FLOOD VULNERABILITY OF TECUCI CITY: THE ROLE OF NATURAL AND SOCIO-ECONOMIC FACTORS

LILIANA ZAHARIA, SIMONA CATANĂ, EUGEN CRĂCIUN, GABRIELA IOANA-TOROIMAC

ABSTRACT. - Flood vulnerability of Tecuci city: the role of natural and socio – economic factors. The present paper deals with natural and socio-economic factors of flood vulnerability of Tecuci city. The main natural factor is the hydrological one, due to the presence in the city area of two watercourses, namely the Bârlad and its tributary, the Tecucel. The characteristics of their hydrological regimes (and especially the maximum flow) and their flooding potential are taken into account, the flood of 5 – 7 September 2007 being particularly analyzed. Among the natural factors that enhance flood vulnerability of the city an important part is played by geomorphologic conditions. The social and economic causes of flood vulnerability are emphasized through the analysis of some specific aspects regarding the population, economic activities, communications network infrastructure, public utilities and land use. Also, the paper analyzes the structural and non-structural measures for flood control in Tecuci city.

Key words: vulnerability, inundation, flood, natural and the socio-economic factors, Tecuci.

In September 2007 Tecuci city (about 43,000 inhabitants) was affected by a strong flood that brought about extremely serious social and economic effects. Damage dimensions were determined both by the exceptional character of the natural phenomenon (the flood that occurred on the Tecucel) and by the city vulnerability to floods. If the natural phenomenon is randomly, flood vulnerability may be assessed based on the analysis of the three major causes that determine it: natural, social and economic.

The present paper aims at emphasizing the natural and socio-economic factors that make Tecuci city vulnerable to floods. Getting to know these factors is useful from the perspective of taking adequate measures to reduce the vulnerability and, in consequence, to lower the risk of a flooding event.

The paper relies on statistical data (hydrological, climatic, and socio-economic), on cartographic materials (1:25000 and 1:50000 scale topographic maps), on orthophotoplans, as well as on information gathered by personal observations and field surveys. The data have been processed by statistical analysis methods, computational cartography and GIS techniques.

1. The natural factors of flood vulnerability of Tecuci city

Lying in the north-eastern extremity of the Romanian Plain, at the confluence of the Bârlad and the Tecucel (Figure 1), Tecuci city shows some specific features of the natural background that make it vulnerable to floods. Among these the hydrological and morphological ones are by far the most important:

1. 1. Hydrological factor

The main natural factor affecting flood vulnerability of Tecuci city is the hydrological one, due to the presence in its area of two watercourses, namely the Bârlad and the Tecucel (Figure 1). By the torrential character of their flowing regime and the frequent floods the two rivers have generated during the years many overflowings, some of them bringing about important damages.

The Bârlad River is the Siret's most important affluent from the standpoint of the catchment's area (7,220 km^2)[2] and the second in what concerns the length (207 km). Mean altitude of the river basin is 211 m, while its average slope is 72 m/km. The mean slope of the river is 2 m/km, being higher in the upper course (about 3 m/km), while in the lower course it drops to less than 0.5 m/km (Ujvari, 1972).

In Tecuci city area the width of the river varies, on an average (according to the water level), between 8 – 9 m and 18 – 20 m. The floodplain is large, more than 3 – 4 km wide, and within it, due to the reduced inclination, watercourse has wandered strongly, as shown by the great number of abandoned channels and cut-off meanders. The shallow water table encourages waterlogging and overflowings. As a measure of flood control, in 1980 a former course of the Bârlad was channeled in order to divert high waters in case of necessity. This so-called ***Rateş branch***, 13 km long, separates from the Bârlad at Munteni village and joins it again downstream of Tecuci (Figure 1).

The Tecucel River is a small tributary of the Bârlad, 24 km long[3], having a river basin of 112 km^2. It originates in the southern extremity of the Tutovei hillocks, at an altitude of 180 m, while its mouth is at 31 m, which gives a mean slope of 5 m/km. The river basin, developed on Sarmatian and Pliocene sedimentary formations, is strongly elongated on a general north-south direction (its length is about 30 km and the maximum width is 6 km), the altitudes ranging from 31 m to 307 m (the mean altitude being 179 m).

