HYDRAULIC IMPACT STUDIES ON THE COASTAL ZONE OF BUENOS AIRES CITY

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CHAPTER SYNOPSIS

Background
The city of Buenos Aires is built on the coastal zone of the Inner Rio de la Plata. Buenos Aires has been continually reclaiming land from the Río de la Plata River since the 19th century, through the use of soil produced by the urbanization process. The morphological changes produced by this activity, has impacted on the hydraulic behavior of the coastal zone.
In relation to a new reclamation land project by the Government of the city of Buenos Aires, a numerical modelling study has been undertaken to assess the hydraulic impact. The main issues to be tackled, regarding the hydraulic impact of the project, are the following: changes in water currents in the navigation channels; variations in the sedimentation pattern, especially in the navigation channels; behavior of the heat plumes produced by the discharge from the cooling system of *Central Costanera* power plant; changes in the pollutant transport pattern along the coast.

Results
Impact criteria, based on four impact indicators were built, comparing the model results for the infill scenario with the ones for the present situation. Modeling results were translated into practical and meaningful outputs for decision makers.
The coastal infill produces an impact on velocities zone of approximately 1700 m on the longitudinal extent and 600 m on the lateral extension (from the current coastline). The construction of the island in any of their variants, usually more than doubles the longitudinal and lateral extent of the impact zone.
The presence of infill does not significantly change the longitudinal extension of the thermal plume in either directions, but produces an offshore displacement. The highest sedimentation rates occur in the coastal zone, in the inlets (artificial) and the navigation channel. The introduction of infill generates an offshore displacement of the area of maximum rate of sedimentation.

Conclusions
The study shows that the methodology developed, including the definition of indicators, is suitable to quantify the impact of hydraulic works involving coastal morphological changes. The proposed hydraulic impact criteria, applied to the results of the numerical model, provide impact maps from which the degree of perturbation caused by coastal works can be readily quantified. These impact maps are then ready to be used by decision-makers. The use of MOHID system allowed running nested models with a high efficiency.

1 IMPACT OF A COASTAL INFILL

1.1 Introduction

The city of Buenos Aires (Figure 1) is built on the coastal zone of the Inner Río de la Plata. It has been continually reclaiming land from the Río de la Plata, through the use of soil produced by the urbanization process. Since the 19th century to the current configuration of the coast, the artificially filled surface is about 2,054 ha, with progradation ranging from 400 to 1,000 m, depending on the coastal sector [8].The new land has been incorporated to urban use (city harbor, city airport, parks, university campus, real estate, etc.). The morphological changes produced by this activity, has impacted the hydraulic behavior of the coastal zone. These impacts have induced limitations on other coastal activities, such as navigation, recreation, water pumping, and wastewater disposal.

Presently, reclamation land projects needs for approval an environmental impact study, in which the hydraulic impact assessment is one of the main components. The hydraulic impact can be quantified through adequate mathematical modelling of the system. The results of the model must then be translated into practical and meaningful outputs, to fill the gap that usually exists between the practitioner engineer and the decision maker.

In this work, criteria are defined in order to characterize the hydraulic impact, leading to *impact maps*, ready to be interpreted by decision makers. These criteria are applied to a reclamation land project by the Government of the city of Buenos Aires.

1.2 Problem characterization

The Inner Río de la Plata has freshwater due to the large fluvial discharge (with a mean value of about 22,000 $m^3\ s^{-1}$) from the main tributaries, the Paraná and Uruguay rivers; but, at the same time, the water currents are tidally dominated as a consequence of its large width (of the order of 50 km). Moreover, due precisely to its large width, wind waves are internally generated, which creates a hydrodynamic climate akin to a coastal zone.

The Inner Río de la Plata transports a relatively high load of fine texture suspended sediment, mainly originated in the Paraná River basin. Though the bottom morphology in the coastal zone adjacent to the city of Buenos Aires is relatively stable, siltation occurs in the nearly stagnant sites generated by coastal works.

Figure 1. *Location of study zone. Coastal zone of the southern part of Buenos Aires City.*

The main human activities in the coastal zone of the city of Buenos Aires are the following: water extraction for consumption, disposition of wastewater, commercial and sport navigation, and recreation. In particular, the reclamation project is adjacent to a cooling system discharge from a thermal power plant (*Central Costanera*). The impact indices to be built must provide indications on how these activities could be affected.

