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AIACC Working Paper No. 26
April 2006

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An electronic publication of the AIACC project available at www.aiaccproject.org.

AIACC Working Papers

Distributed by:
The AIACC Project Office
International START Secretariat
2000 Florida Avenue, NW
Washington, DC 20009 USA
E-mail: aiacc@agu.org
www.aiaccproject.org

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The AIACC project is funded by the Global Environment Facility, the Canadian International Development Agency, the U.S. Agency for International Development, and the U.S. Environmental Protection Agency. The project is co-executed on behalf of the United Nations Environment Programme by the global change SysTem for Analysis Research and Training (START) and The Academy of Sciences for the Developing World (TWAS).

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Vulnerability to Floods in the Metropolitan Region of Buenos Aires Under Future Climate Change[1]

Vicente Barros, Angel Menéndez, Claudia Natenzon, Roberto Kokot, Jorge Codignotto, Mariano Re, Pablo Bronstein, Inés Camilloni, Sebastián Ludueña, and Silvia G. González

1. Introduction

The dimensions and shape of the Plata River estuary favor quasi-maritime dynamic conditions; storm winds produce surges that when enhanced by astronomical tides lead to extreme water levels. Thus, most of the Argentine coastal area of the Plata River is subject to recurrent storm surge floods, which will become more frequent as the mean sea level rises due to global climate change.

Population on the coastal area of the Plata River numbers near 14 million, including the metropolitan region of the Buenos Aires. A considerable part of this area is between 2.8 and 5 m above mean sea level, and it could be subject to storm floods in this century. Very low areas, which likely will be permanently flooded by 2070/2080, are now scarcely populated because they are frequently flooded by storm surges. As a result of this adaptation to present conditions, the social impact of future permanent flooding will

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[1] The research reported in this paper was supported by grant number LA26 from Assessments of Impacts and Adaptations to Climate Change (AIACC), a project that is funded by the Global Environment Facility, the Canadian International Development Agency, the U.S. Agency for International Development, and the U.S. Environmental Protection Agency and co-executed on behalf of the United Nations Environment Programme by the Global Change SysTem for Analysis, Research and Training and The Academy of Sciences for the Developing World. Correspondence regarding this paper should be directed to Prof. Vicente Barros, barros@cima.fcen.uba.ar.

be small. Therefore, climate change vulnerability in this coastal zone is mostly conditioned by its future exposure to extreme surges.

From the physical point of view, the southern part of Samborombón bay is the most threatened area by the future sea level rise in the Argentine coast of Rio de la Plata (Fig. 1). However, considering the social and economic exposures, the higher risks are in the low areas of the metropolitan area of Buenos Aires, the most populated area of Argentina.

The questions to be addressed in the paper are:

How many people, infrastructure, and real estate are presently affected by these floods with different return periods?

What are the present conditions of this population in terms of social vulnerability and exposure to storm surge floods?

Under climate change scenarios, how will these return periods change during the present century and, consequently, how much additional population will be affected at each return period? What will be the damage to real estate and infrastructure?

Answers to the second group of questions, namely, those related to climate change, require a scenario specification. In this paper, the SRES A2 scenario used by Intergovernmental Panel for Climate Change (IPCC) in its Third Assessment Report (Church et al., 2001) was chosen. However, other estimates were made for a scenario with much faster sea level rise.

Methods and results reported in this paper were developed by a study entitled “Global Climate Change and the Coastal Areas of the Río de La Plata,” the objective of which was to assess the vulnerability of human activities and natural areas in the coast of the Rio de la Plata to sea level rise in the context of the climate change.

The paper is divided in eight sections. The second section discusses the physical conditions that lead to floods in the coastal areas. The method to assess present and future vulnerability to recurrent floods is outlined in Section 3, and its results are explained in Section 4. The fifth section describes the present socio-economic situation, and Section 6 discusses the present and past adaptation strategies and their influence on future vulnerability. Cultural, social, and institutional factors that worsen vulnerability to climate change are discussed in Section 7. Final remarks are made in Section 8.

2. The Physical System

The Plata River is a fresh water estuary with unique features. It starts with a width of 50 km, and it widens to reach 90 km at the Montevideo – Cape Piedras section (Fig. 1).This area is known as the inner Plata River. The salinity front between fresh and salty water is a little downstream of a line connecting Montevideo and Cape Piedras, where, although salinity is still lower than in the open ocean, it gradually increases toward the boundary line between Punta del Este– - Cape Rasa, where it reaches the ocean's level of salinity. This line of 200- km- wide area is considered the outer border of the Plata estuary.

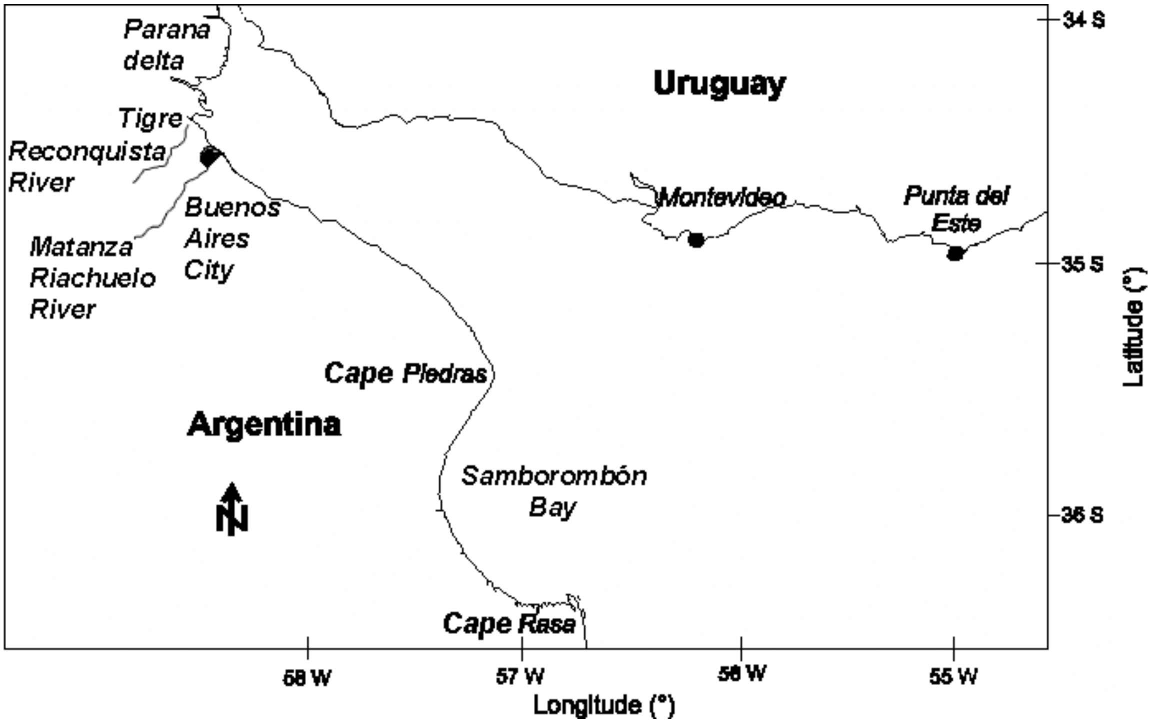

Figure 1. The Plata River estuary.

