# Chapter 8
# Assessment of Flood Risk Areas in the Dniester River Basin (in the Limits of the Republic of Moldova)

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**Abstract** The most catastrophic floods on the territory of the Republic of Moldova are formed on its largest river: the Dniester River. Main measures implemented for flood protection are reservoirs and levees which were built in the middle of the last century. This paper contains first tentative of reevaluation of protection capacity of these measures basing on analysis of new database and modern methods and techniques. Flood hydrographs of different probabilities were calculated basing on new Standards of the Republic of Moldova. HEC-RAS model (USA) was implemented to simulate flood wave of different probabilities from Dubasari Reservoir to Slobazia Village and to evaluate flooded areas, water velocities and depths.

## 8.1 Introduction

Hydrometeorological disasters represent an integral part of the environment. They occur throughout the world and cause damaging consequences for economic activity. Globally, during the period 1980–2013, a half of total hydrometeorological disasters is formed by floods [1]. In the Republic of Moldova hydrometeorological disasters occur more intense and represent more than 90 % of all disasters. For the same period floods count 54 % of the total number of hydrometeorological disasters [1]. The greatest damage is caused by floods manifested on large rivers Dniester and Prut followed by small and medium-sized rivers. Particularly intense flooding occurred in July–August 2008 on the Dniester River which caused damage of 82.5 million lei and in 2010 on the Prut River which cost 84.2 million lei [2].

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In the Republic of Moldova the research in the field of flood risk is centered on collecting information about damages caused by floods and on development of local protection measures. Activities connected with flood researches are only starting. The first detailed research dedicated to development of "Scheme of flood protection of the Republic of Moldova settlements" was performed by the Institute ACVA-Proiect during 1996–1998 years [3]. However, the considerable number of calculations, included in 40 volumes, primarily refers only to assessment of potential flooded areas in case of 1 % probability, basing on old National Standards [4, 5]. In 2002, in Moldova, Associated European Centre for Flood Problems "CIAPI-Moldova" was created at the initiative of Council of Europe This organization existed only 2 years. During this time, the study with the theme "Problems of floods research in the Republic of Moldova" was performed [6]. This study presents the research results in the field of floods, flood generation factors and a summary of international experience on research and development of effective flood protection measures.

Application of modern hydrological and hydraulical software and GIS for flood wave modeling began in 2009 with the project "Elaboration of kinematical flood wave model and assessment of risk areas in case of floods on rivers of the Republic of Moldova" and continued with the second project "Development of geoinformational support for flood risk assessment in Prut River basin" [7, 8]. Main research activities of both projects were performed by Institute of Ecology and Geography of the Academy of Sciences of Moldova. The main purpose of the projects consisted of application of hydrodynamic software HEC-RAS (USA) [9, 10] for simulation of flood wave in case of dam break of Costesti-Stinca Reservoir situated on Prut River and of Dubasari Reservoir situated on the Dniester River.

In this context, we believe that the first tentative of using hydraulical modeling for flood risk assessment on the Dniester River in the limits of Moldova represents a great practical relevance and constitutes a big perspective for the future research.

## 8.2 Study Area

The Dniester River Basin is a transboundary river and spreads on the territory of three countries Poland, Ukraine and Republic of Moldova. Over 70 % of the basin is situated in limits of Ukraine and only 27 % belong to Republic of Moldova. The total area of the basin is approximately 72100 km$^2$ and the length is 1352 km. The basin is conventionally divided in three parts: the Upper Part represents the region from the Dniester spring to confluence with Zolota Lypa River (upstream Zalishchyky Village), the Middle Part is assigned to the region from Zolota Lypa River to Dubasari Town (generally characterized by a highland landscape) and Lower Part characterized by plain landscape (Fig. 8.1) [11]. The Upper part lays in Carpathians and represents only 30 % of the basin area but due to high amount of precipitations, 70 % of the Dniester runoff is generated in this area [11]. Average

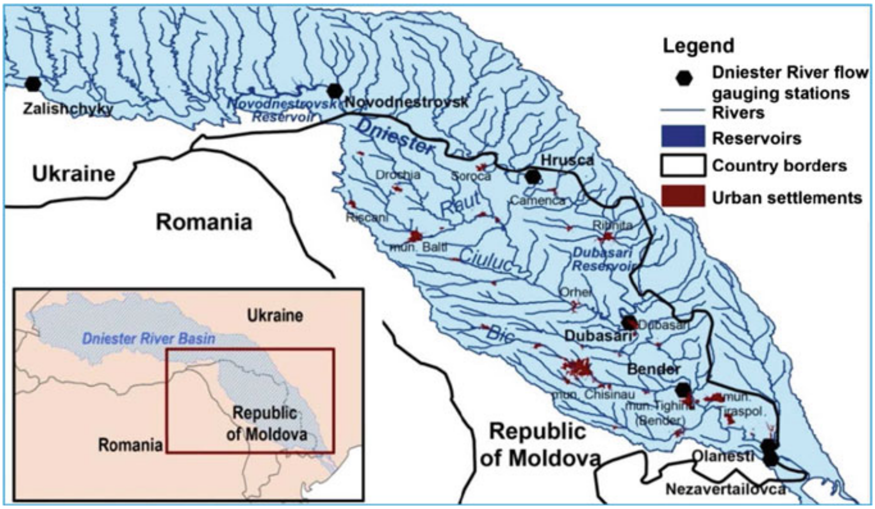


Fig. 8.1 Middle and lower part of the Dniester River Basin

amount of precipitations over basin area decreases constantly from 1300–1000 mm in the Upper part to 400–500 in the Lower Part [12, 13].

The Dniester River Basin forms 57 % (over 19000 km$^2$) of the territory of the Republic of Moldova and the length is 660 km. In the limits of Moldova, the Middle part of the basin is characterized by high land with the altitudes from 150 up to 400 m, the floodplain enlarges up to 3 km. The Lower Part of the basin differs from the other with a plain landscape lower 150 m. The floodplain extends from 4 to 6 km (on the region Dubasari- mun. Bender), up to 6–12 km till Turunchiuc branch, and up to 22 km near river mouth [13].

