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Urban water resources management in tropical climates

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Abstract This paper presents the main issues that the less developed countries face with the implementation of integrated urban water resources management, particularly with respect to flood control. Emphasis is given to the importance of having the appropriate technology. Formulae and models developed for temperate climates are not directly applicable to designing urban flood control systems in tropical countries. The problems of the largest metropolitan region of South America, São Paulo, are presented. It is shown how the urban area growth was not followed by the necessary infrastructure. This is an example that illustrates the situation in many tropical areas of the world. The current developments in terms of structural and non-structural flood control measures have provided some hope that in the near future the problems of that metropolitan region should be much less critical than they are today.

Gerenciamento de recursos hídricos urbanos en climas tropicales

Resumen Este trabajo presenta las principales cuestiones relacionadas con los países en desarrollo en el sentido de la puesta en marcha de la gestión integrada de los recursos hídricos urbanos, particularmente con respecto al control de crecidas. Se pone énfasis en la importancia de la tecnología adecuada. Las fórmulas y modelos desarrollados para climas templados del hemisferio norte no son directamente aplicables a los proyectos de drenaje de los países de clima tropical. Los problemas de la mayor región metropolitana de América del Sur, Sao Paulo, son discutidos a la luz de esta dicotomía con los países de clima templado. Este ejemplo ilustra la situación semejante que enfrentan otros países tropicales. Se presentan las medidas estructurales y no estructurales en uso en aquella región.

INTRODUCTION

The urbanization process observed in the last 40–50 years in all parts of the world has developed an unprecedented demand for flood control. In particular, in less developed countries, located in the so-called humid tropics, urbanization was explosive. The relation was 30% urban and 70% rural population in the 1940s. Presently, this relation is reversed, indicating 30% of rural population and 70% of urban population. Traditional urban drainage systems have been utilized in these countries using the concept of getting rid of the flood as fast as one can. It is common for civil works to enlarge cross sections, lining of canal walls and the like. These end-of-pipe solutions solve flooding problems at a particular site and create even greater ones downstream. Planners and decision-makers of conurbations of the humid tropics will have to examine in detail these procedures in order to incorporate other methods of source control of urban drainage in the early stages of urban planning and development.

The concept of urban drainage has evolved from pure collection and fast disposal of surplus undesired surface water to a much more elaborate process in which other water uses have to be considered on a watershed basis. This implies the consideration of macro-drainage systems conveying outflows of minor drainage systems and related contaminated sediment loads. In both developing and developed countries, the concern for environmental protection has raised the level of awareness not only for flood hazards but also for other related aspects of urban drainage such as: flood prediction and prevention; protection of receiving waters against pollution, encompassing in-catchment quality control and peak runoff reduction as a result of land use and drainage patterns.

From an even broader perspective urban drainage systems should be part of the integrated urban water resources plan and management system. Water resources, including their quantitative and qualitative aspects, are means of achieving a higher quality of life for the population and as a result should be included in the integrated planning that encompasses other social, environmental and political issues. Modern decision support systems technology is required to accomplish this holistic approach in a reasonable way. These new technological advances based in computer sciences and engineering allow know-how transfer among countries. Their effective use in the less developed countries of the humid tropics, however, will require capacity building at the local level.

In this paper the issue of urban drainage is discussed under the general umbrella of integrated water resources management and of the new technologies based on source control with special attention to the humid tropics environments. Consideration is given to both the technical and the capacity building issues associated with the problem. The metropolitan region of São Paulo is presented with its urban drainage problems and some of the solutions implemented using new management concepts.

URBAN DRAINAGE IN THE HUMID TROPICS

From a climatological standpoint, the humid and sub-humid tropics absorb high quantities of energy with lower emissivity when compared with other climatic regimes. Their main climatic characteristics are related to high annual rainfall totals and high average monthly temperature with seasonal and spatial variability. In this paper the definition based on temperatures, wet month and gross primary productivity of Chang & Lau (1983) is used.

The concept of designing urban storm drainage systems in harmony with other environmental processes is apparent in large metropolitan areas of humid tropical climates. These areas in general have higher ambient temperatures, where growth of bacteria is more intense and faster, thus imposing an extra threat to humans, as well as to other living organisms in the food chain. Besides that, competing water uses impose important restrictions in the parameters of the urban drainage system which is a small part of a more general water resources urban management system. This water management system, in turn, must be inserted in regional development plans which are more encompassing and include other societal sectors such as: energy, transportation, environment, sanitation, education, health, and the like.

