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Urban drainage planning in Brazil

CARLOS E. M. TUCCI

Institute of Hydraulic Research, Federal University of Rio Grande do Sul, Caixa Postal 15029, CEP 91501-970 Porto Alegre, RS, Brazil

Abstract Planning an urban infrastructure is especially difficult where the increase of urbanization is rapid and where the Urban Master Plan does not take into account its impacts. In the major cities of Brazil, one of the main impacts has been increased peak flows, which also increase flood damage. In Brazil there are more than 12 cities with populations greater than one million. The main difficulties are: (a) lack of an urban drainage master plan; (b) uncontrolled invasion of public green areas by the poor; (c) illegal developments near the city boundaries; and (d) unplanned public drainage works. These actions have created a large cost for the population and the township investments. This paper describes these main problems and the impact of the unplanned procedures and outlines the actions which cities can follow to reduce the impacts of urbanization on drainage. The paper also describes the flood control strategy being implemented in the Metropolitan Area of Curitiba in Brazil.

La planificación de la infraestructura urbana en Brasil

Resumen La planificación de la infraestructura urbana es especialmente difícil en lugares de rápido crecimiento de la urbanización y donde los Planes Maestros no toman en cuenta sus impactos. En las principales ciudades de Brasil uno de los mayores impactos ha sido el incremento de los caudales máximos que también aumentan los daños ocasionados por las crecidas. Brasil cuenta con más de una docena de ciudades con poblaciones superiores a un millón de habitantes. Las principales dificultades son: (a) falta de un plan maestro de drenaje urbano; (b) invasión descontrolada de los espacios verdes públicos por la población marginal; (c) asentamientos ilegales próximos a los límites de las ciudades; y (d) no planificación de obras públicas de saneamiento. Estas acciones han significado altos costos para la población y elevadas inversiones para las autoridades municipales. Este trabajo describe los principales problemas, el impacto de los procedimientos no planificados y señala las acciones que pueden adoptar las ciudades con el objetivo de reducir los impactos de la urbanización sobre el drenaje. También describe la estrategia de control de crecidas que lleva a cabo el Area Metropolitana de Curitiba en Brasil.

URBAN DRAINAGE DEVELOPMENTS IN BRAZIL

At the beginning of this century, only 15% of the world's population lived in cities; by the year 2000, it is estimated that this percentage will have risen to 50%. In Latin America and Caribbean countries, urban population growth is from 3 to 5% a year. At the turn of the century, about 30–35 cities in the world are expected to have above 10 million inhabitants (Foster, 1990). In most developed countries the urban population is above 70%.

In recent decades, Brazil has had a high urban population growth mainly in the Metropolitan Regions, which are usually the State capitals. The present urban population in Brazil is about 80%. This population growth in the major cities occurred without any urban drainage planning. This had, as a consequence, the followings impacts:

- occupation of the river flood plains by the population, which increased flood damage;
- increase in flood frequency due to the basin urbanization.

One of the main examples of this is the Tiete River in São Paulo city. The river valley has been occupied since the beginning of the twentieth century. The government has increased the river flow capacity, and the flood frequency decreased for some years, so that population density increased in the flood plain and upstream. Flood peaks and their frequency increased again following urbanization, and flood damage also increased. Today during the rain season there are more than five events creating large damage (to private property and public infrastructure), high cost (traffic jams) and lost income due to difficulties in mobility. The actual cost of improving the capacity of the main channel is more than US$1 billion.

Brazilian cities have been developed according to Urban Master Plans, which usually do not take account of the impact of urbanization on drainage flow. The impermeabilization associated with upstream development transfers its effect downstream, resulting in flood increase. Usually the city engineering departments do not have the hydrologic support to cope with this problem; engineering works such as channels and pipes are designed without taking into account the possible downstream impacts, where built-up areas leave no space for impoundment during flood events to decrease peak flows.

The concept basic to the design of stormwater drainage works is to drain water from urban plots as quickly as possible through pipes and channel networks. However, this increases the peak flow and the cost of the drainage system. There is no control of peak increase at microdrainage level and most of these impacts will appear in the major drainage.

To cope with this problem, city and state administrations have developed many works such as channels in the major drainage network and pipes in the secondary drainage network. This type of solution has only transferred the flood problem from one section of the basin to another, with costs from US$2–50 million per kilometre of channel.

Besides this lack of planning in the drainage network, the municipality has many difficulties in enforcing legislation, as follows:

- Due to the high urbanization increase, most of the new developments within the city boundaries are not approved by the township and do not have the required facilities, such as stormwater and sewer networks. This arises from lack of control.
- There are public areas, such as planned open spaces, which are invaded by slums due to the social pressure from the poor population.

