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FLOOD RISK AND PLANNING OF RECREATIONAL TERRITORIES IN THE AKMENA-DANĖ RIVER BASIN OF WESTERN LITHUANIA

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Abstract. Intensive summer rain showers in 2005 and 2007 caused floods in most rivers of Lithuania. A large majority of the worst problems occurred in the basins of the Akmena-Danė and Minija rivers that are adjacent to the seashore. In many cases possible dangerous consequences can be avoided by predicting and forecasting spring floods caused by heavy rain or thawing snow. As a natural disaster, a high flood occurs unexpectedly and results in a rapid rise of river level, which can cause dam failure. It is especially evident when a high water level in the Baltic Sea caused by deep cyclones results in additional surplus of river level leading to extreme gauge readings in a theoretical aspect andto flooding of territories in a practical aspect.

The current research focuses on the consequences of the past, present and future possible dam failure cases in the Akmena-Danė river basin. Modeling of possible impact to other dam-protected reservoirs is also analyzed in together with some other processes, including extremely high river level raises, caused by storm water surges either from the sea or the coastal lagoon. Attention is paid to the territory planning problems, that occur in the flood risk area, with a particurlar focus on residential and recreational territories sustainable planning which plays an important role in the quality of natural surroundings of the man. Implementation of EU Floods Directive 2007/60/EC is dealt with as well.

Keywords: seaside river basin, seawater surge, dam, flood, territory planning, residence, recreation.

Introduction

Hydrographic network of Lithuania is divided into 6 major basins. The Akmena-Danė river basin belongs to the Basin of Seashore-related or Seaside rivers that make 3.3 percent of the state territory (Fig. 1). The length of the Akmena-Danė river is about 62 km, the basin area covers 580 square kilometres that make 0.9 percent of the territory of Lithuania (Fig. 2). From the headwaters down to 45 km the river is called Akmena, and down to the mouth the river name is Danė. The most significant towns in the Akmena-Danė river basin are Klaipėda with more than 180 000 inhabitants, 5 000 of which live in the closest vicinity to the river and Kretinga with the population exceeding 20 000, 1 000 of them living in the flood risk area. The most significant territory planning priorities within the urban areas are these of residential, commercial, recreational and industrial ones. Accordingly in the rural areas priorities of agriculture, residence, forestry and recreation use to prevail.

During their specific natural and anthropogenic factors some territories in the Akmena-Danė river basin,especially those adjacing the rivers, are very sensitive to inundation. It was proved to be true during the summer floods of 2005 and 2007 when residential and recreational areas, agricultural land and territories for other activities were inundated after prolonged rainshowers.

The aim of this paper is to describe some processes and factors influencing the flood occurrence in the mentioned basin and discuss the tools of its assessment and of prevention.

