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MACRO DRAINAGE AND RETENTION OF FIRST RAIN IN CLOSED CATCHMENTS

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ABSTRACT: This paper deals with an unconventional solution of urban drainage for Natal city, RN, Brazil. The city is on closed drainage basins so that runoffs flow radially to the lowest points where lagoons or hydraulic detention reservoirs are situated. Originally, under natural conditions, the shallow areas formed ponds during rainy periods. However, urbanization and bad planning for land use increased runoff and shallows so that resulting quickly in frequently flooding damages. Construction of reservoirs with sufficient volumes to store rainwater and / or pumping systems to transfer the surplus water to other places were continuously implemented as the developing city urbanization occurred. This macro drainage alternative has been established itself in the city. However, as the system drainage increased and becomes complex it should be necessary to integrate water diversion by some new transposition system. The present study refers to the design of the Integrated South Zone Macro Drainage System of Natal City. The main system project design evolves sizing of the main gallery, tunnel type built by nondestructive method. Macro drainage system involves six neighborhoods, a large part of south zone of Natal city. In order to solve permanently the problem of flooding it was designed an integrated drainage system, consisting of a complex system of detention reservoirs, which correspond resizing existing ponds, interconnecting them in series by galleries and tunnels, which act as spillways system to the Potengi estuary. The implementation of this system reduces to acceptable levels the risk of flooding in the area. The design system evolves also water quality aspects. The effluent quality of an urban drainage system changes enough during the rainy season with the washing of paved drainage basin, gradually reducing their polluting head. This aspect justifies thus the incorporation of absorption devices for the retention of the first rain in the design and construction of macro drainage systems. In the design of detention reservoirs. It considers also the effective precipitation (P_{efe}) which determines the volume capacities of the hydraulic detention reservoir.

Key Words: Urban Catchment, Macro Drainage, First Runoff Detention

1. INTRODUCTION

In recent years, Natal city-RN, Brazil, has developed the greatest macro drainage of its history. A project for the preparation of the Consolidated Master Plan of Drainage and Stormwater Management (SEMOP-RN Government, 2010). This stands the proposition of the integrated macro drainage of Natal South and East zones, which currently is being implemented within the body of work that made possible the deployment of Arena das Dunas stadium, host of the world soccer cup in Natal.

The Macro drainage system area involves the neighborhoods of Dix - Sept Rosado, Lagoa Nova, Nossa Senhora de Nazareth, Nova Descoberta, Candelaria and Cidade da Esperança, sited at West and South zones of the city of Natal.

Because of dune origin undulating terrain, five closed drainage basins direct water abstracted by the minor drainage systems to ponds. The reservoirs are: Potiguares, Prea, Administrative Center, São Conrado and Cidade da Esperança.

The Project area has precarious drainage structures, causing frequent floods at various points during periods of heavy rainfall due to several critical factors that interact with each other, which highlights the deficiency of the macro-drainage, related to catchment excess water captured to the ponds. Existing pumping systems in these lagoons are poorly operated but help reducing the time of flooding near it.

In order to solve permanently the problem of flooding in the project area it was designed an integrated drainage system, consisting of detention reservoirs, which correspond to the existing ponds, resized, and interconnected in series by galleries in tunnels to be built by non-destructive method, which work as spillway of integrated Potengi River estuarine system.

With the implementation of this system, it will be possible to reduce to acceptable levels the risk of flooding in the project area.

The environmental impact consequence of these works is to mitigate the impacts of the release of drainage effluent in the estuary of the river Potengi that borders the city of Natal, adjusting the pollution of the effluent to the self-purification capacity of the coastal system. In this way, it was necessary to incorporate integrated mitigation aspects into the executive design of detention reservoirs, described in this work.

The effluent quality of an urban drainage system modifies significantly during the rainy season with the washing of impervious areas as roofs and pavements in the watershed, gradually reducing its polluting capacity, justifying thus the incorporation of absorption devices of the first rains in the project of macro drainage systems (Tucci 1995, Righetto 2009).

