudo 3D representation. Two layers of flow are vertically connected. The superficial layer that represents the surface of the basin, joining streets, squares and open channels, interacts with the layer that represents the network of underground galleries. Figure 4 shows a schematic view of MODCEL, in a real basin of Rio de Janeiro city.

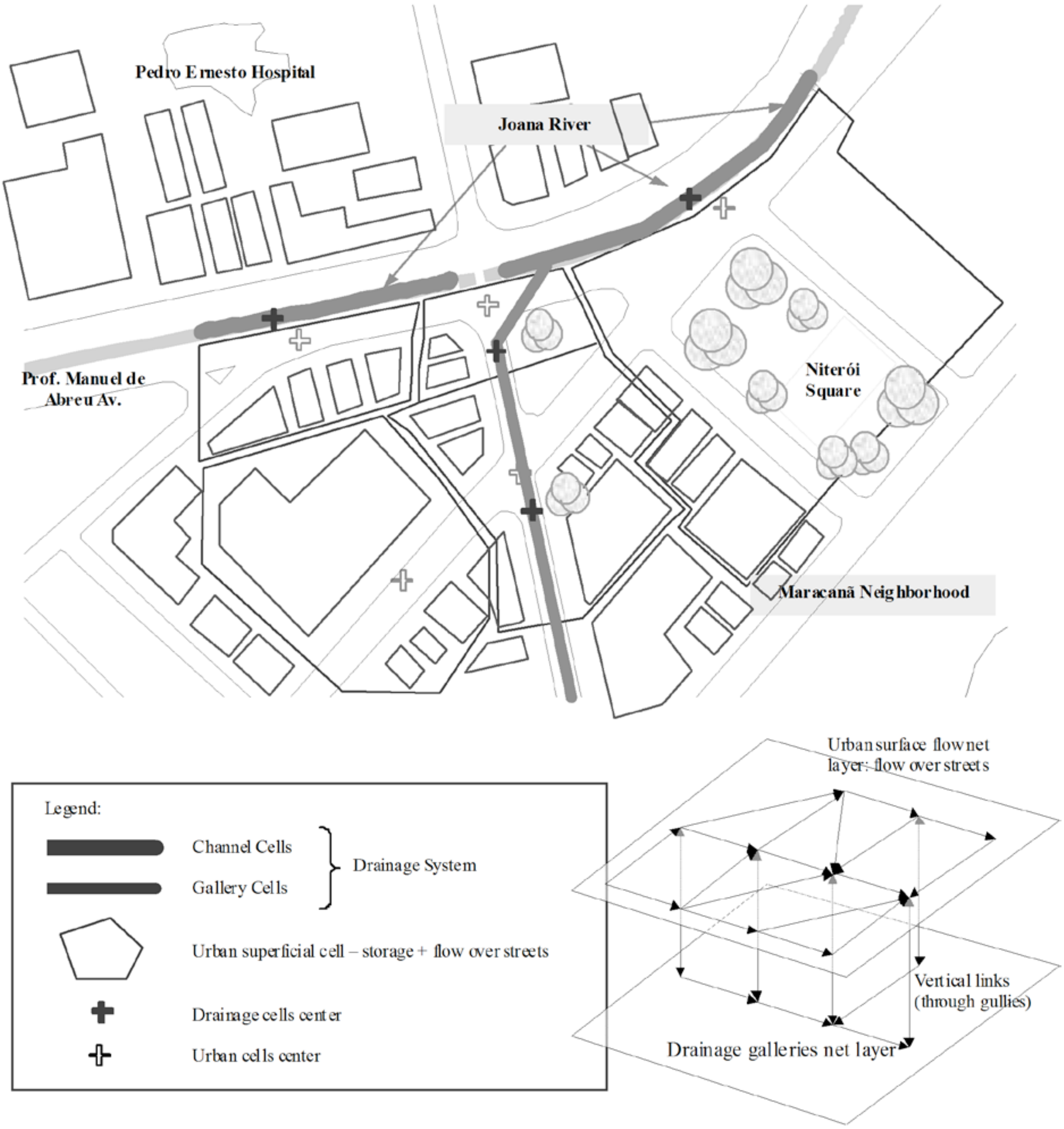

Figure 4: Schematic view of a MODCEL representation.