The current policies used in the development of master plans in the less developed world are sectorial. It is common to see water supply master plans and urban drainage master plans that, most of the time, are civil works master plans rather than a set of structural and non-structural measures. The problem in less developed countries of the humid tropics is that urban drainage projects have received less attention from the decision makers than other infrastructure plans including water supply and sanitation, transportation and energy. Under low development levels the highest priority is given to water supply and sanitation. Other elements of the urban system such as urban drainage, aesthetic and even ecological processes show low priority levels. Urban flooding, due to the low level of development, imposes little economic damage. As the region develops the latter aspects show higher and higher importance.

Maksimovic *et al.* (1993) present significant differences between urban drainage problems in the tropics and in temperate climates. Frequently solutions developed for temperate climates are not applicable to the tropics. They show that many of the important problems in the tropics are socio-political rather than technical-climatic, hence the importance of the integrated water resources management concept. The majority of developing nations in the humid tropics, including South and Central American countries, have experienced a significant urban development in the last decades. Unfortunately, urban drainage infrastructure, on the other hand, has not followed the same pattern. Most metropolitan regions of the humid tropics experience severe urban flooding during the wet season, which is becoming a restriction to the future economic development of these regions. The main urban drainage problems in the less developed nations of the humid tropics are due to: (a) fast expansion of the population living in urban areas; (b) low level of public awareness; (c) lack of long-range, strategic plans and master plans; (d) low level of utilization of nonstructural measures; and (e) inadequate maintenance of the flood control systems.

APPROPRIATE TECHNOLOGY AND CAPACITY BUILDING

In order to implement such complex approaches in those areas it is necessary first of all to have the adequate quantitative techniques in terms of meteorology, hydrology and hydrodynamics. Two-dimensional mathematical models are required to have a realistic assessment of land use impacts on flooding. Hydrodynamic models are required to compute the river stages for different cross sections of canals and pipes. In general these models require an extremely large quantity of data including: topography, bathymetry, land use, distributed precipitation maps, etc. These data must be adequately handled by GIS software otherwise the problem becomes untreatable. All this together leads to the well-known Decision Support Systems (DSS) that have been employed in various water resources problems such as reservoir systems management (Labadie & Sullivan, 1986; Loucks, 1995) and conflict resolution in urban water resources management (Braga *et al.*, 1995), etc.

The advantage of using these DSS is that nonstructural controls including legal and institutional measures can be simulated. The impact of new city codes imposing limits for lot occupation and the impact of a storm drainage tax as an incentive to infiltration at source are two nonstructural measures that can be analysed using a DSS. Since the laws of physics warn us that we cannot get something for nothing, the use of these models is only possible if all of the voluminous database is available. Hence, it becomes evident that, if the integrated approach is to be implemented in any basin, it will be necessary to convince authorities of the importance of gathering all these data in a systematic and continuous way.

It becomes clear that there is a need for researching new methods of analysis and design of urban drainage systems involving structural and nonstructural control measures. This situation is even more critical in the developing world where the lack of infrastructure and of capital resources for large civil works pose serious limitations on the traditional urban drainage methodologies. Basin committees involving governmental and nongovernmental organizations are essential elements to implement integrated planning and management at the basin level. Universities should provide continuing education on novel approaches to urban drainage to allow engineers the production of master plans that integrate different sectors of society including: transportation, energy, environment, social communication and the economy.

CASE STUDY: THE METROPOLITAN REGION OF SÃO PAULO

General description

São Paulo Metropolitan Region is the largest urban conurbation in South America and the largest industrial complex of Latin America. Its 16 million inhabitants spread over an area of approximately 8000 km^2, having 950 km^2 of urbanized area, which is entirely contained within the Upper Tiete River basin, shown in Fig. 1. The upper Tiete River basin at Edgard de Souza Dam has a drainage area of approximately 4000 km^2. Gentle slopes (of the order of 0.17 m km^{-1}) characterize a meandering Tiete River. From its headwaters until Edgard de Souza Dam the Tiete River flows through 161 km, having as its main tributaries the Tamanduatei and the Pinheiros rivers. The Tiete River basin is being urbanized at a very high rate upstream of Penha Dam and is almost completely urbanized downstream of this dam. Flood hydrographs for the upstream basin show a slow rising limb with moderate peaks, typical of rural areas, while downstream of that dam, flood hydrographs are typically urban. Due to the lack of adequate wastewater treatment, these urban watercourses are highly polluted, conveying all sorts of municipal and industrial wastes imposing thus a serious threat to human health and so, complicating even more the usual flooding problems.