The Dniester River represents the main fresh water source of the country. In the limits of Moldova, the Dniester average discharge is 312 m$^3$/s, increasing up to 450–500 m$^3$/s in April and decreasing below 200 m$^3$/s during winter months. Total Dniester average volume is approximately 9.8 km$^3$. In years with humidity deficit Dniester water resources are estimated at 6 km$^3$, in years with high humidity the volume increases over 12 km$^3$, being 2 times higher than in dry periods. Being a transboundary river the Dniester water resources are equally divided by Ukraine and Republic of Moldova [2]. These water resources are considered as country propriety.

## 8.3 Methodology and Data Base

Basically, in the Republic of Moldova, HEC-RAS is the first and, for now, the main hydraulic model utilized for flood wave modeling in case of reservoirs dam break on big transboundary rivers [14, 15]. In this study HEC-RAS is also used to

**Table 8.1** Characteristics of flow gauging stations of the Dniester River (in limits of Moldova territory)

| River | Flow gauging station | Basin surface till gauging station, km$^2$ | Mean maximal discharge, m$^3$/s | Distance to river mouth, km | Measurement period |
|---|---|---|---|---|---|
| Dniester | Hrusca | 48700 | 1516 | 509 | 1968-present |
| Dniester | Dubasari | 53600 | 1295 | 351 | 1956-present |
| Dniester | Bender | 66100 | 1269 | 214 | 1881-1915; 1945-present |
| Dniester | Olanesti and | 68900 | 1099 | 77 | 1959-present |
| | Nezavertailovca | | | 69 | 1971-present |

appreciate the potential flooded areas, water depth and water velocity. The main component used for this purpose is unsteady flow routing. Maximal discharges and flood hydrographs of different probabilities necessary as input data for unsteady flow routing were modeled basing on recommendations from National Standard of the Republic of Moldova [16].

Spatial data preprocessing and postprocessing was made using GIS and HEC-GeoRAS extension. Triangular irregular network (TIN) was generated in GIS basing on contour lines and elevation points extracted from topographic maps of scale 1:25000 [17]. The same maps were used for creation of levees, river banks, river centerline, obstructions and ineffective areas layers.

Main source of hydrological time series is the archives of State Hydrometeorological Service of the Republic of Moldova—organization responsible for stage and flow measurements. In limits of the Republic of Moldova territory the flow measurements are made at 5 from 11 gauging stations situated on the Dniester River: Hrusca, Dubasari, Bender, Olanesti and Nezavertailovca (Fig. 8.1). According to water cadastre [18], the time series of maximal discharges are available from 1881 to present (Table 8.1).

## 8.4 Results and Discussions

### *8.4.1 Flood Events and their Generating Factors*

The general idea of the size and frequency of the Dniester floods can give instrumental observations, as well as historical and archival records which contain valuable information about the spontaneous nature of this phenomenon. The Dniester floods chronology covers a period of seven centuries (1146–1840 years) [19, 20]. First mention of the most powerful floods of the Dniester River is given in Hypatian chronicle in 1146. The Dniester floods, which took place in 1230, 1572, 1649, 1668, 1700, 1730, 1757, 1814, 1823, 1864 are described in details in

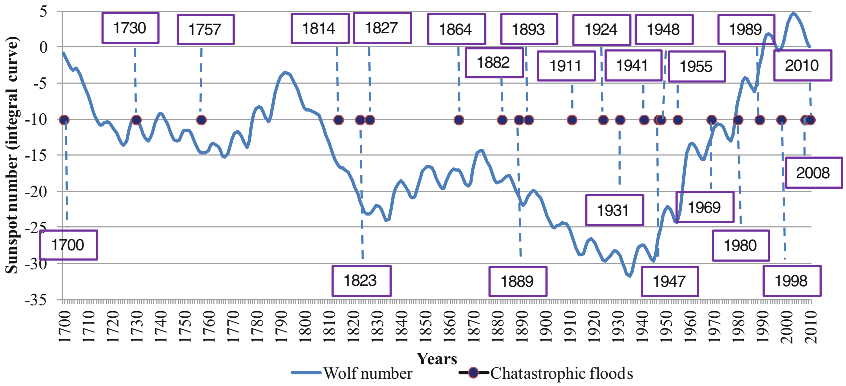


**Fig. 8.2** Solar activity and the Dniester floods over the XVIII–XXI century

archival documents [21]. During instrumental observations the most powerful floods of the last century were reported in 1911, 1941, 1955, 1969, 1980, 1989, 2008 and 2010 [22]. The total damage from flooding in Moldova for the period from 1947 to 2000 amounts to 285.4 million lei [23].

The main climatic factor which generates the Dniester flood events is extreme meteorological conditions in Carpathian region, manifested especially in summer period. In this region rainfall intensity exceeds 250 mm/day and its spatial distribution spreads on a scale from 100 up to 3000 km$^2$ [24] .The effect of heavy rains is amplified by Carpathian steep slopes and as a consequence fast slope runoff, high debris flow and water levels are formed. The most dramatic flood of the last 20 years was observed in 2008. This flood was generated by stationary cyclonic activity over Western part of Ukraine, in Carpathians. At three gauging stations, located in the center of this cyclone, the total sum of rain exceeded 300 mm [25]. This resulted in the flooding of the territories and settlements along the river in both countries: Ukraine and Moldova. Generated discharges of the Dniester River exceeded 3400 m$^3$/s (at Hrusca gauging station) which is 10 times bigger than the average.

