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TWO DIMENSIONAL HYDRODYNAMIC SIMULATION OF THE *OLHO D'ÁGUA* LAGOON, JABOATÃO DOS GUARARAPES (PE).

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ABSTRACT: The objective is to verify the influence of the evolutionary process of unplanned urbanization, caused by poor planning and land use, on the natural dynamics of storm water runoff in areas susceptible to flooding in the watershed of the Olho d'Água Lagoon in Jaboatão de Guararapes - PE. This study was part of the Sustainable Development Plan for the Olho d'Água Lagoon. The MIKE FLOOD simulation system was used as the primary technology in hydrodynamic analyses of 4 scenarios, proposed from structural interventions defined by experts and connoisseurs of local problems. Some of the proposed solutions consider future projects and civil works. The results of simulated scenarios and the solution adopted under the project are also presented.

Key Words: Hydrodynamic Simulation, MIKE FLOOD, Flood maps, Olho d'Água Lagoon.

1. INTRODUCTION

The accelerated development of cities has resulted in large-scale changes in the environment and serious problems for urban infrastructure, especially with regard to environmental impacts caused by the uncontrolled occupation of such areas.

In addition to being accelerated, as a rule the process of urbanization has taken place in an unchecked manner, without the planning and actions necessary for adequate land use. In the majority of cases the consequences are negative and the impacts on mankind and natural resources are often irreversible. One of the impacts arising from the urbanization process, but which has often been treated in a secondary manner, relates to the drainage of rainwater in urban areas. Perhaps the most evident problem associated with rainwater drainage is urban flooding. Nevertheless, other problems, such as the pollution of water sources and erosion, are also directly related to urbanization and rainwater drainage (SILVA, 2006).

As a result of urban development, the original surface, which may have permeable soil and be covered with vegetation, is transformed into small straight paved and practically impermeable channels and roofs, altering the spaces that otherwise would be occupied by rainwater. These changes alter the water cycle, modifying the magnitude of hydrological processes such as: reduced infiltration capacity and loss of natural storage, increased volume of surface water runoff, increased peak flows, reduced concentration time and reduced aquifer replenishment (MAYS, 2001; WRIGHT and HEANEY, 2001) .

According to Roesner et al. (2001), peak flows following the land occupation process increase between two and more than ten times when compared to non-urbanized situations. Moreover, the frequency of the occurrence of greater flows in urban situations increases following urbanization and the difference is more significant in periods with less reoccurrence.

As such, more than just a set of works aimed at enabling water to be transported, drainage should be viewed from a global perspective, recognizing the complexity of the relationships between natural ecosystems, artificial urban systems and society.

Within this scenario, the area corresponding to the Olho d'Água Lagoon micro-basin located in the municipality of Jaboatão dos Guararapes-PE has certain peculiar characteristics, both from the physical and land use and occupation point of view, as well as from the point of view of urbanization standards.

2. PHYSICAL CHARACTERIZATION OF THE STUDY AREA: OLHO D'ÁGUA LAGOON MICRO-BASIN

The Olho d'Água Lagoon, also known as the Náutico Lagoon, is the largest natural lagoon on the coast of the state of Pernambuco. It is one of the largest lagoons located in an urban area in Northeast Brazil. Its surface covers an area of 3.75 km^2 and it is approximately 3.5 km long and 1.9 km wide (Santos and Kato, 1997).

The micro-basin of this lagoon system is part of the Jaboatão River Basin and is located close to the estuary of the Jaboatão and Pirapama Rivers (Figure 1). The micro-basin has an area of 33.5 km^2 and covers that part of the municipality where population density is large and increasing, stretching from the seashore (Piedade, Candeias and Barra de Jangada beaches) to the BR-101 Sul Highway in a east-west direction, and from the boundary with the municipality of Recife to the Jaboatão River estuary region in a north-south direction.

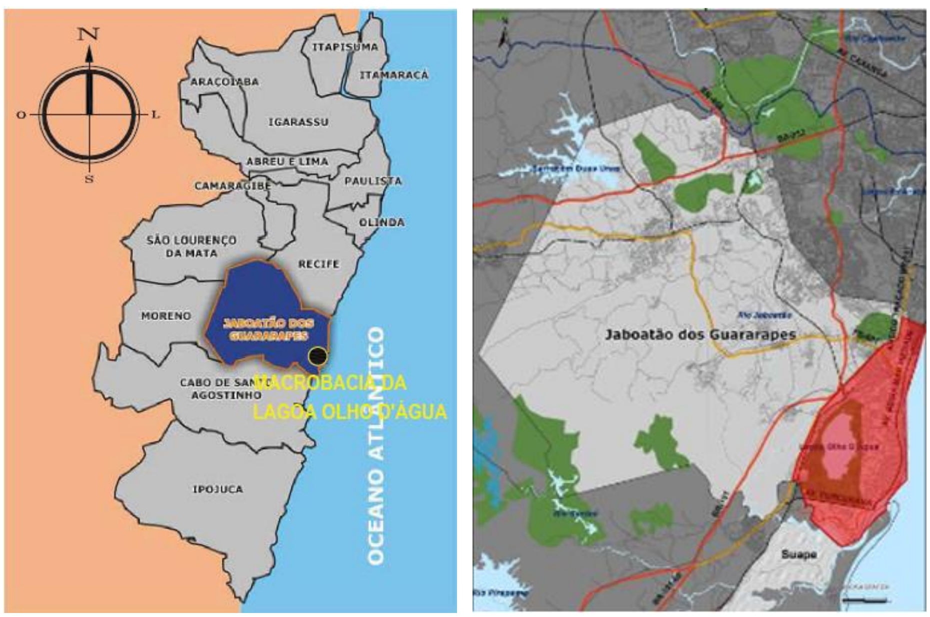

Figure 1 – Location of the study area.

Source: Olho d'Água Lagoon Sustainable Development Plan (2011).

The lagoon is also unique in that it forms a waterway link between two estuaries in the Metropolitan Region of Recife. Via the Olho d'Água Channel it is linked to the estuary formed by the mouth of the Jaboatão and Pirapama Rivers, at Barra de Jangada, and via the Setúbal Channel it is linked to the Pina River estuary at the confluence of the Tejipió, Jordão and Capibaribe Rivers in Recife (Santos and Kato, 1997). In addition to these main draining elements responsible for the hydraulic functioning of the Olho d'Água Lagoon, other channels flowing into the Lagoon also receive, on a lesser scale, part of the rainwater running off the surrounding areas (Figure 2).