In the first phase of the project, the infill area is around 11 ha adjacent to the coast, in order to dispose soil to be extracted for the construction of a diversion tunnel for an urban stream (scenario CR). For the second phase, a 30 ha island is proposed. Different scenarios considering both phases were studied, Figure 2 (scenarios IE and IS: island with and without bridge abutments; and scenario IR: with a different design for the island). The case without infill is scenario SR.

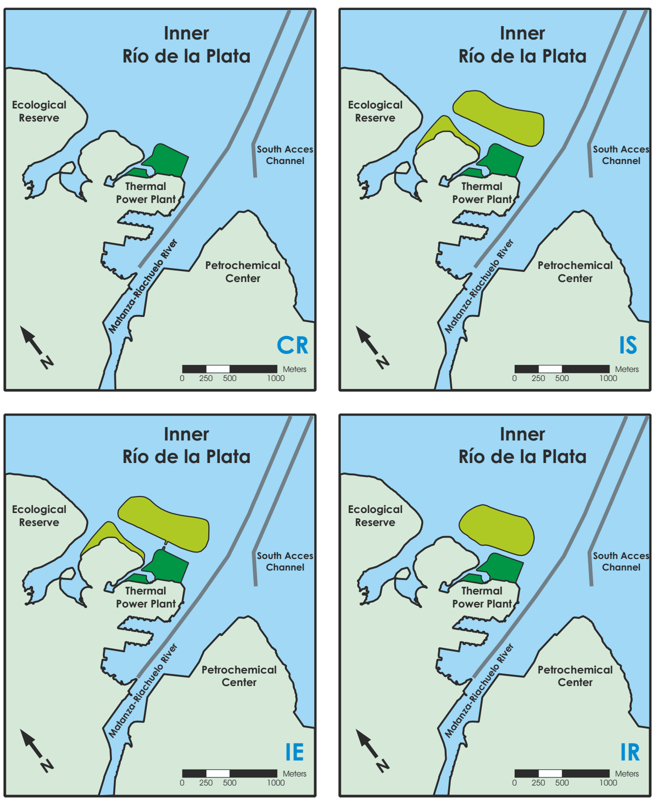

Figure 2. *Reclamation project scenarios. Scenario CR: a coastal infill area of 11 ha. Scenario IS: the coastal infill and a 30 ha island. Scenario IE: the coastal infill and a 30 ha island, considering the bridge abutments. Scenario IR: the coastal infill and a 30 ha island, considering a different design.*

2 MODEL SETUP

2.1 Model implementation

Modeling system MOHID, developed by MARETEC (Marine and Environmental Technology Research Center) at the Instituto Superior Técnico (IST) of the Universidad Técnica de Lisboa, was used for the present study. It allows 3D modelling of hydrodynamic problems, using the Navier-Stokes equations with the hydrostatic and Boussinesq approximations, and including sediment and pollutant transport. It is specially suited for coastal and estuarine problems [1, 2, 3, 9, 10, 13, 14].

The model has been implemented in three nested domains (Figure 3). Domain #1 (Río de la Plata), the largest and with the lowest resolution, provides boundary conditions to Domain #2 (intermediate resolution), which in turns feeds with boundary conditions to Domain #3, the submodel where the problem-zone is represented with the highest resolution. Thermal stratification effects are solved only to the scale of Domain #3; hence, 2D modelling is used for domains #1 and #2. Each domain was delimited based on the criteria to avoid effects of the infill on the boundary conditions. The Digital Elevation Model (DEM) for the river bottom was built based on point-elevation data provided by the Navy Hydrographic Service (SHN). Domain #3 includes the representation of the navigation channels to access the coastal ports (Buenos Aires and Dock Sud).

Two of the driving forces of the system are imposed as boundary conditions for Domain #1: the tidal wave at the ocean-side open boundary, and the discharge from the main tributaries (Paraná and Uruguay rivers) at the river head. The wind field is considered as a source term for domains #1 and #2, and as a surface boundary condition for Domain #3. Additionally, in Domain #3 the coastal discharge of the Matanza-Riachuelo River is explicitly considered, together with the inflow and outflow of the cooling system of the thermal power plant (Figure 4). The ocean tidal wave was specified at the mouth of the Rio de la Plata, from results obtained with the regional model RPP2D [11, 12]. The surface wind field was generated with NCEP/NCAR reanalysis data [6].