Atmospheric activity is driven mainly by the Sun. Analysis of Sun activity fluctuations [26] and flood time series can give an idea about a relationship between these phenomena (Fig. 8.2). Through, from XVII to XIX century, the flood appearance is equal to 1 in every 16 years. In period of decreasing solar activity (till 1935), one flood occurred every 12 years. In the period of increasing of solar activity: 1935–2010 the appearance of floods raised and 1 flood was observed in every 10 years already [21].

The comparison of these graphs shows that on the background of secular variations of solar activity there are complex flood events. Years, in which the disastrous floods are observed, in most cases, coincide with 11-year cycle of solar

**Table 8.2** The main parameters of the biggest reservoirs located on the Dniester River [13, 27, 37]

| Parameters | Novodnestrovsk | Dubasari (1956) |
|---|---|---|
| Country | Ukraine | Moldova |
| Distance to river mouth | 677.7 | 351 |
| Surface of the basin, km$^2$ | 40500 | 53600 |
| Lengths, km | 194 | 128 |
| Year of construction | 1982 | 1956 |
| Levels | | |
| Maximum water level (MWL), m | 125 | 30.0 |
| Full reservoir level (FRL), m | 121 | 28.0 |
| Minimum pool level (MPL), m | 102.5 | 24.2 |
| Volume, mln m$^3$/Surface, km$^2$ | | |
| at MWL | 3600/160 | 633/80.0 |
| at FRL | 3000/142 | 485/67.5 |
| at MPL | 1000/75 | 272/46.8 |
| Maximal discharge, m$^3$/s | 8320 | 8200 |

activity. This fact should be taken into account when assessing the floods probability.

### 8.4.2 *Flood Protection Measures: Reservoirs and Levees*

Management of river floods becomes easier in comparison with other disasters because this disaster is manifested on river specific neighboring territories. In the Republic of Moldova flood protection measures are: reservoir operation, levees, channels, ponds, polders and others. The main measures taken to avoid the Dniester floods are dammed reservoirs and levees along the river. Two reservoirs are constructed on the Dniester River Bed: first is Novodnesrtovsk which is managed by Ukraine and second is Dubasari situated within the Republic of Moldova territory (Table 8.2). Both reservoirs are situated in the Middle Part of the basin and are constructed for multipurpose: water supply, irrigation, hydroelectric power generation, flow balancing, flood mitigation, fishery, recreation, navigation [13, 27].

Assessment of flood protection capacity of both reservoirs can be made basing on analysis of flood peaks changes along river bed for three time periods: 1st period 1981–1955 corresponds to natural flow, 2nd period 1956–1982 comprises the period of only Dubasari Reservoir operation, 3rd period from 1987 till present—covers the period of both reservoirs operation. For this purpose the most powerful floods were analyzed at the gauging station Zalishchyky situated upper Novodnestrovsk Reservoir and representing the unchanged flow by reservoirs and the gauging station Bender located in the Lower part of the basin, downstream Dubasari Reservoir (Table 8.3).

**Table 8.3** Flood peak modifications for three periods of the Dniester flow measurements [38]

| First period: 1887–1955 | | | | Second period: 1956–1982 | | | | Third period: 1987–2010 | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Year | Zalishchyky | Bender | K | Year | Zalishchyky | Bender | K | Year | Zalishchyky | Bender | K |
| 1900 | 3730 | 1270 | 0.34 | 1969 | 5970 | 3000 | 0.50 | 1989 | 2700 | 1510 | 0.56 |
| 1906 | 3070 | 1260 | 0.41 | 1970 | 2950 | 1730 | 0.59 | 1998 | 4080 | 1800 | 0.44 |
| 1913 | 4120 | 1400 | 0.34 | 1974 | 3300 | 1960 | 0.59 | 2008 | 5600 | 2610 | 0.46 |
| 1948 | 3420 | 1730 | 0.51 | 1980 | 3910 | 2490 | 0.64 | 2010 | 2765 | 1700 | 0.62 |
| Average | | | 0.40 | | | | 0.58 | | | | 0.52 |

Before reservoirs operation, spatial reduction of flood peaks was determined by growing area of the Dniester River Basin from 24600 $km^2$ (at Zalishchyky gauging station) to 72100 $km^2$ (at river mouth), and by enlarging of floodplain width. Coefficient of flood peak transformation (K) for this period is relatively constant, averaging 0.40. (Table 8.3). Reduction of flood peaks in Lower part of the Dniester River Basin increased in period of Dubasari reservoir operation. Regulation capacity of the reservoir was only 30 % of its full capacity (148 mln $m^3$), therefore, in the case of a rare probability flood with a maximum discharge greater than 3000 $m^3$/s, and a flood volume over 2000–3000 mln $m^3$, the flood peak reduction by reservoir was only on 10–15 % which means that flood wave passes through reservoir in transit. Operation period of both reservoirs changes the Dniester water flow regime during the phase of high flow. If prior to reservoirs peak flow transformation processes were associated with the distribution and accumulation of flow volumes in the natural river bed and floodplain, after the construction of reservoirs transformation of flood waves is carried out by their flood regulation capacity. This fact induced a better flood management in the region which is shown also by increasing K to 0.52–0.58. However, Dubasari Reservoir loses its capacity of flood protection because of significant decreasing of its parameters. Due to high silting processes useful storage volume was twice reduced, dead storage practically disappeared, decreasing from 272 to 80 mln $m^3$. [13]. Flood regulation capacity was also reduced because of decreasing of volume at MWL from 632.8 to 370 mln $m^3$. [13]. Thus, at present Dubasari Reservoir is not able to reduce the projected flood discharges without causing accident conditions and is operating in high-risk regime. For last 60 years of operation period no desilting activities were taken.