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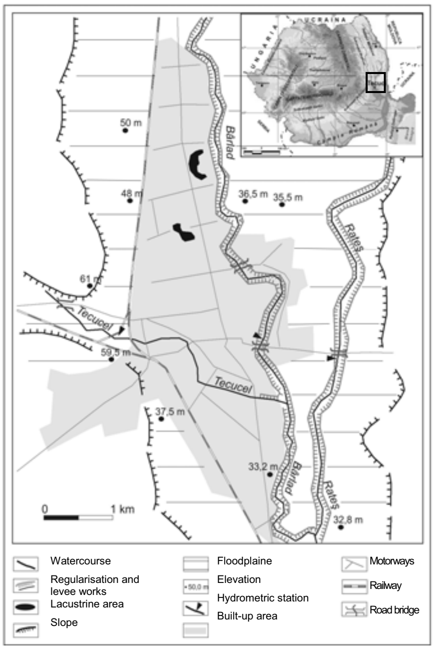
[2] The data regarding the area, length, mean altitude, mean slope of the catchment and mean slope of Barlad river channel correspond to the Romanian Water Cadastre Atlas, 1992.

[3] Morphometrical data on the Tecucel and its catchment have been taken from the Romanian Water Cadastre Atlas, 1992.



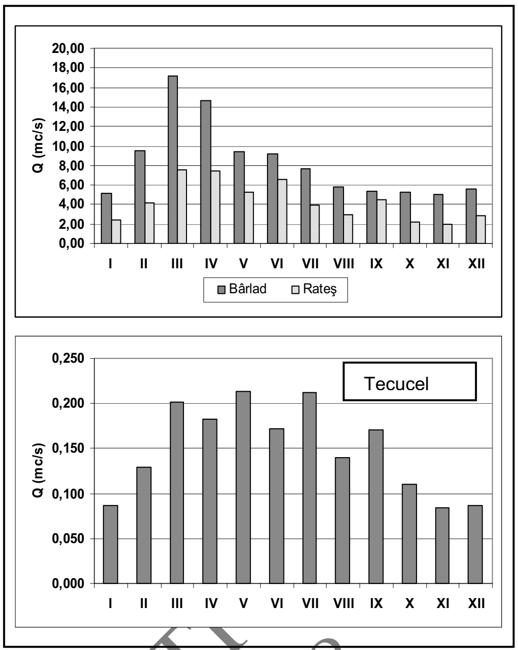


Figure 1 (left) The sketch of Tecuci city and its position within Romania
Figure 2 (right) Hydrographs of mean monthly discharge of the rivers Bârlad (1950 – 2007), Rateş (1985 – 2007) and Tecucel (1950 – 2007) at Tecuci hydrometric station

The Tecucel crosses Tecuci city on a general west-east direction. Its channel resembles a ravine, 2 – 3 m deep and 8 – 10 m wide at the upper level, with a thick vegetation cover. Along it, on both sides, and in most cases in its immediate vicinity, private buildings (together with farmsteads), as well as socio-economic units are found.

1.1.1. General hydrological characteristics and the flooding potential

Hydrological characteristics of the Bârlad and the Tecucel in Tecuci city perimeter are monitored through measurements and observations undertaken at 2 hydrometric stations. The Rateş channel is also under observation since its creation.

The mean multiannual discharge of the Bârlad during the interval 1950 – 2007 at Tecuci hydrometric station is 8.33 m^3/s. Its annual flowing regime shows high waters in spring (with the greatest discharges in March – 17.4 m^3/s and April – 14.9 m^3/s, corresponding to shares of 17% and respectively 15% of the mean yearly volume) and low waters in autumn and winter (with relatively constant discharges, of about 5 m^3/s, equivalent to shares of 5% for every month from September to January) (Figure 2). The minimum annual discharges of the Bârlad for the interval 1954 – 2007 oscillated between 0.003 m^3/s (in 2003) and 4.25 m^3/s (in 1982).

On the Rateş branch flows a mean multiannual discharge of 4.32 m^3/s (1984 – 2007). The highest mean monthly discharges are specific for March, April and June (7.56 m^3/s, 7.48 m^3/s and respectively 6.51 m^3/s), while during the October – January interval mean monthly discharges are below 3 m^3/s (with a minimum in November – 1.96 m^3/s). The maximum transport capacity of the Rateş branch is of 350 m^3/s.