The dimensions and shape of the Plata River estuary together with its very small slope (of the order of 0.01 m/km) creates quasi-maritime dynamic conditions with wind as well as astronomical tides. The level of these tides grows as they propagate toward the inner part of the estuary that has less depth and width.

Wind storms with southeasterly winds produce the highest wind speeds, especially when they are combined with the astronomical tides. These events are called *sudestadas* in the local vocabulary and are the cause for floods in the low-lying areas along the coast (Escobar et al., 2004). The floods are more severe on the Argentine coast than on the Uruguay side because of the Coriolis effect. In addition, the Argentine coast is lower and therefore subject to frequent flooding, especially at the Samborombóm Bay. Other low-lying coastal areas are found in the south of the Great Buenos Aires, the floodplains of the Matanzas–Riachuelo and Reconquista Rivers and the tip of the Paraná Delta.

The level corresponding to the shoreline defined as the intersection between the mean high water line and the coast is at the Buenos Aires port at 0.99 m above mean sea level. Water that exceeds this level floods part of the land surface. However, in most of the city's coastal area, the alert level for the populated area is not raised until 2.30 m because the land immediately near the shoreline has usually an elevation over mean water level of 1 m or more.. Table 1 shows the recurrence of water heights that cause floods calculated from a 50-year tide record at the Buenos Aires port. Floods caused by *sudestadas* typically last from a few hours to 2 or 3 days. Values shown in Table 1 are only representative for a single location on the coast because, as already mentioned, the coastal storm surge intensifies as it progresses toward the interior of the estuary.

Table 1. *Water heights (over mean sea level) at the Buenos Aires port for return periods. Adapted from* D´Onofrio et al (1999).

Return Period (years)	**Height Over Mean Sea Levels (m)**
2.5	**2.50**
5	**2.80**
11.2	**3.10**
27.5	**3.40**
79	**3.70**

366	**4.00**

A hydrodynamic model of the estuary, previously calibrated, was used to make a sensibility analysis to assess the response of the RP water level to changes of the mean sea level, of direction and intensity of surface winds, and of tributary contributions (Barros et al., 2003)

2.1 Tributary forcing

The Plata River mean discharge is about 25,000 m^3/s, coming 20,000 m^3/s from the Paraná River, and 5,000 m^3/s from the Uruguay River. The record maximum discharge from the Paraná River in a century was almost 60,000 m^3/s, and the one from the Uruguay River was near 50,000 m^3/s However, they did not occur simultaneously, and the most extraordinary flooding from both rivers totaled 80,000 m^3/s in 1983 (Re and Menéndez, 2003). Even with this extraordinary streamflow, the Plata River level change was almost insignificant in the outer part of the estuary and was very small in its inner part, except in the Paraná delta front. At Buenos Aires, with streamflows greater than 75,000 m^3/s, the water level only rises 5 cm (Barros et al., 2003).

2.2 Sea level forcing

Because of its small slope and its exceptional high rate between width and length, sea level changes will propagate toward the inner part of the Plata River without great alteration. This hypothesis was verified with hydrodynamic model simulations. Only in the inner part of the Plata River, some attenuation of the sea level rise, which reaches barely 10 % at the Paraná delta front (Re and Menéndez, 2003), could be expected.

2.3 Wind forcing

Wind modifies the Plata River water level. Its tension over the river surface drags water into or out of the estuary, according to its direction. Hydrodynamic model simulations forced by wind data from the National Center for Environmental Prediction / National Center for atmospheric Research (NCEP/NCAR) reanalysis (Kalnay et al., 1996) indicate that changes of wind direction and intensity during the 1951–2000 period, resulting from a displacement toward the south of the South Atlantic high (Escobar et al., 2003), could explain about 5 cm out of the 13 cm rise observed at the Buenos Aires port during the twentieth century. In addition, model experiments indicate that the difference of water level between the summer and winter of about 15 cm is caused by the directional shift between these seasons (Menéndez and Re, 2003).

3. Methodology for Assessing Present and Future Vulnerability to Recurrent Floods

Assessment of vulnerability followed a multidisciplinary approach considering both physical and social conditions. Natural processes of erosion and accretion, as well as the geological conditions of the coast were evaluated, but not discussed here; they are second-order processes in an environment that is under the pressure of rapid anthropogenic change and of rapid eustatic change resulting from the sea level rise.

Physical and social information was integrated in a Geographical Information System (GIS). The GIS was used to estimate for different return periods of flood, the population and the public infrastructure affected (number of schools, hospitals, etc.), and real estate property damage. For present conditions, input data, both physical and social, were mainly of statistical origin. Social data were taken from the census. For future scenarios, as a first approach, social data were considered as in present with a modest 1% annual population rate growth, whereas physical conditions were assessed using IPCC scenarios and the hydrodynamic model of the Rio de la Plata estuary.

Mean and storm surge levels were adequately represented by a two-dimensional hydrodynamic model with high spatial (2.5 km) and temporal resolution (1 minute). The model is based on a finite difference implicit alternating direction method, implemented in the software HIDROBID II (Menéndez, 1990). It is forced with the astronomical tide at the southern border, the river discharges at the upstream border, and the wind field is over the whole domain. The model domain is large enough to include the fetch zone for the storm surges, which are then entirely generated within the domain.

The model was calibrated to astronomical tides and storm surges. Then, it was verified that it reproduces the water level distribution at the Buenos Aires port for 1990–1999 period (Figures 2 and 3). After confidence in its capacity to reproduce the basic features of storm surges was acquired, the tuning of the model allowed estimating extreme tide values along the coast of the Plata River,, thus overcoming the lack of basic data (Figure 4).

Future scenarios of mean water level were built forcing the hydrodynamic model with the mean sea level from scenarios of the IPCC 2001 (Fig. 11.12, Church et al., 2001, webpage http://www.grida.no/climate/ipcc_tar/wg1/fig11-12.htm) and from winds calculated from the IPCC scenario A2 of the Hadley model HADCM3, taken from the web page of the Datum Distribution Center of the IPCC (www.dkrz.de/ipcc/ddc/html/SRES/SRES_all.html). In both cases, for the 2030 decade, it is almost indistinct which scenario is used. For the 2070 decade, for the sea level, two scenarios were considered, the A2 scenario and the maximum of the range of all the global climate models for the 35 scenarios of the IPCC 2001 Report.

