The detention dams system of Mexico City: new challenges

Le système de bassins de détention à Mexico : nouveaux défis

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RESUME

Le système de drainage et contrôle des inondations de Mexico est composé de structures de sous-systèmes régionaux dont la gestion et le contrôle sont très difficiles à mener en raison de sa complexité. Les barrages de rétention de l'ouest font partie d'un réseau de drainage dédié fondamentalement au contrôle des inondations de la saison humide (mai à octobre). Tout le système est soumis à des difficultés de gestion des inondations à cause de l'accroissement de la ville, du changement des conditions du drainage et de priorités de contrôle imprévues. Gérer ce stress est possible si l'on intensifie les mesures des variables hydrauliques et hydrologiques, la maintenance du système et la construction de nouveaux éléments de drainage. Cette contribution cherche à montrer les actions les plus importantes à accomplir dans un cadre de pratiques durables.

ABSTRACT

Mexico City's drainage and flood control system is composed by several structures ordered by regional sub-systems which are difficult to control and manage because of its complexity. The western detention dams belong to a drainage network and are mainly dedicated to floods control during wet weather (May to October). The whole system is nowadays facing difficulties to deal with floods because of the city's growth, changes in drainage conditions and unattended control priorities. The stress could be managed by the intensification of hydrological and hydraulic variables measuring, the construction of new drainage elements and the system's maintenance. This contribution outlines some of the most important actions to accomplish on the detention basins in a framework of sustainable practices.

KEYWORDS

Detention basins, Mexico City, urban drainage.

1 INTRODUCTION

Multiple efforts to improve urban stormwater management have been done worldwide recently. In this context, the design of detention structures ranges between “traditional” developments (Zawilski & Sakson, 2005; Calabro & Viviani, 2006) and innovating implementations (Bettencourt *et al.*, 2001; Dziopak, 2001; Tullis *et al.*, 2005). The possibility of combining the optimization of urban drainage elements (Sreeja *et al.*, 2005; Thorolfsson, 2001; Gomez *et al.*, 2001; Duong *et al.*, 2001) with sustainable environmental criteria (Fryar, 2001; de Graaf & van de Ven, 2005; Silveira & Goldenfum, 2004; Wong, 2005) has been intensively studied.

Regarding detention basins, Nascimento *et al.*, (2001) underline the importance of hydraulic and hydrologic simulations for a basins system design at Belo Horizonte, Brazil, and evaluate inundation risks. Mitchel et al. (2005) propose several scenarios to optimize stormwater use under different climatic conditions.

In this paper we present a diagnosis of the actual state of the detention basins in Mexico City, including their measuring and control instruments. We offer a critical analysis of the functioning scheme of the dams system; we propose some variables to be measured and recommendations on the additional needed equipment. Criteria to achieve this goal and proposed simulations to optimize it are presented. Finally, sustainable alternatives for drainage are outlined.

2 OVERVIEW OF MEXICO CITY’S DRAINAGE AND FLOOD CONTROL SYSTEM (MCDFCS)

Mexico City’s flood control system consists of structures to regularize and drain used and precipitated water in order to avoid inundations. Its general functioning was planned more than 30 years ago following hygienist criteria: to drain outside the endorheic basin the city’s water overflows. The drainage system was planned to function in two stages: 1) during dry season when wastewater is regulated by lakes and retention dams and evacuated by rivers and channels; 2) during rainy season when drainage is mainly done through the Deep Drainage System (DDS), a series of tunnels more than 50 m below the ground surface and with diameters up to 6.5 m. This DDS would not operate during dry season in order to allow its inspection and maintenance.

The growth of suburbs had two significant effects on the hydrological regime: increase of non-permeable surfaces and decrease in conduction capacity of surface structures. The phenomena is due to soil sinking caused by aquifers’ over-exploitation, which, among others, also increases the electricity consumption at pumping stations. This situation led to a continuous use of the DDS since 1994: any inspection was performed since then. However, some evidences indicated decrease in the DDS’s conduction capacity. A recent inspection (2005-2006) confirmed damages on the walls of the DDS that raised its roughness. These facts suggest a scenario that implies, a series of structural and non-structural actions to allow the maintenance of the system, as the definition and construction of structures for water runoff and flood risk management. Since surface drainage is compromised by the soil’s sinking process the proposed works foreseen the construction of tunnels and retention lakes that would mainly serve the eastern part of the city. For the western side, another deep tunnel is proposed to increase the wastewater drainage availability.