Besides reservoir, another method designed to protect agricultural areas and settlements against floods consists of a levees system built along river banks. Levees construction along the Dniester River began in the 50's of the last century. The total length of protection levees in the end of construction process was equal to 220 km along the Dniester River. [28] According to project calculation existing protection levees on the Dniester River in the limits of the Republic of Moldova are designed for ensuring a free-accident flow of 2600 $m^3$/s. However, flood events from 2008 and 2010 showed that the protection capacity of levees dramatically decreased. During 2008 flood the water level exceeded 6 m and over flooded constructed levees, also some part of levees were practically destroyed by high waters. In total, renovation together with elevation increasing activities must be taken for a length of 80 km of levees [28].

### *8.4.3 Flood Wave Modeling*

Even if the last century was characterized by high flood protection activities like reservoir and levees building, at present these measures cannot show a high protection capacity. However, an illustrative approach about parameters of present or projected flood protection structures can be made by hydraulic model HEC-RAS. Evaluation of potential flooded regions was made on the sector situated downstream Dubasari Reservoir till Slobozia Village, the total length of the area is 185 km, landscape is characterized by a floodplain which enlarges from 3 km near Dubasari up to 8 km from Bender to Slobozia.

First phase of model development consisted of creation of geometry the Dniester floodplain [29, 30]. Automatic extraction of cross sections from TIN using HEC-GeoRAS gave a satisfactory result for river banks but not for river bed. Correction of cross section, especially of rived bed was made using cross sections database basing on field survey made in the 70–80' of last century [31]. Every cross section was manually corrected and adapted to reality in HEC-RAS environment, also appropriate Manning's value and contraction and expansion coefficients were chosen independently for the Dniester banks and bed [9].

After a detailed analysis and correction of river geometry model evaluation was made basing on simulation of real flood events from 1969, 1980, 2008, 2010 [32–35]. The pilot sector for model evaluation was considered region Dubasari Reservoir—mun. Bender. Observed runoff database is present at both points. Observed and modeled hydrographs are shown in Fig. 8.3. Simulation results of four flood events are shown in Table 8.4.

Assessment of modeled runoff quality was made by using four efficiency criteria: coefficient of determination ($R^2$), Nash–Sutcliffe efficiency (E), logarithmic Nash–Sutcliffe efficiency (ln E) and percent BIAS (PBIAS) [36]. High $R^2$, E and ln E (Table 8.5) meet general quality requirements [36] but PBIAS is still low simulated, probably because of TIN and cross-sections precision.

Even if simulations (PBIAS) are at the limit of satisfactory results, the model was applied for assessment of potential flooded areas, water depth and velocity in case of flood wave of different probability. Hydrographs of different probabilities were constructed on example of a real hydrograph from a recent period (2008 flood) which represents the actual situation of the Dniester runoff and protection measures capacities.

The first flow gauging station which meets the Dniester River on the territory of the Republic of Moldova is situated at Hrusca Village, upper the Northern part of Dubasari Reservoir. Hydrological information on pluvial floods characteristics (flood peaks, maximal stages, total volumes) at Hrusca gauging station comprises 2 periods of time: before (1968–1982 years) and after Novodnestrovks reservoir construction. Due to this fact the homogeneity of Hrusca time series was analyzed. The results of this analysis show that statistical parameters calculated for flood peaks as well as for flood volumes estimated separately for both periods are close to each other. Basing on statistical parameters and theoretical ordinate of gamma-distribution, flood peaks and volumes of 0.1, 0.5, 1 and 5 % probabilities were estimated for the Dniester time series of Hrusca gauging station (Table 8.6). Hydrographs of different probability were modeled on example of real hydrograph of 2008 flood basing on recommendations outlined in National Standard of the Republic of Moldova [16].

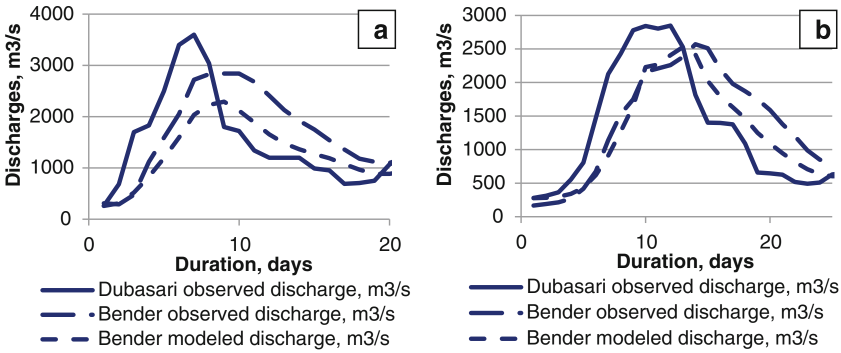


**Fig. 8.3** Observed and modeled flood hydrographs of 1969 (**a**) and 2008 (**b**) floods

**Table 8.4** Simulation results of the Dniester four flood events

| Event | Hrusca observed flood peak, $m^3/s$ | Dubasari observed flood peak, $m^3/s$ | Bender observed flood peak, $m^3/s$ | Bender modeled flood peak, $m^3/s$ | Bender observed maximal stage, m | Bender modeled maximal stage, m |
|---|---|---|---|---|---|---|
| 08.06.-02.07.1969 | 4430 | 3600 | 2840 | 2293 | 12.07 | 10.66 |
| 25.07-16.08.1980 | 3420 | 2630 | 2480 | 2284 | 12.33 | 11.11 |
| 21.07.-16.08.2008 | 3450 | 2847 | 2570 | 2528 | 12.75 | 11.19 |
| 18.05.-30.07.2010 | 1700 | 1600 | 1690 | 1423 | 10.85 | 10.50 |

**Table 8.5** Performance statistics for the Dniester four flood events simulation

| Event | $R^2$ | E | Performance rating of E | ln E | PBIAS, % | Performance rating of PBIAS |
|---|---|---|---|---|---|---|
| 08.06.-02.07.1969 | 0.99 | 0.70 | Good | 0.82 | 21.07 | Satisfactory |
| 25.07-16.08.1980 | 0.98 | 0.91 | Very good | 0.88 | 11.95 | Good |
| 21.07.-16.08.2008 | 0.96 | 0.88 | Very good | 0.90 | 13.43 | Good |
| 18.05.-30.07.2010 | 0.96 | 0.62 | Satisfactory | 0.70 | 19.41 | Satisfactory |

Hrusca hydrographs are considered as inflow hydrographs to Dubasari Reservoir. The reservoir outflow hydrographs were calculated basing on reservoir water balance approach, flood storage volume being considered as projected in 1956 equal to 148 mln $m^3$.