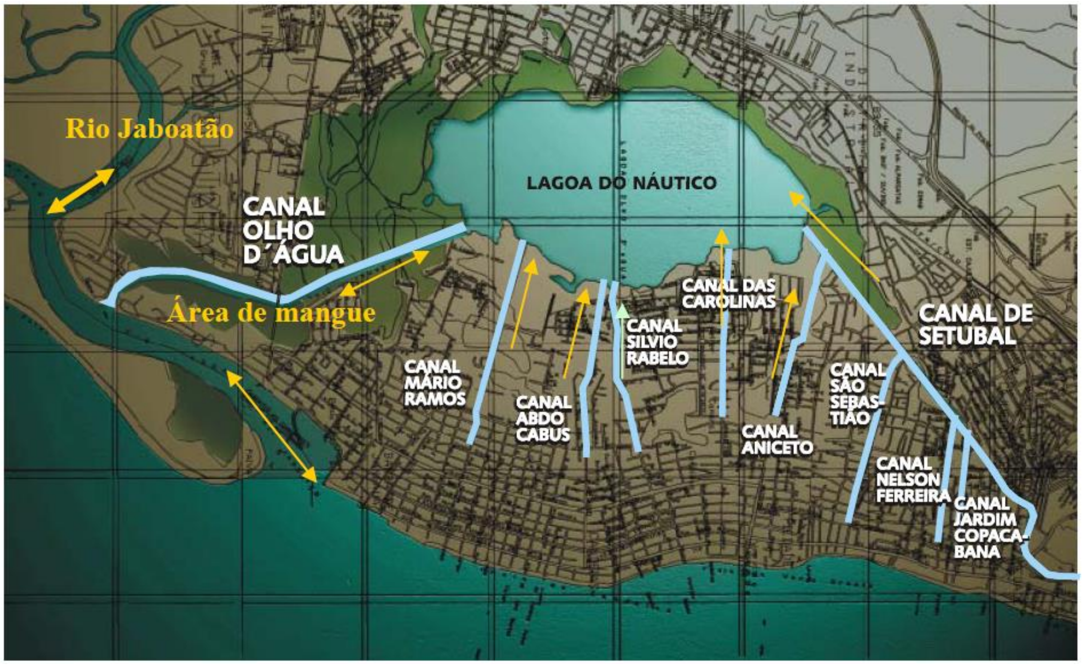

Figure 2 – Location of channels flowing into the Olho d'Água Lagoon.

Source: PMSS (2007).

The Lagoon is fed by water coming from the Jaboatão River when its level rises during rainy periods and also by the cyclical entry of sea water via the Olho D'Água Channel (CPRM, 1997).

Rainfall in the Olho d'Água Lagoon micro-basin is around 1,628.6 mm and is heavier between the months of March and August. During this period, rainfall usually exceeds losses from evaporation or infiltration and, consequently, water volume increases, flooding the banks and reaching a level of between 2.0 and 3.0 metres, forming a large number of temporary pools containing mostly freshwater and with low salinity (PDPJG, 2006).

The consequences of such rainfall events are demonstrated by the situation of the area surrounding the Lagoon as represented by FIDEM in 1978 as per Figure 3. The Figure shows that many areas, which in 1978 had little urbanization and were classified as being permanently and temporarily flooded, are now heavily urbanized especially in the western region of the Lagoon. This has resulted in consequences not only for the natural dynamics of the Lagoon, but also for bank-side housing which faces constant flooding caused by rain when rainwater is not able to flow away owing to the level of the water in the Lagoon at high tide.

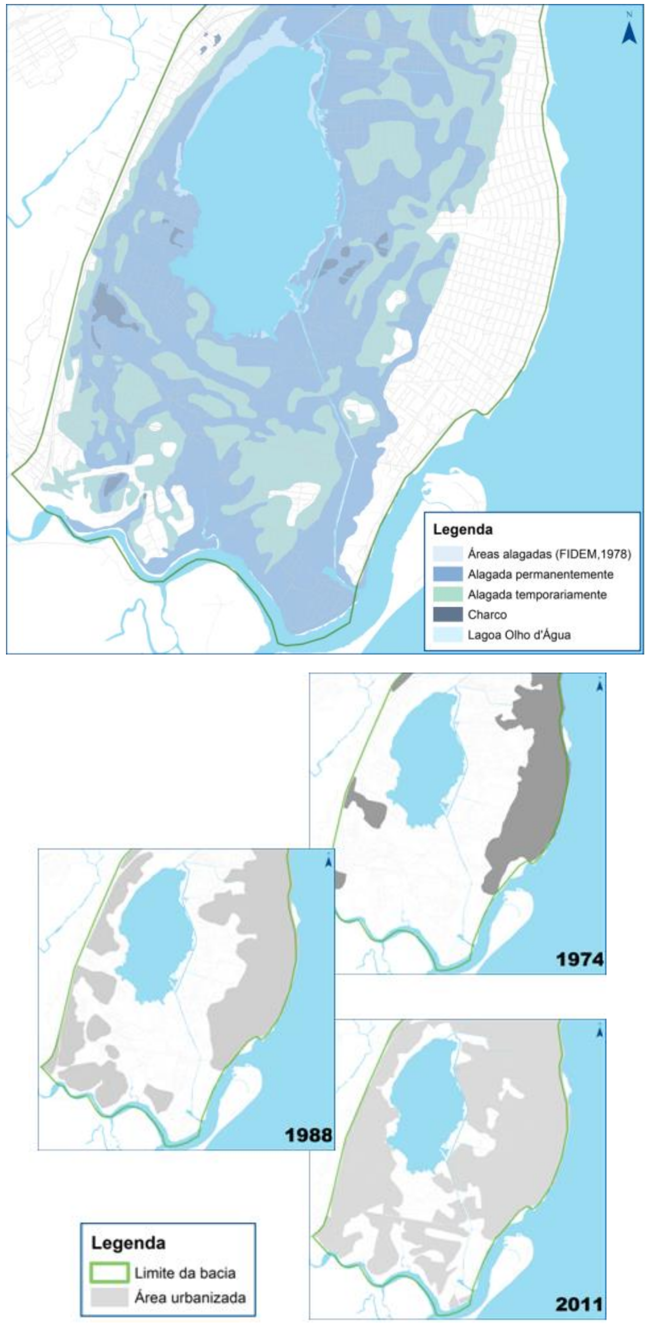

Figure 3 – Temporarily and permanently flooded areas in 1978; Evolution of the process of occupation in the areas surrounding the Olho d'Água Lagoon.

Source: Olho d'Água Lagoon Sustainable Development Plan (2011).

According to CPRM (1997) the surrounding area is morphologically and geologically homogenous and the water level in the entire area is less than 1.50 m at any time of the year.

3. MATERIALS AND METHODS

The methodology used by this study sought to verify the influence of the evolution of disorganized building resulting from poor planning of land use and occupation on the natural dynamics of surface rainwater runoff in areas subject to flooding. Moreover, focus was placed principally on the simulation of 04 scenarios based on structural interventions proposed for the Olho d'Água Lagoon, as defined by experts and specialists familiar with the local problem. Some of the solutions proposed took into consideration future undertakings and projects which in the long or short term will be developed in the study area.

Generally speaking, the following stages were defined in order to achieve the overall objective of the study:

- Acquisition of images from the past in order to map the evolution of the human occupation of the areas surrounding the Olho d'Água Lagoon over time, using:
    - Orthophoto chart dating from 1986 for a Córrego Alegre coordinates system - Zone 25S, on a scale of 1:10,000, acquired by Condepe/Fidem.
    - Black and white aerial photographs of the area in 1974, 1988 and 1997 using the SAD69 coordinates system - Zone 25S, obtained by Condepe/Fidem.
    - 1978 orthophoto chart of areas temporarily or permanently flooded, obtained by Condepe/Fidem.
- Delimitation of the Olho d'Água Lagoon flood plain as a result of an extreme event recorded between June 14-19, 2010. A high resolution satellite image from June 2010 for the WGS84 – Zone 25 coordinate system prepared by GEOEYE was therefore obtained.
- Performance of hydrological studies in the area in question, using the heavy rainfall equation for Recife as defined by FIDEM/ACQUA-PLAN in the 1980 Recife Metropolitan Region Macro-Drainage Master Plan, given the duration and return period of the event (Figure 4), and the delimitation of 13 drainage sub-basins, taking into account the concentration times (SCS Lag Formula) and the CN (Curve Number).