2. INTEGRATED SYSTEM DESCRIPTION

The area of the macro drainage system project is a plateau with an average altitude exceeding 30 m that lies between the Dunas Park (to the east) and the estuary of the River Potengi (west), and this is the main natural water which receives water storm from the presented studied region.

The macro drainage watershed design encompasses much of XII and XV sub areas of Drainage System of Natal City defined in Plan Director of Drainage and Stormwater Management (PDDMA) (PMN, 2010), according to Table 1 and Figure 1 following.

Table 1 – South and East Natal Drainage Areas

Number	Drainage Area	Area (ha)	
		Opened	Closed
VII	Potengi / Rocas – Ribeira	376.3	
VIII	Urban beaches	218.2	
IX	Baldo Creek	714.8	
X	Potengi / Quintas	304.1	
XI	Dunas Park		1194.0
XII	Lavadeiras Creek	1264.8	
XIII	Coast Avenue	116.2	
XIV	Potengi / Felipe Camarao	712.6	
XV	Jaguarari Lagoons		431.8
XVI	Pitimbu River	1048.9	
XVII	San Vale / Pitimbu		1145.4
XVIII	Jundiai River / Guarapes	398.0	
XIX	Lagoinha		1016.0
XX	Ponta Negra beach	949.3	
	Total East / West / South Zones	10413.1	3787.2

South and West Zones Natal Macro drainage is one of the main structural facilities proposed by the Natal Plan of Drainage and Stormwater Management (PDDMA) 2010.

In the Project, the closed drainage areas (XII and XV of drainage system) become opened. Much of waters of catchment XII are transposed which currently are pumped to Lavadeiras Gallery; and, directly by gravity, through a gallery tunnel that will receive the surplus waters of detention reservoirs of Potiguares, Prea, Administrative Center and São Conrado. The integrated system should also receive the transposed waters of Cidade da Esperança drainage area. Figure 2 shows the South and West Zones and the layout of Macro Drainage System of Natal city.