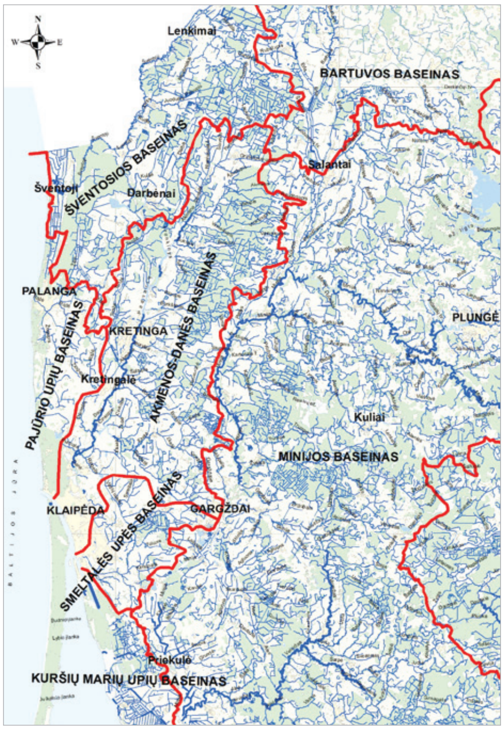
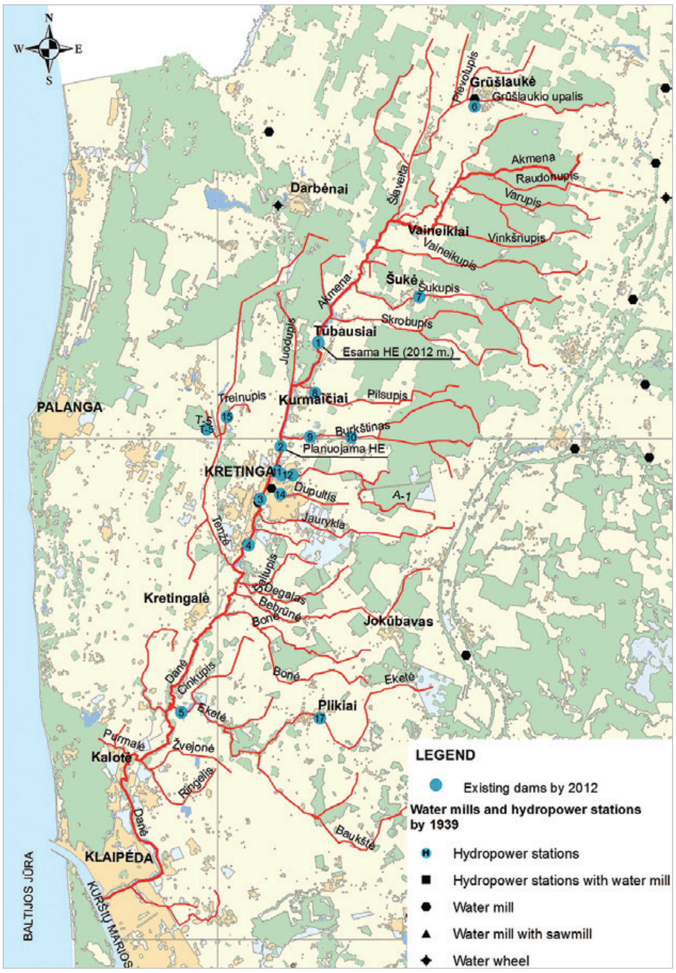


Fig. 1. River basins of Western Lithuania

The specific factor of the area of the Akmena-Danė river basin is that the river drains the western part of the Žematija (Samogitian) Highland and then reaches the Western Seaside Lowlands and plains where the river bed slope decreases significantly from 1.3 to 0.2 m/km (Fig. 3). Moreover the Akmena-Danė river basin has a particular hydrographic network form, because most of more than 20 tributaries are left banked. This phenomenon is typical of the adjacent Minija river Basin too. The other important hydrogeological factor is that heavy moraine clay or loam grounds prevail in the basin eliminating the rapid ground filtration process. The ground water supply of lowland rivers does not exceed 10–15% and that correspondingly increases the share of rainwater and water from melting snow. On the contrary, the share of groundwater supply in the rivers of East Lithuania make some 50–60%. The investigated basin is also exceptional in the Lithuanian territory because of the highest annual discharge hydromodule of 13.0 l/s/km² (Gailiušis *et al.* 2001; Bagdžiūnaitė-Litvinaitienė 2005).



Position	Reservoir Name	River name	Area of reservoir, hectare
1	Tūbausiai	Akmena	84.9
2	Padvariai	Akmena	82.0
3	Kretinga Center	Akmena	7.1
4	Bajorai	Akmena	1.5
5	Laukžemiai	Eketė	37.1
6	Grūšlaukė	Grūšlaukis	4.9
7	Šukė	Šukupis	2.5
8	Kumaičiai	Pilsupis	1.4
9	Padvariai on Burkštinas	Burkštinas	3.0
10	Klibiai	Burkštinas	5.7
11	Kretinga Park III	A-1	0.5
12	Kretinga Park II	A-1	4.0
13	Kretinga Park I	A-1	4.0
14	Pastaunykas	Dupultis	1.7
15	Ankštakiai	Treinupis	3.3
16	Kveciai	T-5	2.2
17	Plikiai	Eketė	3.0

Fig. 2. Hydrographic network of the Akmena-Danė river basin (present hydrotechnical impoundments are marked by tick marks with the relevant number)

