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Evaluation of Water over Flowing Risk of Oryx Lake In Dakar, Senegal

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ABSTRACT:- *The oryxlake, was once a lake designed to recharge the groundwater in Dakar. But, nowadays, because of anarchic and raging urbanizationit is confronted with serious modifications involving imbalance on ecosystem and causing devastating floods. In that area, flooding becomes more and more catastrophic, worrying for Senegal government. Progressive urbanization leads a waterproofing surfaces thus reducing the infiltration of rainwater. This reduction has as a corollary increased amounts of runoff. The object of this present article is, through numerical modeling, to assess the risk of flooding linked to the excesses of the waters of the lake representing the outlet of the catchments areas of Grand Yoff, Castors and Front de Terre. To do this, we used the software Storm Water Management Model (SWMM) to simulate dripping rainwater and make forecasts to horizon 2025. The results show that in 2025, an amount of water estimated at 371 149 m^3 could overflow from the lake if a ten years return period for rainfall, like a Kiefer one, is recorded. This result shows that accompaniment measures are necessary to prevent flooding.*

Keywords -*Urbanization, rain water, Overflowing risk, Oryx lake, Dakar*

I. INTRODUCTION

The Senegal, with an area of 196,722 km^2, is one of the smallest countries in the Sahel [1]. Dakar, its capital, with an area of 550 km^2, occupies more than a quarter of the national population which, in 2013, was estimated at 12.88 million inhabitants [2]. This rapid demographic change is due, on the one hand, to a natural growth rate of 3% per year [2] and, on the other hand, to very large migratory flows. Indeed, with the drought of the 1970s, Dakar saw its populations increase considerably because of the deterioration of living conditions in rural areas. The massive rural exodus caused by drought has precipitated the population growth and development of the Senegalese capital. Seasonal labor migration then turned into a permanent rural exodus from the 1980s [3], [4], [5], [6], [7].

This increase in the population is at the origin of a multiplication of spontaneous neighborhoods. In fact, the scarcity of land used for housing has led to a rush to undeveloped land that is particularly favorable to long stagnation of rainwater. This situation results in the anarchic occupation of the space, without any consideration of the natural ways of circulation of rain water [8], [9]. Thus, the lowlands that normally constitute areas of concentration of runoff or simply outcropping of the ground water, are fragmented and occupied, without any prior arrangement. For long periods, the authorities allowed the populations to illegally take possession of these areas, yet declared non aedificandi (not habitable) by the Master Plan of Sanitation established in 1994. This phenomenon has become widespread everywhere in the periphery of Dakar. Indeed, before 1964, the urban watersheds of Grand Yoff, Castors and Front de Terre that have Oryx lake as their outlet were only small neighborhoods [10]. Over the years, they have experienced a disturbing rate of urbanization, resulting in their waterproofing with as a corollary, an ever increasing development in the runoff coefficient of these basins. Oryx lake, following rains recorded in August 2005, experienced an overflow that caused significant damage in surrounding neighborhoods [11]. However, this lake, had once had the essential function of serving as an infiltration zone for all the rainwater drained by the Grand Yoff, Front de Terre and Castors basins for the recharge of the aquifer. Today, it acts as a clipping basin for rainwater originating from these watersheds (photo 1).

Photo 1: ORYX lake with one of its parts backfilled and intended for housing

With the urbanization, this area has experienced floods during the month of August 2005. Indeed, in the week of 16 to 22 August 2005, a cumulative rain of about 188 mm, fell on Dakar and its surrounding areas, resulting in the flooding of large areas, resulting in dysfunctions in urban mobility, particularly at the low points of the Dakar motorway [12] see photo 2. To combat these floods, emergency solutions, consisting of pumping water, were mostly adopted. Today, it is envisaged the application of sustainable solutions consisting of structural networks for rainwater drainage as part of the ten-year flood control program.