Basing on reservoir outflow hydrographs which are considered as input values, HEC-RAS modeled the hydrographs at Slobozia Village (Fig. 8.4). In the end potential flooded areas in case of flood wave of different probabilities as well as water velocity and water depth of the region Dubasari Reservoir—Slobozia Village were calculated and extracted to GIS environment (Figs. 8.5, 8.6, 8.7).

**Table 8.6** Simulation results of the Dniester flood wave modeling of different probability

| Exceedance probability, % | Hrusca modeled flood peak, $m^3/s$ | Dubasari modeled flood peak, $m^3/s$ | Slobozia modeled flood peak, $m^3/s$ | Region Dubasari Reservoir – Slobozia Village | | | | |
|---|---|---|---|---|---|---|---|---|
| | | | | Total flooded area, $km^2$ | Flooded settlements area, $km^2$ | Maximal water velocity, m/s | Maximal water depth, m | Period between flood peaks, hours |
| 0.1 | 7382 | 7108 | 6254 | 329 | 28.6 | 3.1 | 10.35 | 91 |
| 0.5 | 5712 | 5456 | 4653 | 315 | 23.0 | 3.5 | 9.43 | 105 |
| 1 | 5009 | 4760 | 4006 | 308 | 21.2 | 3.3 | 9.10 | 123 |
| 5 | 3442 | 3212 | 2849 | 200 | 13.4 | 2.6 | 8.23 | 129 |

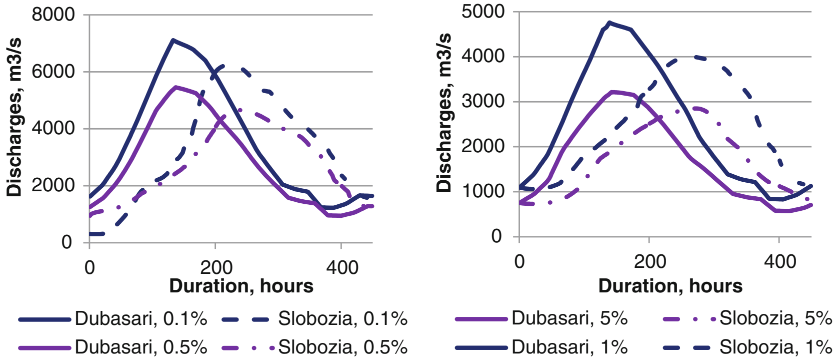


**Fig. 8.4** Modeled hydrographs of different probablilities

The most vulnerable areas to floods are settlements as well as agriculture areas. Period between flood peaks from Dubasari Reservoir and Slobozia Village (Table 8.6) allows predicting the possible flood wave in the downstream part of the region and gives time to estimate the necessary flood protection measures. Adequate decisions on flood protection measures can prevent settlements from flooding and infrastructure damages, as well as decrease the number of affected people or victims.

Performed HEC-RAS model is capable to give an answer on protection capacity of levees as well as to show the impact of chances of levees positions and characteristics. Present levees system is capable to protect the area from flooding with a maximal discharge of 2600 $m^3/s$ but modeled discharges exceed this value. Basing on these data a recalculation of levees characteristics can be made and modeled in HEC-RAS to understand the efficiency of their new measures.