Due to the climatic conditions with aridity influences specific for the region (mean annual precipitations do not exceed 500 mm), the Tecucel River shows a very low multiannual discharge (0.146 m^3/s, during the 1950 – 2007 interval) and a high coefficient of interannual variation of the mean flow (0.71). Its hydrological regime has a torrential character and shows three maximum values, relatively close to one another: 0.216 m^3/s, 0.215 m^3/s and 0.203 m^3/s in May, July and respectively in March (Figure 2). The main minimum occurs in November – January interval, when the values of mean monthly discharges do not exceed 0.1 m^3/s, ranging from 0.083 to 0.087. Low water discharges are very low and sometimes the river channel dries out. During the 1968 – 2006 interval the drying phenomenon occurred in 7 years, having longer or shorter durations (the longest period was recorded in 1968, when the phenomenon was observed from May till August, that is for 4 months).

The flooding potential of the Bârlad and the Tecucel rivers is determined by the evolution of maximum discharges. This was analyzed for the intervals 1954 – 2007 for the Barlad and 1968 – 2007 for the Tecucel.

In the case of the ***Bârlad***, maximum annual discharges show values ranging from 8.42 m^3/s (in 2000) to 579 m^3/s (2004). The strong interannual variability of maximum discharge is emphasized by the high value of the variation coefficient of maximum annual discharges, which is 1.09. After the creation of the Rateş channel maximum annual discharges of the Bârlad have diminished (below 100 m^3/s), with the exception of the years 2004 and 2007 when important floods occurred on the Bârlad.

During the analyzed period, 25 overflowings occurred on the Bârlad River, with discharges higher than the danger level established for the Tecuci station (107 m^3/s) and another 62 added up, with discharges superior to the flooding level (62 m^3/s).

From the analysis of the monthly distribution of the high waters that exceeded the flooding level it results that the highest flooding potential is held by the months March and April, when 19% and respectively 16% of total floods occurred. In the case of the floods that exceeded the danger level, most of the 25 occurred in April (5), March (4), May (4) and July (4). (Figure 3A).

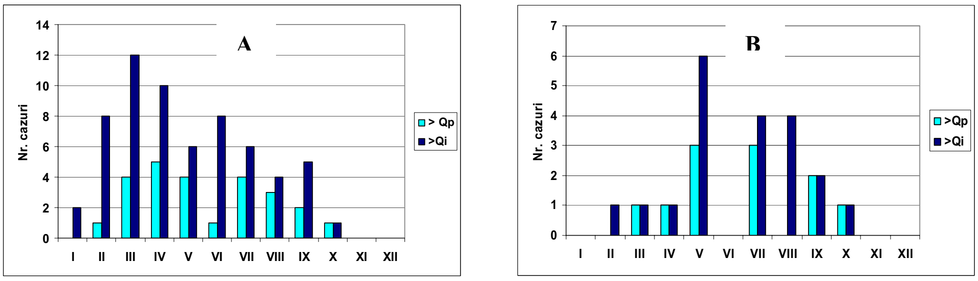


Figure 3. Monthly frequency (in number of cases) of the highest floods that occurred on the Bârlad (A) and Tecucel (B) (Q_p = danger level discharge; Q_i = flooding level discharge)

The randomly character of floods is reflected by the fact that several important overflowings took place on the Bârlad during the same year. Thus, in each of the years 1969, 1970, 2003 and 2004, 3 floods exceeding the danger level were recorded at Tecuci station.

The yearly maximum discharges of the ***Tecucel River*** have a strong interannual variability (CV = 1.38). In the analyzed interval these ranged between 0.230 m^3/s (in 1994) and 183 m^3/s (in 2007).

The number of overflowings that exceeded the discharge corresponding to the danger level (400 m^3/s) was 11, while those higher than the discharge corresponding to the flooding level (24 m^3/s) amounted to 20. The months with the highest frequency of flood occurrence with discharges superior to the flooding level are May (30% of the cases), July and August (20% of the cases each). Considering only the overflowings that exceeded the danger level, from the total of 11, most of them occurred in May and July (3 in each month), as well as in September (2) (Figure 3B). The monthly frequency of the highest floods shows their predominant pluvial origin, an important role being played by summer showers. As in the Bârlad case, there were years when many important floods occurred on the Tecucel, too (with discharges above the danger level). Thus, in 2006 four such phenomena were recorded (in February, March, April and May) and in 1971, 1972 and 2002 there were 2 each year.