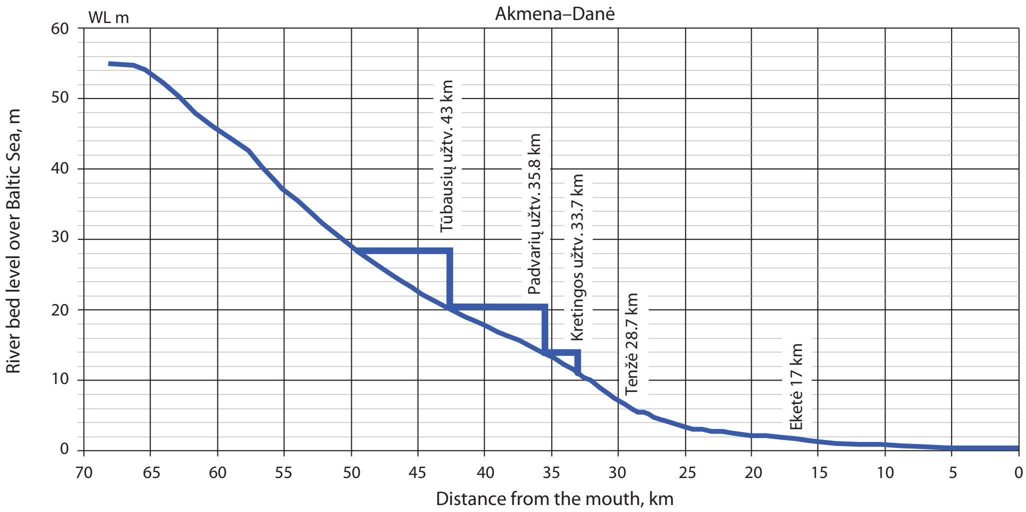


Fig. 3. Topographic profile of Akmena-Danė river gradient and major impoundments

Differences in water supply also determine the nature of annual flow regime. Most rivers of Lithuania overflow in spring, but in summer or winter their water level is low, maintained only by the groundwater supply. Short-term floods often occur in summer after heavy rains. In autumn when the vegetative season and an intensive evaporation period are over they become longer. The change of water level in rivers do not reach the extent of spring floods. Spring floods in small rivers of Lithuania last approximately 20–30 days. The total average duration of summer floods is 15-20 days, while the floods in winter are the longest ones, they usually last 45–50 days.

Methods and materials

River level observations in the Akmena-Danė river were started in Klaipėda in 1846 at the Borsenbrücke Bridge which is less than 1 km away from the mouth. Data were necessary for port services but the collection was terminated during World War II. In 1948 a new river level gauge was installed at the settlement of Tūbausiai 41.6 km up the Akmena-Danė river, which enabled collecting data till 1991. From 1945 to 1959 and since 1992 river level and discharge data have been collected at the level gauge in the southern part of Kretinga Town. This level gauge is used nowadays. The mouth area data are obtained from Klaipėda hydrological station, which operates in the Port of Klaipėda in the closest vicinity to the place where the river water gets into the Klaipėda Strait linking the Curonian Lagoon and the Baltic Sea. 3 kilometres further northwards the combined water mass enters the Baltic Sea. Both the level gauge and runoff data both are presented in hydrological annuals and various reports (Gailiušis *et al.* 2001).

The flooded territories of 2005 and 2005 researched by the means of DGPS techniques. Simultaneously technical parameters of all major impoundments were revised or newly recorded. Photography techniques helped to show the real situation at some significant objects and illustrate it more obviously. Besides, historical cartography and hydrometeorological data we exploited as well.

The data used in assessment were collected by Hydrometeorological Board of Lithuania and supplemented by the evidence measurements both by the Institute of Maritime and Cultural Landscapes of Klaipėda University and the Lithuanian University of Agriculture. The hydrological and meteorological observations data were used for the investigation. Modeling of the flooded areas was performed using Hydrological Centres River Analysis System (HEC-RAS) software developed for the United States Army Corps of Engineers (HEC-RAS River Analysis System 2010).

Long-term river and basin adjustment procedures

Priorities of the hydrotechnical structures introduced into the Akmena-Danė river basin as well as into the most of other basins of Lithuania could be determined by several time periods, which were typical of the some types of engineering installations (Dubra, Grecevičius 2006). These hydrotechnical impoundments represent the priorities of the territory and land use in the closest vicinity of river.