The A2 scenario assumes a world with regional identities well differentiated, high population growth rate and high economic growth with little emphasis in environment care. It was chosen because it may be indicative of what could occur if not rapid and important reductions in the greenhouse gas emissions were not taken in the next decades. The model HADCM3 was chosen because it was the best in reproducing the present climate (1960–1990) in southeastern South America (Camilloni, 2004). Its outputs of monthly pressure were processed to develop daily wind data, assuming that present relations between pressure and wind fields will hold in the future scenarios.

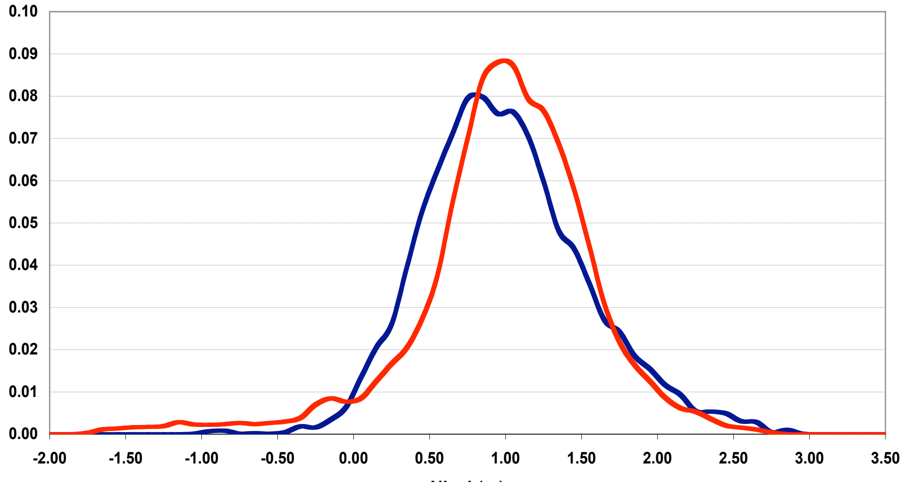

Figure 2. Frequency of levels (m) over mean sea level at the Buenos Aires port (1990–1999). Observed frequency is shown in blue, and simulated frequency by the HIDROBID II model is shown in red.

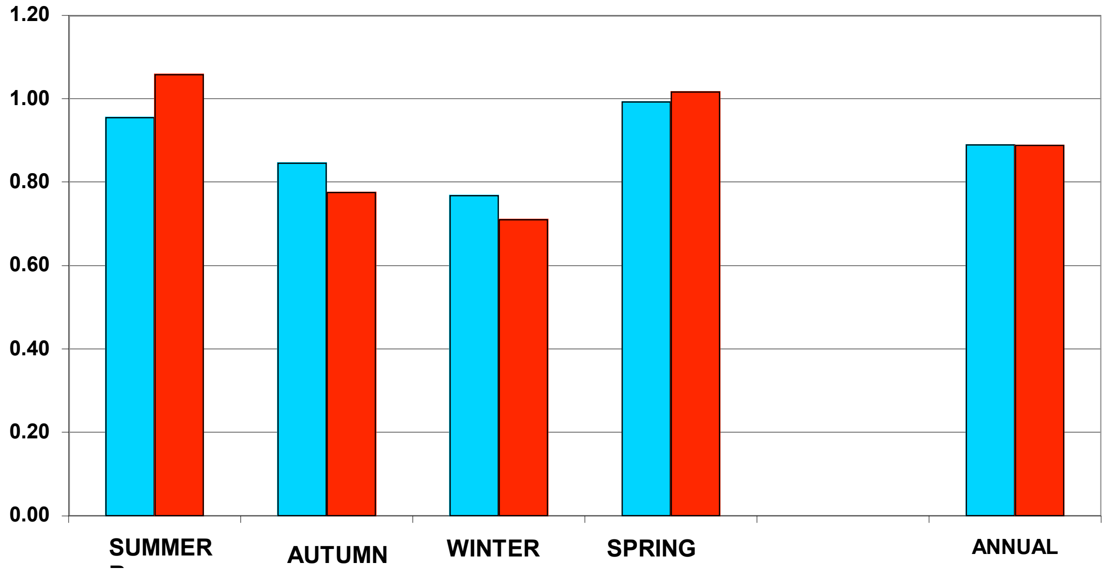

Figure 3. Mean Plata River level (m) calculated by the HIDROBID II at the Buenos Aires port (1990–1999). Modeled level is shown in red and observed level is shown in blue.

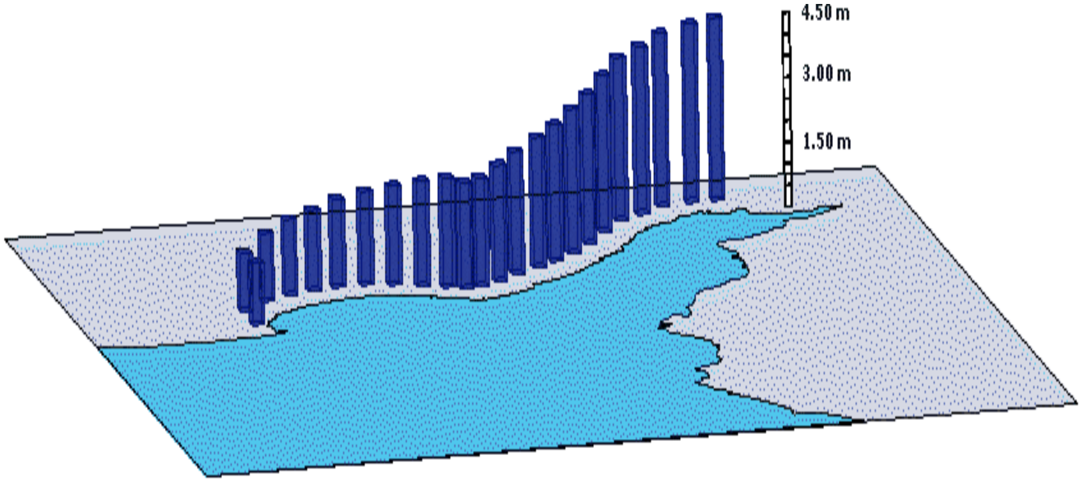

Figure 4. Maximum heights calculated for the storm surge tide with return period of 100 years in the one Buenos Aires port.

For calculating the return periods of floods over land, a surface level model was constructed with adequate vertical and horizontal resolution. The topography was put together with data from different sources: topographic maps or the Military Geographical Institute, altitude measurements taken by the Buenos Aires city at certain points, field measurements with a differential GPS, and altitude maps constructed with satellite radar. The four sources of data present difficulties. The topographic maps have an altitude resolution of 1.25 m and in some areas 2.5 m, too low for the study of present floods and for assessment of future changes in the affected areas. The GPS measurements, taken as a unique source would require too lengthy and costly campaigns. In addition, access to certain areas is very difficult. The radar data are very accurate, but the built areas and forests introduce errors. Thus, the three sources of data were blended to produce a digital model of the altitude with 0.25 m vertical and 1 km horizontal resolution.