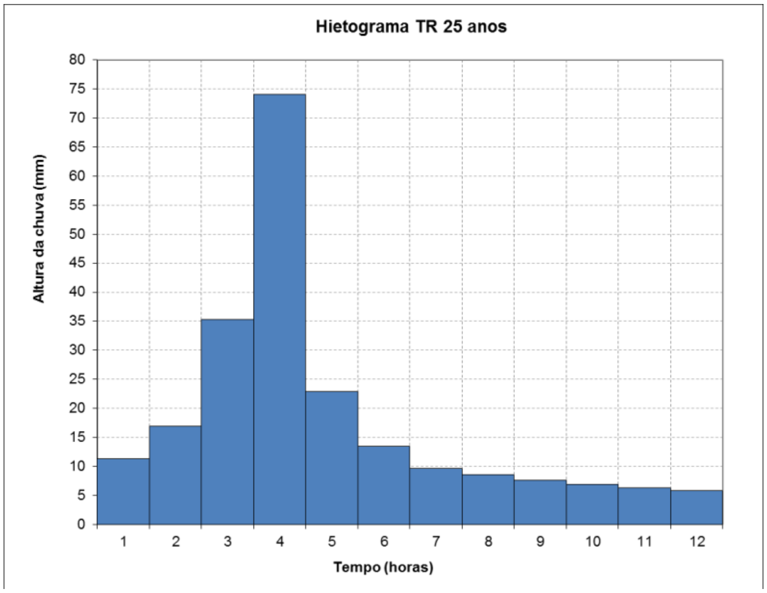

Figure 4 – Project hyetograph defined for 12 hour duration reoccurring every 25 years.

- A survey of 74 cross-sections in the Setúbal and Olho d'Água channels, as well as batimetry readings of the Olho d'Água Lagoon, with altimetric elevations set at the IBGE reference level. During the cross-section survey base, crest and axis points were measured, also taking into consideration sections with changes in direction, declivity, channel width, obstacles (bridges).

- Installation of meter rulers to accompany water level at 4 distinct points (Figure 5), so as to verify the behaviour of the Lagoon in relation to changes in the level of the tides. To this end, 6 measurement campaigns were undertaken in spring tide and neap tide conditions on March 26-27 2011, April 03-04 2011 and April 17/18 2011. The readings covered a 10 hour cycle with instantaneous measurements every 15 minutes, taking the Port of Recife Tide Table as the basis (Figure 6).

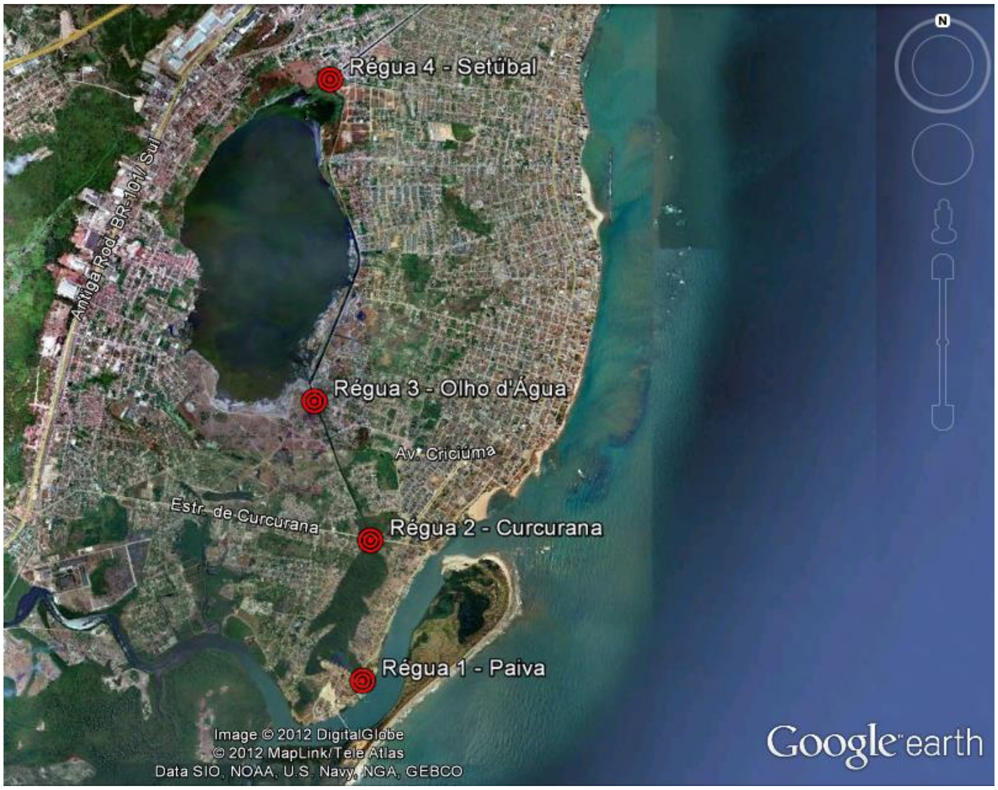

Figure 5 – Location of the metric rulers.

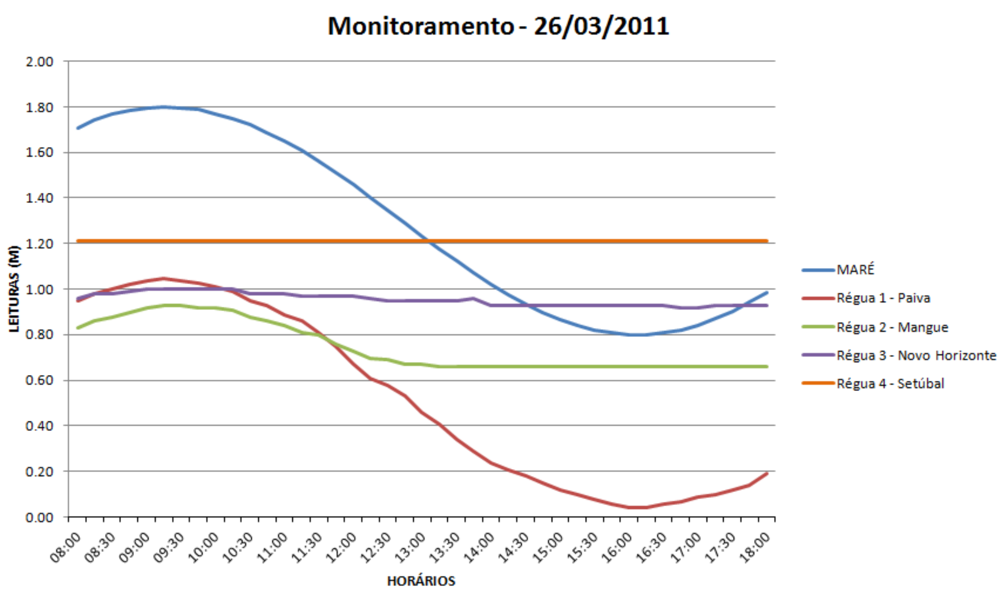

Figure 6 – Level measurements for the 4 points monitored on 26/03/2011 (Neap Tide)

- Development of the scenarios proposed based on studies or projects defined for the area in question. Existing projects were examined, as well as perspectives for their execution, with the aim of contemplating these constructive interventions in the mitigation alternatives proposed so as to ensure better hydraulic functioning of the Olho d'Água Lagoon.