Military and defensive structures such as castles, manors, dams and city fortifications were constructed earlier than in 18th or 19th century with rare additions in the 20th century. These structures are the oldest hydrotechnical constructions in the river basins. Generally their effect on the flood regime cases is not significant or is of some small significance on a very local scale. For instance a castle in the mouth of Akmena-Danė river is known since the 13th century

Water transport structures including constructions of ports, canals, piers, bridges and execution of bed deepening and other activities have started to be installed into the river basins of Lithuania beginning with the 18th century. A variety of structures of these installations is obvious and in most of the cases and it results to the changed parameters of the channel. Depending on the type of installations their effect on the flood regime can be defined from moderate to high significant. Examples of the mentioned ones in the Akmena-Danė river basin are: the Port of Klaipėda, river embankments, local berths; deepening works. Till the World War II the Akmena-Danė river was navigated upstream from the mouth to 11 km, but now this distance dropped down by 3 times.

Survived **water mills, sawmills and wool combering installations** are very important objects of the historical and technical heritage. The peak of their appearance and operation lasted from the 2nd half of 19th century until the 1st half of 20th century. These old hydrotechnical structures are neither in a target use any longer nor completely destroyed nor even removed. Their effect on the flood regime is regarded to be of low significance. Over 20 mills were constructed in the Akmena-Danė basin (8 of them were on the Akmena-Danė river). Most often sawmills and wool combering techniques were combined with mills, but they happened to exist as separate installations, too. Exact number of them is not known now but probably it was over 10.

Installation of drain systems and adjustment of rivers reached the peak in the 2nd half of the 20th century. These works were performed with the purpose of draining wetlands and forests for the needs of agriculture and forestry. The other important feature was draining bogs and marshes. Effect of these systems on the flood regime should be regarded as a very significant one because of a more rapid appearance of drain water in the rivers with no accumulative processes. Most of the arable drainage area of the Akmena-Danė river basin is equipped with drain systems. Besides, the watercourse of the main river in upper reaches and its tributaries is adjusted.

Dams and water reservoirs now are very common sights of the landscape and most of them appeared in the 20th century with the peaks in the 8th and the 9th decades. Dams and water reservoirs are constructed for single or multiple purposes. In Lithuania storage of water for urban supply in open reservoirs is still not performed. However, installation of water reservoirs for irrigation and farming accelerated in the period between 1960 and 1990 with the maximum in 1970–1985. Most of dams are earth dams with drop-in let spillway and do not serve the flood mitigation, which importance is obvious now. Flood mitigation procedures by the technical means of the gravitational concrete dams could be performed, but this important option is still very rare in Lithuania. Power generation by means of dams and water reservoirs has been performed since the middle of 20th century, but the process of acceleration of installation of power generating equipment has started in 1993. Unfortunately, even nowadays in the Akmena-Danė river basin the installation of hydropower generating equipment is in an initial state. The most increasing potential for reservoirs would come with rising needs of recreation and tourism as well as aquaculture. The effect of dams and water reservoirs on the flood regime is very significant (Fig. 3). The number of impoundments in the Akmena-Danė river Basin now counts to 17 ones (Fig. 2). Currently, many water reservoirs are losing their role as objects of irrigation and farming but at the same time they start being more significant in leisure activities and recreation, i.e. bathing, fishing, surfing, boating, etc.

Discussion

The amount of precipitation in the Akmena-Danė river basin is one of the highest ones all over the Lithuania and can reach 926 mm annually. The biggest amount of precipitation of 90 mm occurs to be from August to December and the least one of 50 mm is usually observed from March to May. Recurrence of heavy rain showers is mostly probable in July and August, and the monthly balance can overcome 200 mm. Until now the highest known daily amount of precipitation of 109 mm in the Western Lithuania was observed on 6 August 1930 (Climate Reference … 1968).