1.1.2. Hydrological event of September 2007 and its consequences

On September 5, 2007, in the afternoon, a flash flood occurred on the Tecucel (with a total time of 26 hours), which generated the most serious overflowings that have affected Tecuci city in the last hundred years. In only 5 hours time (between 16:00 and 21:00 hours) water level rose at Tecuci station from 182 to 807 cm (with an average speed of 1 m/hour), while the discharge reached from 0.54 to 183 m^3/s (Figure 4)! These have been the highest levels and discharges ever recorded at Tecuci station since it was set up in 1968. They were superior by far to those corresponding to the danger level at this station, namely 500 cm and respectively 40 m^3/s. Statistical analysis has shown for the maximum discharge reached during this flood a probability of occurrence of about 0.2%, which corresponds to a mean return rate of 500 years!

The cause of this flood is the heavy precipitations fallen in the afternoon of September 5, 2007, in the eastern part of Romania. In the south of the Bârlad river basin, on September 6 at 6:00 hours were recorded total amounts of rainfall in 24 hours above 200 mm. In the upper half of the Tecucel catchment the precipitations exceeded 130 mm in 24 hours. At Tecuci, the total amount of precipitations in 24 hours was of 105 mm (almost a quarter of the mean annual amount!).

The heavy rainfalls resulted in floods on the Bârlad and its Rateş branch, too. Thus, on the Bârlad water discharge rose in 20 hours from 1.40 m^3/s (on September 5 at 6:00 hours) to 245 m^3/s (on September 6 at 2:00 hours). Due to the larger area of the Barlad catchment flood peak came 7 hours later from the moment when maximum rainfall was recorded. An important volume of water was taken over by the Rateş branch, whose discharge enhanced from 0.085 m^3/s (on September 5 at 6:00 hours) to 326 m^3/s (on September 6 at 4:00 hours), thus contributing significantly to the mitigation of the Barlad discharge (Figure 4).

The flood on the Tecucel affected about 60% of the Tecuci city built-up area, in many places the thickness of water layer exceeding 1.5 m (Figure 5). Damages recorded with that occasion were extremely serious. Because of the overflowings 3 people lost their lives, more than 1,000 private properties were affected and more than 200 houses were completely destroyed. The street infrastructure and the public utilities one were strongly deteriorated. Total cost of the damages was estimated at 6 million Euros[4].

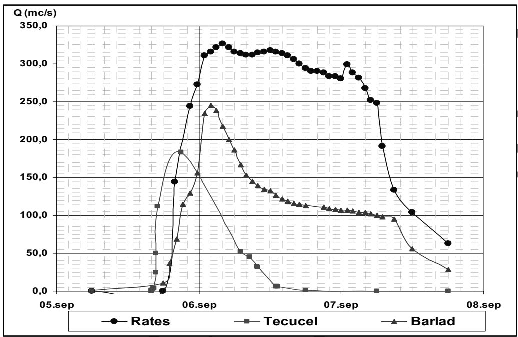


Figure 4 Hydrographs of the flood of 5 – 8 September 2007 on the Tecucel, Bârlad and Rateş rivers

Figure 5 Water level mark left on a house wall by the flood of September 2007

1.2. Geomorphologic factor

[4] The information regarding the damages was released by the County Inspectorate for emergencies and the data were published by the newspaper *Evenimentul zilei* no. 4983, from 12 September 2007

Approximately 80% of the city's built-up area lies in the Barlad floodplain (Figure 1). The absolute elevations are frequently between 35 and 40 m. Only one neighbourhood in the southwest of the city lies a little bit higher, at 50 – 60 m. Specific for the floodplain morphology are the abandoned channels, either dry or filled with water. The flat aspect of the ground and the shallow water table encourage waterlogging. The specific morphological conditions of Tecuci city allow the stagnation of waters proceeded from river overflowings, as well as the accumulation of rain waters and of those flowing along the slopes that flank the floodplain. In addition, the shallow water table leads often to waterlogging.

2. Socio-economic factors

Flood vulnerability of a region is determined to a large extent by its socio-economic features. The population and its material assets, the units and the economic activities (industrial, agricultural, etc.), the institutions and public services (social, cultural) and the communications infrastructure (roads, railways, special transports) are more or less vulnerable to floodings, depending both on an ensemble of specific characteristics and on the protection measures that were previously adopted.

Demographic features. The population and its characteristics make a territory socially vulnerable. Demographic growth and the resulting increase of population density determine the enhancement of social vulnerability.