The first step was the cartographic compilation of available information and construction of a digital map in AutoCAD format. The coordinates were Gauss-Krügger, a system used locally by the Military Geographical Institute. The map includes the Argentine coastal area of the Plata River from the Paraná Delta to the Cape Rasa and extends inland to the height of 5 m over mean sea level.

Field measurements with a GPS differential system were obtained during 12 campaigns. The measurements were taken at places that bring key information, according to geomorphologic maps that were previously constructed. The information was processed with the software Ashtec, which indicates the height of the ellipsoid according to the system WGS 84. This system presents difficulties when used in urban areas, because of interference caused by the presence of trees, buildings, and cars that interrupt the satellite's reception: This was a problem in part of Buenos Aires, but in this area, altitude data were available from early city measurements.

Data obtained from satellite radar interferometry were processed to generate a digital model with a horizontal resolution of 90 m. These data were filtered, eliminating noises caused by the presence of buildings, vegetation, and small ponds. For this purpose, the other three sources of data were used. Finally, a 1000-m horizontal resolution grid cell was built. The initial radar data of 90 m horizontal resolution were used to produce an altitude model with a 1-km cell size that includes the maximum, average and minimum value within the grid cell. In urban and suburban areas, the minimum value is likely more representative of the real mean altitude because it may stand for the areas without or with less buildings and trees. In addition, these minimum values are more functional to the purpose of the map, which is to assess the frequency of flooding.

There were also difficulties with data with estimating the present population and infrastructure exposure to floods. Though population data were disaggregated in small areas, social indicators are only known for county districts, and the same happens with the public infrastructure. Therefore social vulnerability was estimated at the district scale, recognizing that this option leads to only a first-order approximation of the geographical distribution of this vulnerability.

Social vulnerability index (SVI) permits the identification of areas with higher vulnerability. The index calculated in this case includes indicators related to the three aspects: demography, living conditions of the population, and structural production and consumption processes. Indicators were selected for each of these aspects. These indicators were chosen on the basis of data availability for all the administrative units under survey, which implied reducing their number to only five for each aspect. Values ranging from 1 (lower vulnerability) to 5 (higher vulnerability) for every indicator were averaged to produce the social vulnerability index. The data used were for the year 1991, the last census available to date for most of the indicators and administrative units.

An index of social risk (SRI) was developed multiplying the social vulnerability index by an index of exposure to floods (EFI). The latter was calculated from the recurrence of floods at each cell of 1 km^2, and it is approximately the inverse to the return period of flooding (RPF). Its formulation was 20/RPF +1. The idea behind this formulation is that although the exposition index should somehow be inverse to RPF, the implications of a flood that happens every 20 years is larger than one-twentieth of the one that takes place every year because it affects zones where the phenomenon is less expected and generates negative expectations that are already incorporated in the other case. On the other hand, there is not much difference in the perception of the flood risk, if a flood has a recurrence of 20, 50, or 100 years, because in any of these cases, some precaution has to be considered. For this reason, the index reflects little changes for areas with expected recurrence values greater than 20 years. Then, the EFI ranks from a little more than 1 to 21, while the SVI, by construction, will be between 1 and 5. Thus, the product of the social and the exposure index, the SRI was hypothetically bounded by 1 and 105. Finally, the SRI was normalized to have a supposedly maximum value of 100 in the area of the study, although the maximum value it actually reaches is about 80.

Public buildings' exposure was evaluated by a survey made in each of the 27 administrative districts of the Plata River basin that have territory under the 5 m above sea level. The assessment of present and future risk of the infrastructure of public services includes water supply, sewage network, power facilities, highways, and railroads. This assessment was also made for real estate property. For each of these items, it was estimated the resulting costs as a function of the Plata River level rise over its mean present level. In the case of infrastructure, the functions were calculated from the effects of water rise in each system. To estimate damage to the real estate property, the areas under present or future recurrent floods, were classified in 8 zones with different status according to the present value of their real estate. Fig 5 shows the function of cost of each flood event, including its depreciation effect in real estate property as function of the rise of the Plata River over its present level. Similar functions were calculated for each component of the infrastructure.

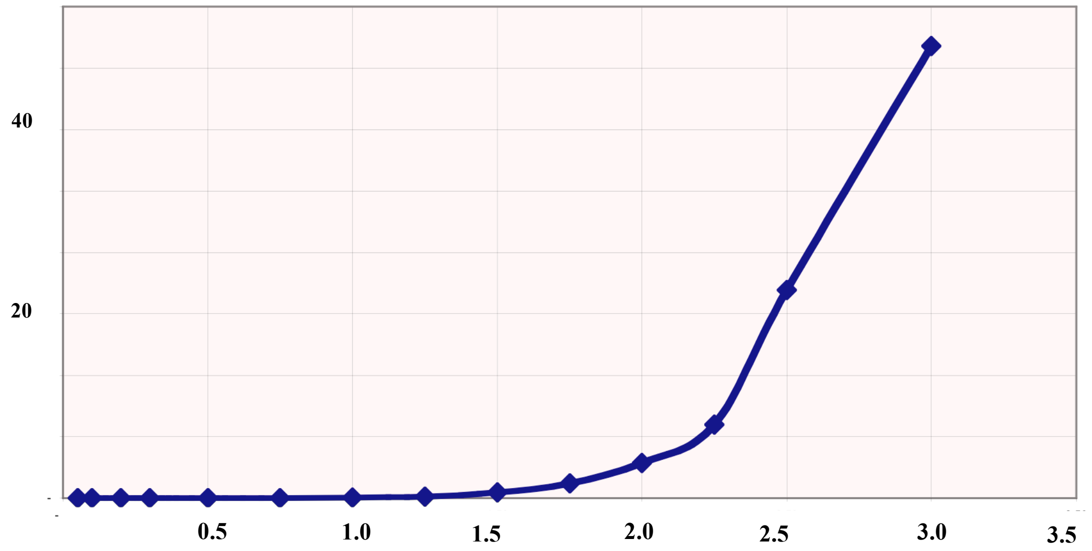

Figure 5. Damages in real estate per event in millions of U.S. dollars (USD) as a function of the water rise over the mean present level.

To assess the mean annual costs of flooding, both for present and future scenarios, the damages per event of each of the infrastructure component and of public and private real estate costs were added. Then, these costs were combined with the modeled recurrence period of each level and its duration in time under different scenarios of mean water rise. This permitted to assess the damages associated to each scenario of mean water rise.

4. Present and Future Vulnerability

The fact that physical and social information was quantified, either by direct values or by indexes with a geographic distribution, permitted calculation of a number of products geographically distributed, which resulted from the combination of that information in a GIS.

The area with permanent flood risk during the 21st century in the Great Buenos Aires coast is very small. The only major concern with regard to permanent flooding could be in the tip of the Paraná delta and in its new lands that could be added to it in the next few years. Therefore, climate change impacts will be felt mostly because of the increasing reach inland of storm floods.