- Carrying out of hydrodynamic simulations of the current situation and the 4 proposed scenarios using MIKE FLOOD software developed by DHI Denmark. MIKE FLOOD is the dynamic linkage between 1D and 2D simulation models, enabling it to model virtually any flooding problem involving rivers, floodplains, drainage networks, coastal areas, dam and dyke busts or any combination of these. This wide-ranging and flexible tool enabled us to model the various components necessary for reproducing flows and levels in the lagoon, including the Olho d'Água Lagoon floodplain, rain drainage channels, the mangrove area and structures proposed for the interventions suggested and included in the scenarios. MIKE FLOOD has virtually never-ending options of possible applications, including:

  - Rapid flood assessments
  - Mapping of areas at risk of flooding
  - Analysis of flood risks in industrial, residential or cultural heritage areas
  - Contingency planning for flooding, e.g.: planning evacuation routes and priorities
  - Evaluation of the impact of climate changes
  - Studies of flood prevention measure failures
  - Integrated modelling of floods relating to urban drainage, rivers and coastal areas

4. RESULTS

The following are the results generated by the hydrodynamic simulations developed regarding the existing scenario and the 4 (four) proposed scenarios in order to verify the hydraulic and hydrodynamic functioning of the Olho d'Água Lagoon.

The first simulation of the Existing System took into consideration the worst spring tide event high tide conditions and extreme rainfall lasting for 12 hours and recurring every 25 years in accordance with the heavy rainfall equation for Recife. This first simulation defined the Lagoon's floodplain at an elevation of 1.63m (Figure 7).

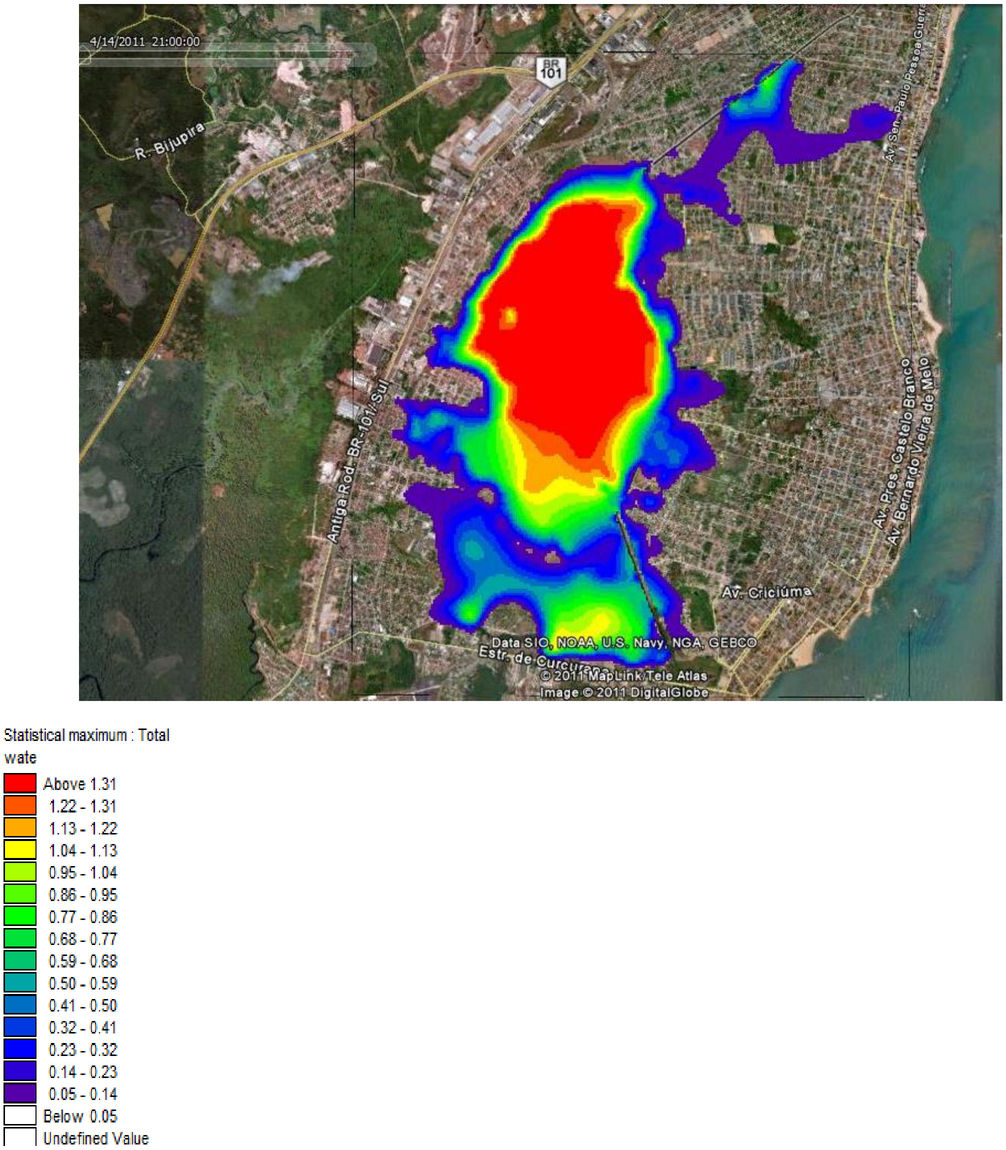

Figure 7 – Representation of the extent of flooding in the Existing Scenario.

Source: Olho d'Água Lagoon Sustainable Development Plan (2011).

Based on these results, interventions were proposed aimed at reducing the influence of the tide, so as to enable the runoff of rainwater during extreme precipitation events. Scenario 1 proposed an intervention to provide macro-drainage solutions by widening the Olho d'Água Channel, transforming it into a 40m wide rectangular concrete-lined channel with a base elevation of 0.0 m. The implantation of this channel would cover the entire stretch between Olho d'Água Lagoon and the bridge on the Curcurana highway, extending the channel to a point 200m downstream of the bridge, as per Figure 8.