The population of Tecuci city amounted in 2006[5] to 43,287 inhabitants, which led to a density of 499 inhabitants/km^2. In comparison with the situation at the beginning of the 20th century the number of inhabitants grew almost three times.

Flood vulnerability of population depends on age and sex. Thus, children and elder people, as well as female persons are more exposed to flood risk. In Tecuci city female population is larger than the male one, holding 52% of the city's total number of inhabitants. In what concerns age structure the share of children (0 – 14 years) is 18.6%, the adult population (15 – 59 years) holds 66%, while the elderly (more than 60 years old) represent 15.4%[6]. One should notice that female elder population is more than 2% higher than its male correspondent, which shows the higher vulnerability of this category. This aspect was confirmed with the occasion of the flood recorded on September 2007, when all the 3 deceased persons were aged females.

Apart from demographic characteristics, social vulnerability is influenced

[5] According to the data issued by the County Board of Statistics Galati

[6] The data referring to the city's population structure on age and sex correspond to the year 2000 and have been taken over from the site hosted by Ethnocultural Diversity Resource Center http://www.edrc.ro/recensamant.jsp?regiune_id=503&judet_id=700&localitate_id=702

by the extent to which the population has what has been called "a culture of risk". This notion encompasses two main components: 1) a previous experience of some catastrophic events (in our case the floodings), which stands for the "risk memory" and 2) the education level (in various forms) with respect to flood risk (or other risks that may affect the settlement) and to the actions that need to be taken under such circumstances (Ledoux, 2006). The development and keeping of a "risk culture" contribute to the reduction of social vulnerability through adequate preventing measures and through a proper behaviour during the event.

Land use. The land use is an index that allows the establishment of vulnerability level of a territory. Thus, according to a document issued by the European Commission and quoted by Ledoux (2006), the residential, commercial and industrial areas, as well as those having infrastructures of national importance and special equipment (water cleaning plants) have the highest degree of vulnerability.

Tecuci city stretches on 8,676 ha[7], out of which 6,576 ha (76%) is the outside city and 2,100 ha (24%) the built-up area. Agricultural lands amount to 7,179 ha (83% of the city's area), the highest share being hold by arable lands (67% of the total area). Non-agricultural lands totalize 1,457.45 ha, out of which: forests (2.60 ha), waters and areas covered by reed (69.43 ha), roads (67 ha), built-up areas (1,317.33 ha) and unproductive lands (0.45 ha).

Built-up areas hold 15% of the city's territory. They include 14,500 dwellings, out of which 507 are public property and 13,993 privately owned[8].

According to a 2008 report issued by the County Committee of Emergencies Galati 1,394 buildings in Tecuci are placed in flood risk areas, a fact that makes the city so vulnerable to overflowings. As mentioned previously the flood of September 2007 affected more than 1,000 private properties, 200 houses being completely destroyed. An important element of vulnerability is represented by the age of the buildings, as well as by their technical characteristics. In Tecuci city, at the time of the catastrophic event, most of the damaged houses had no strength structure and were built up from materials with low water resistance (trellis work and adobe).

Economic activities. The elements of economic order are vulnerable to floodings by the size of direct and indirect potential cost of the resulting damages.

Tecuci city is an important communication junction. This has led to the development of a dense infrastructure of railways and motorways, which made necessary that embankments and cuttings be accomplished, as well as bridges to

[7] Land use data have been taken over from Tecuci Town Hall site and are valid for 2006. (http:// www.primariatecuci.ro/tecuci.html)

[8] According to the data shown on Tecuci Town Hall site (http:// www.primariatecuci.ro/tecuci.html)

allow the crossing of watercourses. The undersized bridges and the embankments may act during floods as obstacles that obturate water flowing, thus increasing its pressure and making it overflow with great force. Consequently, flood effects are amplified. This fact was demonstrated in September 2007, when during a flood event on the Tecucel the flowing of its waters was blocked at the entrance in Tecuci city by the bridge on the road to Tisita, by the undersized bridge on the Iassy railway line and by the embankment for the railway earthwork. Under the circumstances, water accumulated, got pressure and overflowed with great velocity in the streets, wiping the city from west to east, according to the general slanting towards Barlad River. The flood temporary affected a railway section.

Among the specific economic activities of Tecuci city one can mention the industrial, agricultural and commercial ones. From the industrial point of view there are food industry units (tinned vegetables, fruits, meat and mustard), the heavy equipment factory, the metal packing factory and the motor vehicles repairing unit. Agriculture is represented especially by plant growing (mainly cereals, technical plants and vegetables).