Photo 2: Flooding of Dakar Highway in August 2005

II. METHODS AND MATERIALS

II.1. Presentation of the study area

Oryx lake, also known as the storm water catchment area, is the natural outlet of the Grand Yoff (BVUGY) urban watersheds, the Front de Terre and Castors [12] (Fig. 1). These watersheds have housed the so-called “bocager” of the district municipality of Grand Yoff. The latter was composed of euphorbia hedges. This “bocager” was a real green space especially during the rainy season [12]. With urbanization, green spaces have decreased, giving way to infrastructure and housing. The soils of watersheds belong to the series of sandy soils called “diors” according to Maignien's classification [12]. These are permeable and allow the infiltration of water [13].

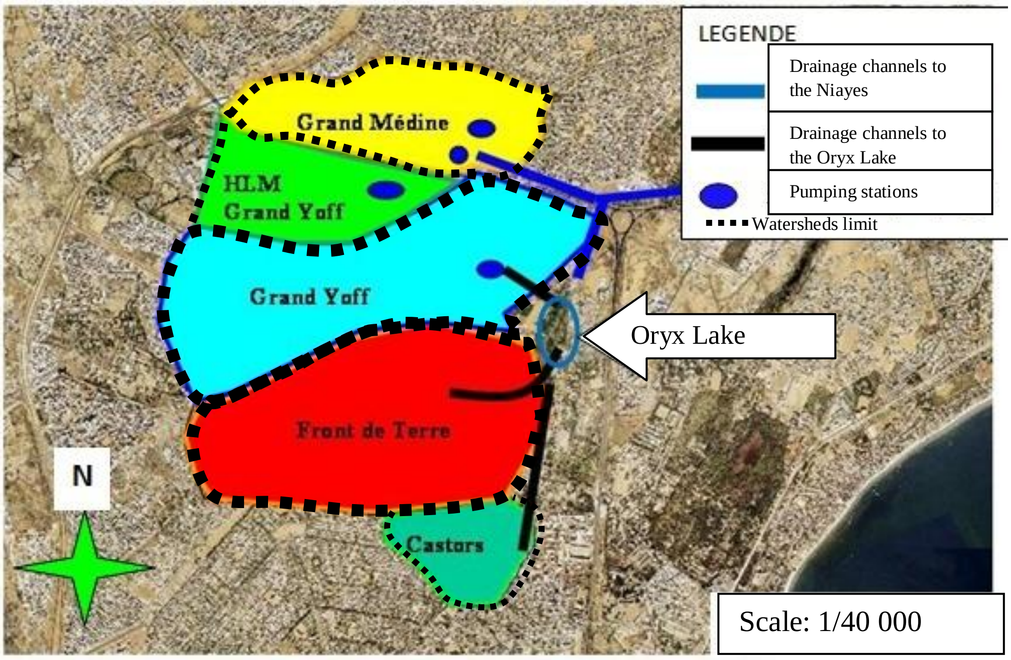

Figure 1: location of drainage basins drained by Oryx lake [11].

II.2. Data and material

In 2005, the ORYX lake had only a storage capacity of 80,000 m^3 because of its gradual refilling by people seeking housing [11]. However, its capacity was 300,000 m^3 in 1990 [11]. With the rain event of August 2005, there was an excess volume that overflowed to cause flooding of the banks of the lake and riparian areas. Table 1 gives the characteristics of the runoff generated by this rain.

Table 1: Characteristics of runoff generated by the rain event of August 2005

Watershed	Area (ha)	runoff water thickness (mm)	Volume streamed (m^3)	runoff coefficient (%)	Max flow (m^3/s)
Front de terre	200	71.3	142,600	51	15.84
Grand Yoff	200	71.24	142,490	50	15.58
Oryx lake	8	132.16	10,573	94	0.99
Bank of Oryx lake	15	70.95	10,643	50	1
Castors	40	71.56	28,624	50	3.63
Total	**463**	**72.34**	**334,930**	**51**	**37.04**

For a lake capacity estimated at 80,000 m^3, the data in Table 1 show an excess volume of 254, 930 m^3 overflowing the lake. The flooded areas rise to 24 ha occupying the banks of the lake, part of the highway of Dakar and the City "Belle vue" is a height of flood of 1.06 m.

The 2005 floods on the shores of ORYX lake and surrounding areas alerted the appropriate authorities who tried to address it by undertaking its rehabilitation. The latter gave the lake in 2006 the characteristics mentioned in Table 2.