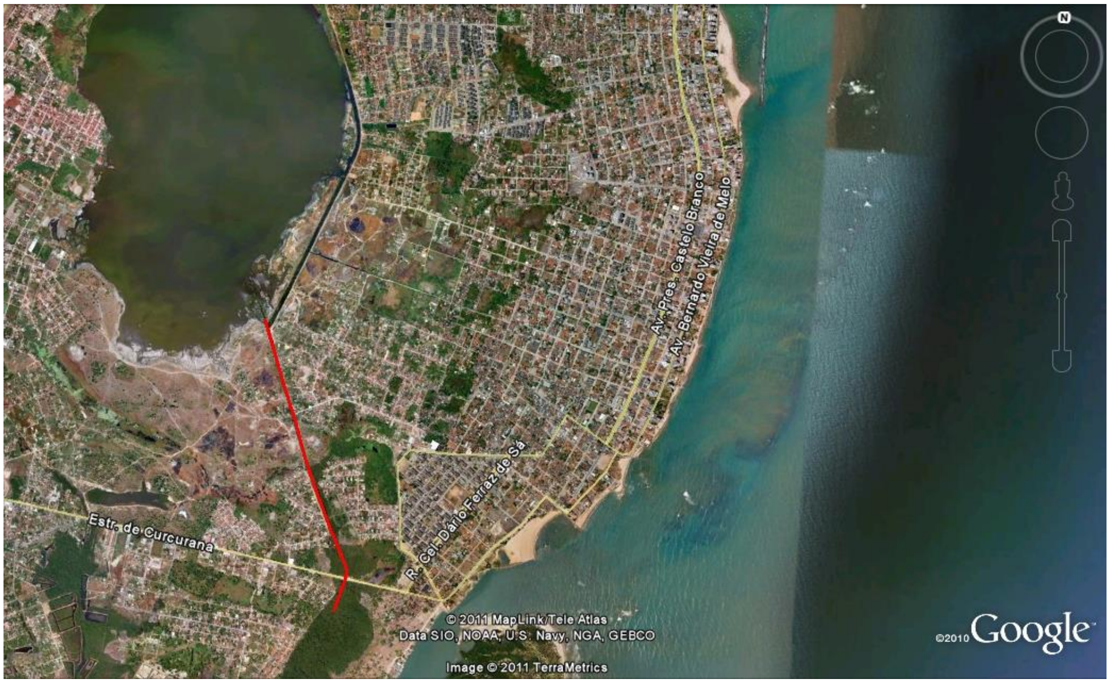

Figure 8 – Stretch of the Olho d'Água Channel extended to 200m downstream of the Curcurana highway bridge.

Source: Olho d'Água Lagoon Sustainable Development Plan (2011).

The Olho d'Água Channel is currently the micro-basin's only drainage element as far as the outflow of water from the Lagoon is concerned. The Channel is approximately 3.0 km long with a declivity of 0.0035 m/m. The geometry of its unlined section is undefined. The banks of the channel are occupied by dwellings and vegetation which cause it to become silted, thus hindering the efficient rainwater runoff.

As a result of the Scenario 1 simulation, the effect of the intervention proposed was not found to be significant, principally with regard to the alteration of the Lagoon's waterline (1.59 m), producing a variation of 3 to 4 cm when compared to the current scenario. This intervention was seen to increase the influence of the tide in the Lagoon, although it would enable more drainage at low tide (Figure 9).

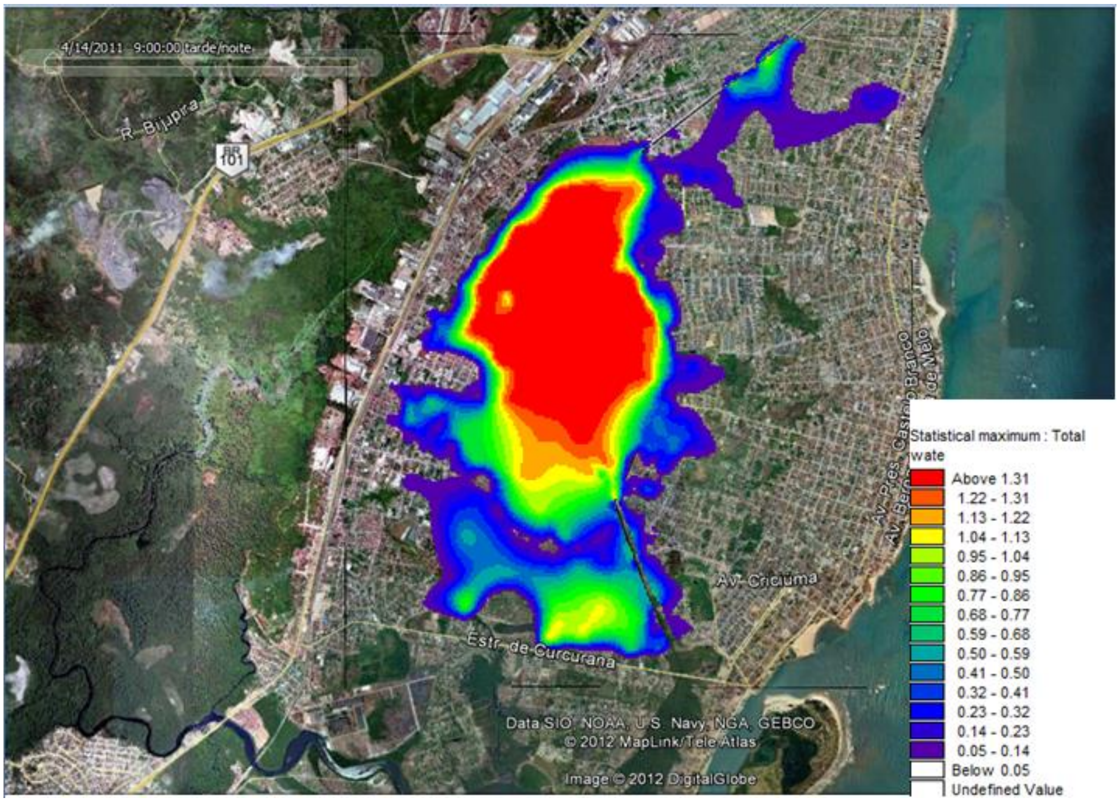

Figure 9 – Extent of flooding under Scenario 1.

Source: Olho d'Água Lagoon Sustainable Development Plan (2011).

Under Scenario 2, the geometry of the section was changed to trapezoidal with a surface width of 40 m and sides with 1:1 declivity. An elevation of 0.25m (in the Lagoon) was maintained at the junction of the Lagoon and the Olho d'Água Channel, and an elevation of 0.0 m at the Curcurana highway bridge. The aim of this was to increase runoff velocity in the channel by increasing declivity. A spillway was also included at the junction of the Olho d'Água Channel with the Lagoon, having the same width as the channel and a sill with planned elevation of 0.80 m.

This measure resulted in a smaller decrease in the level when compared to Scenario 01, with a variation of 1 to 2 cm, reaching the level of 1.61 m (Figure 10).