One century of mismanagement

Ever since the beginning of the century a number of hydraulic structures have been constructed in the basin. Most of these were built by a private power generating company, formerly Canadian owned, and presently owned by the government of the State of São Paulo. To generate hydroelectric power, a series of dams, reservoirs and pumping stations were built so as to divert the flow of both Tiete and Pinheiros rivers by impounding water at Edgard de Souza and pumping it back to Billings Reservoir through two pumping stations, namely Traição and Pedreira, as shown in Fig. 2. From Billings Reservoir, water is transferred to Pedras Reservoir from which electricity is

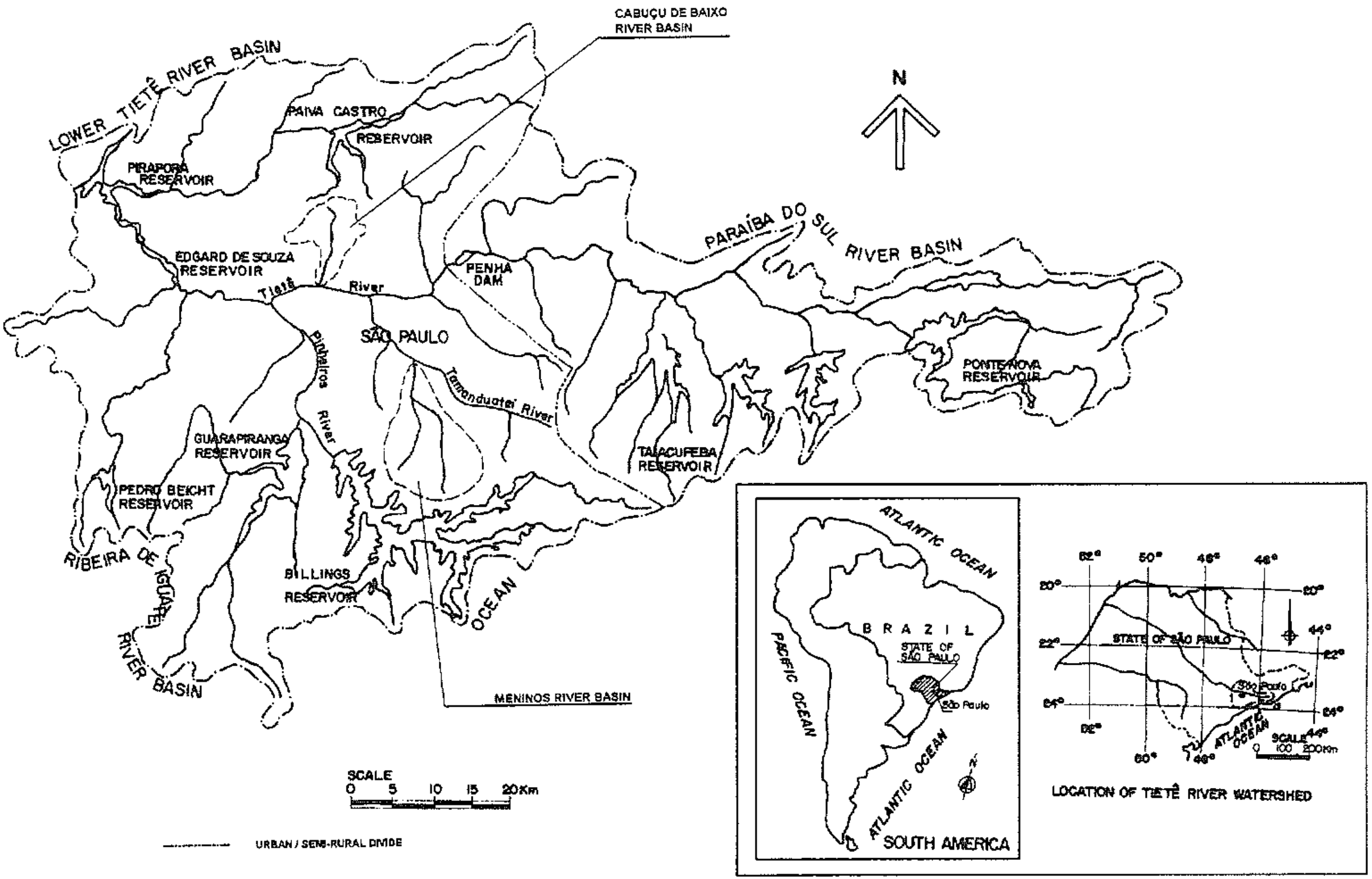

Fig. 1 The Upper Tiete River basin and the Metropolitan Region of São Paulo.