3 ROLE OF THE DETENTION BASINS IN THE CITY'S DRAINAGE FUNCTIONING

The westerly inundation control system of Mexico City (WICS) was created in 1954 to diminish flood risk towards the city's lowest zones (Figure 1). The west zone of the valley corresponds to the region of most important rains since the annual precipitation varies between 1100 and 1300 mm. The system is composed by 29 detention basins (dams) on every single river and conformed to regulate the river's floods. Regulated volumes are then discharged to other hydraulic structures (mainly to the West Interceptor tunnel) to be conducted, re-regulated and/or discharged. To raise the joint basins' detention capacity, interconnection tunnels were constructed between neighboring dams; water exceeding volumes are thus derived from basins and structure's overflow risk is limited. No control devices exist in these tunnels. The detention control provided by the basins takes place on daily basis: once a storm had finished the basins are emptied to get them ready for the next day's rainfall. This daily criterion is justified by the daily rainfall frequency: the most important storms in Mexico City are very intense (convective type) and occur during the afternoon or the night.

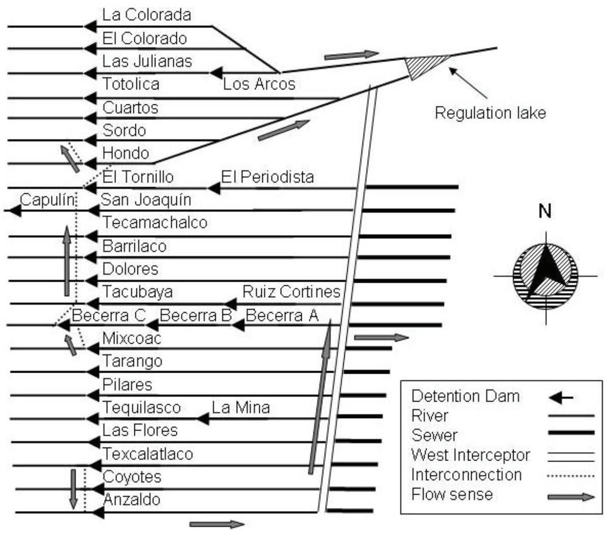


Figure 1. Scheme of Mexico City's West Detention Basis

Despite the consideration of urban growth on the region where the basins were built, the design's original conditions were outgrown by population's arrival. The complete filling of the 7 basins of this system is not yet possible because of settlements (Franco *et al*., 1992). Downstream some basins, residential constructions had also reduced or impeached the operative capacity of the spillways. The floods sediment material also diminishes the real retention capacity. In the case of the basins within the *Distrito Federal* territory, the installed detention capacity reaches 3'128,000 m^3, but 312,000 m^3 are occupied by sediment material; nevertheless, in real terms, the loss of detention volume in 2004 reaches 1'122,000 m^3, which is about 36 % of the total originally available. The sediment deposition problem in the basins has been partially solved by annual dragging campaigns, but this solution is not sustainable because it is expensive and a place to dump the material is needed. The price of the basin's sediments extraction during 2004 was 1,600 Mex$/$m^3$; if it would be desired to remove all the basins' sediments, about 38.4 millions of € should be paid.

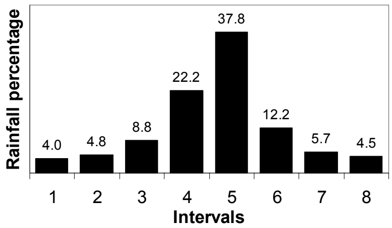
In a study to diagnose the basins' situation (Franco *et al.*, 1992) it was found that some dams' components were in bad conditions. For example, 10 basins' outlet weirs were out of order, this has obliged to have them opened all the time and loose their regulation capacity. Interconnection tunnels are very important, particularly in the case of some basins with lost detention capacity, but in some cases sediment deposition is also occurring. The operation of still functioning control devices is done by empirical criterion, which raises the system's vulnerability.

Franco *et al*. (1992) simulated the runoff considering the observed drainage conditions in the basins. These simulations were done with the VASOS software, elaborated at the *Instituto de Ingeniería* of the National Autonomous University of México (IIUNAM). Besides the hydraulic equations for every structure, the Soil Conservation Service (SCS, nowadays USEPA) adimensional hydrographs and the Kirpich equation for the concentration time t_c were employed in the simulations. Daily rainfall conditions were considered in the use of the SCS' design storm: a 24 h and 5 years return period storm (under Mexico City conditions). An important rainfall event associated to the Gilbert hurricane (September 1988) was also considered for the simulations. Finally, weighted runoff coefficients C_E from 3 types of surface (urban, suburban and rural) were used on each catchment. 4 different scenarios were studied based on the variation of the basins' filling conditions and opening degree of the outlet structures (when possible). It was observed from the results that the functioning of some detention dams would not generate inundations on the invaded zones, but in the rest of the structures the water level reaches these zones in most of the simulated operation conditions. The comparison of the results obtained with the two storms showed that the SCS method supplies greater runoffs, which indicates that its use is quite conservative.