Case Study: Iguaçu-Sarapuí River Basins and the particular problem of Pilar-Calombé Rivers, at the Metropolitan Rio de Janeiro Region

A case study was developed for a heavily occupied and densely populated urban area, at the Metropolitan Region of Rio de Janeiro, in the Iguaçu-Sarapuí River Basin, located in the western portion of the Guanabara Bay. Figure 5 shows a map of this area, with the Cities that are inside this basin. This is one of the most critical areas in the state regarding urban flooding. The region presents great urban and industrial areas, as well as wide rural zones in an urbanizing process, and reminiscent areas of natural Atlantic Forest on the upstream reaches of the basin. This basin was included by the State Governmentin a Program of Environment Recuperation, and the Federal University of Rio de Janeiro was responsible for the flood control studies. The basin was modeled with MODCEL, in order to provide the basis for assessing present situation, prospecting future scenarios and proposing flooding control measures. There were very few measurements available for calibrating the model. In fact, there was one river gauge at Botas River, the main upper tributary of Iguaçu River. There was a set of four control points at Sarapuí River, associates to a previous hydrological Study and there were maximum levels registered for one single event on Iguaçu River. This set of information was combined to give a minimum support for calibration. At downstream, Guanabara Bay was represented by tide levels. Figure 6 shows the mapped flood conditions for present situation, represented over the modelled flooded area of Iguaçu River Basin. Figure 7 shows a future scenario considering that there will be no control on land use. Considering these situations, regarding present problems and the future perspective, a set of measures intending to control land use and recover storage capacities were proposed. In particular, several different areas were modelled in details, using the general model to provide the set of boundary information. One of these cutouts refers to the case study focused in the sequence and which is used to exemplify the differences between the two approaches discussed in this paper for flood control: the traditional one and the sustainable one.

The basin of the Pilar-Calombé Rivers, in the city of Duque de Caxias, at Rio de JaneiroState, in Brazil, suffers from floods, in a very low land, called Baixada Fluminense. This area is experiencing an important urban growth. The PilarRiver has approximately 11.3 km, and drains a basin with 10.8 km2 of surface area. The CalombéRiver has an approximate length of 9.3 km, draining an area of about of 15.0 km². The CalombéRiver is, in fact, a tributary of PilarRiver, arriving from its left margin. After the confluence, this basin flows to the IguaçuRiver, an important river of Rio de JaneiroState, mainly because of its localization in the metropolitan area and its outfall to Guanabara Bay.

MODCEL was used to construct a flooding map for the basin, considering a design rainfall of 20 years of recurrence time. Figure 8 shows the division of the basin in cells. The obtained flooding map can be seen in Figure 9.

In order to solve this problem, two approaches were developed in different design propositions. The first set of measures focused on the traditional approach, and the rivers conveyances were raised. Rivers were canalized in rectangular concrete sections, with sufficient capacity to avoid overbank flows. The second set of measures were based on urban waters sustainable management concepts and focused on:

Recovery of implemented flow sections, by cleaning local obstructions and redefining a trapezoidal section in natural soil;

Recovery of the vegetation in strategic areas of the basin, especially on hill slopes;

Recovery of natural flooding areas of the basin (riverine lowlands) and implementation of a floodplain river park along the right bank of Pilar River and at some parts of Calombé River, where urbanization is still not too dense;

Use of detention reservoirs in urban public squares.

After the simulation of the proposed scenarios, all flooded areas inside the basins of the Calombé and Pilar Rivers were mitigated, for both sets of measures. However, the traditional approach led to downstream flooding, where it did not happened before, as it can be seen in figure 10. Table 1 summarizes the discharge results for both scenarios, at the outfall of the basin. The concrete canalization approach almost doubled discharges to downstream reaches. The sustainable approach, however, solved the flooding problem without changing significantly downstream discharges.