Groundwater supply of lowland rivers does not exceed 10–15% and that correspondingly increases the share of rainwater and water from melting snow. On the contrary, the share of groundwater supply in the rivers of East Lithuania makes 50-60% of annual flow. The greater part of annual precipitation reaches the river basins in rain form (over 77 percent), the 15 percent belong to sleet and the rest 8 percent appear as snow. Differences in water supply also determine the nature of annual flow regime. Short-term floods often occur in summer after heavy rains but in autumn they become higher due to the end of the vegetative season and the end of intensive evaporation period. However this change of the water level in rivers does not reach the extent of spring floods. The Akmena-Danė river basin does not suffer extremely high spring floods. The highest discharge occurs within the cold period from November to April due to snow melting and liquid precipitation.

Spring floods in small rivers of Lithuania last approximately 20–30 days. The total average duration of summer floods is 15–20 days, while the floods in winter are the longest, they usually last 45–50 days (Gailiušis *et al.* 2001).

Argillaceous ground in the Akmena-Danė river basin results in weak ground filtration. Consequently, the amount of ground water in river balance is not very significant. Upper reaches of the river and the most part of tributaries have suffered serious adjustment procedures. Due to that and because of occurrence of bigger amount of water after prolonged rains the river level rises rapidly. After installation of many impoundments the influence of evaporation on the river water balance is increasing.

Within the period of 1949–2004 the biggest monthly amount of water carried by Akmena-Danė river was observed in November 1994. The maximum runoff values until 2004 were calculated on 29 December 1955 (Gailiušis *et al.* 2001).

In early August of 2005 strong southern cyclones caused heavy prolonged rain showers over the territory of Lithuania. As a result, high river levels and big runoffs occurred in some river basins especially in those in the western part of Lithuania. From 10 to 12 August 2005 the total amount of precipitation in Kretinga was about 180 mm doubling the usual monthly amount. According to our data on 11 August 2005 the river level in Kretinga reached 923 centimetres (Baltic Elevation System). This tide mark overcame the highest river level of 845 cm known previously. The other important event of the mentioned flood was breaking of small dam on the Burkštinas, the tributary of Akmena-Danė river which quickly added over 55 000 cubic metres of water to the basin. On 10 July 2007 under the similar hydrometeorological and hydrological conditions the maximum river level was exceeded once more and reached 924 centimetres. Sequence of hydrometeorological factors resulting in surge level appearance in the Akmena-Danė river according to the example of August 2005 is given in Fig. 4.

Results

If no preventive measures are taken, flood can bring serious damages to residential and recreational territories. This subchapter of paper deals with some preventive simple modeling procedures in order to obtain minimum knowledge for decision making concerning the discussed basin of the Akmena-Danė river. Two biggest reservoirs of this river basin store about 4.5 million cubic metres of water. Consequently, the potential risk appears to residential and recreational areas within the river basin in Kretinga and Klaipėda Towns.

HEC-RAS software was used to assess the possible scenarios in case if any of dams was broken. This software has graphic interface with GIS tools. The first task included evaluation of study area relief model using Topogrid method of ArcINFO software.