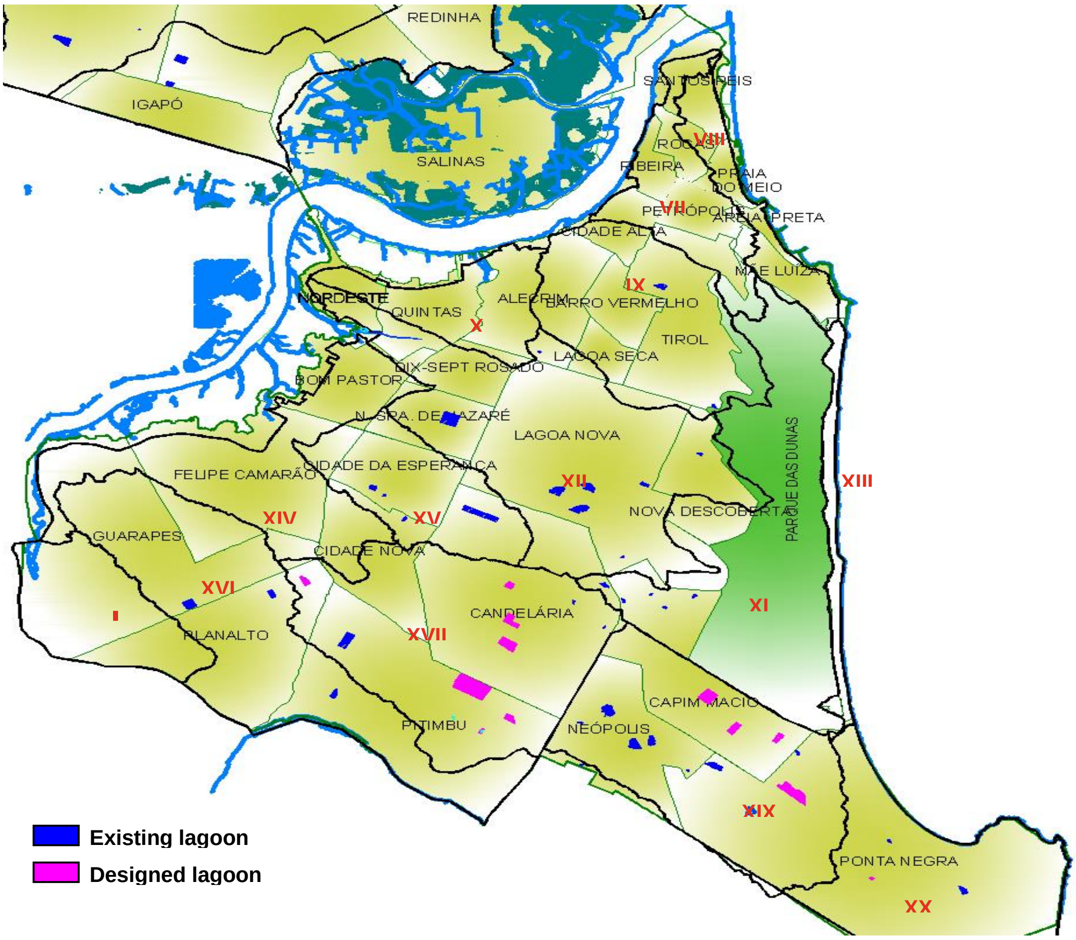

Figure 1 – South and West Natal Drainage areas (PDDMA 2010)

3. MAIN CONDUITS OF THE INTEGRATED SYSTEM

Main conduit of the integrated system is composed of five reaches, starting at RD 1 and following up the gallery whose outlet is the first rains absorption reservoir absorption of the first rains sited near Potengi River.

The Integrated System, consisting of galleries in tunnels built by non-destructive method, receives contributions from seven reservoirs detention as illustrated in Figure 4. Table 2 summarizes the characteristics of the main segments of the integrated collector.