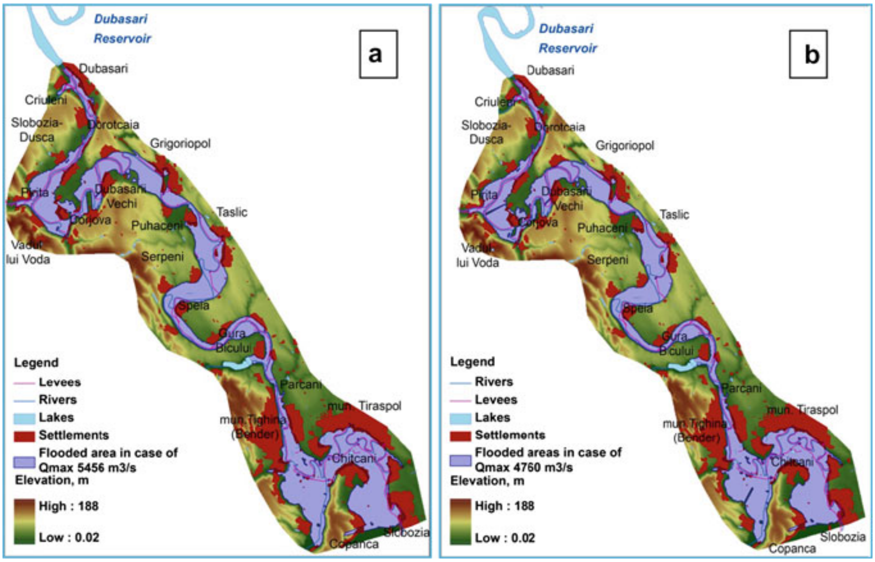


**Fig. 8.5** Modeled flooded areas in case of floods of 0.5 % (**a**), 1 % (**b**) probability

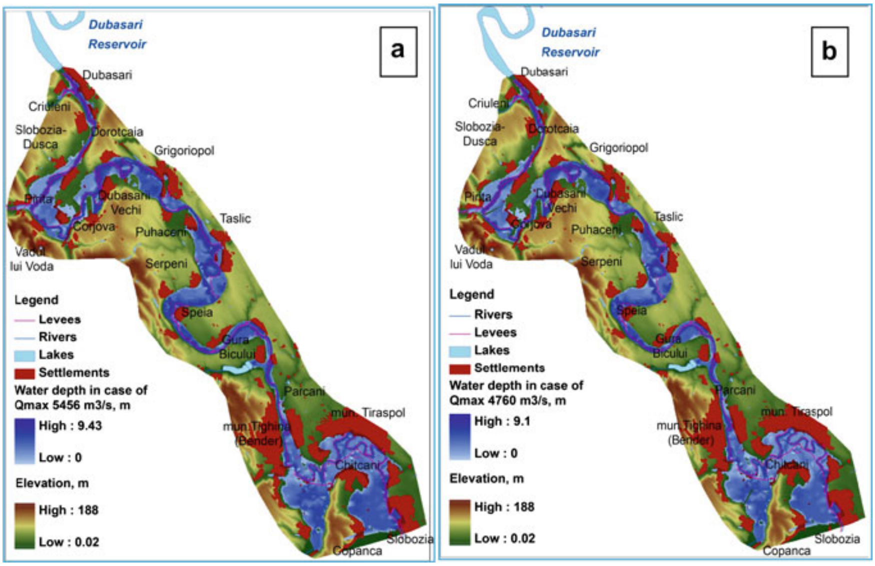


**Fig. 8.6** Modeled water depth in case of floods of 0.5 % (**a**), 1 % (**b**) probability

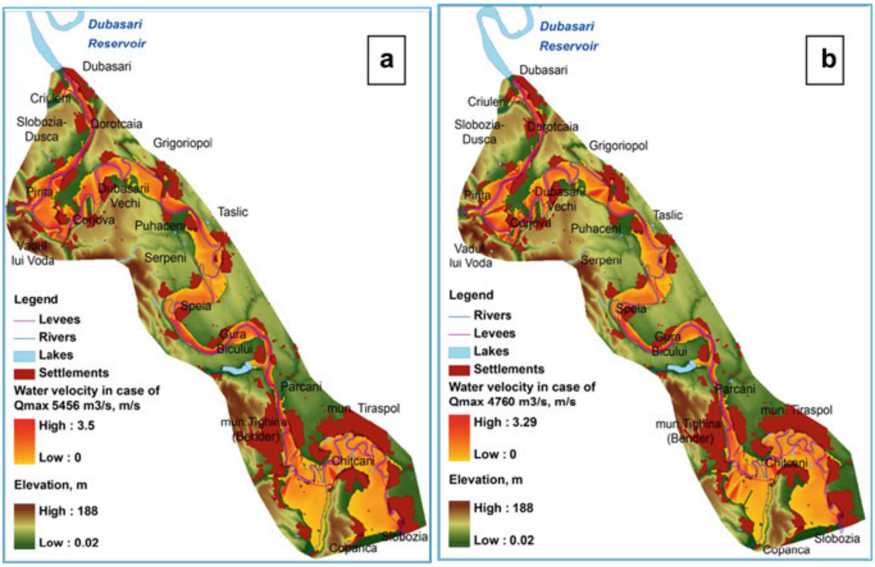


**Fig. 8.7** Modeled water velocity in case of floods of 0.5 % (**a**), 1 % (**b**) probability

## 8.5 Conclusion and Recommendations

Instrumental observations of flood wave on the Dniester River began in 1881(Bender gauging station). The long range of observation dataset allows performing a detailed description and assessment of flood risk of the Dniester River during the time. Analysis of observed flood peaks and flood volumes showed that depending on flow regulation measures the coefficient of flood peaks changes along the river differs. A higher flood management capacity was achieved after construction of Novodnestrovsk and Dubasari reservoirs as well as levees system. However, due to reductions of protection structures characteristics during last 60 years, the flood risk increases.

The assessment of flood peaks and flood hydrographs of different probabilities for the Dniester River was performed basing on methods from new National Standards (at Hrusca) and also with consideration of low flood regulation capacity of Dubasari Reservoir (at Dubasari). Comparison of modeled and real hydrographs shows that the observed floods from 1969, 1980, 2008 are close to 3–8 % probabilities. Modeled hydrographs have a typical triangular shape and represent the input data for flood wave modeling in HEC-RAS environment.

The results of flood wave modelling in HEC-RAS can be considered reliable corresponding to input data set used in the study. Due to the inaccuracy of available elevation data used from topographic maps created in the 1980s of the last century, and their insufficient scale, modelled results cannot be considered sufficiently accurate. In other words, the elevation values, distances, data on riverbed and levees on these maps may not correspond exactly to reality. Model improvements can be done only in case of using modern elevation data or at least topographic maps with a scale of 1:10000 in combinations with actual data on the Dniester riverbed. It is imperative to make field survey and to obtain detailed information of river banks and adjacent territories and adequate and qualitative cross sections. All hydraulic structures located along the river and in the Dniester basin, such as pumping stations, reservoirs, irrigation channels and others and also the Dniester tributaries must be included in the model for more modern water management.

Also, a good water management of the Dniester River basin requires coordination and full cooperation between water management authorities of two bordering countries Ukraine and Moldova. For a better understanding of the processes which take place inside of the river basin and simulate the possible future environmental changes the Dniester River basin should be analyzed as a whole system which means that only basing on a common effort of Moldova and Ukraine the efficient measures a sustainable water use, flood mitigation and complex water management can be achieved.

A complex water management must also include hydraulic as well as hydrological modelling. A platform for this purpose can represent common implementation of HEC-HMS and HEC-RAS models.