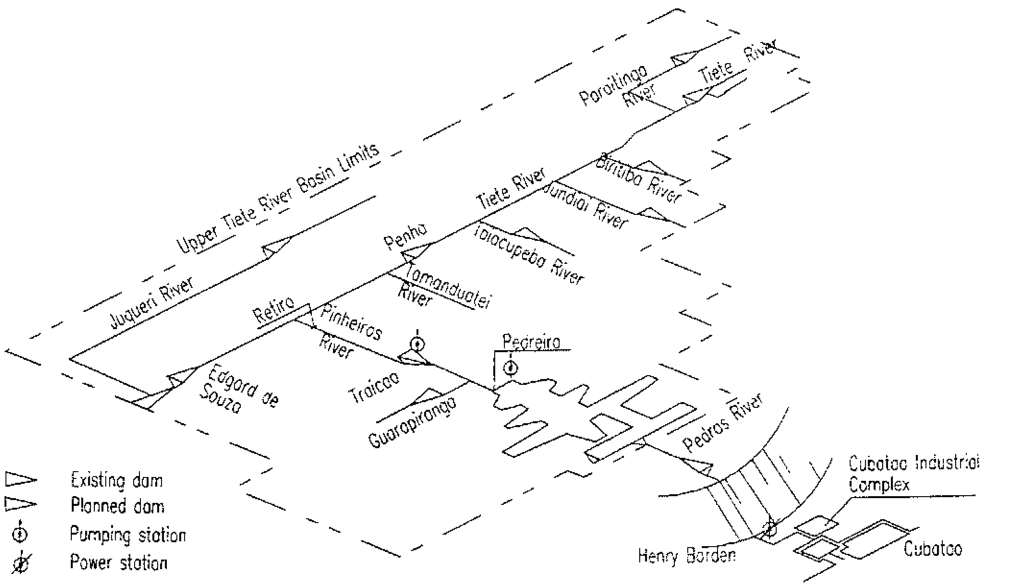

Fig. 2 Manmade effects on the Upper Tiete River basin.

generated at Cubatão power plant at sea level, with a hydraulic head of 710 m. This large amount of electric power available at the demand area allowed economic activities to grow at an exceptionally high rate. Figure 3 shows the expansion of the urban area from the beginning of this century. The population of the region jumped from a medium size city (300 000 inhabitants) in 1905 to a megalopolis of 16 million inhabitants in 1995. Unfortunately, the urban infrastructure did not improve at the same rate as the growth of population and urbanization in the region. During large floods, all runoff generated at the Pinheiros basin is pumped back into Billings Reservoir. Edgard de Souza spillway gates are opened so that the Tiete River flows according to its natural east–west direction. This is a very sensitive system which has to be operated with the due rainfall forecast since the backwater of Edgard de Souza Dam reaches the downtown, very populated area of Sao Paulo.

Due to inadequate land use in the basin, floods are becoming more severe in small creeks and the problem is being transferred to the Pinheiros and Tiete river basins. The situation has become extremely critical since the main freeways of Sao Paulo are located exactly at the banks of the Tiete and of the Pinheiros rivers. During the wet period (December–March) the population is frightened; radio, television and newspapers give much importance to the problem. It is clear that any hydraulic work done in the Tiete or Pinheiros will be of little use in the future if flood control is not carried out in the contributing basins. The design flows of the Tamanduateí River at Glicério have increased more than five fold in the last century for the same return period. The silting of the macro-drainage system, mainly in the alluvial plain, is another important consequence of the inadequate land use in the basin. The cost of US$36 million per year for dredging 3.2×10^6 m^3 of sediment is an important expenditure in the State of Sao Paulo annual budget. Additionally there is a discharge