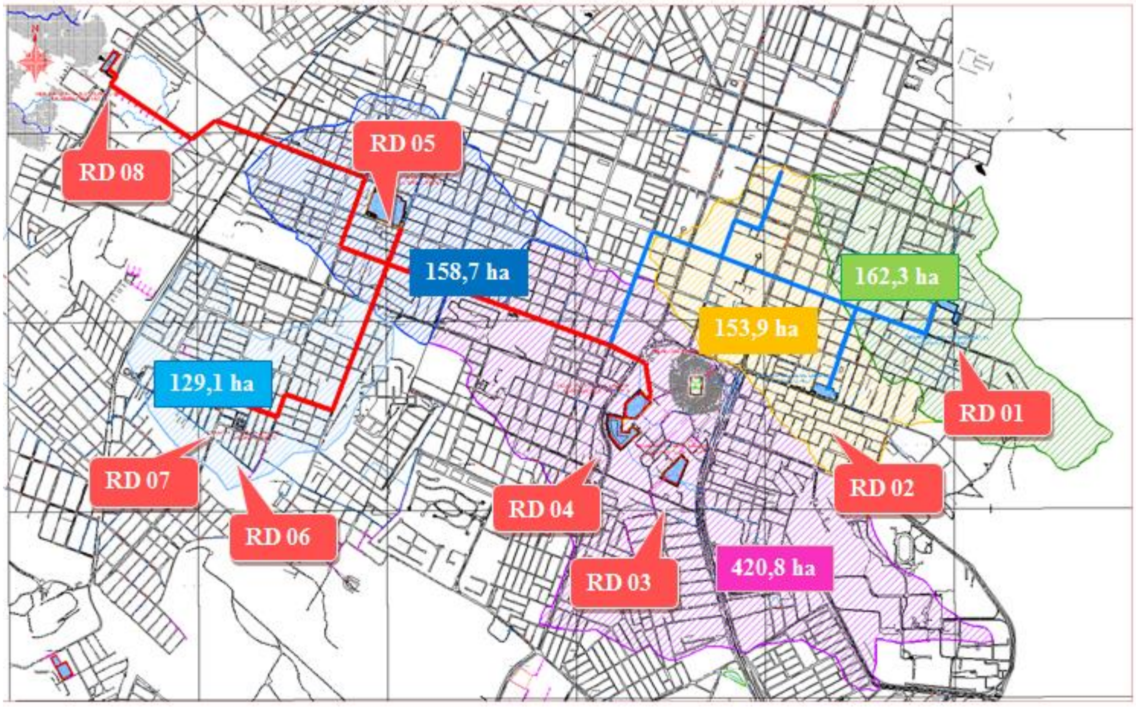

Figure 2 – South and West Drainage Areas and de Macro System

Table 2 - Characteristics of the reaches of the integrated conduits

Reach	Length (m)	Characteristic
101	658	Tunnel RD1 until the connection of gallery outflow of RD2 tunnel.
102	952	Tunnel after connection RD1 and RD2 until Jose Gonçalves street.
103	1186	Reach which receives contributions from the watershed surrounding J. Gonçalves street until detention reservoirs RD3 and RD4 at Administrative Center.
104	2184	It follows Jerome Avenue until section of receiving waters from RD5.
105	1934	From RD5 until RD8 - reservoir for absorption of first runoff near Potengi River.

4. HYDROLOGIC MODELING

For the design of the macro drainage system, a conceptual model that expresses the set of hydrological processes in the catchments of the integrated system was developed. Return period considered in this project was of 50 years.

Without detention reservoirs, concentration time was estimated in 70 min, which would result in a very high peak discharge and consequently large dimensions for tunnel sections. However, by considering new dimensions for detention reservoirs and outlet devices, it was possible to increase concentration time for 6 hours, which resulted in dimensions for the tunnel sections between 2.0 and 3.0 meters, values considered viable technical and economically.

The hydrological modeling is composed of three steps: I. concentrated hydrological modeling for all catchments. II. Simulation modeling for the operation of the detention reservoirs; III. Integration of effluent hydrographs of the detention reservoirs for the computation of water discharges in the tunnel. Table 3 gives the discharges in the main conduits of the integrated system and Figure 3 presents some hydrographs by considering the time lag due to the path of the water along Integrated Conduit System.