In 1997, Mexico City's government asked the IIUNAM for a new diagnosis on the whole Drainage and Flood Control System (MCDFCS) conditions, which motivated a new revision of the WICS runoffs (Dominguez, 1997). Weighted C_E were used in the runoff simulations of urban and non-urban surfaces. The use of an urbanization degree factor ranging from 0.6 to 1.0 and regionalized C_E for rural areas were considered. The rainfall depths (P) were computed on each basin in terms of the annual rainfall maximum for 30 minutes and on duration, return period and area depths. The duration of each storm was considered equal to 8/3 * t_c on each basin but less or equal to 8 hrs. The rainfall was distributed in 8 *dt* intervals within this duration as shown in Figure 2, following the recommendations for Mexico City (DGCOH, 1982). The hydrographs shape is also shown in this Figure, where t_1 and t_2 are the lowest and greatest values between t_c y *dt*, respectively. To obtain the peak discharge (Q_p), the water volume under the curve is equalized to the direct runoff volume stated as $0.5 * Q_p * (2 * t_2 - t_1 + 1.67 * t_c) = C_E * P * A$, where A is the basin's area. The study as performed in 2 stages:

i. Three different rainfall scenarios were considered using 3, 10 and 50 years return period in the simulations in order to verify the dams system functioning with total opened and closed outlets. The regulated wastes by the basins with opened outlets vary between 26 and 30 % of the income runoffs, but with closed weirs the regulation reaches 76 to 89 %. For the first case, bigger the return period bigger are the regulated volumes, but with closed weirs and high return periods important wastes over the spillways are obtained. These results indicate that it must be reached an operation criterion to regulate wastes, alleviate the conduction of ulterior hydraulic structures and guarantee their security and the one of surrounding urban zones.

ii. A more demanding scenario was simulated in the second stage. Extrapolated population for 2010, an 8 hrs design storm and closed weirs at each dam were considered in the search of the safety regulation of a 10,000 years return period rainfall event. The dams' performance was evaluated in terms of the reached water levels during simulation with respect to the spillway level. The analyses' results indicate that, among the 26 studied dams, 15 are capable to retain the river floods and 4 reach this goal with the support of their interconnecting tunnels towards other basins. In 7 other structures water depths would overflow the spillways. By their side, water wastes obtained with full regulation would deliver 7.5 m^3/s downstream only, but without regulation the maximum waste would get up to 52.5 m^3/s.



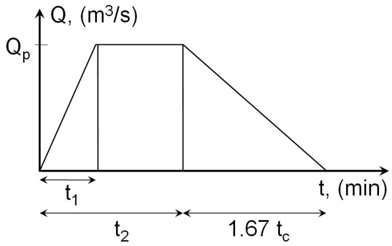


Figure 2. Design Storm's hyetogram and synthetic hydrograph

A series of recommendations derived from this study were outlined for the year 2010:

a. Construction of 2 detention dams, new interconnection tunnels and dambreaks
b. Construction of a drainage tunnel towards the San Buenaventura River (south of the city) to raise the water transit time before reaching greater drainage structures
c. A dams' revision to guarantee their structural safety
d. To stop the population to install and to remove existing invading urbanizations
e. Functioning verification of operation and regulation mechanisms
f. To repair and complete the hydraulic and hydrologic variables measuring system
g. To continue the annual programs of sediment removal and to impulse reforestation

In 1997 a fire took place at the forest at the Magdalena and Mixcoac rivers summit areas. Afterwards an important rainfall event caused a flood at the Mixcoac basin and produced great damages and 2 dead persons. From Environmental and hydrological points of view, the reconditioning of this area is needed, but the zone has not yet been reforested because of legal impeachments, producing important hydraulic erosions in both basins and sediment deposition.

The rehabilitation of these rivers is an important subject on the dams functioning (Figure 3). Besides the problems of solid waste and landslide danger of river banks, López (1998) underlines the necessity to conclude the construction of wastewater pipelines on the rivers' margins that would connect to the MCDFCS. These combined conduits would avoid wastewater discharge to the rivers and would diminish river and groundwater pollution during dry season. López also found that the west rivers length surrounded by urbanization reaches 142 km, but only 56 km have pipelines.

The treatment of urban water has neither received enough attention. The average annual waste water discharge in the city is of 45 m^3/s, but only 7 m^3/s are designated for reuse in the Valley of Mexico (Jiménez et al., 2004), mostly for irrigation of parks and crops (67 %), infiltration to the soil (20 %) and commercial/industrial uses (13 %). The main reason for the restricted use of these practices is multifold, first of all waste water treatment plants are in far places from potential commercial and industrial consumers; second, local farmers firmly oppose its use and, third, infiltration to the soil is limited by legal and technical aspects. As far the west basins are concerned there are six waste water treatment plants with a capacity of 0.145 m^3/s.