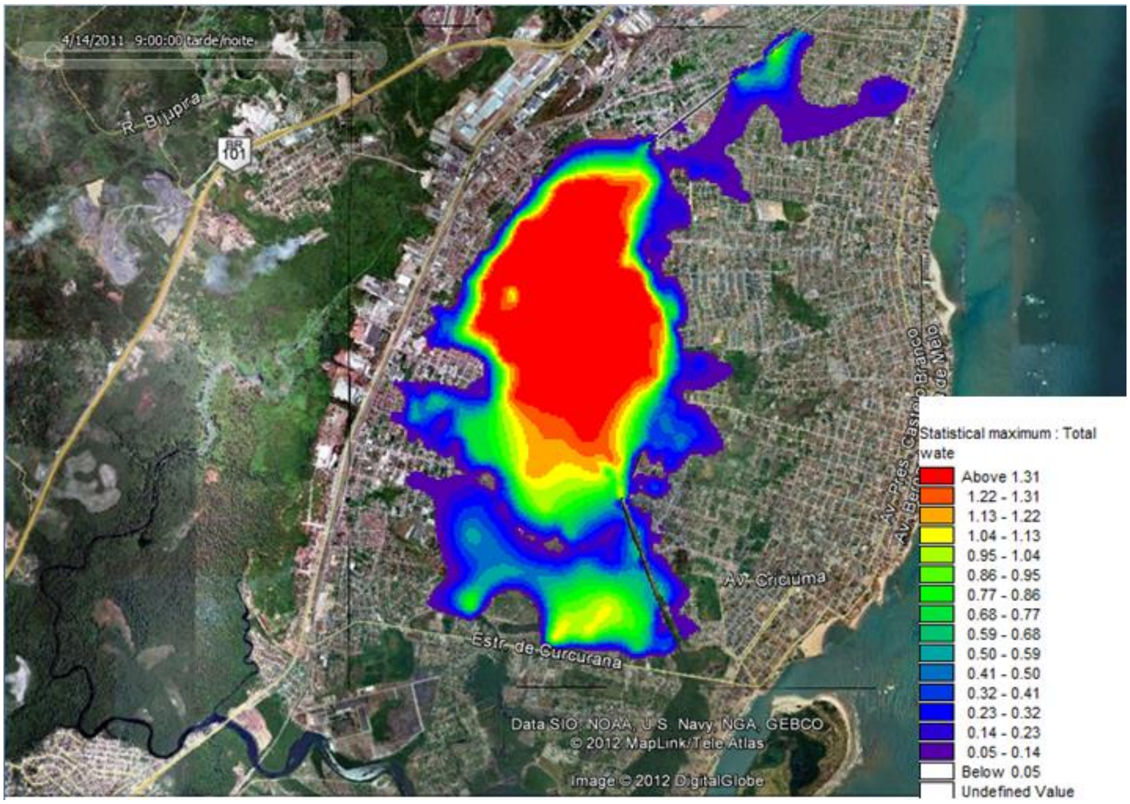

Figure 10 – Extent of flooding under Scenario 2.

Source: Olho d'Água Lagoon Sustainable Development Plan (2011).

Scenario 03 used the intervention proposed in Scenario 02, plus a 40 m wide channel with an elevation of -0.8m in the Ponte do Paiva section crossing the Mangrove. In addition, a channel was excavated in the Lagoon itself, being 0.25 m deep, 40 m wide and approximately 600 m long, as can be seen in Figure 11. Sluices were included at Ponte do Paiva to prevent the influence of the tide during extreme precipitation events and to buffer the rise in the water level caused by the Lagoon.

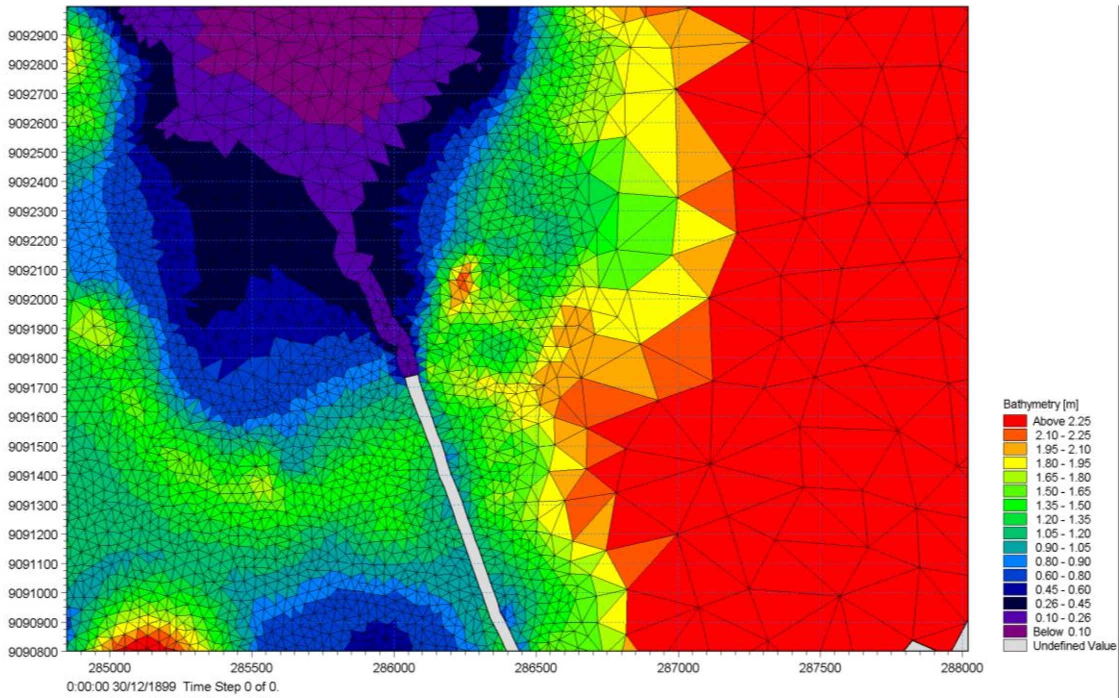

Figure 11 – Representation of the channel excavated in the bottom of the Olho d'Água Lagoon.

Source: Olho d'Água Lagoon Sustainable Development Plan (2011).

This measure enables increased runoff flow from the Lagoon to the sea in more extreme conditions. This intervention was found to reduce the level of water in the Lagoon to an elevation of 1.50 m. Despite the reduction of the level of the Lagoon in extreme events, certain aspects made this intervention infeasible:

- Limiting the natural tide cycle in the Mangrove. Mangroves are a coastal ecosystem where a transition occurs between land and sea environments. They are humid zones characteristic of tropical and subtropical regions. Mangroves are associated with the banks of bays, coves, spits, river mouths, lagoons and coastal inlets, either where rivers meet the sea or directly exposed to the coastline where they are subject to the variations of the tides. They are full of typical vegetable species as well as other vegetable and animal components. Differently to what happens on sandy beaches and dunes, vegetation coverage in mangroves takes hold in recently formed slightly sloping mud substrata, subject to the daily tidal action of sea water or brackish water. If this scenario were implanted it would cause the degradation of this ecosystem.

- Sluice operation. Incorrect sluice operation and maintenance could limit the efficiency of the sluice gates during their use. Mistakes relating to their operation could cause even more flood damage in the Olho d'Água Lagoon micro-basin, having impacts on the population and the municipality, such as: material and human losses and damage and interruption of commercial activities in the flooded areas.

- Type of materials to be used to excavate the channel in the Mangrove. The type of materials to be used could cause impact on natural conditions in the Mangrove.