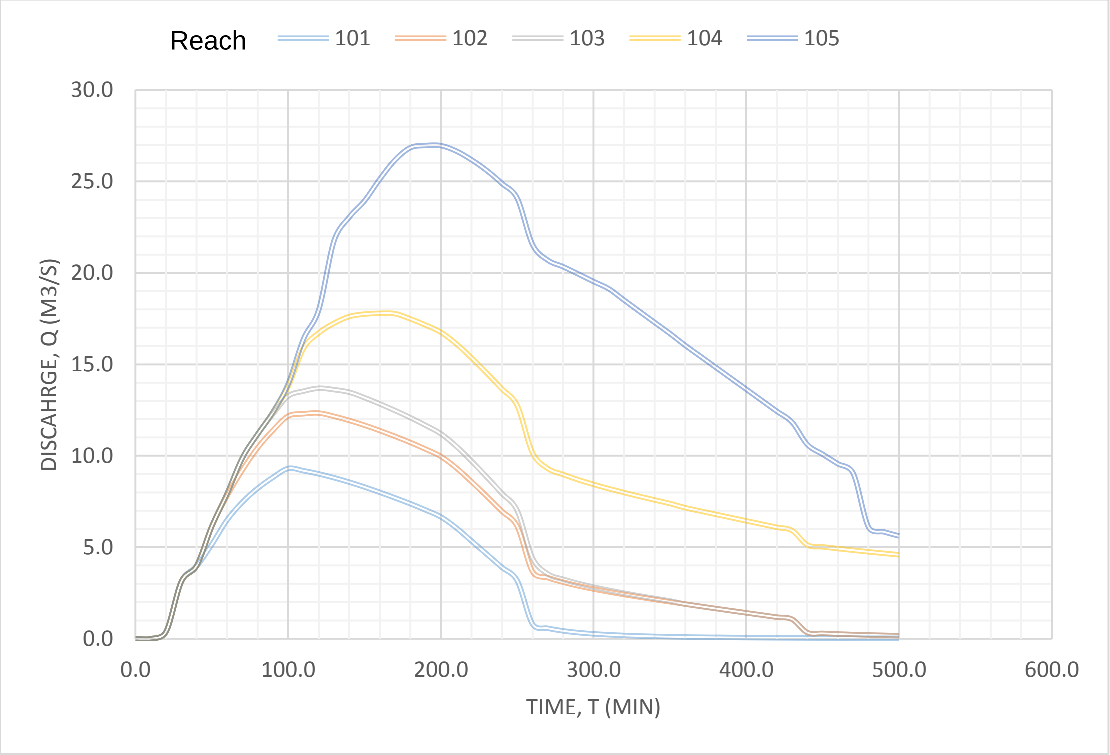

Figure 3 – Main discharges of the Integrated Conduit System

Table 3 - Discharges in the main conduits of the Macro Drainage

Reach	101	102		103		104		105	
	Contributing Area								
	RD1	RD2		J. Gonç. St.		RD3 + RD4		RD5 + RD6 + RD7	
	Discharge (m³/s)								
t (min)	1	2	3 = 2+1	4	5=3+4	6	7=5+6	8	9=7+8
0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
10	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
20	0.4	0.0	0.4	0.0	0.4	0.0	0.4	0.0	0.4
30	3.1	0.0	3.1	0.0	3.1	0.0	3.1	0.0	3.1
40	4.0	0.0	4.0	0.0	4.0	0.0	4.0	0.0	4.0
50	5.2	1.0	6.2	0.0	6.2	0.0	6.2	0.0	6.2
60	6.5	1.3	7.8	0.1	7.9	0.0	7.9	0.0	7.9
70	7.5	1.8	9.2	0.7	9.9	0.0	9.9	0.0	9.9
80	8.2	2.2	10.4	0.7	11.2	0.0	11.2	0.0	11.2
90	8.8	2.6	11.4	0.9	12.3	0.1	12.4	0.0	12.4
100	9.3	2.9	12.2	1.1	13.3	0.5	13.8	0.1	13.9
110	9.2	3.1	12.3	1.2	13.5	2.3	15.9	0.5	16.4
120	9.0	3.3	12.3	1.4	13.7	3.0	16.7	1.3	18.0

Table 4 presents the drainage area, reservoir horizontal area, and runoff coefficient for each reservoir and corresponding catchment.

Table 4- Drainage area, reservoir horizontal area and runoff coefficient

Detention Reservoir	Drainage Area (ha)	Reservoir Horizontal Area (m^2)	Runoff Coefficient (C)
RD 1	162.3	6635.4	0.554
RD 2	153.9	6039.7	0.523
RD 3 + RD 4	420.8	40464.5	0.444
RD 5	158,7	29635.4	0.534
RD 6 + RD 7	129.1	4125.8	0.537
Integrated System	1024.8	86900.8	0.493

5. HYDRAULIC DESIGN OF THE MAIN CONDUIT

Table 5 shows the worksheet for calculating the hydraulic elements of the main conduits of the integrated. The calculation is based in Manning equation, considering n=0.013. Each column represents the following:1. Reach number; 2. Length; 3. Maximum discharge; 4. Diameter; 5. Slope, S; 6. Inlet base elevation, Zin; 7. inlet base elevation, Zout; 8. Uniform flow factor, $Zh=n.Q.D^{8;3}S^{1/2}$; 9. Relative depth, h/D; 10. Flow depth, h; 11. Dimensionless Hydraulic radius, R_H/D; 12. Velocity, $V=R_H^{2/3}.S^{1/2}.n^{-1}$; 13. Relative coefficient for critical flow regime, $k=Q.D^{5/2}$; 14. Dimensionless critical depth, $h_c/D=0.5684.k^{0.5106}$; 14. Regime definition.