CONCLUSIONS

The traditional end-of-pipe approach tends to transfer flooding problems downstream and require frequent investment to resize the channels in order to meet the needs of increasing runoff flows generated by the urban development. Cities are growing faster, especially in developing countries, and the urbanization is not always planned nor controlled. This is probably one of the main challenges that cities will face: rationalize land use and develop in a sustainable way. In this way, the sustainable management of urban rainwater provides a viable alternative to face the trends of urban floods aggravation. The recovery of hydrological functions and the reorganization of flow patterns in space and time may be the solution for urban flood control. In order to adequately assess the effects of a proposed set of measures, the aid of mathematical models may be very useful. The case study shown in this paper shows that it is possible to evaluate the present situation at the Calombé-Pilar River basin, to identify the problem of transferring floods downstream when canalizing the rivers, and to

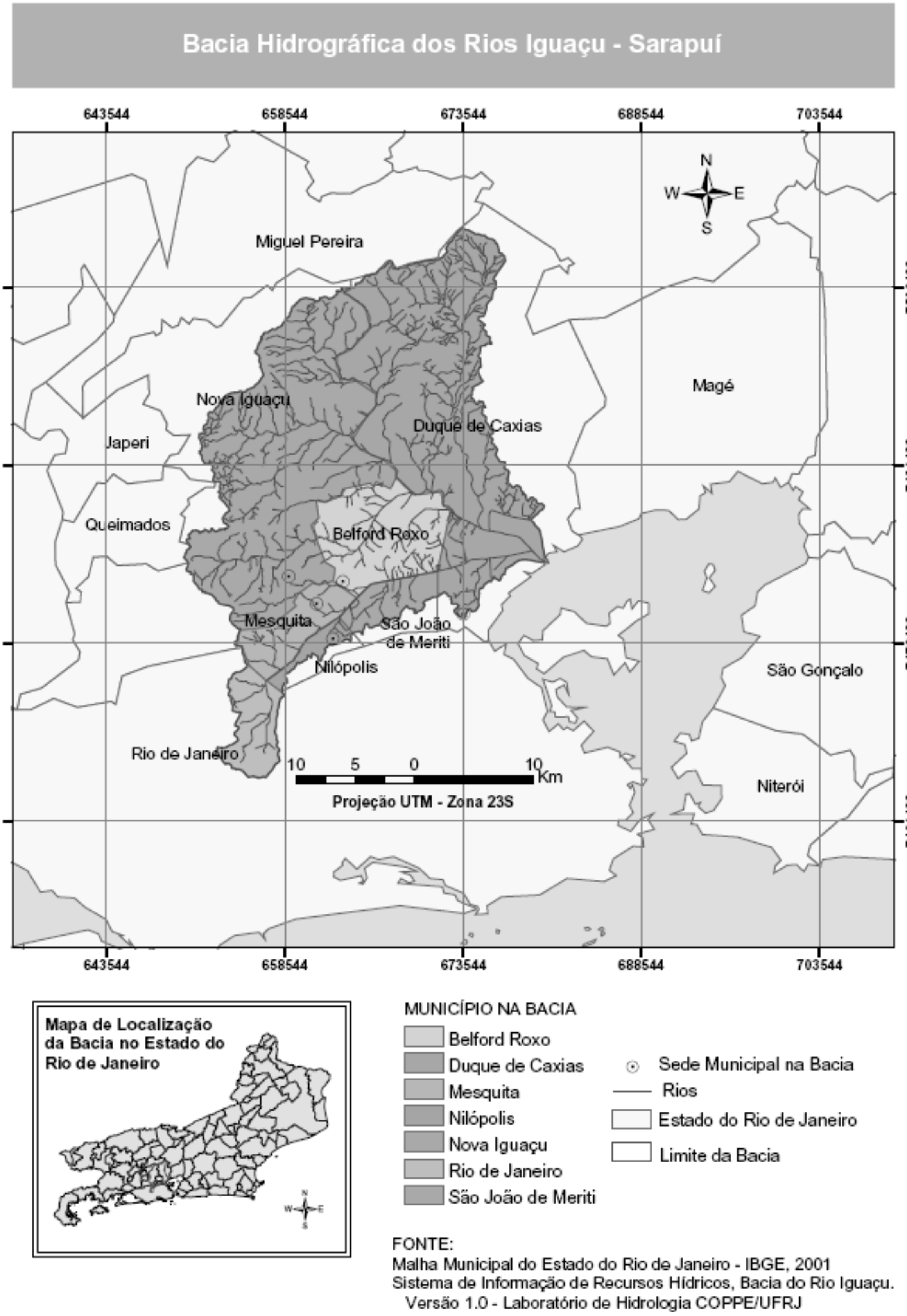

Figure 5:Iguaçu-SarapuíRiver Basin at Baixada Fluminense Lowlands in the Metropolitan Area of Rio de Janeiro.

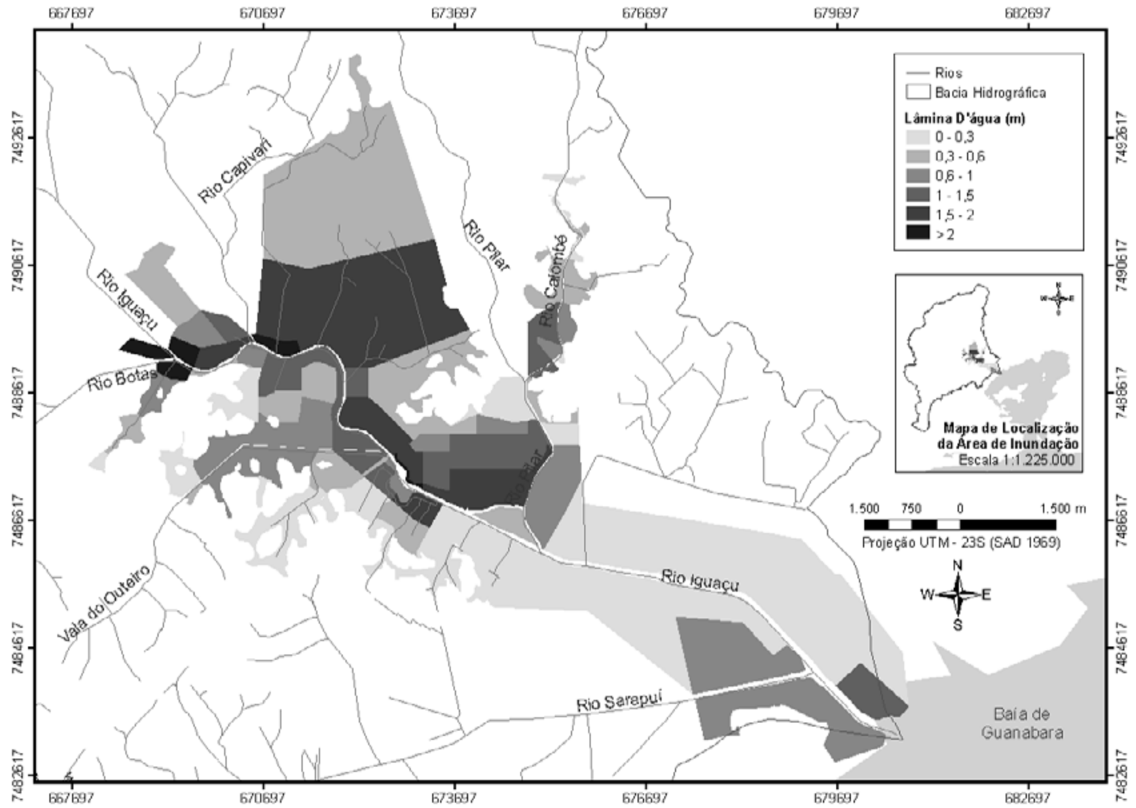

Figure 6: Flood map for Iguaçu River Basin, in the present situation, for a design rainfall of 20 years of return period, calculated with MODCEL