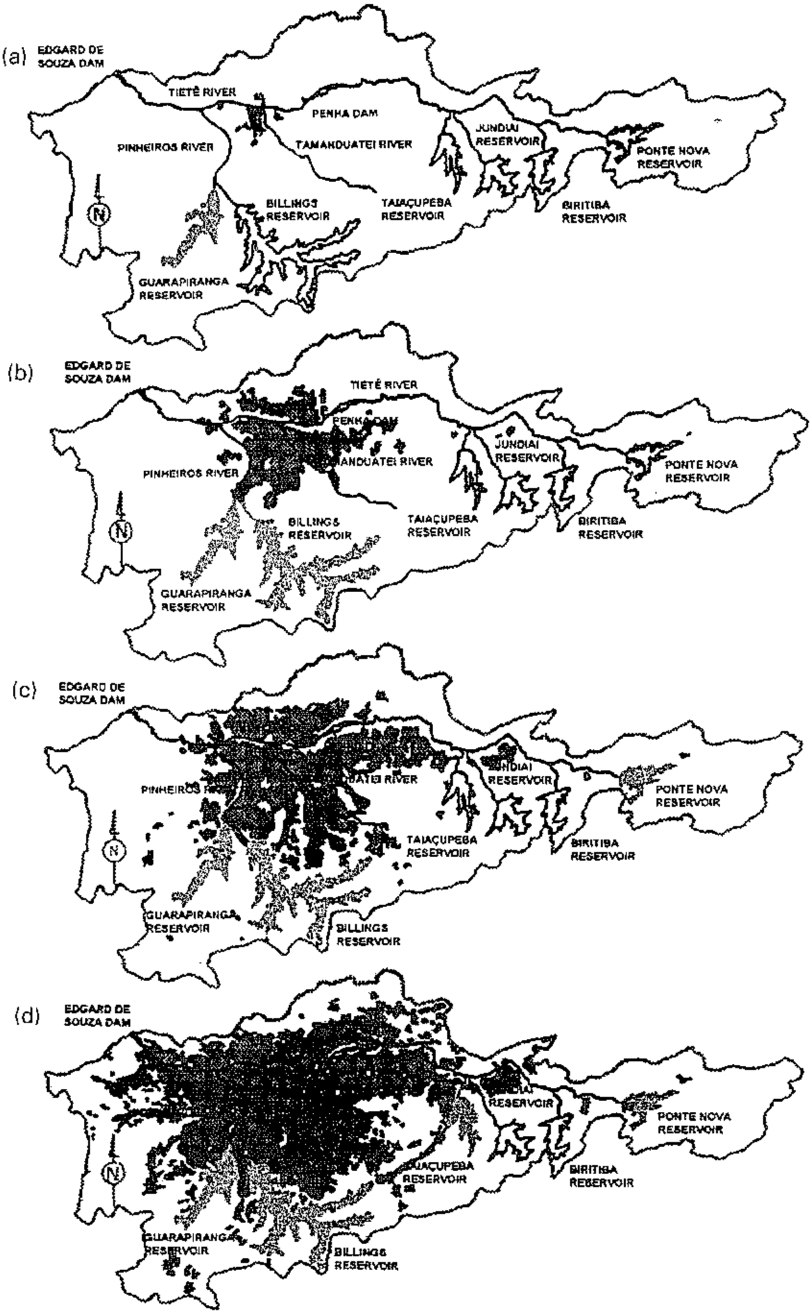

Fig. 3 Urbanization of Sao Paulo Metropolitan Area 1905-1985; (a) 1905, (b) 1954, (c) 1973 and (d) 1985.

of 50 $m^3 s^{-1}$ of untreated urban and industrial waste water to the drainage system. Consequently, not only the water but the sediment to be dredged is contaminated, and environmentally safe measures have to be adopted to avoid impacts at the disposal site.

Signs of changing attitudes

As depicted in the previous sections, flooding is a major issue in the Metropolitan São Paulo water resources management. The solution of this extremely complex engineering problem has basically three phases: (I) information, (II) corrective measures, and (III) sustainable long-range structural and nonstructural measures. Phase I involves flood warning systems to mitigate the inevitable problems which result from the lack of flood control infrastructure. In phase II, structural measures (e.g. canals, reservoirs, etc.) must be built to provide the required safety of the population against floods. Phase III involves a series of structural and nonstructural measures related to a change in attitude towards development including, among others, demand management, source control and taxation.

Several measures are currently being developed to enable the Metropolitan Region of São Paulo to accomplish goals at the three different phases. They involve canalization of small tributaries of the Pinheiros and Tiete rivers to provide flood control in these small basins, a flood warning system, and some legal instruments related to the city of São Paulo building code. Underground reservoirs have been implemented with considerable savings when compared with traditional canalization procedures. The population and the media are highly motivated towards the utilization of detention ponds in the direction of source control instead of end-of-the-pipe control methods. Unfortunately, major hydraulic works on the Tiete and Pinheiros Rivers are still waiting for appropriate funding. These are State rivers as opposed to the small tributaries which are municipal rivers.