Energy dissipation, due to horizontal axis eddies generated at the bottom, is parameterized with an effective roughness height, equivalent to a Manning factor of 0.015 [5], and a constant value eddy coefficient (0.001 $m^2\ s^{-1}$), as recommended for estuaries. The vertical axis eddy dissipation is considered through Samgorinsky's model [15]. The temporal step is chosen so as the Courant Number does not exceed 4, the recommended limit for MOHID.

2.2 Model validation

Three hydrodynamic scenarios were defined: i) Mean scenario: a period with a moderate wind situation (representative of a mean hydrodynamic scenario), ii) Survey scenario: the period when an ad-hoc survey was performed at the problem-zone and, iii) Extremes scenario, storm surges situations (*Bajante* and *Sudestada*).

2.2.1 Mean scenario

Current velocity measurements for the period 10 March to 20 April 2004, obtained by the water supply company (AySA) at two different locations, were used to validate the hydrody-

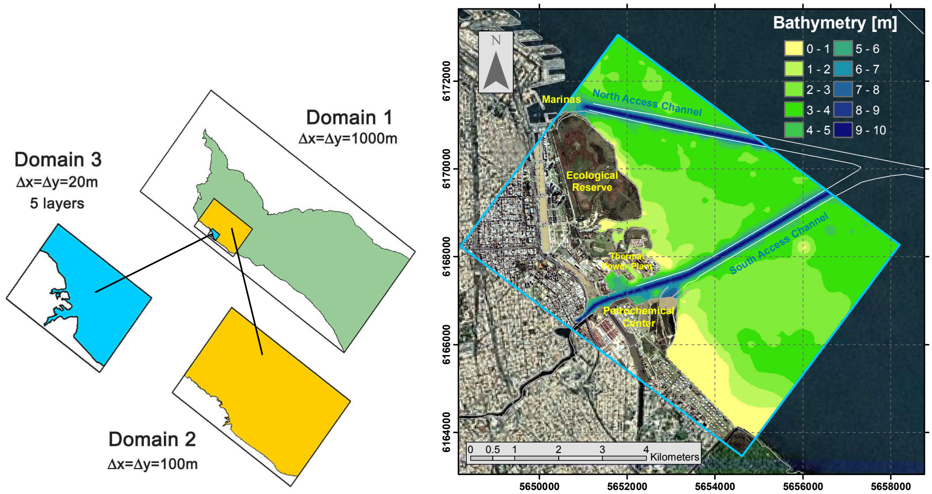

Figure 3. *Domains and bathymetry (Domain 3).*

namic model out of the thermally stratified flow region. The comparison between data and results from the submodel of Domain #2 is considered as satisfactory (Palermo and Bernal), as illustrated in Figure 5 for a six days time window.

2.2.2 Survey scenario

An ad-hoc survey was performed on 21 January 2009, in order to obtain vertical profiles of flow velocity and temperature in the neighborhood of the power plant cooling water discharge. Measurements were taken at 11 stations, with three points per station (at 0.2, 0.6, and 0.8 of the local depth). Figure 6 shows the comparison between simulation and instantaneous measurements of velocity for one of the stations, showing a good agreement.

2.2.3 Extremes scenarios

Water level measurements in Buenos Aires provided by SHN, were used to validate the model during two significant extreme events: *Bajante* at November 2002 (negative storm surge) and *Sudestada* at May 2000 (positive storm surge). Figure 7 shows a very good agreement between observed and simulated levels.

3 HYDRAULIC IMPACT ASSESSMENT

3.1 Impact criteria

Four impact indicators were built, based on the comparison of the model results for the infill scenario with the ones for the present situation, considered as a reference:

#1: Absolute value of the flow velocity difference vector, for the instants of maximum ebb and flood velocities, i.e., the instants for which the impacts are highest; this is an indicator of the change both in intensity and direction of the velocity vector, significant to establish impacts on navigation;