Table 2: ORYX lake Characteristics in 2006

Perimeter	**1,600 m**
Area	**8 ha**
Capacity	**170,000 m^3**
upper level of the basin	**9.75 m**
Level of the lowest point	**7.49 m**

To avoid potential overfilling during the winter of 2006, technical provisions were made. Thus a pumping system, intended to evacuate excess water from the lake to the sea using a pump delivering 950 m^3/h with a pumping time of 9 hours per day, was put in place. However, despite these measures taken by the authorities, the risks of overflowing lake water were real.

Based on these data provided by the DGPRE [11], the results of its studies, we used the EPA SWMM software to evaluate the ORYX lake overflow risks in the case of a decennial rainfall event (a rainfall likely to fall on average once after all ten years). The input data required for the software is as follows: area in ha or percentage of impervious surface area (Simp) of catchment area, catchment area, daily rainfall in mm and average slope of catchment.

To estimate the volumes of water received in Oryx Lake, we need the surface areas of the watersheds that supply the lake. For this, we used a satellite image extracted from "google earth", with a resolution of 1 m (Fig. 1), provided by the DGPRE that used this structure for the delimitation of watersheds and the determination of their areas.

Rainfall data, in daily time steps over the period 1971-2013 were provided by the National Agency of Civil Aviation and Meteorology (ANACIM).

As part of the Dakar Drainage Master Plan [8] (SGI/CABINET MERLIN/EDE GROUP, 2012), project rains of return period T=10 years have been defined. They are five (5) in number and are defined as follows:

• Four (4) short duration rains, elaborated according to the double-triangle method [8], characterized by their intense durations: 15, 30, 60 and 120 minutes, over a total duration of 4 hours;

• A long rain, Kiefer type, lasting 24 hours.

Table 3 gives the rainfall height according to the type of rain.

Table 3: Height of DPP project rains

Types of rain	4 H-15 mn intense duration	4 H-30 mn intense duration	4 H-60 mn intense duration	4H-120 mn intense duration	Kiefer Type duration 24 H
Height (mm)	101.94	102.03	102	102	129.8

For the simulations, to put ourselves in the most critical case, we used the Kiefer type rain.

The estimation of the volumes that have elapsed also requires the determination of the runoff coefficients of the watersheds. To do this, we used the EPA Storm Water Management Model software (SWMM) which uses hydrological models such as Horton, Green Ampt, Curve Number [14]. It is a simplified model of hydrological and hydraulic simulations used for hydrodynamic modeling study of the quantity of runoff water on urban and rural watersheds in the case of a short or long-term rain event.

EPA SWMM input data provides the maximum daily flows, water slides, and runoff coefficient for each studied watershed.

The runoff model used by EPA SWMM is a conceptual model [15], [16], [17], [18]. Its 1971 version produced by US Environmental Protection Agency Dresser Camp & McKee Engineering Inc. represents the watershed as a rectangular channel with free surface (Figure 2)