## References

1. EM-DAT (2014) The OFDA/CRED international disaster database, Université Catholique de Louvain—Brussels—Belgium. www.emdat.be. Accessed 21 Jan 2014
2. Starea mediului in Republica Moldova in 2007–2010 (Raport national) [State of environment in the Republic of Moldova in 2007–2010 (National report)]. 2011. Chisinau, Moldova, p 192 [In Romanian]
3. Schema de protectie impotriva inundatiilor a localitatilor din Republica Moldova [Scheme of protection against floods of settlements of the Republic of Moldova]. 1998. Institute "ACVAproiect". V. 3, Chisinau, p 79 p [In Romanian]
4. Opredelenie osnovnich raschetnich gidrologhicheskih haracteristic CP 2.01.14-83 [Appreciation of main calculation hydrological characteristics. CP 2.01.14-83]. 1983. Moscow, p 122 [In Russian]
5. Posobie po opredeleniu raschetnih gidrologicheskih harakteristik [Recommendations for appreciation of calculation hydrological characteristics]. 1984. Leningrad, p 448 [In Russian]
6. Melnichiuc O, Lalykin N, Bejenaru G (2002) Probleme de studiu a inundatiilor in Republica Moldova. Dare de seama stiinfica [Problems of floods research in the Republic of Moldova. Scientific report]. Institute of Ecology and Geography of Academy of Sciences of Moldova. Responsible coordinator: Menichiuc O. CIAPI-Moldova, Chisinau, p 115 [In Romanian]
7. Elaborarea modelului undei cinematice a viiturilor si evaluarea zonelor de risc in caz de inundatii pe riurile din Republica Moldova. Dare de seama stiintifica [Elaboration of kinematical flood wave model and assessment of risk areas in case of floods on rivers of the Republic of Moldova. Scientific report]. 2009. Institute of Ecology and Geography of Academy of Sciences of Moldova. Responsible coordinator: Melnichiuc O., p 95 [In Romanian]

8. Elaborarea suportului geoinformational pentru gestionarea situatiilor de risc hidrologic in bazinul riului Prut [Development of geoinformational support for flood risk assessment in Prut River basin. Scientific report]. 2012. Institute of Ecology and Geography of Academy of Sciences of Moldova. Responsible coordinator: Boboc N., p 46 [In Romanian]
9. HEC-RAS River analysis system. Hydraulic reference manual (2008) U.S Army Corps of Engineers. Hydrologic Engineering Center, Davis, USA, p 410
10. HEC-RAS river analysis system. User‘s manual (2010) US Army Corps of Engineers. Hydrologic Engineering Center, Davis, USA. p 790
11. Lebedynets1 M, Sprynskyy M, Kowalkowski1 T, Buszewski1 B (2005) Evaluation of hydrosphere state of the Dniester River Catchment. Pol J Environ Stud 14(1):65–71
12. Dubis L, Kovalchuk I, Mykhnovych A (2006) Extreme geomorphic processes in the eastern Carpathians: spectrum, causes, development, activization and intensity, Studia Geomorphologica Carpatho-Balcanica. Landform Evolution in Mountain Areas. Recent geomorphological hazards in Carpatho-Balcan-Dinaric region, pp 93–106
13. Resursele acvatice ale Republicii Moldova. Apele de suprafata [Water resources of the Republic of Moldova. Surface waters] 2007, compiled by Cazac V., Mihailescu C., Bejenaru G., Gylca G., Chisinau, Moldova, p 248 [In Romanian]
14. Boboc N, Melnichiuc O, Bejan Iu, Jeleapov A, Muntean V, Amghelutsa V (2012) Utilization of the HEC-RAS for flood wave modeling on example of the Prut River. Geographic information systems. Vulnerability and risk assessment using G.I.S. Cluj-Napoca, Romania, pp 71–76
15. Bostan V, Tambur M, Burleai E (2009) Simularea numerica a inundatiilor pe riul Nistru [Numerical simulation on the Dniester River floods]. Academos, nr. 3(14), Chisinau, Moldova, pp 88–94 [In Romanian]
16. Determinarea caracteristicilor hidrologice pentru conditiile Republicii Moldova. CP D.01.05-2012. Cod practic in constructii. Constructii hidrotehnice si pentru imbunatatiri funciare [Definition of hydrological characteristics for conditions of the Republic of Moldova. CP D.01.05-2012. Code of practice in constructions. Hydraulic and land reclamation structures]. 2012. Chisinau, Moldova, p 190 [In Romanian]
17. Topographicheskie karti, mashtab 1:25000 [Topographic maps. Scale 1:25000]. 1957–1961, 19711978. Glavnoe upravlenie geodezii i kartografii pri Sovete Ministrov SSSR, Moscow
18. Cadastru de Stat al Apelor al Republicii Moldova. Date multianuale despre resursele si regimul apelor de suprafata [State Cadastre of Waters of the Republic of Moldova. Multiannual data on surface water resources and regime]. 2006. Chisinau, Moldova, p 550 [In Romanian]
19. Mihailescu C (2004) Clima si hazardurile Moldovei—evolutia, starea, predictia [Climate and hazards of Moldova—evolution, state, prediction]. Chisinau, Moldova, p 192 [In Romanian]
20. Svet G (1972) Vidaiushiesea gidrologicheskie iavlenia na iugo-zapade SSSR [Exceptional hydrological events in the South-West of USSR]. Leningrad, p 210 [In Russian]
21. Melnichiuc O (2012) Pavodki i navodnenia na rekach Moldovy [Floods and inundations on rivers of Moldova]. Chisinau, Moldova, p 233 [In Russian]
22. Melnichiuc O, Arnaut N, Shvets V, Chishchiuc A (2009) Analiz prichin in haracteristic catastroficheskih navodnenii v baseinah rek Dnestr i Prut [Analysis of causes and characteristics of floods in the Dniester and the Prut River basins]. Buletinul Institutului de Geologie si Seismologie al Academiei de Stiinte a Moldovei, nr. 2, Chisinau, Moldova, pp 90–98 [In Russian]
23. Palamarchiuk G, Bujac V (1999) Schema zashity naselennih punktov Respubliki Moldova ot zatoplenia kak vajneishii component uluchshenia protivopavodkovoi situatsii i ecologicheskogo sostoiania reki Dnestr [Scheme of protection of settlements of the Republic of Moldova from flooding as an important component of improvement of situation against floods and ecological state of the Dniester River]. Conservarea biodiversitatii bazinului Nistrului: materialele conferintei international, Chisinau, Moldova, pp 185–186 [In Russian]