Figure 4. *Discharges and intakes at* Central Costanera*.*

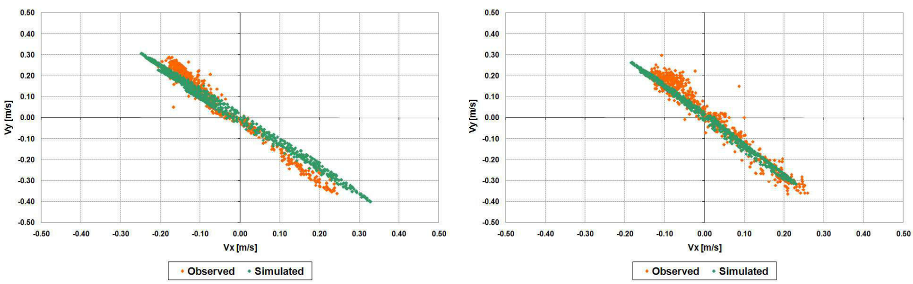

Figure 5. *Current velocities rose. a) Palermo. b) Bernal. Domain 2 results.*

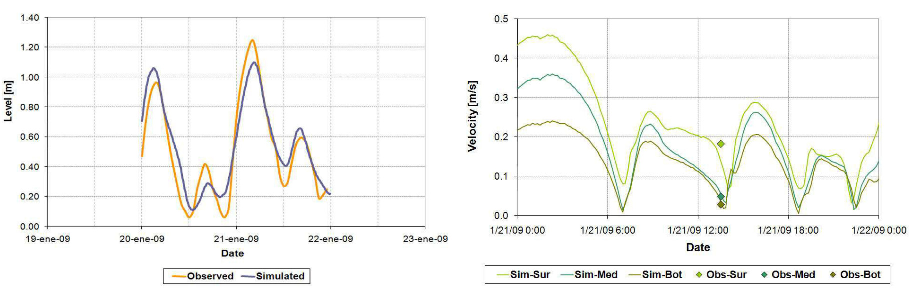

Figure 6. *Levels at Palermo during the survey and velocities at problem zone (three depths at the same point: 0.2 h, 0.6 h and 0.8 h).*

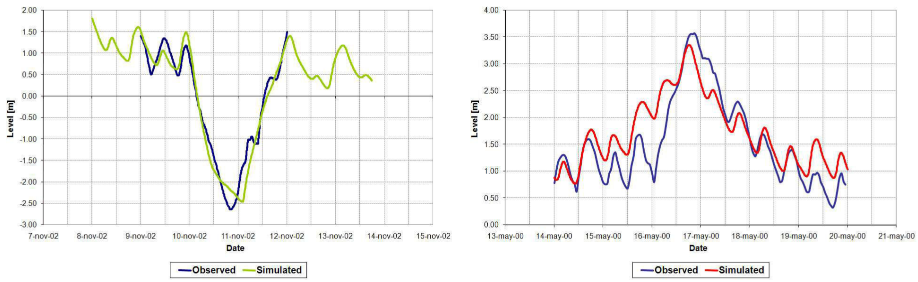

Figure 7. *Levels at Palermo (Buenos Aires). a)* Bajante *Novermber 2002. b)* Sudestada *May 2000.*

#2: Difference between the absolute values of the flow velocity, for the instants of maximum ebb and flood velocities; this is an indicator of the change in the intensity of the velocity vector, also significant for navigation;

#3: Temperature difference, for the instants of maximum ebb and flood velocities; this is an indicator for the impact of the thermal plume issued by the thermal power plant;

#4: Difference between the mean values of Krone factor (T_r) for a tidal cycle; this is an indicator of the change in the siltation rate, especially significant for dredging activities along the navigation channels.

Krone factor is calculated as [7]:

$$T_r = \begin{cases} 1 - \frac{u_*}{u_{*d}} & \text{if } u_* < u_{*d} \\ 0 & \text{if } u_* \geq u_{*d} \end{cases} \tag{1}$$

here u_* is the instantaneous shear velocity, and u_{*d} its critical value for deposition, which has been estimated from previous studies [4] and was adopted as u*d = 8 mm s^{-1}. Krone factor ($0 \leq T_r \leq 1$) affects the maximum potential siltation rate, which is the product between the silt concentration and the fall velocity corresponding to its mean diameter.

3.2 Thermal stratification

Thermal stratification effects were not found to be significant. Besides, 2D modelling provided thermal plumes somewhat more extended than the 3D model, i.e., the results of the former are conservative. These effects are illustrated in Figure 8, which shows the plumes for a particular instant during ebb flow. Hence, the limits of the impact zones were determined based on the 2D model, which is much more efficient from the computational point of view.