An important component of this new approach towards urban drainage management in the region is the flood warning system developed by Braga *et al.* (1995) depicted in Fig. 4. It involves the collection of all the data generated by the telemetric network and meteorological radar, and processing of the data for consistency and storage. These data are then used by rainfall and river stage forecasting models to issue quantitative rainfall forecasts (up to three hours in advance), and subsequent flows and river stage forecasts. A considerable amount of data has been stored since the beginning of the operation of the system. Approximately, 80 000 weather radar volume scans are stored in 650 magnetic tapes from May 1988 when the Ponte Nova weather radar began its operation. As of March 1991, storage of telemetric data was systematized comprising 120 Mb of ASCII information.

The Information Management System (IMS) in operation at the University of São Paulo, through an agreement with the Departamento de Aguas e Energia Eletrica, has several users including hydroelectric power companies, city administrations, civil defence commissions, environmental control agencies, television stations, and the general public. These users communicate with the system, either through dedicated telephone lines, or through regular telephone lines under a menu-operated software that allows the user to request different products generated by the IMS. These products include: rainfall intensities and accumulated rainfall, CAPPI, rainfall forecast and river stage forecast. Since 1990, a regular programme of reliability assessment of the system has been implemented. In terms of flood forecasting using the hydrologic state model (HSM) for the city of Sao Paulo, a previous survey by Braga *et al.* (1992) indicates a margin of error in the range of 10%. It is clear from these results that even very simple models can provide reliable results once a good spatial rainfall estimation is available.

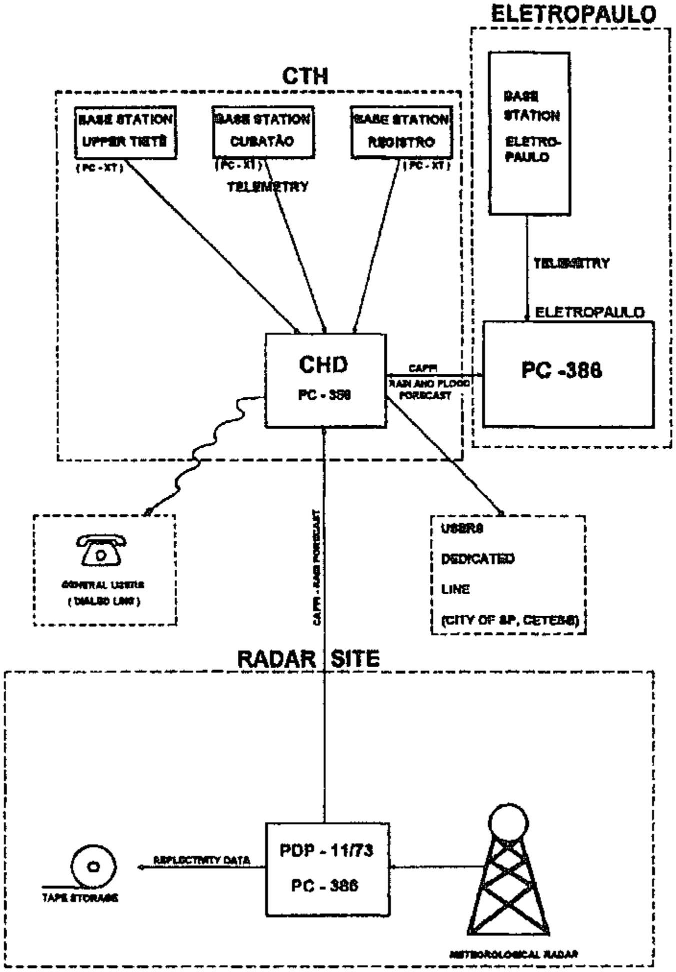

Fig. 4 Hydrologic Information Management System of São Paulo Metropolitan Region.

CONCLUSIONS

The subject of urban drainage has evolved considerably from the traditional concept of structural measures that emphasize end-of-the-pipe solutions (e.g. canals, reservoirs, etc.) to a more elaborate system in which these measures are used jointly with nonstructural measures (e.g. flood warning, relocation, legal acts, etc.). This new approach utilizes the watershed as the planning and management unit and encompasses other sectors of society in the process, including: transportation, energy, environment and socio-economy.

Examples from less developed tropical countries show that this is a viable approach and should be pursued by analysts and decision makers. Flood warning systems represent a very important part of the flood control system. The costs of structural measures can be made much smaller if at the onset of the project the joint use of a flood warning system is considered.

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