Figure 7 shows the flood return periods for the present time. The areas more affected by storm surges are the southeastern coast of the Great Buenos Aires and the district of Tigre. In both areas, there is a mix of socially vulnerable population and upper middle class gated communities. The differences in the return period for the 2070/2080 A2 scenario with respect to present conditions are shown in Figure 8. It can be seen that in the Plata River coast of the Buenos Aires and in the districts located to the north of it, there will not be a significant change. On the other hand, toward the south of the city and in the Tigre district, there will be a significant increase in exposure to recurrent floods (Figure 8). The A2 scenario predicts a considerable reduction of the return periods in valleys of the Reconquista and Matanzas-Riachuelo rivers, where a socially vulnerable population predominates.

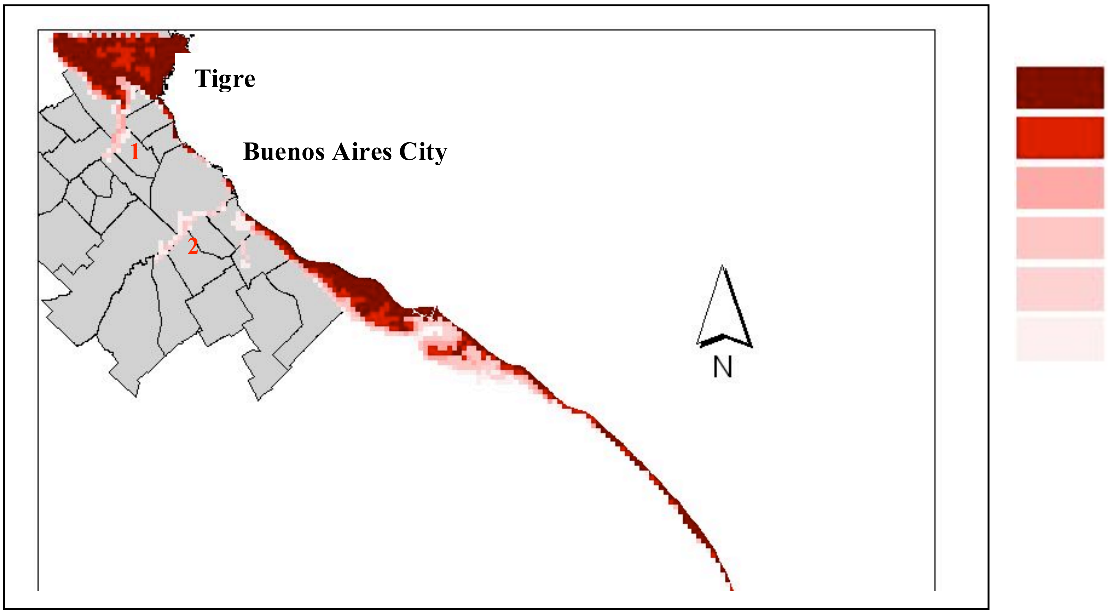

Figure 7. Flood return periods in years for present time: black, 1; red, 5; dark pink, 10; pink, 20; light pink, 50; very light pink, 100. In grey: the districts of the metropolitan area of Buenos Aires. The number 1 denotes an area below the Reconquista Valley, and the number 2 denotes the Matanzas-Riachuelo Valley.

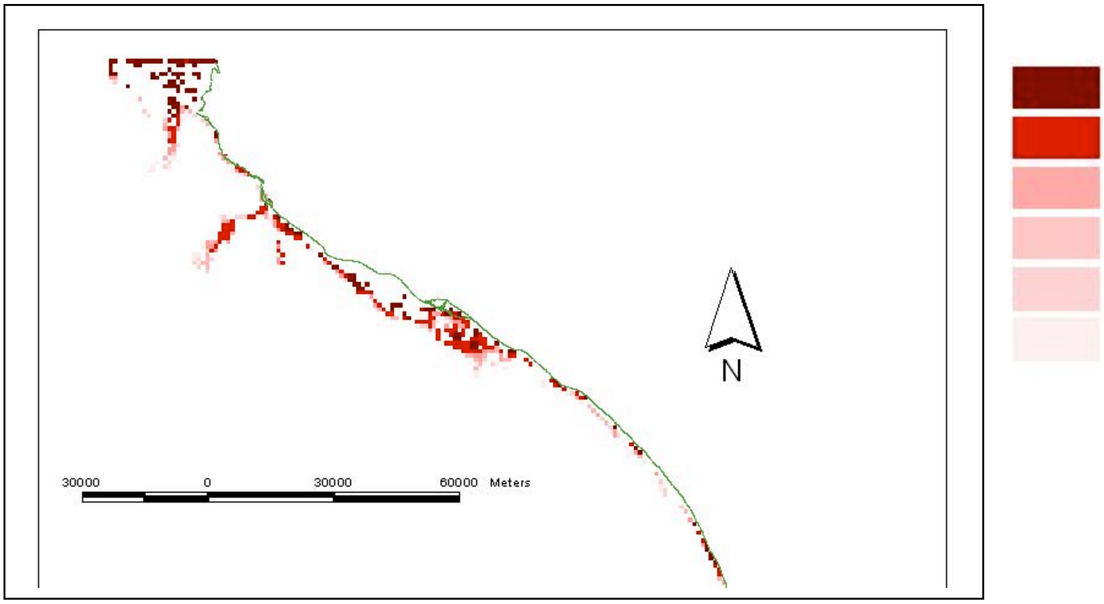

Figure 8. Changes in the return period between 2070/2080 and present time in years, colors as in Figure 7.

The survey of public properties now located into the area that could be affected by floods at least once in 100 years in the 2070/2080 A2 scenarios indicates that there are 125 administrative public offices, 17 social security offices, 205 health centers, 928 educational buildings, 92 security buildings, and 306 recreational areas, including parks and squares. In addition, there are also 1,046 private industries.

If it is assumed that that population density and distribution will not have considerable changes, in the scenario of maximum sea level rise during the 2070 decade, the people living in the area with flood risk with a return period of 100 years will be about 900,000, almost doubling the present population with such risk. The relative increment of affected population is even larger for recurrence time of 1 to 5 years, which will triple in the 2070_{max} scenario (Table 2). These figures were calculated without considering the very likely growth of population. With a modest 1% annual growth of the population during the next 70 years, maintaining the present geographical distribution, the number of people affected for each return period in the year 2070 would double the values of Table 2. This means that the population exposed to some risk of flood recurrence every 100 years would amount to about 1,700,000.

