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Rusnė-Šilutė Road Impact on Nemunas River Dynamics near Rusnė

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ABSTRACT: The paper assesses the impact of various design of Rusne-Šilute road on the hydrological regime (velocity and water level) of the Nemunas river. Currently, the road is flooded almost every year thus interrupting the only road to the Rusne island. The in-house software SwEvolver was used for hydrodynamical modeling. Road design impact was examined by 18 case studies which includes calculations for the 3 flood scenarios for each road design variant. Road design variants included the current state of the road, the viaduct over the lowest section of the road, long viaduct and the variations of the road surface levels. We concluded that the road design which prevents its overtopping should be chosen carefully, and modeling allowed for balancing between (1) maintaining the passage of the water over the floodplain, (2) avoiding risk to existing constructions (mainly – bridges), and (3) avoiding significant raise of the critical water levels in the nearby inhabited locations.

Keywords: Nemunas, Rusne, Flood

1 INTRODUCTION

Nemunas river is the largest stream of Lithuania (annual mean discharge 616 m^3/s) flowing into Curonian lagoon located at the southeast part of the Baltic Proper. Nemunas has a well-developed delta with three main branches Skirvyte, Atmata, Pakalne separating at the village of Rusne. Extensive flooding of the floodplain reaching up to 6-10 km width is characteristic for lower reaches of Nemunas. High flood level is mainly caused by snow melting in spring and the peak discharge and water level near Rusne may reach, respectively 5894 m^3/s and 2.93 m for 1% flood events. Even the annual flood events can completely interrupt transport connection with Rusne island because the only road to the island (Rusne-Šilute road) is being regularly overtopped.

2 HYDRODYNAMICAL MODEL

The hydrodynamical modeling software SwEvolver (PAIC (2006)) is finite element (FE) based non-steady two-dimensional software. Hydrodynamical software requires a triangular mesh of the computational domain which needs to contain topographical data, surface roughness parameters and boundary. Let us consider each component in details.

2.1 *Modeling domain*

The modeling domain for the hydrodynamical model of Nemunas near Rusne is shown in Fig. 1. Upstream boundary is chosen appropriately near the confluence of Gege river. The north-eastern border is chosen according to the terrain at non-overflowing heights. The south-western boundary is chosen along the non-overflowing dam in Russian Federation. Nemunas river separates in three branches at the town Rusne. The island formed by these branches is protected from flooding by dams which are selected as the borders of the modeling domain. The outflow boundaries are set downstream Rusne on the Pakalne and Skirvyte branches, and downstream Šysa confluence on the Atmata branch.