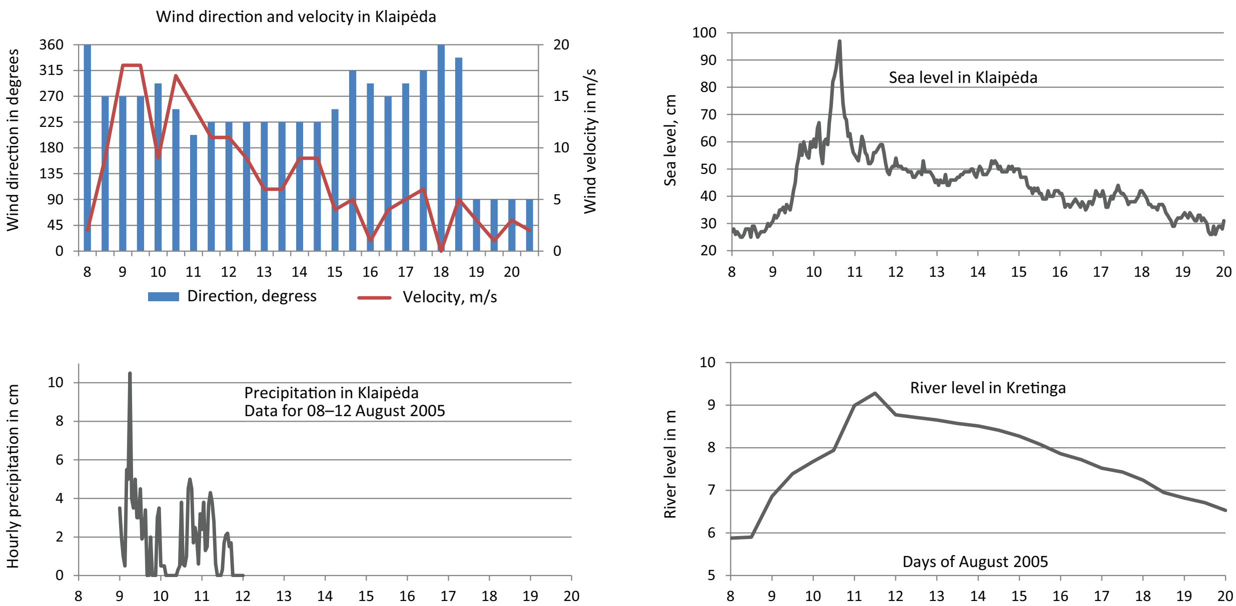


Fig. 4. Sequence of hydrometeorological factors resulting in the surge level appearance in the Akmena-Danė River, given by August days of 2005

According to Froesch formula (Feasibility study... 2006) maximum discharge in case of Padvariai dam breaking down in the Akmena-Danė river basin can reach the values from 250 to 350 cubic metres per second. Then hydraulic modeling using HEC-RAS software was performed, using the initial conditions as pre-described earlier.

The model calibration and validation was performed for two cases. The first one included the presence of known summer mean runoff and river levels at bridges and dams. The second variety was focused on the flood discharge with the additional calibration of roughness coefficients according to the recorded river levels in four points.

The model was calibrated for a steady flow, as well as for the unsteady flow in order to get the river level hydrographs and runoff curves in various cross sections (Fig. 5). The picture gives the area of potential risk in Kretinga Town according to the proposed scenario if the dam of 10.5 metres high is damaged up the river.

The other important application of modeling results is of a suggestive function within the general, special and detailed territory planning procedures. The use of hydraulic model gives the example of modeled flooded territories by the Akmena-Danė river in the City of Klaipėda and its suburbs (10–12 August, 2005) under the combined impact of intensive discharge and marine water surge. Flooded residential and recreational areas within the territory of the Town of Klaipėda are outlined in Fig. 6.

Fig. 5. Overlay of modeled water surface and area topography on the aerial photograph of the Akmena-Danė river basin area in the central part of Kretinga Town (grid 5 m). Potential flood risk zones are not shadowed