Table 2. *Present Population Living in Areas That Are, or Will Be, Flooded Under Different Scenarios*

	Return Period (years)					
	1	5	10	20	50	100
1990/2000	33,000	83,000	139,000	190,000	350,000	549,000
2030/2040	102,000	297,000	390,000	500,000	643,000	771,000
2070/2080	113,000	344,000	463,000	563,000	671,000	866,000

Current real estate damage was estimated in 30 M USD/year, and if no socioeconomic changes were assumed or defenses built, it would reach 80 and 300 M USD/year in the 2030/2040 and 2070/2080, respectively, under the assumption of a 1.5% annual growth rate in the infrastructure. However, these figures do not include the current gated communities, the increased trend of building of these expensive towns on the coastal areas and the losses of working hours, which can be inferred as very important from the figures of the former paragraph. Thus, these figures should be considered as a lower bound of an uncertain estimate.

Figure 9 shows the social risk index that combines social vulnerability with flood exposure. The qualitative picture is similar to the return period figure because of the coincidence of the areas of maximum exposure and social vulnerability. However, there is an important difference in the north, because the very exposed district of Tigre has little social vulnerability. Therefore, the area of maximum social risk is to the south of this district and in the Reconquista River valley. Changes in the social risk index in the 2070/80 A2 scenario worsen the situation of the more socially vulnerable areas along the Reconquista and Matanza valleys and in the south of the Great Buenos Aires in a zone relatively far from the coast where few gated communities are expected (Fig 10).

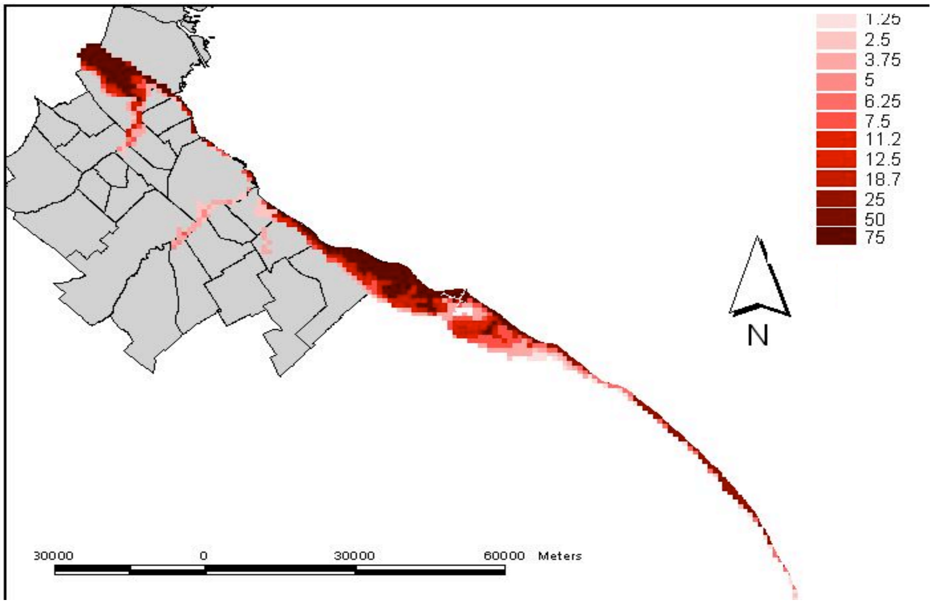

Figure 9. Social risk index. Present conditions; values attached to colors indicate the lower value of the corresponding range. Thus the darkest color stands for the range of 75 to 100.

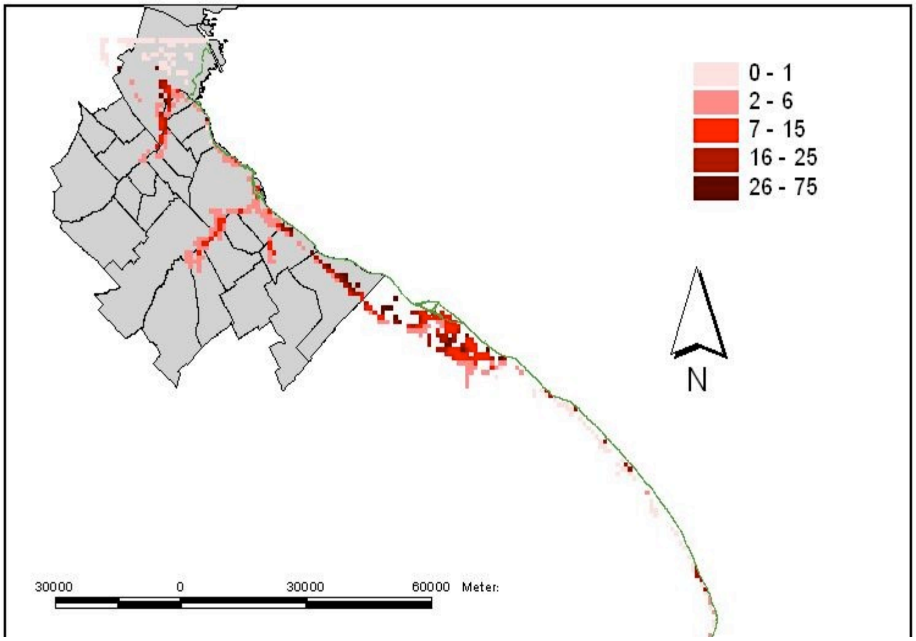

Figure 10. Variation of the social risk map between 2070 and present.

5. Socioeconomic Aspects

The Plata River Argentine coast is a dense populated area that includes the metropolitan region of the Buenos Aires, which is the political, financial, and cultural center of Argentina with one-third of the country population. In the past, until the middle of the last century, areas frequently flooded by storm surges were generally not occupied, with the exception of downtown areas, which were populated and later defended with infrastructure. A couple of these cases will be discussed in Section 6, including the description of their long tradition of both cultural and institutional adaptation strategies.

After about 1950, the areas exposed to frequent floods and not close to the downtown area either remained little inhabited or in some cases were occupied by poor settlements where squatters often occupied. This population has a large percentage of unsatisfied basic needs, a higher than national average child mortality rate, and a high percentage of the population without access to social security. In many cases, women are family heads. Social vulnerability of these settlements is worsened by floods, which will likely become more severe as the mean sea level rises. The most socially vulnerable areas that are at the same time affected by floods are not over the coast of the PR, but on the flood valleys of two tributaries of it, the Reconquista and the Matanzas-Riachuelo River.