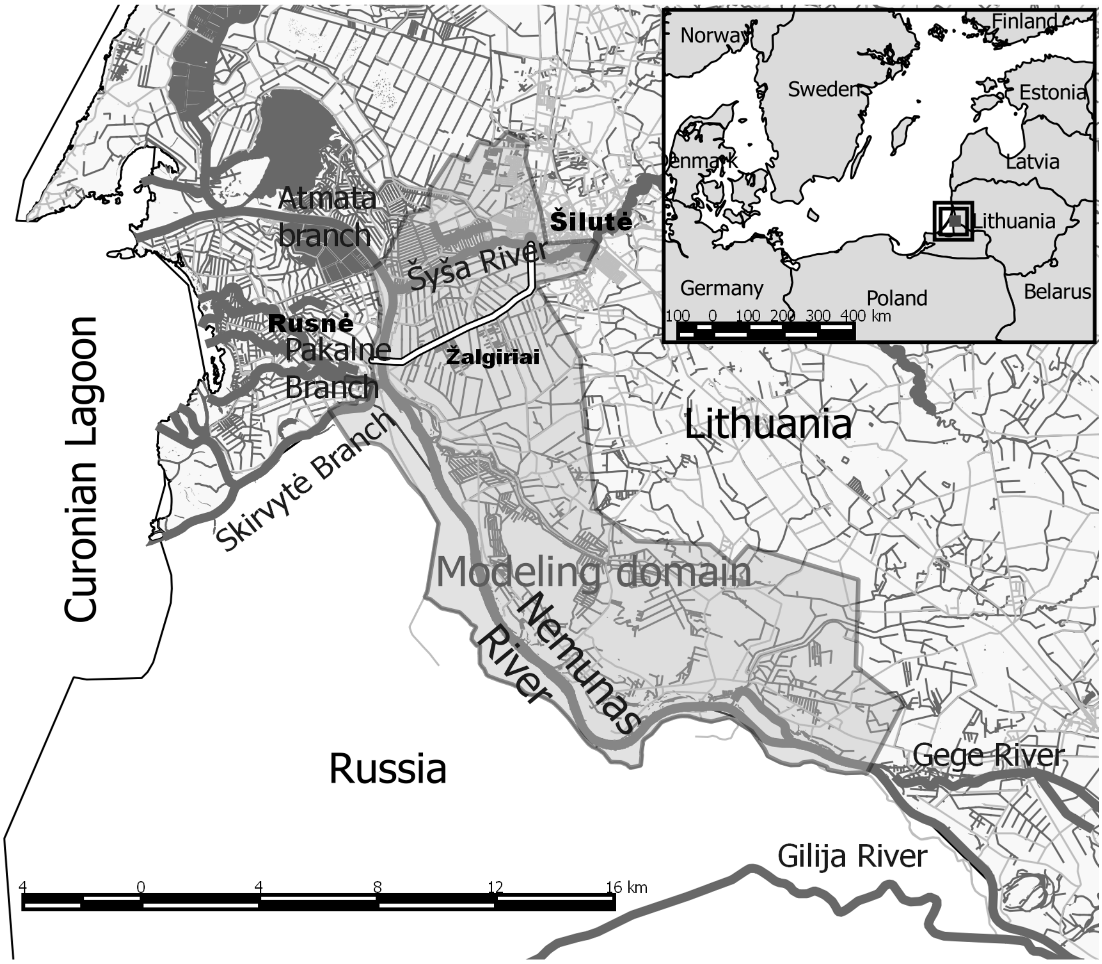

Figure 1. Modeling domain.

2.2 *Mesh and topographical data*

The building of the FE mesh is illustrated in Fig. 2. The typical spatial resolution of the FE mesh varied from meter to several hundreds of meters, and number of mesh points exceeded 380000. FE mesh is adapted to account for the orientation of the linear objects and locally refined in vicinity of the proposed viaduct on the road Rusne-Šilute – road elevation can be seen on the upper part of Fig. 2.

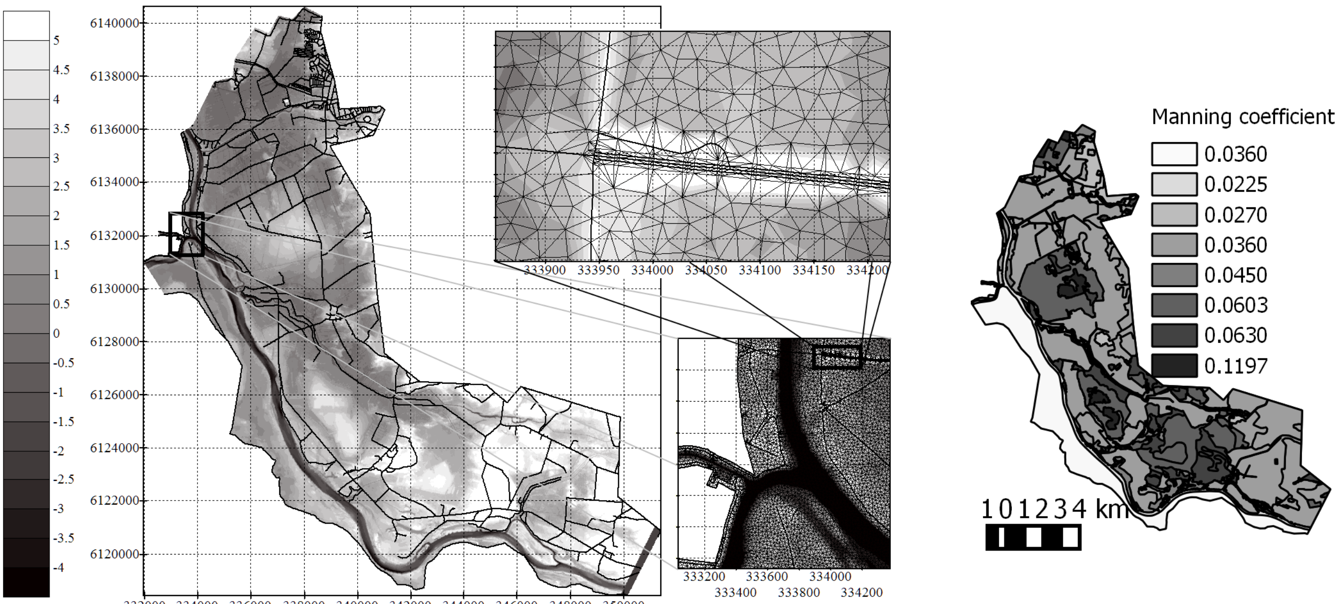

Figure 2. Triangular mesh with dams, digital terrain (color scale indicates elevation above sea level) and surface roughness parameter (Manning's N coefficient).