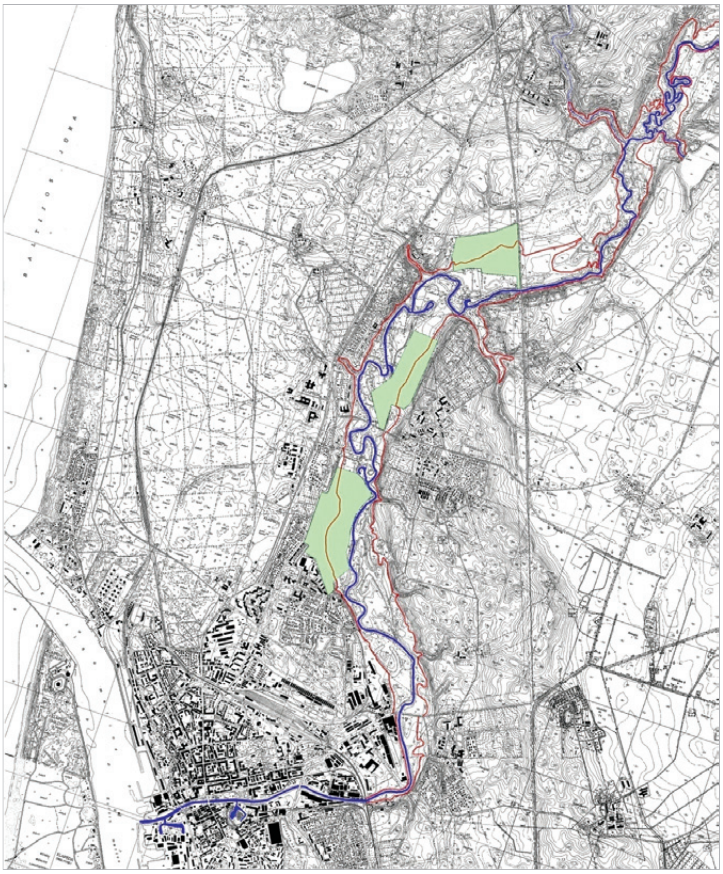


Fig. 6. Modeled flooded territories by the Akmena-Danė river within the City of Klaipėda and its suburbs (10–12 August, 2005) under the combined impact of stormy runoff and marine water surge. Red line shows maximum flood extent but flooded residential and recreational areas are shadowed by green

The obtained results play an important role in decision-making procedures concerning the territories that are under potential risk of flooding (Tome-Schmidt 2003; Snorasson *et al*. 2010). If to analyze the scale-based sketch of green corridor of the Town of Kretinga with the adjacent recreational territories, it is evident that the significant part of spatial frame within green corridor (Fig. 7) is under the risk of flooding and the most part of it will potentially suffer if the Padvariai Dam is damaged (Fig. 5). All these facts force to sustainable thinking and acting when planning and constructing within the analyzed areas.

Conclusions

High spring floods in the Akmena-Danė river basin that were prevailing during earlier decades are observed rarely, but there is a tendency of discharge increasement during winter months.

Extreme runoff can be induced by a large amount of precipitation and these figures could be enlarged by natural and anthopogenic barriers, marine water surges and accidents in the hydrotechnical structures. Extreme or even catastrophic runoff figures appear when all the above mentioned factors work together. A number of water reservoirs that appeared after having constructed dams induced leisure making and attracted tourism industry of the area. Insufficiently reinforced dikes of earth dams (especially the ones of older construction and smaller ones) could be damaged under discussed conditions then resulting in catastrophic consequences.

During the procedures of general, special and detailed territory planning flood appearance should not be missed and relevant preventive measures should be applied, including the calculation and modeling of probability of water levels in residential and extreme discharge storage areas, etc. The most important thing here is harmonization of planning and implementation of priorities in the planned territories. All these procedures should be implemented on national, regional and local level in agreement with the guidelines from the EU Floods Directive (2007/60/EC). Flood extreme river flow modeling must be performed and boundary conditions should be defined under any available cir-