3.3 Impact on velocities

3.3.1 Mean Scenario

Taking a velocity of 2 cm s^{-1} as a detection threshold of change, coastal infill (scenario CR) produces an impact zone of approximately 1,700 m on the longitudinal extent and 600 m on the lateral extension (from the current coastline). The construction of the island in any of their variants, usually more than doubles the longitudinal and lateral extent of the impact zone at the maximum of the flood period. At the maximum of the ebb period, there is a doubling of the longitudinal length and a lower increase (about 50%) of the lateral extent, except for the scenario IS. The inclusion of the bridge abutments (scenario IE versus scenario IS) implies an increase of about 15% in the longitudinal extent and 30-80% in the lateral extent of the impact area (Figure 9).

For all scenarios, there is an impact on velocities on a stretch of the South Channel, but not in the case of the North Channel. In the flood flow, the impact on the South Channel is a decrease in the intensity of the current, which is a positive impact on commercial navigation. In the ebb flow, there is an increase and a decrease, although this increase of intensity (negative impact) only exceeds 5 cm s^{-1} for the scenario IR.

3.3.2 Extremes Scenario

The areas of impact on current velocities, adopting the same detection threshold, are generally larger during extreme events (negatives and positives storm surges).

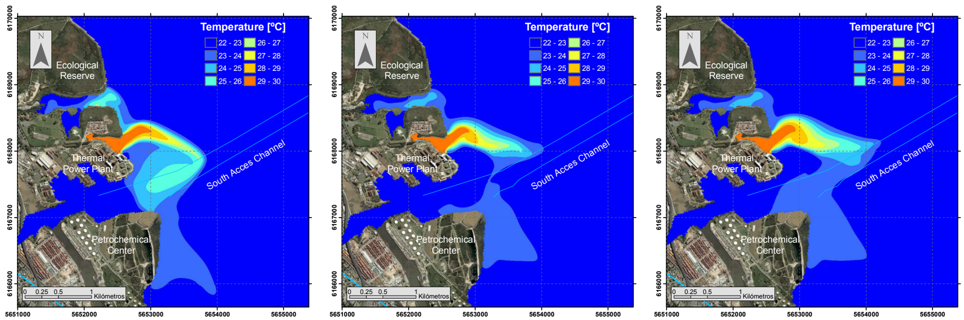

Figure 8. *Comparison of plumes according to 3D and 2D models. a) 2D. b) 3D, bottom layer. c) 3D, surface layer.*

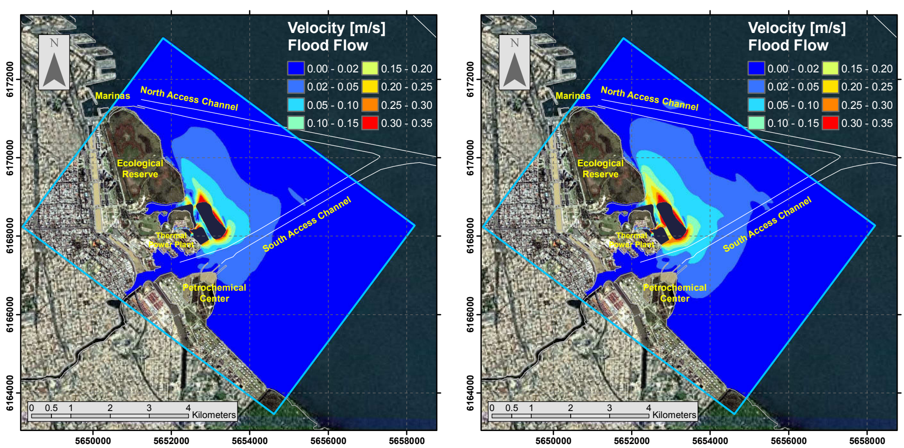

Figure 9. *Absolute value of the velocity difference. a) Scenario IS. b) Scenario IE.*

Tables 1 and 2 show ratios between longitudinal and lateral extents of the impact zone, related to mean conditions extents. Unless the longitudinal extent (which decreases), in the case of the rising period during the negative storm surge, the extensions have an increase ranging from 0 to 150%, with extremes exceeding 400% for the lateral extension during the ebb flow for both events.