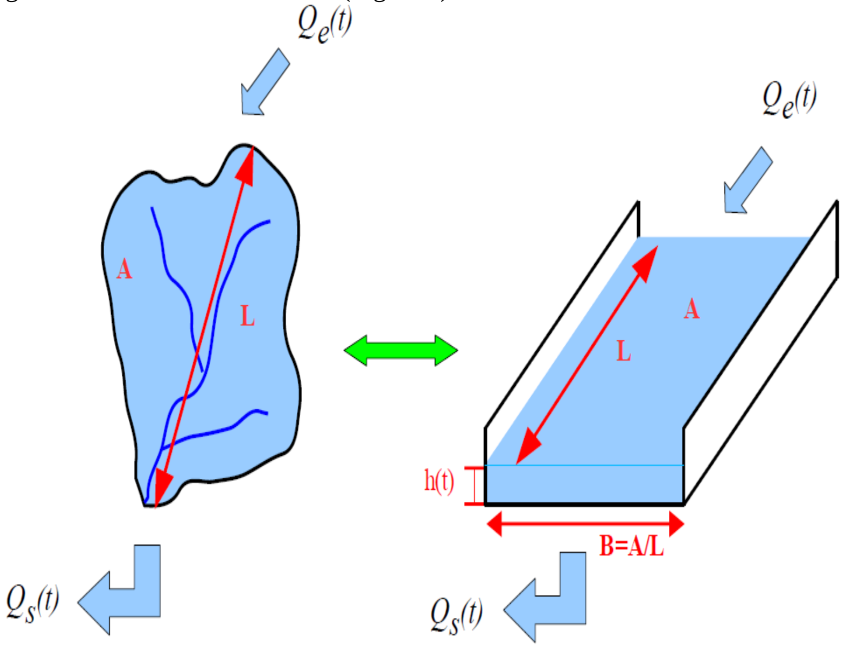

Figure 2: Schematic diagram of the runoff model by EPA SWMM

The inflow $Q_e(t)$ corresponds to the excess precipitation (precipitation-infiltration-evaporation-interception by vegetation or depressions at the surface of the catchment).
The outflow $Q_s(t)$ is calculated at each time step using the Manning-Strickler formula based on the channel characteristics (width and roughness) and the height h(t) of the water slide that flows in. the canal.

$$Q_s(t) = S_H(t).S_H(t)^{\frac{2}{3}}.\sqrt{i} \quad (1)$$

In which $S_H(t) = B.h(t)$ and $S_H(t) = \frac{B.h(t)}{B+2.h(t)}$

Finally, a conservation equation of water volume (or storage law) connects at each time step, the water level h(t) which flows, at inflows $Q_e(t)$ and outgoing $Q_s(t)$ equation

$$\frac{dV(t)}{dt} = Q_e(t) - Q_s(t) \quad (2)$$

In which V(t) is the volume of the channel.
This model is part of nonlinear reservoir models. The impervious areas required for EPA SWMM modeling are determined on the basis of interpolations, based on data provided by DIA's method [19].

III. RESULTS AND DISCUSSIONS

III.1. Assessment of flood risk by overflow of Oryx Lake

The results of the EPA SWMM model (Table 4) show that a Kiefer-type decadal rainfall could cause flooding in 2006.

Table 4: Runoff characteristics for a decadal rainfall in 2006

Watershed	Area (ha)	runoff water thickness (mm)	Volume streamed (m^3)	runoff coefficient (%)	Max flow (m^3/s)
Front de terre	200	77.34	154,680	54.8	16.78
Grand Yoff	200	77.31	154,620	54.7	16.50
Oryx lake	8	130.88	10,470	92.7	0.98
Bank of Oryx lake	15	76.98	11,547	54.5	1.05
Castors	40	77.66	30,850	54.6	3.84
Total	**463**	**78.27**	**362,167**	**55.4**	**39.18**

Indeed, for a ten-year Kiefer rain event, a quantity of 362,167 m^3 could access the lake for a storage capacity of 170,000 m^3. In this case, the populations of the banks of ORYX lake would be exposed to 183,617 m^3 which would have overflowed corresponding to a height of flood of 0.77 m for a flooded surface of 24 ha. In 2006, such a rain event was certainly not noted but the lake has often threatened to overflow following simple rains. This did not fail to alert the authorities about the lake's low storage capacity. Consequently, the State has undertaken work to increase the storage capacity to prevent overflow risks during the winter of 2007. This work involved the construction of a 1.20 m storage capacity from 170,000 m^3 to 266,000 m^3. In addition, a new pump delivering 1 m^3/s has been installed. Table 5 gives the characteristics of runoff that would have been generated by a Kiefer-type 10-year rainfall event in 2007 according to EPA SWMM forecasts.