These urban constructions usually create less impact downstream, but they are developed in risky areas. Usually these areas are (a) near to the rivers with high flood frequency; and (b) on the hillslopes with risk of landslide during the rainy season.

IMPACT OF URBANIZATION AND ITS EVALUATION

The Brazilian procedure for calculation of urban discharge is to use the Rational Method for small areas (DAEE, 1979; McCuen, 1989) and the SCS (Soil Conservation Service) model (SCS, 1975) for major drainage. The evaluation of urbanization impact in the major urban rivers requires a projection of the future urban occupation of the area, which is difficult because of the lack of legislation enforcement in the city boundaries. Since in most major cities the developments are in the downstream to upstream direction, there is the possibility of conflict between the upstream population, which causes the flood frequency increase, and the downstream one, which suffers its impacts. The solution will come through public budget, supported by all the population.

To plan for this future impact, the real impact of developments must be evaluated in advance. Motta & Tucci (1984) evaluated the impact of the Master Plan Developments in Porto Alegre (Brazil) using a hydrologic model and a relationship of urban density to impermeable area (Fig. 1). The urban density is the tool of urban planning and the impermeable area is the important parameter of the model. The relationship obtained was for a residential type of occupation and the values were obtained by measurement of aerial photographs. Tucci *et al.* (1989) used a hydrologic and hydrodynamic model to simulate the Tiete River and evaluated the future scenario of 2005 in São Paulo. The relationship between density and impermeable area was updated with data from São Paulo city which gave similar values.

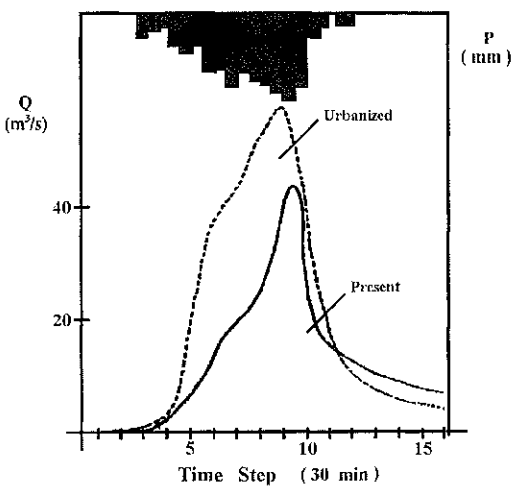

Fig. 1 Urbanization flow increase in Diluvio basin, Porto Alegre, Brazil (Motta & Tucci, 1984).

Campana & Tucci (1994) using remote sensing techniques through fuzzy mathematics calculated the impermeable areas (above 2 km^2) for three major Brazilian cities: São Paulo (population: 16×10^6), Curitiba (population: 2.5×10^6) and Porto Alegre (population: 3×10^6), using Landsat images and field observation.

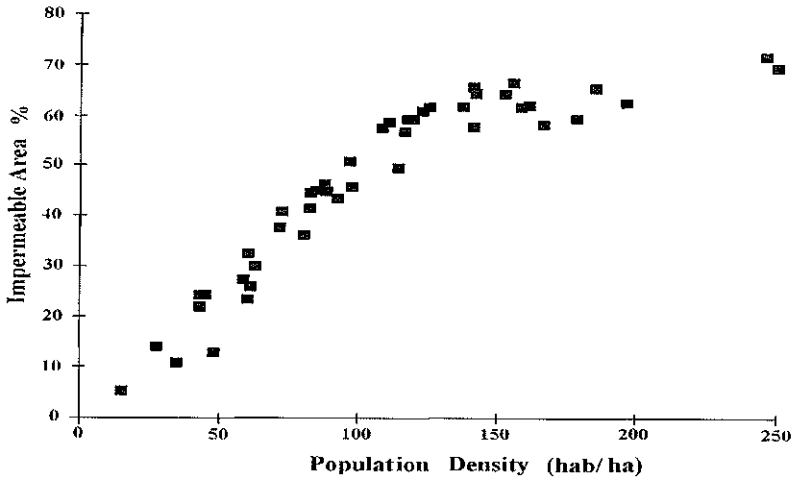

Fig. 2 Impermeable area and population density. Data from São Paulo, Curitiba and Porto Alegre (Campana & Tucci, 1994).

The values are presented in Fig. 2, which shows a good relationship between these two parameters. Most of the areas used are mainly residential and most plot sizes are around 300–400 m^2. As can be seen, the asymptotic value is around 65% of impermeable area, which is the value recommended by SCS (1975) for lot size development less than 500 m^2. This curve cannot be used for small areas of non-uniform developments such as high concentration of commercial and industrial occupation or green areas surrounded by high population density.