For the scenario CR, impact on South Channel is only observed on the falling period of the negative storm surge and on the rising period of the positive storm surge (Figure 10a), but not during periods of mean levels recovery. There is no impact on the North Channel. As for the IS scenario, there is impact on the South Channel for all circumstances, affecting the North Channel during the rising period of the positive storm surge (Figure 10b).

Table 1. *Impact zone extents related to mean conditions. Maximum ebb velocity.*

Scenarios	Negative storm surge (*Bajante*)		Positive storm surge (*Sudestada*)	
	Longitudinal extent [m]	Lateral extent [m]	Longitudinal extent [m]	Lateral extent [m]
CR	1.75	2.14	1.25	1.00
IS	1.76	5.83	1.49	5.00

Table 2. *Impact zone extents related to mean conditions. Maximum flood velocity.*

Scenarios	Negative storm surge (*Bajante*)		Positive storm surge (*Sudestada*)	
	Longitudinal extent [m]	Lateral extent [m]	Longitudinal extent [m]	Lateral extent [m]
CR	0.59	1.17	1.76	2.50
IS	0.75	1.13	1.38	1.88

3.4 Impact on the thermal plume

3.4.1 Mean Scenario

The presence of an infill does not significantly change the longitudinal extension of the thermal plume (resulting from the discharge of the thermal power plant), but produces an offshore displacement, which not exceed 300 m (Figure 11).

Taking a temperature difference of 3 ^{o}C as a threshold of thermal plume significant impact, scenarios CR and IS only produce impact at the ebb flow, with increases in temperature not exceeding 4 ^{o}C (negative impact), and decreases that can reach 5 ^{o}C (positive impact). For the two remaining scenarios increases to 5 ^{o}C at the flood flow are generated, and increases and decreases of up to 5 ^{o}C during the ebb flow.

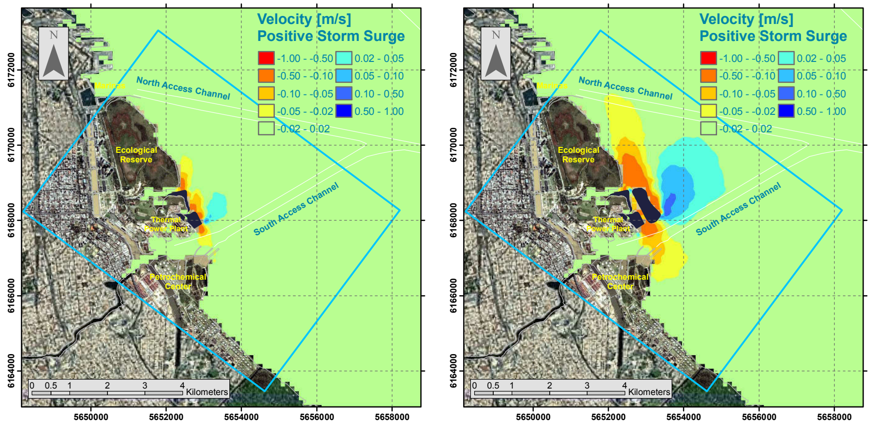

Figure 10. *Difference between absolute values of the velocity vector for the instant of maximum velocity (rising period, positive storm surge). a) Difference CR-SR. b) Difference IS-SR.*

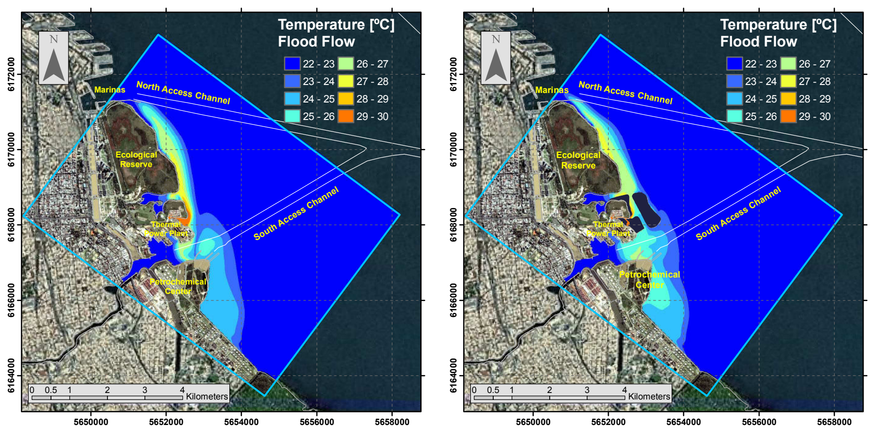

Figure 11. *Thermal plumes for the instant of maximum flood velocity. a) Scenario SR. b) Scenario IS.*