Table 5 - Worksheet for calculating the hydraulic elements of the main conduits

Reach	L	Q	D	S	Zin	Zout	Zh	h/D	h	Rh/D	V	k	ho/D	Regime
	(m)	(m3/s)	(mm)	(m/m)	(m)	(m)	(m)		(m)		(m/s)			
[1]	[2]	[3]	[4]	[5]	[6]	[7]	[8]	[9]	[10]	[11]	[12]	[13]	[14]	[15]
101	658.24	9.32	2.20	0.0019	22.400	21.149	0.3388	0.9188	2.021	0.3084	2.59	1.295	0.649	subcr.
102	881.81	12.33	2.40	0.0022	20.949	19.009	0.3302	0.8873	2.13	0.3088	2.95	1.378	0.670	subcr.
103	1186	13.71	2.40	0.0028	19.009	15.689	0.326	0.8727	2.094	0.3087	3.33	1.535	0.707	subcr.
104	2193.4	17.83	2.60	0.0029	15.489	9.128	0.3382	0.9090	2.363	0.3086	3.58	1.633	0.730	subcr.
105	1755.3	27.02	3.00	0.0033	8.728	2.935	0.3364	0.8741	2.622	0.3087	4.20	1.732	0.752	subcr.

6. ABSORPTION SYSTEM OF FIRST RAINS

In order to mitigate the impacts of effluent release in the estuary of Potengi, the detention reservoirs work as absorption device of first waters. For that objective, each reservoir has been designed considering the following:

a. reinforcing the holding tanks at 1.0 m below the discharge threshold devices for volume creation waiting for water infiltration from the bottom surface of the reservoirs ;
b. Deployment at the bottom of Detention Reservoirs battery infiltration wells to alleviate the clogging process that decreases the infiltration capacity of the soil at the bottom of reservoirs , enlarging thereby recharging the aquifer from the reservoirs of detention ;
c. Implementation of grid structure with mobile devices to retain solid waste carried by the drainage system.

The impact of the incorporation of the first rains of the container assembly detention Integrated System is evaluated from the effective rainfall (SPEP) given below, which expresses the maximum retention capacity of the container assembly detention Integrated Drainage System.

The impact due to the absorption of first waters by the net detention reservoir is evaluated from the effective precipitation, $P_{efe,,}$ which is determined by simple expression, and corresponds to de maximum capacity by the net detention reservoirs. Its value is

$$P_{efe} = \frac{86.900{,}8\ (m^2) \times 1{,}0(m) \times 1000(\frac{mm}{m})}{1024{,}8\ (ha) \times 10.000(\frac{m^2}{ha})\ \times 0{,}493} = 17{,}2\ mm$$

52 years statistical analysis of Natal daily precipitation data (Pfafsteter 1957) shows that (in percentage): Rainy days in Natal: 39.1%. Rainy days with precipitation less than 17.2 mm: 81.1%. Absorption of drainage basin rainfall by detention reservoirs (related to the total rainfall): 35.5% (approximately equal to the natural recharge of the catchments).

These values demonstrate that the detention reservoirs will effectively remove first pluvial water most of time, preserving against contamination waters discharged in Potengi River Estuary.

7. CONCLUSION

Flooding problems in the lowlands of Natal because of the increased volumes of waters entering to the detention ponds are solved through a system of tunnels that will allow the transportation of water excess of the ponds to Potengi River.

This is an important and unconventional hydraulic structure that will eliminate the risk of flooding at various points in the city; particularly, in the Govern Administrative Center and the Arena das Dunas stadium sport center planned for activities for a population of 40,000 people.

The integrated system consists of a network of tunnels built by nondestructive method and matched with the existing infrastructure in the city. It is planned to be built in two stages. The main network is composed of five tunnels reaches with diameters between 2.20 to 3.00 m and total length of 6674 m. Flows happen by gravity so that to ensure automatic operation without the need for mechanical and electrical devices.

The project considers volumes of normal pluvial waters for retention and infiltration in ponds; and, mainly, the retention of first pluvial waters that will minimize contaminated effluents during high rains.

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