The other two areas of the Great Buenos Aires that have large social vulnerability are the southern coast of the PR, 20 to 50 km to the southeast of Buenos Aires and the county of Tigre, immediately to the south of the Paraná delta. However, starting in the 1980s, and with definite momentum since the 1990s, there has been a dramatic change in the urban tendencies of these zones. New highways and increased demand for private communities were making these areas attractive for new settlements for upper middle-class people. In this process, the drive to private neighborhoods come from two perceptions of the upper classes: the fear linked with more insecure urban conditions and the idea that “nature,” “countryside conditions,” and “green scenery” are better conditions of life (Ríos, 2002). At the beginning of the 1990s, private neighborhoods had an area rounding 34.4 km^2, whereas by 2000, the area had grown nearly 10 times: 305.7 km^2. A third perception is related to the scenery benefits of the shorelines; Argentina has not escaped the global phenomenon of population migration toward the coasts. Thus, it was very common that these private neighborhoods were located initially in cheap suburban lands, those with waterlogged conditions. To have an idea of the momentum of this process, since 1998, when in the district of Tigre, 90 private residential developments had been authorized, out of which, 50 have already been constructed. This implies that now 40% of the district population lives in these gated communities. New projects spring up all along the coast, both in the southeastern and in the northern extremes of the Buenos Aires metropolitan area, and even in the front of the Paraná delta (Ríos, 2002).

The modification of the low-lying lands by gated communities has many effects—mainly, in the land hydrological drainage—that affects the people living around the closed urbanizations. The urbanization of initially low sectors, historically frequently flooded requires a massive transformation of the terrain and of the surface drainage with the destruction and replacement of the original ecosystems in order to obtain an assumed secure altitude (Danielle et al., 2000). However, before the project results were made public, most of the private neighbourhoods considered the altitude value of 4.4 m above sea level to be safe, which may not be safe in the future. With the wide distribution of these gated communities, a new awareness of vulnerability and risk has been raised. Inhabitants in these gated communities have seen their crime insecurity mitigated, but they now face the threat of flood. The population outside these gated communities, while living with crime insecurity, unemployment, violence, and other insecurities face the highest amount of flood damage because of the loss of drainage due to land elevation of these gated communities.

6. Present Adaptation Strategies and Their Influence on Future Vulnerability

As stated in the introduction, very low-lying areas, which will likely be permanently flooded by the end of this century, are either scarcely populated because they are frequently flooded by storm surges or are in process of being elevated to be used for private residential development. As a result of this adaptation to the current storm surge conditions and because the permanent flooding will extend over small areas in the metropolitan area of Buenos Aires, large social impact due this type of flooding is not expected. Therefore, climate change vulnerability in this coastal zone comes only from future exposure to extreme surges.

Neighborhoods that currently experience a relatively low recurrence of floods, and are therefore densely occupied, are those where the storm surge recurrence changes will create the greatest economic impact. They are now occupied by different social classes, ranging from upper middle class to socially vulnerable population. Thus, these changes will lead to social damages, as well as to important real estate losses.

Areas exposed to frequent floods, but close to the downtown area were occupied as early as in the late 19th century. They are La Boca neighborhood and the Avellaneda district. After more than a century, part of this area was finally protected by infrastructure.. Both cases are interesting examples of adaptation to storm surge floods and present qualitative aspects of the social vulnerability components—institutional, political and cultural—that may highlight future responses of the Argentine society to increased storm surges over the entire Plata River coast. This population constitutes a group that has historically developed alternative strategies (cultural aspects), which reduce its vulnerability to flooding.

6.1 La Boca neighborhood

This is one of the oldest city's neighborhoods, which in 2001 had 40,000 inhabitants. It was built as a harbor town in a marshy area on the left side of the mouth of the Riachuelo River, and since then, it has been one of the poorest areas of the city. La Boca's main hazards are floods by sudestadas and intense rainfall. Its inclusion into the Buenos Aires district—the most important of the country—provide an opportunity for the neighborhood to develop institutions, plans, and actions addressing potential flood disasters. The main structural action of the last decade was the building of defense dams that were successful in preventing the recent floods. However, this created a new problem: a feeling of complacency regarding the population's security. With the passage of time, this feeling of security could be dangerous, as the coastal defenses were built without consideration of river level rise resulting from climate change (Gentile, 2002).

The neighborhood has a strong social participatory tradition and cultural approach to defending itself against floods. However, in the institutional sphere, there were communication gaps among the involved institutions, and between them and the population. In addition, both the urban flood defense and flood management programs have usually not been articulated, until recently when the urban planning and the public works activities were placed under the same management agency.

6.2 Avellaneda district

The Avellaneda district is south of La Boca on the other side of the Riachuelo river: It is one of the oldest populations located in a floodplain. It has been an industrial town since its beginning (1840), with high levels of urbanization (more than 90%, since 1940). Its total population in 2001 was 330,000 inhabitants. The main hazards in Avellaneda are floods and water and air pollution.

The authority in charge of disaster management is the Civil Defense District Board, integrated by many institutions from the government, as well as from civil society. However, this participation is mostly nominal since flood management is practically decided by its director. The efficiency of this board is also hindered by the lack of continuity since its director is politically appointed and renewed with each government every four years, or less. Other problems are a lack of accurate and direct communication with the population, as well as distrustfulness and rivalry among institutions involved with flood management. However, these institutions do have highly trained and experienced personnel that facilitate the flood management when required.

7. Factors That Worsen Vulnerability to Climate Change

As in many developing countries, certain local circumstances make it difficult understanding climate change vulnerability or hamper the processes of adaptation. Some of these circumstances are described in this section, as well as the actions taken in the context of the project to overcome or reduce their negative impact. The most important problems are the lack of basic information, either physical or social, institutional weakness, and the lack of public awareness of the climate change process and its local consequences.

7.1 Lack of basic information

When the data required for vulnerability or adaptation studies are lacking or deficient, it depends on the nature of the variables whose data is needed, if they can be obtained in a relatively short time.. Geographical and geological variables that only change at a very slow rate can be often obtained by a specific observational program within the lapse time of a short-term project. This is not the case with other variables that undergo rapid changes, and whose long-term statistics although required, could be missing or not available. In these cases, it is not possible to build a long record within the time frame of a typical project. Therefore, another approach is necessary to assess the missing variables. In some circumstances, modeling of the physical system can be a possible alternative solution. Because a lack of basic data is more common in developing countries, modeling is perhaps more useful in these countries, as it can generate proxy data that otherwise would take long time to obtain.

Two examples of these two different approaches were faced while developing the project. The first was the case of the documentation of land altitude (maps or records of some locations), which was old and not up-to-date enough to take into account the man-made modifications of terrain during the past 20 years, especially in the Plata River shoreline. In addition, this documentation had a low vertical resolution, which was, in general, insufficient to cope with the description of changes that will be caused by mean water level rise IPCC scenarios that for the 21st century range from 0.20 to 0.8 m. The project developed a new digitized model of the land altitude as explained in Section 3. The other example was the lack of enough tide data records on the Plata River coast. Because the floodwaters reach different heights along the coast, it was necessary to assess this data. As it was also explained in Section 3, this was done through a hydrodynamic model of the Plata River hydrology...

7.3 Institutional weakness

As in many other aspects of national institutions, the organizations related to flood management are not stable, and even when they persist over a long time, usually their policies change frequently. In general, the institutional management style, typical of the national culture, is not adequate for long-term planning. In the case of flood management, even the little planning and the few successful programs and projects in flood management unfortunately were not always continued with each change of government. One example of this is the Emergency Federal System created in the 1950s. Since then, it was moved many times to and from different ministries, and it has had its plans and policies changed.