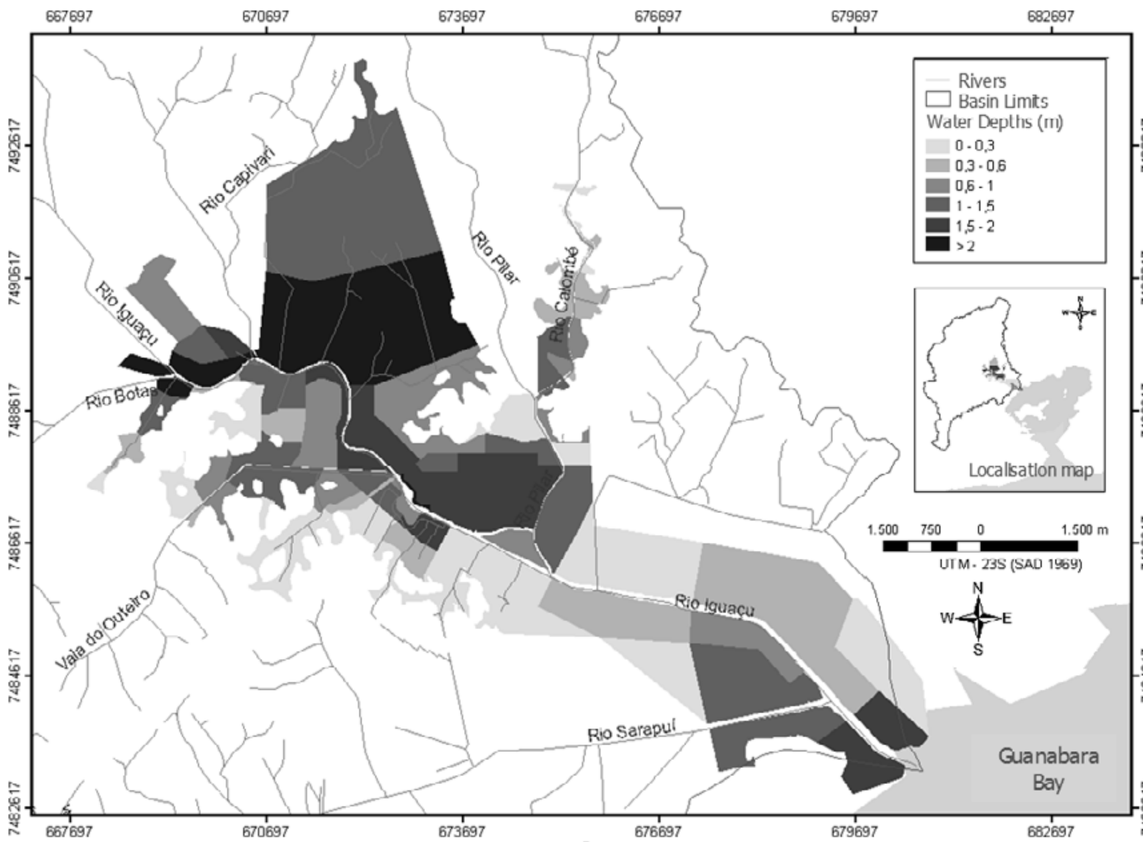

Figure 7: Flood map forIguaçuRiver Basin, in a future uncontrolled urban growth situation, for a design rainfall of 20 years of return period, calculated with MODCEL.