Figure 3. Sediment in El Capulin dam (left) and solid waste in La Colorada dam (right)

The artificial recharge of the aquifers below Mexico City has not received sufficient consideration. An example of this type of solutions constitutes Wisconsin, USA (Montgomery *et al.*, 2005). The major part of the water consumed in Mexico City comes from underground sources maintained by the elevated regions of the valley. The zone with the western dams is extremely important as far the natural recharge of the aquifer is concerned. However, given the continuous overexploitation of the aquifers below the city it is indispensable to establish sustainable criteria such as artificial infiltration (forced or induced) in order to continue to benefit from this water source. As far the induced recharge is concerned (lagoons, trenches, etc.) in this zone would be possible only in the higher parts of the basins given that the rest of the surface is not adequate for such practice or it is already urbanized. On other hand, actual legislation imposes certain limitations on this practice such as 1) a quality criteria for the water to be injected in order to fit the quality of the aquifer's resident water and 2) the water should be used after a year of residence time. Regardless to legislation, in many parts of these zones there are clandestine discharges that don't comply with this regulation. In such context, during the yearly rainy season a natural recharge process takes place originated by urban and rain waters, but during the dry season the quality of infiltrated water is very low. The situation could be improved by placing collectors parallel to the rivers such that they could drive water towards waste water treatment plants (that could be constructed nearby the dams) and in consequence at least part of the water could be treated and injected to the underground.

On other hand, the available budget of Mexico City's Water System (SACM, in Spanish) is insufficient to respond to all functional necessities attended by this institution given that certain tasks can't be let aside. For drainage purpose, for example, now is under construction a new tunnel of the Deep Drainage System that will easy the city's drainage problems. Besides priorities in internal management there is also the constant diminishing of the available yearly budget that prevents periodical works of sediment removal at the damns. For example, the yearly budget of SACM in 2004 was 13 and 22 % lower when compared with budgets of 2003 and 1998, respectively. Under such circumstances is almost impossible to attend the proposed technical recommendations.

These technical and financial conditions had even motivated the computation of the inundations that would occurred at the city whether the DDS could not conduct water because of a structural collapse, which would mean a drainage capacity of 55 m^3/s only (Dominguez & Carrizosa, in press): considering the observed city's sinking, annual average rainfall depths and the use of superficial drainage structures, an inundation scenario would take place, beginning in May and reaching its maximum on October (Figure 4), with a 217 km^2 inundation surface, 407 millions m^3 of stocked water volume and up to 5 m water depth. It's difficult to estimate the related cost to this scenario, but it is evidently much higher than the cost of the required works for the dams and basin's maintenance, and for the whole MCDFCS.

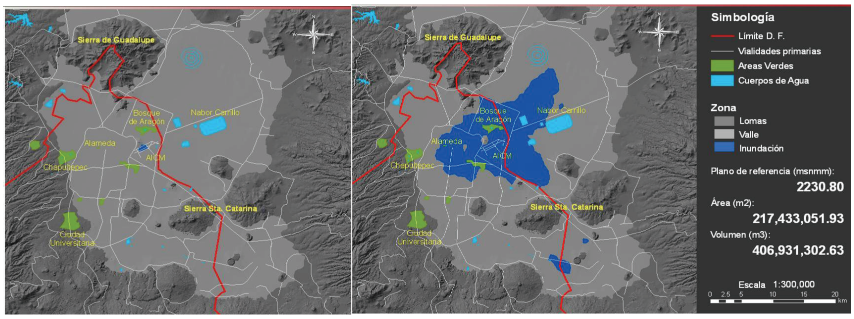


Figure 4. Inundation scenario without DDS functioning for May (left) and October (right)

4 TOWARDS THE OPTIMIZATION OF THE DETENTION BASINS. CONCLUSIONS

The arguments described above motivate the optimization of the detention basins system's complex functioning. The actions enumerated here are complementary to the ones mentioned in previous studies:

a) Measure continuously the i) discharges in the emptying structures of the dams and the ii) fill level in the reservoir; the first annual campaign of measurements will allow the advancement of the system's dynamic simulation and the preparation of the dams' operational criteria such to optimize their regulation and avoid the flooding of the urban zone (during events with low return period). Besides, it would be necessary to promote the incorporation of the meteorological radar data into the simulation. In the case of rainfall, all the raingauge stations should be integrated in a RTC system.

b) Rehabilitate the basins by reforestation, action that could diminish the volumes of sediment to be removed each year.

c) Construct waste water treatment plants in the nearing of the dams in order to impulse the rehabilitation of the rivers to which the parallel collectors arrive. The quality of the treated water should be good enough to allow its reuse or its injection to soil such to limit overexploitation of the aquifer.

d) Revise the legislation related to this matter in order to avoid contradictions in the management of rain and urban water.

There are two main benefits of exerting a complete control of the runoff at the study region. First, rainwater management at the lower part of the city could be significantly relieved and, second, there would be an important electrical energy savings at the pumping stations.

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