Table 5: Runoff Characteristics for Kiefer Decadal Rainfall in 2007

Watershed	Area (ha)	runoff water thickness (mm)	Volume streamed (m^3)	runoff coefficient (%)	Max flow (m^3/s)
Front de terre	200	83.35	166,700	59	17.70
Grand Yoff	200	83.33	166,660	59	17.41
Oryx lake	8	132.26	10,581	93.6	0.93
Bank of Oryx lake	15	82.96	12,444	58.7	1.11
Castors	40	83.70	33,480	59.3	4.08
Total	**463**	**84.20**	**389 865**	**59.6**	**41.29**

The EPA SWMM forecast shows that there would be a surplus of 149,465 m^3 which would overflow, taking into account the volume of 58 000 m^3 occupied by the wastewater generated by the illegal connections. This corresponds to a flooded area of 22 ha for a flood height of 0.68 m. Indeed, knowing that Grand Yoff has a population estimated at 100,000 inhabitants and that 60% of the population is legally connected to the wastewater drainage network. National Office of Sanitation of Senegal (ONAS), an average monthly volume of 18,250 m^3 of wastewater would be discharged into the lake (It is assumed that 25% of the population is clandestinely connected to the rainwater network for 20 l/day/hbt spilled on average in the lake). For an annual evaporation of 1.1 m, a volume equivalent of 120,000 m^3, the quantity of wastewater available in the lake could reach 58 000 m^3 at the beginning of the rainy season (Photo 3).

Photo 3: ORYX lake flooded with sewage due to illegal connections

This means that the drainage plan, despite the changes made between 2005 and 200, still had limits that would have the main consequences of the floods that would occur in the case of a decennial rainfall event.

The maximum daily rainfall (10 years) is considered to be 142 mm (corresponding to the adjusted value of the last decennial rainfall observed in Dakar in 2005). Knowing the duration of the rain, assumed to be equal to 7 hours, the runoff coefficient and the total volume of run-off water per hour on the catchments concerned, the volume stored by the lake is calculated after pumping. The expected results (Table 6) show that the existing network has limitations with respect to the lake's storage capacity of all runoff volume.

Table 6: Simulation of the behavior of the Oryx lake in 2007 in the case of a Kiefer-type decadal rain event

Duration (hour)	Precipitations (mm)	Collected Volume (m^3)	Pumped Volume (m^3)	Stored Volume (m^3)
initial Volume				**58,000**
1st hour	26	69,817	3,600	**124,217**
2nd hour	10	26,853	3,600	**147,470**
3rd hour	13	34,908	3,600	**178,778**
4th hour	23	61,761	3,600	**236,939**
5th hour	34	91,299	3,600	**324,638**
6th hour	12	32,223	3,600	**353,261**
7th hour	24	64,446	3,600	**414,107**
8th hour	0	0	3,600	**410,507**
9th hour	**0**	**0**	**3,600**	**406,907**

Rainfall similar to that of 2005, that is to say, a decennial type of rain could still cause overflows at the ORYX lake which would amount to 140,907 m^3 corresponding to a floodable surface of 22 ha, ie a height of flood of 0.64 m.

Therefore, we propose that a new network be sized considering the forecasts by 2025.

III.2. Proposal for a new stormwater drainage plan

In the drainage network that we will propose, we will consider the characteristics of watersheds by 2025 in order to make a dimensioning whose results will allow the realization of networks that will function efficiently and sustainably.

In what follows, we will resize the drainage network by considering the values that could take the coefficient of runoff at this horizon. Indeed, if nothing is done to stop the rate of urbanization in the study area, the runoff coefficient could reach 93% in 2025. The results mentioned in Table 7 are provided by EPA SWMM to the horizon 2025.

Table 7: Characteristics of runoff that would be generated by a decadal rainfall in 2025

Watershed	Area (ha)	runoff water thickness (mm)	Volume streamed (m^3)	runoff coefficient (%)	Max flow (m^3/s)
Front de terre	200	131.29	262,580	93	24.38
Grand Yoff	200	131.23	262,460	93	23.96
Oryx lake	8	132.26	10,581	93.6	0.99
Bank of Oryx lake	15	130.57	19,586	92.4	1.52
Castors	40	131.84	52,736	93.3	5.68
Total	**463**	**131.31**	**607, 943**	**93**	**56.54**

A problem of space arises at the level of ORYX lake to collect all the waters emanating from the watersheds of Grand Yoff, Castors and Front de Terre. In fact, the cumulative incoming volume estimated at 607,943 m^3 is greater than the estimated outgoing volume of 32,400 m^3 according to the performance of the planned pump delivering 1 m^3/s for a duration of 9 hours corresponding to the sum of the duration of the downpour and the concentration time of runoff from decadal rainfall. And since the storage capacity of the infiltration basin amounts to 266,000 m^3 and the quantity of sewage discharged illegally is estimated at 58,000 m^3, the excess volume to be evacuated would be 371,149 m^3 (Table 8) which corresponds to a flooded area of 24 ha for a flood height of 1.55 m: an alarming case.