It is particularly remarkable the effect of the presence of bridge abutments (scenario IE), because the increase of flow resistance that they generate increases the temperature at the NW of the island (Figure 12). For the same reason, and associated with narrowing of the channel between coastal infill and island, scenario IR also produces greater increases in temperature. For scenarios CR and IS there is no negative impact over temperature along the existing shoreline.

3.4.2 Extreme Scenario

For all the infill scenarios, changes in the thermal plume extension related to the case without infill, are not considered too significant for both extreme events. If a temperature difference of 3 °C is taking as a threshold of significant impact of the thermal plume, it is observed that the impact is related to the channel between the coastal infill and the island.

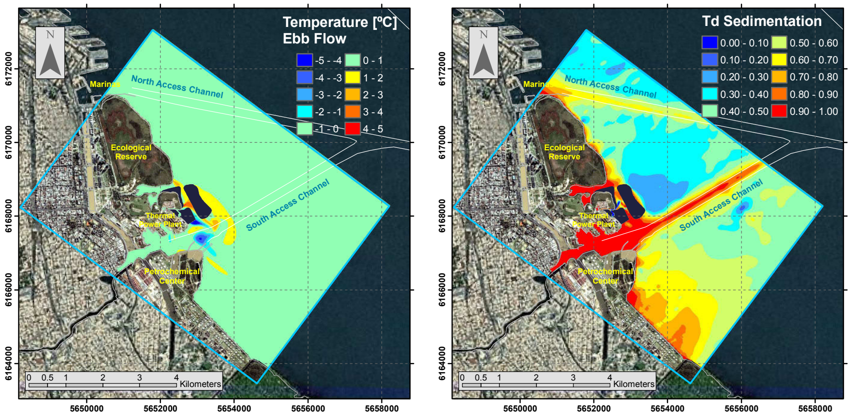

Figure 12. *Temperature difference for the maximum ebb velocity. a) Scenario IS. b) Scenario IE.*

3.5 Impact on sedimentation

3.5.1 Mean Scenario

The highest sedimentation rates occur in the coastal zone, in the inlets (artificial) and the navigation channel (Figure 13). The introduction of infills generates an offshore displacement of the area of maximum rate of sedimentation. Considering 0.1 as a significant change in the value of the sedimentation indicator (10%), infills produces rings of increased sedimentation around them (Figure 14), with greater elongation toward the NO. There is no reduction of sedimentation in the lateral of the infill (direction NE) and in the channel between the island and the coast (except in the case of the IE and IR scenarios, because their relatively high hydraulic resistance).

No significant impact on sedimentation was observed in the North and South Channels. This situation indicates that it is not expected a significant variation in maintenance dredging.

3.5.2 Extreme Scenario

As in mean conditions, the greatest impact on sedimentation occurs in the coastal zone, in the inlets (artificial) and the navigation channel. The introduction of infills does not cause significant changes in the sedimentation indicator (Figure 15). Scenario CR indicates no relevant difference. Regarding the scenario IS, during the negative storm surge there are rings of significant decrease in sedimentation around the infill whit an increased in sedimentation on the laterals of the infill. An inverse behavior occurs during the positive storm surge.

4 CONCLUSIONS

The proposed hydraulic impact criteria, applied to the results of the numerical model, provide impact maps from which the degree of perturbation caused by coastal works can be readily quantified. These impact maps are then ready to be used by decision-makers.