The curve can be used together with the forecast density to estimate the impermeable area. Another important parameter which changes markedly during urbanization is the time of concentration. Campana (1995) used GIS techniques to calculate in each sub-catchment of Diluvio basin in Porto Alegre, the change in time of concentration, and used the curve of Fig. 2 to estimate the impermeable area. The future scenario was given by the City Master Plan Development Plan and the simulation used in a hydrologic–hydrodynamic model.

Those figures were estimated by modelling and Tucci (1995) used data on the metropolitan area of Curitiba to evaluate the natural mean annual flow of the Belem River (42 km^2), which has about 60% of impermeable areas with residential and commercial concentration. The drainage sewers cover most of the basin area. Figure 3 shows the relationship between mean annual flood and basin area. By extrapolation, the estimated natural flow is 12.0 $m^3 s^{-1}$ and the present (urbanized) condition, based on recorded data of the last 10 years during which the basin had no major change is 71.7 $m^3 s^{-1}$. The increase is about sixfold.

URBANIZATION CONTROL AND MASTER DRAINAGE PLAN

One of the major difficulties in urban development is to enforce legislation. To control the urbanization impact on flow, it is necessary to create new regulations for urban developments, defining, for example, a limit to peak flow resulting from new

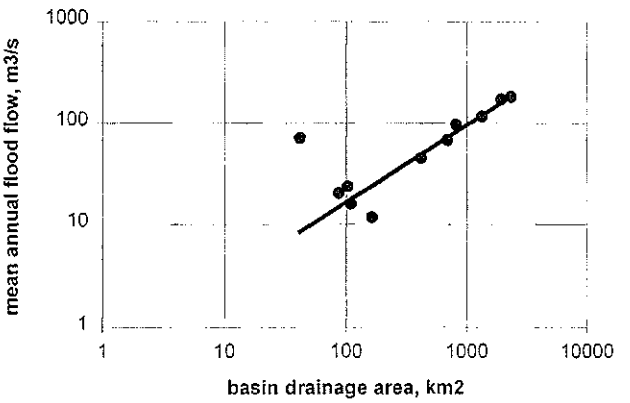

Fig. 3 Mean annual flood and basin area for Iguaçu River basin near Curitiba (the point which is far from the fitted curve is from urbanized Belem basin).

developments. But since invasion of public undeveloped areas is often by squatters, and developments within the city boundaries are made without formal approval by administrations, how can this process be controlled?

In the first place, these difficulties cannot be an excuse for not passing regulations or the Drainage Master Plan. Some strategies can be followed to develop drainage volume control:

- Sub-catchments of urban cities have to be planned for future development by evaluating the city's natural capacity and the limits of the developments in order to cope with the conditions. This can be done through limiting the peak flow increase and by implementing public facilities such as parks with urban detention ponds. The uncontrolled flow of the cities can be damped by these ponds. These areas have to be occupied with public facilities before they are invaded or developed by private users.
- Use of impermeable area limits for the new developments and public areas.
- Increasing public usage of green areas in order to prevent invasion: creating physical difficulties for invasion. In some cities invasion of public spaces has been discouraged by the existence of barriers such as river channels, roads or railway lines.

An example of flood control strategies is presented by Tucci (1995) for Curitiba. The Metropolitan Area of Curitiba (State of Paraná, Brazil; population about 2.5 $\times 10^6$), has developed in the Upper Iguaçu River basin which has an area of 1000 km^2 in J. Belem (Fig. 4). The tributaries are about 100 km^2 in size and the highest density of population is in Belem basin.

The Iguaçu River has a large natural flood plain due to the small river conveyance because of the small river section area and slope. During the flood season the hydrograph is damped by the storage capacity of the valley. During past decades the regional administration ruled against occupation of the flood plain, but there were invasions and unapproved developments and occupation. In July 1983 and January 1995, two major floods occurred resulting in severe damage. The 1995 flood had seven days of rainfall with a return period of more than 100 years (the largest in the 110 years of data). The duration of the main river hydrographs is seven days.