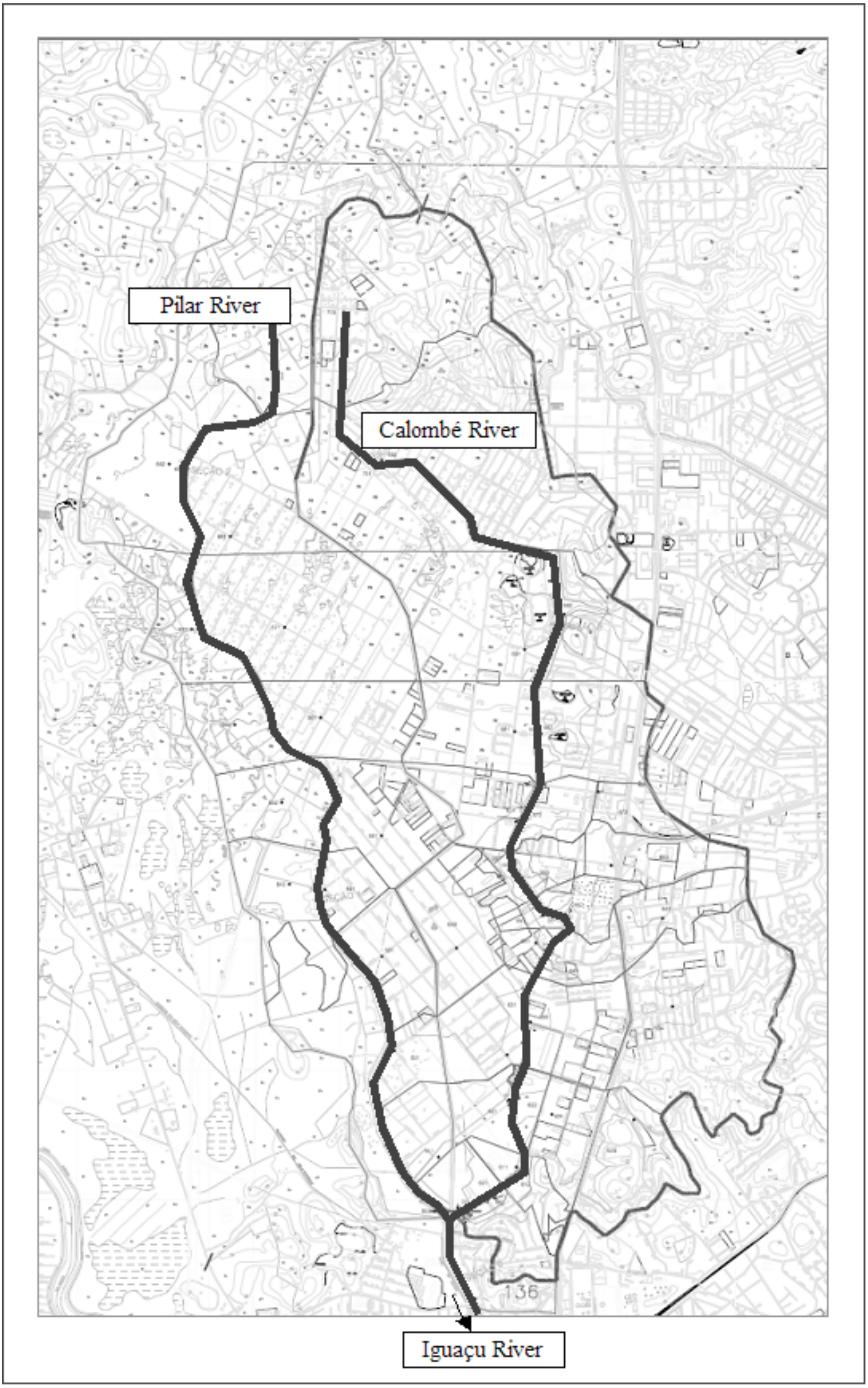

Figure 8: Cell division modeling for Pilar-CalombéRiver basin

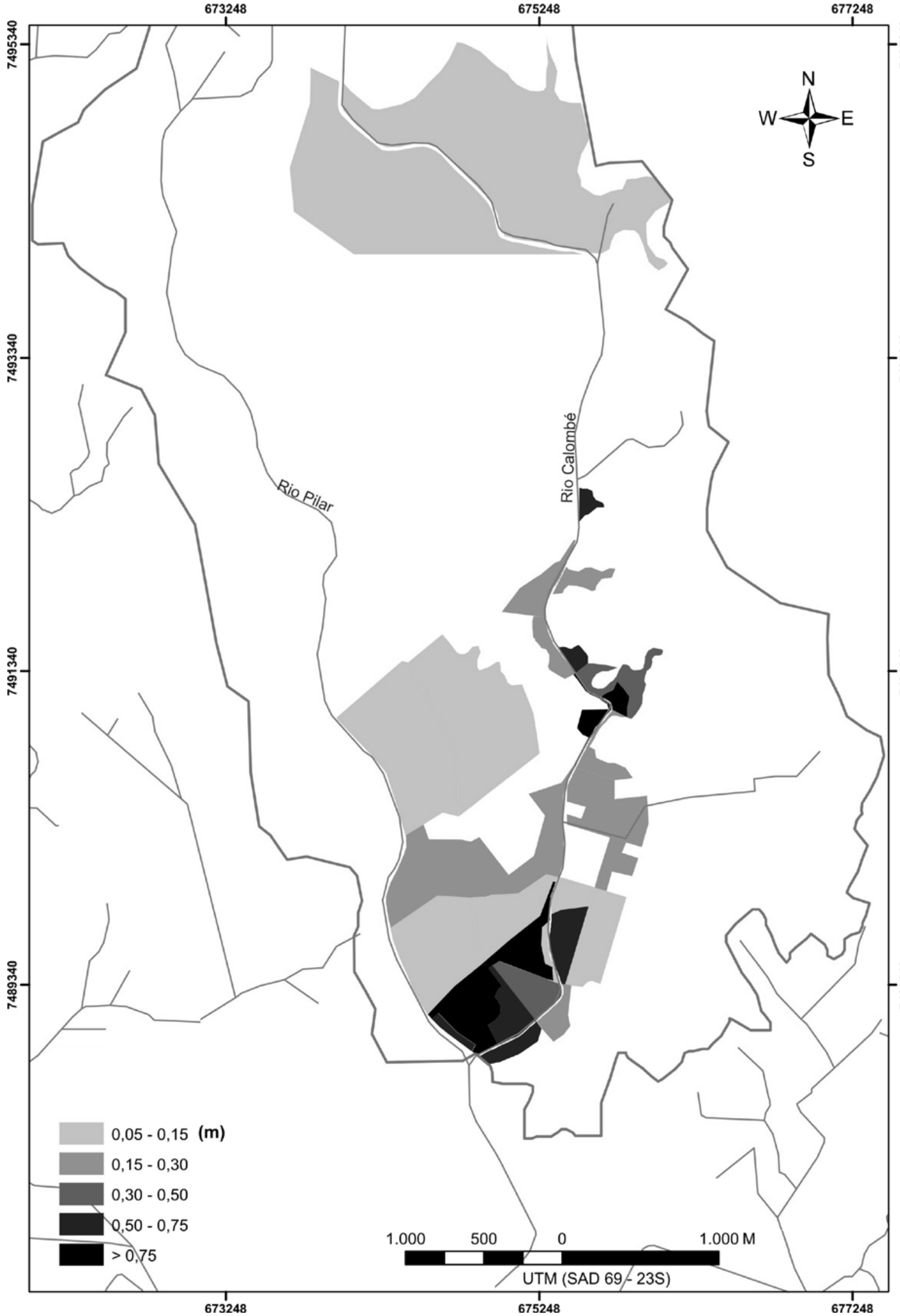

Figure 9: Flooding map for present situation – basin diagnosis

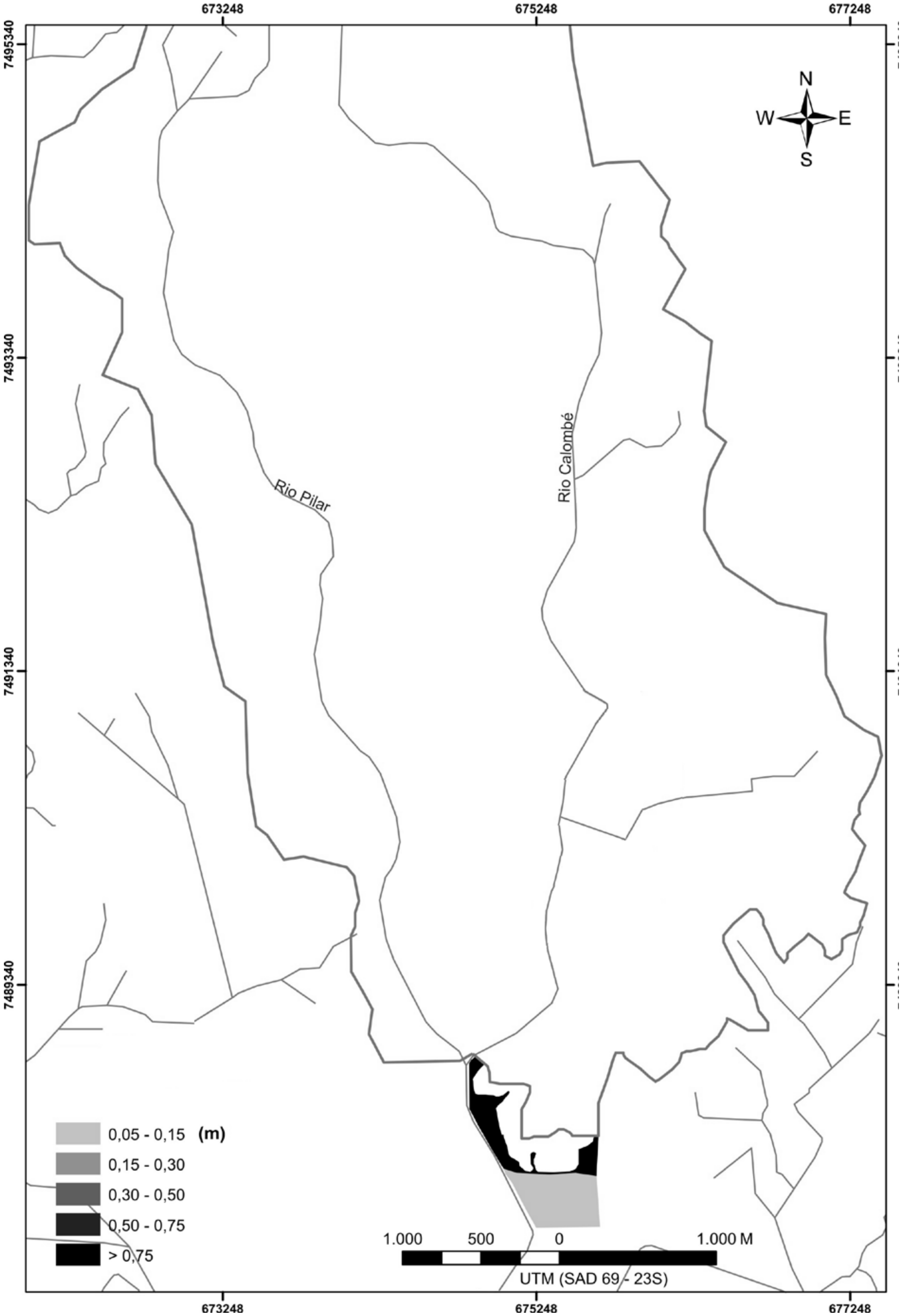

Figure 10: Flooding map for traditional canalization approach – flooding effects transferred downstream.

Tables:

Table 1: Discharges for Pilar-CalombéRiver basin outfall, considering different recurrence times.

TR (years)	Discharges on Macro-Drainage System Outfall		
	Present Situation	Canalization	Sustainable Approach
10	17,17 m^3/s	32,08 m^3/s	15,78 m^3/s
20	17,47 m^3/s	34,73 m^3/s	17,38 m^3/s
50	17,88 m^3/s	36,51 m^3/s	19,35 m^3/s

adequately simulate the distribution of storage measures over the basin, even outside the drainage net.

Urban flood solutions need to be discussed, planned and designed in an integrated way with the city itself, the land use control and the expected urban development.

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