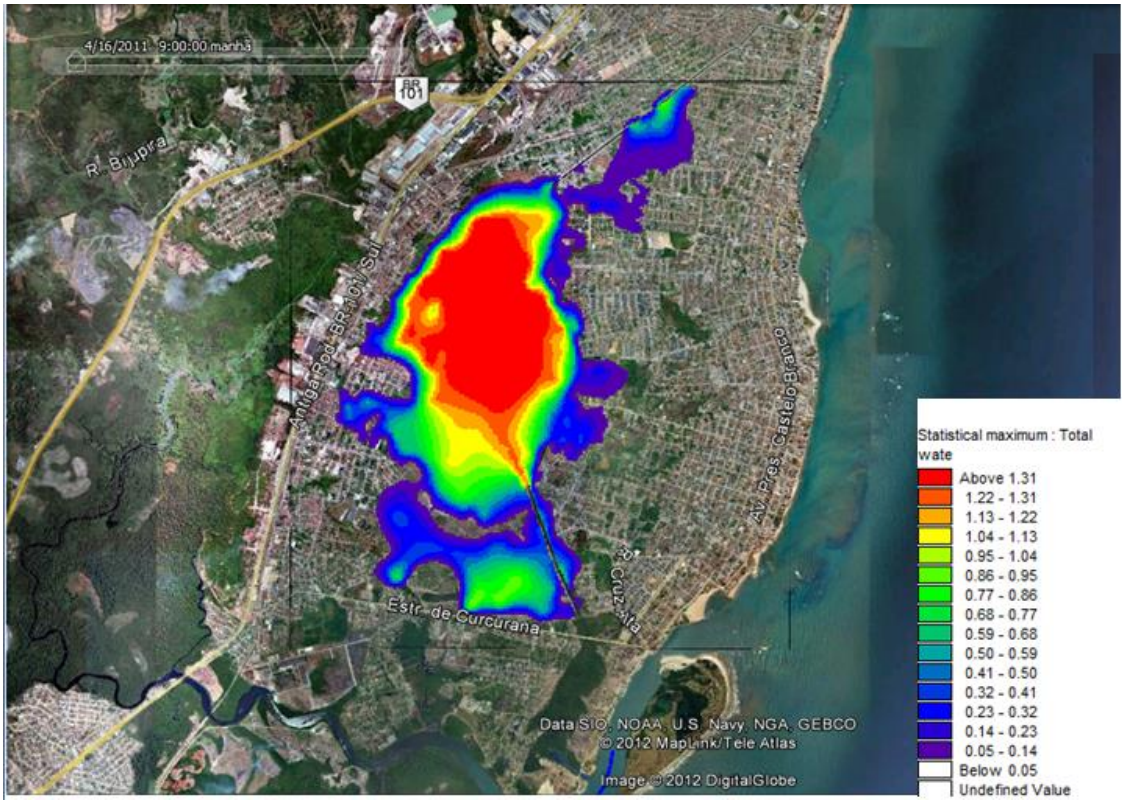

Figure 12 – Extent of flooding under Scenario 3.

Source: Olho d'Água Lagoon Sustainable Development Plan (2011).

The 4th and final scenario took into consideration some of the interventions proposed for the area in question, including the building of access roads on the banks of the Olho d'Água Lagoon. The project entitled "Via Metropolitana Sul" is an initiative of the Pernambuco Planning and Research Agency (Condepe/Fidem) which aims to create yet another road route between the Suape Port Complex and several areas of Greater Recife, alleviating traffic flow in the main streets of Jaboatão dos Guararapes. Given that the local government intends to implement this project, the road in question was included in this simulation. The following factors were therefore considered (Figure 14):

- Implantation of the ring road planned for the area in question;
- Restructuring of the spillway between Olho d'Água Lagoon and Olho d'Água Channel, providing it with a sill with an elevation of 0.80. This proposal will alleviate the influence of the oscillations of the tide and will ensure that the Lagoon always has minimum levels of water at least.
- Structuring of the Olho d'Água Channel, increasing its width to 40 m, with sloping sides (1:2) and crest at 2.5 m; sloping sides lined with Rhine gabions, as per Figure 13.

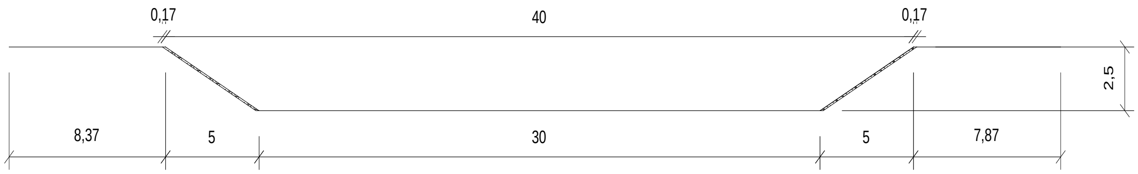

Figure 13 – Cross-section of the Olho d’Água Channel.

- Extension of the Olho d’Água Channel a further 200 m into the mangrove, downstream of the Curcurana highway;

- Restricted dredging in the Lagoon at the entry point of the Setúbal Channel and the exit point of the Olho d’Água Channel.

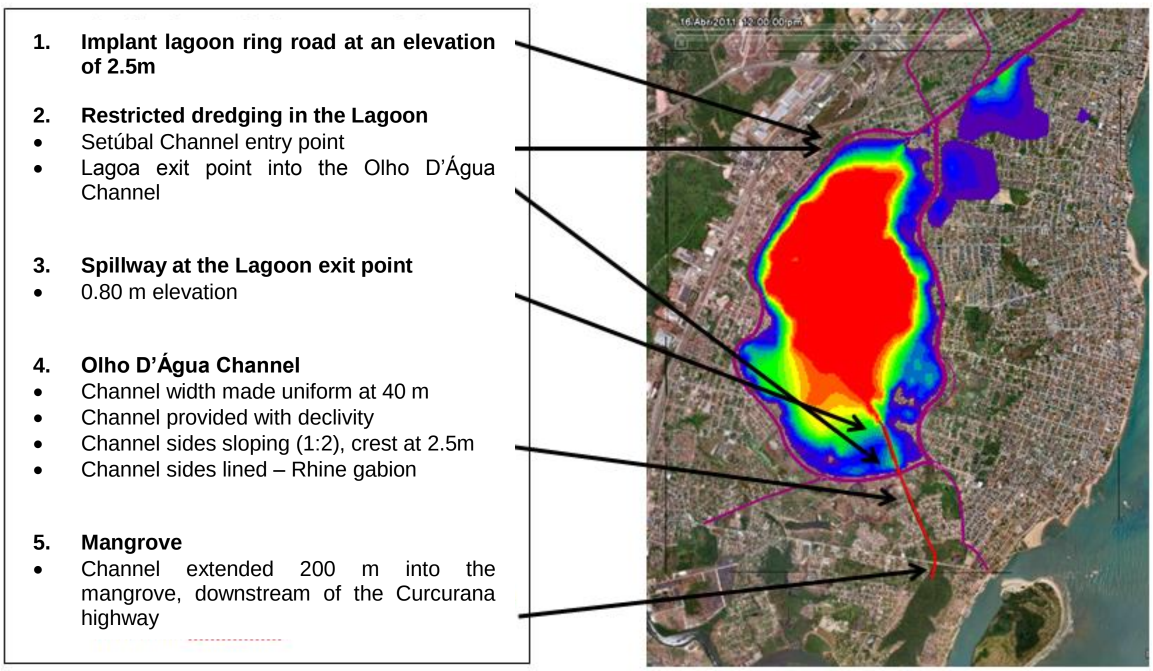

Figure 14 – Scenario 04 interventions.

Source: Olho d’Água Lagoon Sustainable Development Plan (2011).