Street and public utilities infrastructures. The deterioration of street and public utilities infrastructures as a result of floodings may bring about significant financial losses, due on the one hand to the rehabilitation costs and on the other hand to the social and economic dysfunctions they trigger. The total length of the street network of Tecuci city is 117 km, out of which 56 km are modernized streets. The water distribution network amounts to 81.1 km, while methane gas pipes totalize 66.7 km[9]. The flood of September 2007 seriously damaged the street infrastructure (more than 120 streets) and the public utilities one.

From among the elements of urban infrastructure the sewerage network has an important influence on flood vulnerability. If it is properly dimensioned and maintained its role is to reduce flood vulnerability by collecting the waters that fall on the city or flow through it. The total length of the sewerage network of Tecuci city is 72 km. Unfortunately, this is inefficient because it is undersized and poorly maintained. Consequently, when water rises in the Bârlad and Tecucel rivers after heavy rainfalls, as it happened in September 2007, the sewerage network may in fact amplify the negative effects of overflowings. The deterioration of sewerage network can bring about serious sanitary consequences through the diseases that may spread following the infestation with bacteria that live in the spilled wastewaters.

3. Measures to cut down flood vulnerability and flood risk

[9] The data on street and public utilities infrastructures have been taken over from the Tecuci Town Hall site and are valid for 2006
(http:// www.primariatecuci.ro/tecuci.html)

In the case of Tecuci city the measures to reduce flood vulnerability are mainly of **structural order**. A particular attention has been paid to the protection against the floodings caused by the Barlad. After the great floods and overflowings in the 1980s complex management schemes have been accomplished. Thus, Bârlad channel was embanked with dykes and the flow was regularized. On the stretch upstream of Tecuci (Munteni – Malu Alb) the dykes are 18.2 km long on the right bank and 16.0 km long on the left one. In 1980, as a supplementary protection measure against the overflowings generated by the Bârlad the Rateş derivation channel was accomplished. At the same time, erosion prone river channel sectors were consolidated.

Although the dykes along the Bârlad have proved their efficiency in protecting Tecuci against the overflowings of this river, in the case of hydrological event of September 2007 those on the right bank favoured the flooding of the city, as they acted like barriers for the Tecucel overflowing waters that were advancing gravitationally towards the Bârlad.

As far as the Tecucel is concerned, due to its reduced size and low discharges no protection dykes have been built so far, except for its lower course, where, on the left bank, upstream the junction point, an earth dyke was accomplished, about 500 m long, as a prolongation of a dyke on the Bârlad. In 1977, a permanent reservoir was built at Buciumeni, in the upper course of the Tecucel River. With an area of 6 ha and a volume of 40,000 m^3 the reservoir is unfortunately not functional yet. The scarce engineering structures on the Tecucel, the presence of buildings in the immediate vicinity of its channel, the thick vegetation and the high degree of insalubrity (due to waste deposition inside the river channel) turned into major factors that amplified the effects of the September 2007 overflowings.

For cutting down flood vulnerability of Tecuci city it is necessary that special attention be paid to **non-structural measures**. These should focus mainly on the following: raising the awareness and ensuring a good training of the population with regard to the risk induced by overflowings; the maintenance and salubrization of river channels (especially the Tecuci one); a proper territorial planning that should take into account the flood risk; the improvement of local and regional institutions activity that are responsible for managing the flood risk, such as to make them more efficient; and the raising of the number of life and assets insurance policies (Stănescu & Drobot, 2002).

Conclusions

As a result of its location in a flood plain area, at the confluence of the Barlad and Tecucel rivers, Tecuci city has high natural flood vulnerability. The occurrence of overflowings and the magnifying of their effects are determined to a large extent by the socio-economic features of the city.

Although less taken into account the Tecucel River turns to be an important menace. Due to the reduced size and low discharges it has not been subjected yet to engineering works, except for a short stretch. However, the relative high frequency of floods (due to a torrential flowing regime), the thick vegetation that accompanies it, the high degree of insalubrity and the presence of numerous buildings along its course give this river a high potential for flood risk.

In order to diminish flood vulnerability of Tecuci city it is necessary that structural measures should be extended (mainly by proper engineering works on the Tecucel) and greater attention be paid to non-structural ones, as the latter have been largely neglected so far.

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