Table 8: Simulation of the quantities of water likely to cause floods following a Kiefer-type decadal rainfall event in 2025 with a pumping rate of 1 m^3/s

Duration (hour)	Precipitations (mm)	Collected Volume (m^3)	Pumped Volume (m^3)	Stored Volume (m^3)
Initial stock				**58,000**
1st hour	26	111,974	3,600	**166,374**
2nd hour	10	43,067	3,600	**205,841**
3rd hour	13	55,987	3,600	**258,228**
4th hour	23	99,054	3,600	**353,682**
5th hour	34	146,427	3,600	**496,509**
6th hour	12	51,680	3,600	**544,589**
7th hour	24	103,360	3,600	**644,349**
8th hour	0	0	3,600	**640,749**
9th hour	**0**	**0**	**3,600**	**637,149**

Knowing that the expected pumping rate, amounting to 1 m^3/s, is low, it will be necessary to set up a more efficient pumping system that can deliver up to 10 m^3/s to relieve the neighboring populations of possible overflows of the waters of ORYX lake. In this case, Table 9 gives the results of the simulation done for the verification of the quantities of water likely to cause floods by 2025.

Table 9: Simulation of quantities of water likely to cause floods following a decennial rainfall event in 2025 with a pumping rate of 15 m^3/s

Duration (h)	Precipitations (mm)	Collected Volume (m^3)	Pumped Volume (m^3)	Stored Volume (m^3)
Initial stock				**58,000**
1st h	26	111,974	54,000	**115,974**
2nd h	10	43,067	54,000	**105,041**
3rd h	13	55,987	54,000	**107,028**
4th h	23	99,054	54,000	**152,082**
5th h	34	146,427	54,000	**244,509**
6th h	12	51,680	54, 000	**242,189**
7th h	24	103,360	54, 000	**291,549**
8th h	0	0	54, 000	**237,549**
9th h	**0**	**0**	**54, 000**	**183,549**

The results in Table 9 show that a pump station discharging 15 m^3/s would avoid overflows since the volumes to be stored would be bearable at any time by the lake with a capacity of 266,000 m^3, in this case.

IV. CONCLUSION

From this study, it is clear that the floods have become a real problem for the populations of Grand YOFF, the residents of ORYX lake and for the competent authorities. But while it is true that sanitation has long been treated as a poor relation, today, not to mention since the floods of 2005, the state seems to be making it one of its development priorities, according to the significant resources allocated to this sector. However, it is not enough to put means to get Dakar out of the waters in which it bathes almost during the entire duration of each rainy season and even during a large part of the dry season. This means that concerted management of the flood problem has become more than an urgency to harmonize the interventions and reinforce the synergy between the different State structures that are concerned, as well as those of the local communities.

This article will, we hope, provide additional elements of response on the influence of urbanization, which is evolving exponentially, on the floods in Dakar particularly at the level of watersheds with outlet ORYX lake. The study of the evolution of the runoff coefficient according to that of the increasing urbanization made it possible to specify the potential contribution of this one on the waterproofing of the catchment and in fact on the floods in the area of the Niayes.

Oryx lake is to be watched because of the risks of overflowing due to an exceptional rain event. To prevent these risks, it will be essential to ensure that the evacuation capacity of the pumping station is always greater than the volume of water emanating from the watersheds discharging their runoff into the lake.

This preventive measure of risk is to be taken seriously by the administrative authorities of Senegal all the more as with the progressive urbanization, the Oryx lake is already in state of alert. This situation combined with the effects of climate change that could increase the amount of rainwater, leaves a risk more than ever alarming.

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