After having simulated this scenario, the option was made to simulate a further scenario similar to it (scenario 4b). This additional scenario did not include the spillway or the standardized 40 m channel width. The objective is to naturalize the Olho d’Água Channel, maintaining its current width (20 m wide on average).

The final result of these last two scenarios was a flooding elevation of 1.69 m, as per Figure 15. This higher elevation, compared to the previous scenarios, is due to the fact that the flooding area is reduced owing to the limitation arising from the implantation of the ring road. The difference between scenarios 4 and 4b is that the latter reduces the influence of the tide, although it also reduces that runoff capacity of the Olho d'Água Channel.

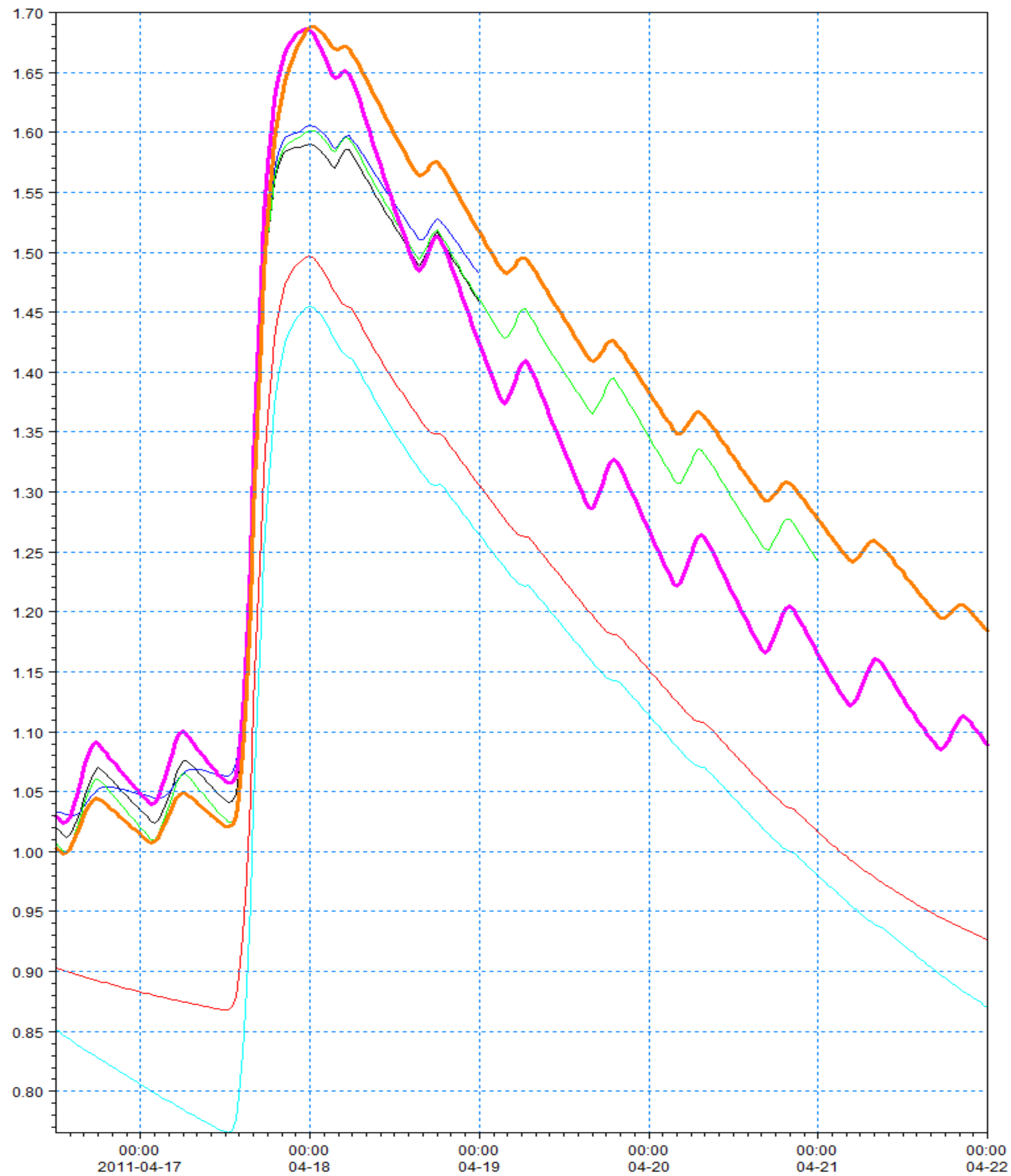

Figure 15 – Variation in water level by scenario (m).

5. CONCLUSIONS

From the scenarios developed, the interventions proposed were found not to result in large reductions in the flood elevation even despite Scenario 3 producing considerable environmental impact.

The solution indicated for this system is that provided by Scenario 4a. Moreover, with regard to the problem of flooding in the communities, other structural and non-structural interventions have been indicated for the area as a whole as part of the aforementioned project.

Despite Scenario 3 causing considerable environmental impact, the inclusion of the sluice at the junction with the Jaboatão River provides contingency measures against flooding during rainy periods, both reducing the level of the Lagoon before the rainwater arrives and also facilitating runoff following the extreme event. The implantation of the sluice can be suggested as a future project, complementing the Scenario 4 intervention, which is more economical and less harmful to the environment.

6. REFERENCES

CPRM - SERVIÇO GEOLÓGICO DO BRASIL. *Diagnóstico Meio Físico Lagoa Olho D'Água. Rio de Janeiro,* 1997. 100 p.

GOVERNO DO ESTADO (CEHAB). *Plano de Desenvolvimento Sustentável da Lagoa olho d'Água.* Jaboatão dos Guararapes-PE, 2011.

MAYS, L. W. (2001). "Historical Perspectives of Storm Drainage." In: Mays, L. W. Storm Collection Systems Design Handbook, McGraw-Hill, EUA.

PREFEITURA MUNICIPAL DE JABOATÃO DOS GUARARAPES (Org.). *Plano Diretor Participativo do Jaboatão dos Guararapes.* Jaboatão dos Guararapes, 2006.

ROESNER, L. A., BLEDSOE, B. P. e BRASHEAR, R. W. (2001) "Are best – management -practices criteria really environmentally friendly." In: Journal of Water Resources Planning and Management, 127 (3), 150 – 154.

SANTOS, M. L. F & KATO, M. *Influência do saneamento ambiental na preservação da Lagoa Olho d'água.* In: Associação Brasileira de Engenharia Sanitária e Ambiental. Trabalhos técnicos. Rio de Janeiro, ABES, 1997. p.13.

SILVA, G. B. L. *Avaliação experimental sobre a eficiência de superfícies permeáveis com vistas ao controle do escoamento superficial em áreas urbanas.* 2006. 180 f. Tese (Doutorado) - Departamento de Engenharia Civil e Ambiental., Universidade De Brasília, Brasília, 2006.

WRIGHT, L. T e HEANEY, J. P. (2001). "Design of Distributed Stormwater Control and Reuse Systems." In: Mays, L. W. Storm Collection Systems Design Handbook. McGraw- Hill, EUA.

DHI (MIKE by DHI 2011) "MIKE FLOOD User Manual – 1D-2D Modelling" September 2012