24. Gueiko L (1997) The role of precipitation in some ecological problems of the Dniester River basin. Destructive Water: Water-Caused Natural Disasters, their Abatement and Control. IAHS Publ. no. 239:263–265
25. Boiko V, Petrenco L, Savchenko L (2009) Ossobenosti gidrometeorologicheskich uslovii formirovania i razvitia vysokich pavodkov na rekach Carpat v iule 2008 [Particularities of hydrometeorological conditions of generation and evolution of high floods on Carpathian rivers in July 2008]. Sbornik mejdunarodnogo seminara Geneticheskie i veroiatnostnie metody v gidrologii: problemy razvitia i vzaimosveazi, Odessa, Ukraine, p 24 [In Russian]
26. WDC-SILSO (2014) Royal Observatory of Belgium, Brussels. www.sidc.oma.be/silso/datafiles. Accessed 12 Jan 2014
27. Pravila eksploatatsii dnestrovskih vodohranilish (pervaia redactsia) [Rules of the Dniester reservoirs operation (first redaction)]. 2011. Kiev, Ukraine, p 194 [In Russian]
28. Melnichiuc O, Gudumac Iu (2011) Jestkie i miagkie strategii adaptatsii rek Moldovi k navodneniam v usloviah ojidaemogo izmenenia climata [Hard and soft strategies of Moldova rivers adaptation to floods in conditions of expected climate change]. Sbornik nauchnih statei Transgranichnoe sotrudnichestvo v adaptatsii baseina Dnestra k izmeneniu klimata. Kishinev, Moldova, pp 82–97 [In Russian]
29. Merwade V (2010) Tutorial on using HEC-GeoRAS with ArcGis 9.3. Purdue University, USA, p 32. http://web.ics.purdue.edu/~vmerwade/education/georastutorial.pdf
30. Meyer S, Olivera F (2007) Floodplain mapping and hydraulic analysis with HECGeoRAS 4.1.1 and ArcGIS 9.1. Texas, USA, p 42. https://ceprofs.tamu.edu/folivera/ECVCD2007A/Exercises/GeoRAS411/HECGeoRAS%20-%20Meyer%20and%20Olivera.pdf
31. Raschet pavodochnih gorizontov reki Dnestr na uchastke Dubossari-Oloneshti. Poiasnenitelinaia zapiska i cherteji. Tehno-rabochii proekt [Calculation of flooding water levels of the Dniester River on the sector Dubasari—Olaneshti. Explanation letter and schematic drawings. Technical-working project]. 1975. Kishinev, p 32 [In Russian]
32. Anuar privind regimul si resursele apelor de suprafata, anul 2008. Partea 1. Riuri si canaluri. Partea 2. Lacuri si bazine de apa. Republica Moldova [Annual data of regime and resource of surface waters, 2008 year. Part 1. Rivers and channels. Part 2. Lakes and reservoirs. The Republic of Moldova]. 2009. Chisinau, Moldova. p 152 [In Romanian]
33. Anuar privind regimul si resursele apelor de suprafata anul 2010. Partea 1. Riuri si canaluri. Partea 2. Lacuri si bazine de apa. Republica Moldova [Annual data of regime and resource of surface waters, 2010 year. Part 1. Rivers and channels. Part 2. Lakes and reservoirs. The Republic of Moldova]. 2011. Chisinau, Moldova. p 148 [In Romanian]
34. Ejegodnie Dannie o rejime i resursah poverhnostnyh vod sushy, 1969 god. T. 2, v. 1. Basein Cernogo i Azovskogo morei (bez Cavcaza) [Annual data of regime and resource of surface waters, 1969 year, v. 2, ed. 1. Basins of Black and Azov seas (without Caucasus)]. 1971. Kiev, p 232 [In Russian]
35. Ejegodnie Dannie o rejime i resursah poverhnostnyh vod sushy, 1980 god. Chasti 1. Reki i kanali. Chasti 2. Ozera i vodohranilisha. T. 2 v. 0. Basein Cernogo i Azovskogo morei (bez Cavcaza). Basein reki Dunai i rek mejdu basseinami rek Dunai i Dnestr [Annual data of regime and resource of surface waters, 1980 year. Part 1. Rivers and channels. Part 2. Lakes and reservoirs. V.2, ed. 0. Basins of Black and Azov seas (without Caucasus). Basin of the Danube River and rivers between the Danube and the Dniester]. 1982. Kiev, p 196 [In Russian]
36. Moriasi DN, Arnold JG, Van Liew MW, Bingner RL, Harmel RD, Veith TL (2007) Model evaluation guidelines for systematic quantification of accuracy in watershed simulations. Am Soc Agric Bio Eng 50(3):885–900

37. Vodohranilisha Respubliki Moldova. Cratkii spravochnik. [Reservoir of the Republic of Moldova. Short data book]. 2004, compiled by Lalykin N., Catrinescu V., Kalashnik A., Sobchenko A., Institut po proiektirovaniu vodohozeaistvennih sistem AcvaProect, Chisinau, Moldova, p 65 [In Russian]
38. Melnichiuc O, Chishchiuc A, Gudumac Iu (2010) Vlianie caskada dnestrovskih vodohranilish na rejim fazy visokoi vodnosti reki Dnestr [Influence of the Dniester reservoirs cascade on high flow regime of the Dniester River]. Basein reki Dnestr: ekologicheskie problemi i upravlenie transgranichnymi prirodnymi resursami. Tiraspol, Moldova, pp 143–145 [In Russian]