In particular, the application of this methodology to the problem of a coastal infill for the city of Buenos Aires, has lead to the following significant conclusions: (i) a zone of around 2 km in

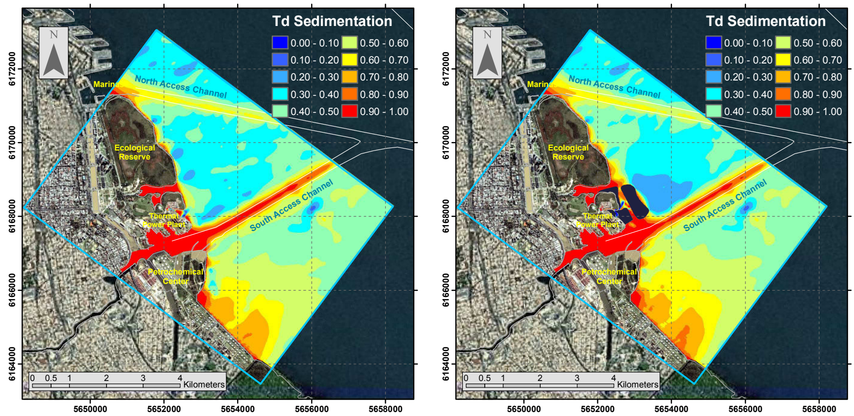

Figure 13. *Distribution of the sedimentation indicator (mean conditions): a) Scenario SR, b) Scenario IE.*

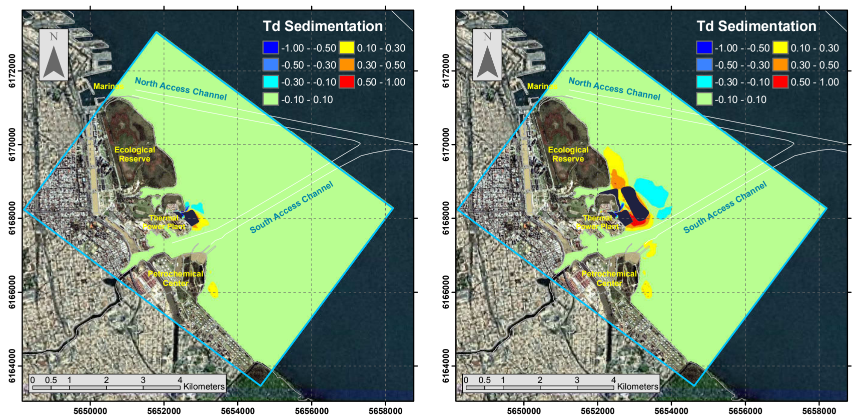

Figure 14. *Difference between sedimentation indicators (mean conditions): a) CR-SR, b) IE-SR.*

length and 700 m in width will suffer from a significant change in the flow velocity; this could only affect negatively sport navigation; on the contrary, commercial navigation is impacted positively due to the decrease of cross velocities relative to the navigation channel axis; (ii) the thermal plume of Central Costanera will only affect the infill border, but not the existing coastline; (iii) a relatively thin (from about 100 to 200 m wide) ring of increased siltation will be produced around the infill, but no impact will occur on sedimentation along the navigation channels.

The use of MOHID system allowed running nested models with a high efficiency. The excellent father-son communication between nested models, made it possible to study the problem-zone in great detail and with an acceptable computational cost.

ACKNOWLEDGEMENTS

This paper presents part of the work performed for the Government of the City of Buenos Aires, whose support is acknowledged.

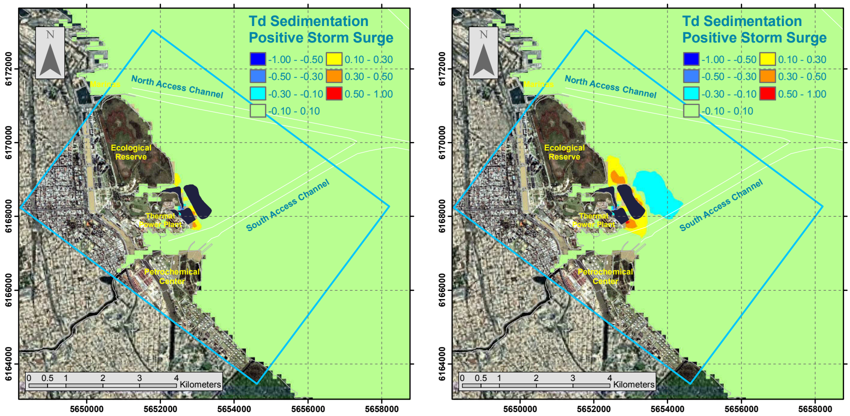

Figure 15. *Difference between sedimentation indicators (extreme conditions): a) CR-SR, b) IE-SR.*

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