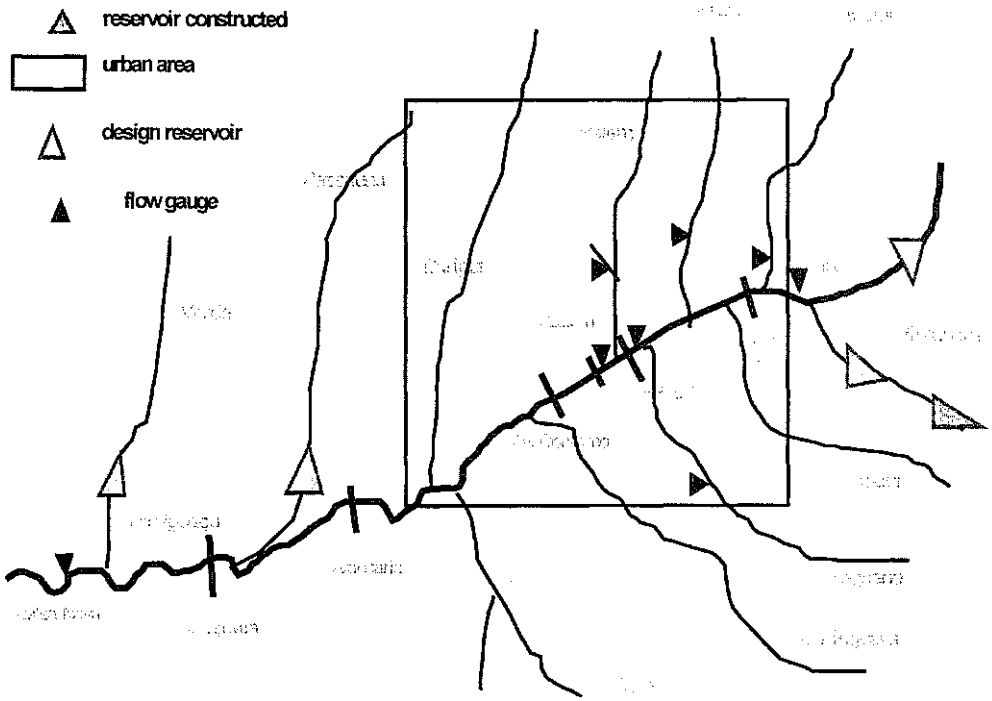

Fig. 4 Curitiba Metropolitan Area and Iguaçu River.

The usual approach would be to increase the Iguaçu River capacity to cope with the 50 or 100-year flood. But if this were done, the population would occupy the flood plain and upstream areas, increasing again the peak flow. In this scenario the cost of control would be of the same order as that undertaken at São Paulo.

The main approach to flood control taken was therefore as follows:

- Create a storage area in Iguaçu River in the Metropolitan Area in the form of a major park (area about 20 km^2). This park is defined by a channel which creates a limit to urban settlement pressure (Fig. 5).
- The park to be designed and implemented together with the channel construction. In addition there must be an important control of this area.
- Development of the Drainage Master Plan for the region using the strategies presented before: (a) developments of urban parks in the tributaries to hold the peak increase of the uncontrolled upstream area; (b) regulation for the controlled area.

CONCLUSION

The problems of urban development in developing countries like Brazil differ from those in developed countries in terms of: (a) density of occupation; (b) regulations; and (c) social impacts of urbanization through illegal occupation of land, whether public or private.

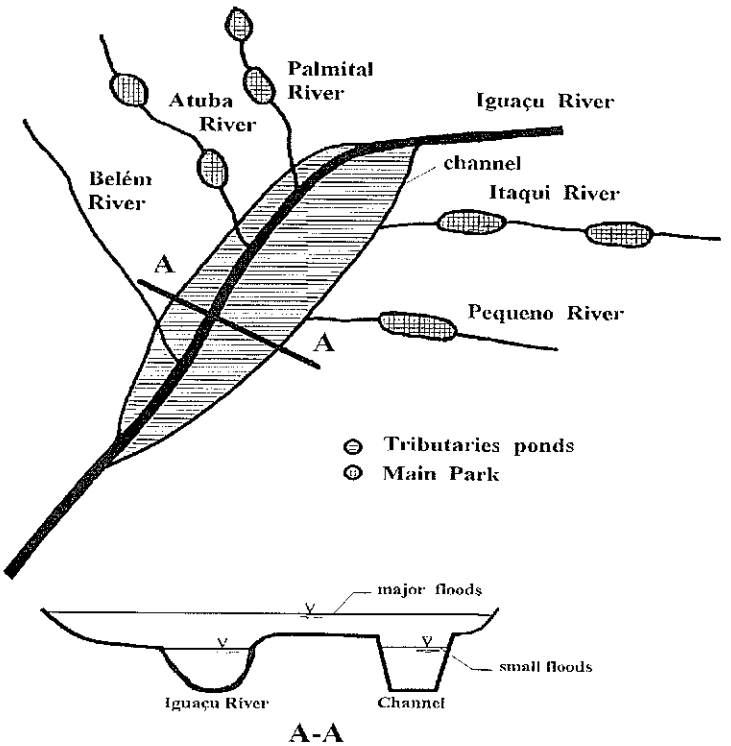

Fig. 5 Flood Control in the Metropolitan Area of Curitiba.

Each problem has its own solution and each situation may require a different approach to minimize the impact on the standard of living of the communities. This requires a good understanding of the urbanization pressures and the water resources of the area. This paper presents some general proposals illustrated using the flood control now being implemented for the Curitiba Metropolitan Area.

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