Another problem, fortunately less common, is the lack of coordination between different institutions. Thus, fragmentation of policies and uncoordinated measurements increases the social vulnerability and generates a high degree of uncertainty that could amplify the damages from each disaster.

7.4 Lack of public awareness

As explained in Section 6, the recent changes in the use of the coastal zone are exacerbating climate risks. There is little awareness of the climate change issue and even less knowledge of its possible impacts, not only over the existing coastal area, but also over the new land environments that have been created for the past 300 years in the Paraná Delta tip. This tip is advancing over the Plata River at a pace of 70 m per year. There are already plans to use these new lands for real estate business, and disputes over its use, jurisdiction, and property have already started. Until now, there is little awareness that these new lands will be highly vulnerable to the water level rise.

Until now, development of the entire coastline has been taken without considering the water level rise. The mean water level increased 17 cm during the last century and is now rising faster. The preliminary results of the project were presented at a forum of stakeholders and at numerous other meetings. These activities create some awareness that have already resulted in frequent consultations. More of an impact in public awareness is expected from the dissemination of two books that present relevant project results, one geared toward the general public (Barros 2005) and other to reach technical professionals and government officials (Barros et al 2005) .

Government officials, investors, and engineers who are making decisions that affect the coastal area are not only unaware of the climate change impacts, but also of the dynamics of the system they are altering. Thus, the systematic disregard of the natural hydrological system increases the vulnerability to natural hazards. To prevent damages, new investments in expensive structures are required, only to support an inadequate coastal management. It is likely that as the issue of climate change gains ground in the public's awareness, better management of the Plata River coast could be achieved.

8. Final Remarks

If the population distribution does not change in the future, the people who will be affected by permanent flooding in this century would be very small. First, the area facing such a prospect in the Great Buenos Aires coast is very small and second, past adaptation to storm surges has prevented the population of that area. Therefore, we conclude that climate change risk in the coastal areas of metropolitan region of Buenos Aires will come from the greater inland reach of the recurrent floods.

Some neighborhoods that currently have relatively low recurrence of floods, and because of that are densely occupied, are those where changes in the storm surge recurrence will create the greatest impact. They are now occupied by a wide social spectrum, ranging from the upper middle class to a socially vulnerable population. Thus, these changes will lead to social damages, as well as to important real estate losses. The lower limit of the total infrastructure losses, including real estate, if no adaptation measures were taken would range between 5 to 15 billion USD for the period 2050–2100, depending on the speed of the sea level rise and the increase in the infrastructure value.

Present trends in the housing industry toward increasing number of gated communities at the coastal or at low-level areas will increase future real estate risks due to more frequent and higher storm surges, if these changes due to climate change continue to be ignored in the planning of these neighborhoods. Some nongovernmental organizations are calling for an urgent regulation of the Plata River coastal zones in the Great Buenos Aires region. According to the results of this project, climate change scenarios and their associated Plata River levels should not be ignored in such regulation.

References

Barros, V. 2005. Climate Change and the coast of the Plata River (In Spanish). City Foundation, Buenos Aires, Argentina, 42 pp.

Barros, V., I. Camilloni, I. and A. Menéndez, A. 2003. Impact of global change in the coastal areas of the Rio de la Plata. *AIACC Notes,* 2:9–11.

Barros, V., A. Menendez and G. Naggy Eds. 2005. Climate Change in the Plata River (In Spanish), Center for Atmospheric and Ocean Research, Buenos Aires, Argentina, 200 pp.

Camilloni, I. 2004. The representation of the climate of southern South America by Global Climate Models (In Spanish). Di Tella Foundation, Buenos Aires, Argentina. Project ARG/03/001. 16 pp.

Church, J. A., J. M. Gregory, P. Huybrechts, M. Kuhn, K. Lambeck, M. T. Nhuan, D. Qin, and J. L. Woodworth. 2001. Changes in sea level. Climate change 2001: The scientific basis, Chap. 11 In: *Changes in Sea Level¨ of the. Intergovernmental Panel on Global Change Third Assessment Report*, New York: Cambridge University Press.

D´Onofrio, E., M. Fiore, and S. Romero. 1999: Return periods of extreme water levels estimated for some vulnerable areas of Buenos Aires. *Continental Shelf Res.* 4:341–366.

Escobar, G., V. Barros, and I. Camilloni. 2003. Desplazamiento del anticiclón subtropical del Atlántico Sur (The shift of the South Atlantic subtropical high) *X Congreso Latinoamericano e Ibérico de Meteorología* (Proceedings of Tenth Latin American and Iberic Congress of Meteorology). Latin American and Iberic Federation of Meteorological Societies, La Habana, Cuba.

Escobar, G., W. Vargas, and S. Bischoff. 2004 Wind tides in the Rio de la Plata estuary: Meteorological conditions. *Int. J. Climatol.* **24,** 1159–1169.

Gentile, E. 2002. La incorporación de la gestión del riesgo por inundaciones en la gestión urbana pública. El caso del barrio de La Boca (The inclusion of flood risk in the urban public management: The neighbourhood of La Boca case), Instituto Gino Germani (Gino Germani Institute). Buenos Aires, Argentina.

Kalnay, E., M. Kanamitsu, R. Kistler, W. Collins, D. Deaven, L. Gandin, M. Iredell, S. Sha, G. White, J. Woollen, Y. Zhu, M. Chelliah, W. Ebisuzaki, W. Higgins, J. Janowiak, K. C. Mo, C. Ropelewski, J. Wang, A. Leetmaa, R. Reynolds, R. Jenne, and D. Joseph. 1996: The NCEP/NCAR 40-year reanalysis project. *Bull. Am. Meteorol. Soc.* 77:437–471.

Menéndez, A. N. 1990. Sistema HIDROBID II para simular corrientes en cuencos. (HIDROBID II System to simulate currents in basins). *Revista Internacional de Métodos Numéricos para Cálculo y Diseño en Ingeniería,* (International Magazine of Numeric Methods for Calculation and Engineering Design) vol.6, 1-6

Re, M. and A. Menéndez. 2003. Modelo numérico del Río de la Plata y su frente marítimo para la predicción de los efectos del cambio climático (Numeric model of the Plata River and its marine front for the prediction of the effects of the climate change), Mecánica Computacional. Vol. 22. M. Rosales, V. Cortínez and D Bambill (Editors). Bahía Blanca, Argentina

Ríos, D. 2002. Vulnerabilidad, urbanizaciones cerradas e inundaciones en el partido de Tigre durante el período 1990–2001 (Vulnerability, closed urbanizations, and floods in the Tigre District during the period 1990–2001). Tesis de Licenciatura en Geografía (Thesis of Degree in Geography) Facultad de Filosofía y Letras, University of Buenos Aires, 191 p.