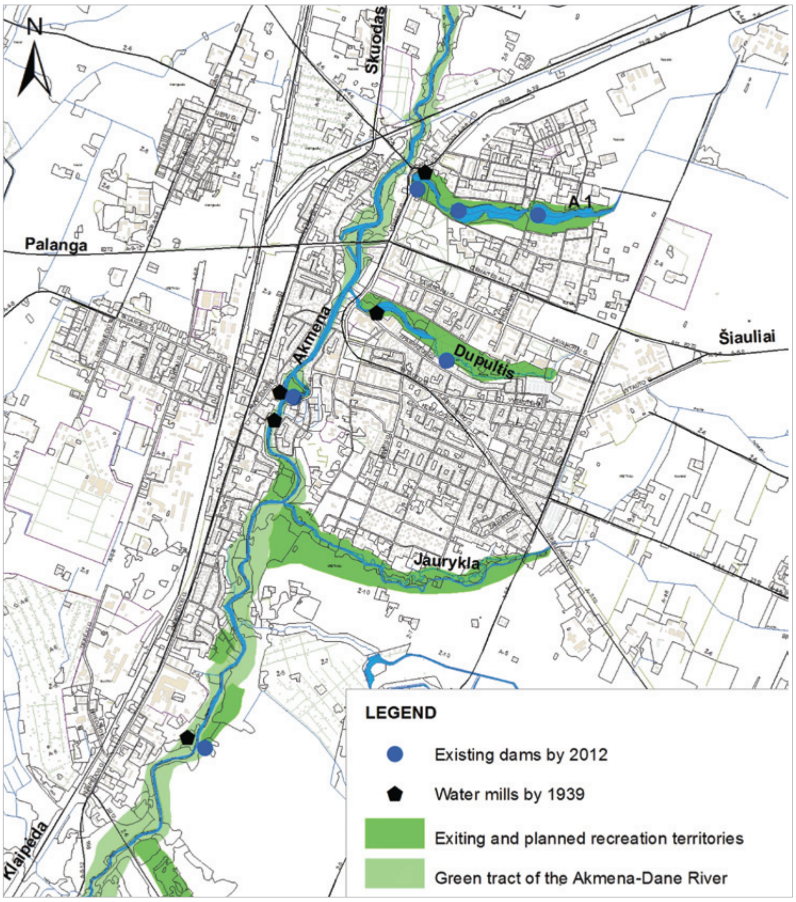


Fig. 7. Green corridor of the Town of Kretinga with the marked hydrotechnical impoundments and adjacent present or planned recreational areas

cumstances causing the appearance of high water level and increasing probability of accidents in hydrotechnical structures. The summer floods in the Akmena-Danė river basin in 2005 and 2007 were very substantial, because of high river levels ever observed. As the maximum values reached the peak the hydrotechnical structures were affected by hazardous loads, depending on the typical situations which were presented during modeling procedures. Flood damage evaluation performed then by insurance institutions stated that residential and recreational areas suffered the greatest loss in the discussed area. Firstly the potential flood risk territories should be pre-studied in respect on the flood probability. Secondly, territory planning and construction procedures within the flood risk area must be performed strictly according to the legal measures or in case of absence of relevant measures good practice ideas should be implemented.

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POTVYNIŲ RIZIKA IR REKREACINIŲ TERITORIJŲ PLANAVIMAS VAKARŲ LIETUVOS AKMENOS–DANĖS UPĖS BASEINE

V. Dubra, J. Abromas

Santrauka. Intensyvios liūtys 2005 ir 2007 m. vasaromis sukėlė potvynius daugelyje Lietuvos upių. Dėl šių reiškinių daugiausia problemų iškilo Akmenos–Danės ir Minijos upių baseinuose, kurie yra labiausiai vakarinėje Lietuvos dalyje netoli Baltijos jūros. Pavasario potvyniai, kuriuos sukelia ilgai krintantys krituliai arba sniego tirpsmas, yra lengviau prognozuojami daugeliu atvejų lyginant su potvyniais, kylančiais kitais metų sezonais. Maksimaliai tikslus kintančių hidrometeorologinių sąlygų prognozavimas subalansuotai planuojamose ir eksploatuojamose teritorijose sukelia žymiai mažiau neigiamų pasekmių. Viena iš didesnių rizikų valdant upių baseinus yra netikėtų potvynių metu iškylanti hidrotechninių įrenginių ir statinių pažeidimų, o ypač avarijų hidromazguose grėsmė. Vakarinėje Lietuvos dalyje ši grėsmė yra dar didesnė, nes pavojus kyla ne tik iš pačių čia esančių upinių baseinų, bet ir iš Baltijos jūros, kurios patvankų į upių žiotis metu susidaro itin aukšti vandens lygiai, keliantys padidėjusią grėsmę teritorijoms, kurioms įtaką daro vandens lygio svyravimo zona.

Šiame darbe pateikti tyrimų rezultatai, apžvelgiantys buvusias praeities, dabarties bei galimas būsimas avarijų upių užtvankose pasekmes. Apžvalga yra pateikta kartu su modeliavimo duomenimis, kurių tikslas įvardinti svarbiausius veiksnius ir procesus, darančius įtaką aukštų vandens lygių atsiradimui upėse, kuriuos gali dar papildomai padidinti vandens patvankos iš jūros arba marių. Itin didelis dėmesys darbe skirtas teritorijų planavimo užliejamose zonose problematikai, iškiriant pirmiausia tuos teritorinius vienetus, kurių subalansuotas planavimas pirmiausia nulemia žmogų supančios aplinkos kokybę, t. y. gyvenamąsias ir rekreacines teritorijas.

Reikšminiai žodžiai: pajūrio upinis baseinas, jūrinė patvanka, užtvanka, potvynis, teritorijų planavimas, gyvenamoji teritorija, rekreacinė teritorija.

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