The most of the geospatial information for this project was presented by Lithuanian Environmental protection agency (Aplinkos Apsaugos Agentūra, referred further as LEPA) as the latest terrain and watercourse data aggregation used in the project "Preparation of flood hazard and flood risk maps for the Nemunas, Venta, Lielupe and Daugava river basin districts", LEPA (2014).

The digital terrain model (DTM) is adapted from LEPA (2014) 1m x 1m DTM grid which contains both surface and underwater elevation distribution. See the DTM of the modelling domain in Fig. 2. The right bank floodplain of Nemunas near Rusne is approximately 6 km wide and with few exceptions it is less than 1 m a.s.l. The exceptions are dams, elevated roads, and Žalgiris forest located on the right bank of Nemunas near the Leite confluence and upstream Rusne-Šilute road.

The DTM is complemented with the linear objects: roads, dams, [small] watercourses and ditches. The geospatial data from LEPA (2014) is used. The location of the linear objects in and near the modeling domain is shown in Fig. 1. One may notice the dense network of the ditches on the right floodplain of Nemunas. Generally all natural watercourses (as Šyša river) have elevated (dammed) embankments.

The spatially variable surface roughness (bed resistance) is used in the model. The aggregated CORINE land cover database from LEPA (2014) is used for the distinction of different surface roughness zones. These zones are shown in Fig. 2.The values of surface roughness expressed as Manning's N coefficient. These values are a result of calibration, see Section 2.4.

2.3 *Hydrological conditions and calculation scenarios*

Three basic scenarios were considered for modeling:
1. A calculation of 1% flood – discharge with return period of 100 years.
2. We considered that 50% flood or flood with return period of 2 years is important to reflect the most expected (typical) spring flood situation.
3. The only thorough measurement of discharges and waterlevels in the modeling domain (in Skirvyte, Pakalne, Atmata and floodplain) were performed during the spring flood of 1979. The report of this field campaign is included in Lietkelprojektas (1982). Flood of 1979 was therefore chosen as a calibration scenario (see calibration in Section 2.4). It is rather close to 10% flood.

Table 1. The characteristics of the probabilistic and 1979 floods: Nemunas discharge and waterlevel at Rusne WMS.

Scenario	1%		10%		50%	
Source	Discharge, m^3/s	Water level, m	Discharge, m^3/s	Water level, m	Discharge, m^3/s	Water level, m
Calculated	5894	2.93	3618	2.44	3502	2.40
Lietkelprojektas (1982)	7500	3.05	-	2.64	-	2.08

Rusne flood waterlevel of 1% and 10% probability is acquired via fitting of the annual maximum water level data series at Rusne WMS by normal distribution. Data series from LEPA (2014) were used; they include 68 year observations in time period 1933-2010.

Rusne flood waterlevel of 50% probability was selected as median value of the data series at Rusne WMS.

Nemunas discharges of 1% and 10% probability at Rusne were calculated as follows:

a. The probabilistic discharges at Nemunas-Panemune were obtained from LEPA (2014).
b. The percentage of discharge through Gilija branch (Fig. 1) was calculated from Pupienis at all (2012), Table 3 as 12.125%.
c. The discharges at Rusne were calculated multiplying the discharges at Panemune (point a) with percentage of Gilijos discharge (point b).

Nemunas discharge of 50% probability was calculated as follows:

a. The 50% discharge at Nemunas-Smalininkai was calculated as median of the maximum yearly discharges at Smalininkai from the time series from LEPA (2014). These time series contained data for years 1958-2010.
b. The discharge at Nemunas-Smalininkai was recalculated to discharge at Nemunas-Panemune assuming that discharge is proportional to the catchment area of respective stations.
c. The percentage of discharge through Gilijos branch was calculated from Pupienis at all (2012), Table 3 as 12.125%.
d. The discharge at Rusne was calculated multiplying the discharge at Panemune (point b) with percentage of Gilijos discharge (point c).

All probabilistic waterlevels calculated in this work are lower as corresponding probabilistic waterlevels in Lietkelprojektas (1982). It might be associated with various natural and anthropogenic influences beyond the scope of the current study; most probable cause to our opinion is a general decrease of the spring flow maximum since 1979 due to changing climate.

Note, that in the area of interest the dependence of the water level on the discharge during the flood event is ambiguos. It is influenced by sea waterlevel, ice conditions in the river, possible ice blockages, and snow/ice conditions in the overflowing floodplain.

To resolve this ambiguity we assumed that the respective scenario (1% or 50% flood) is a synthetic flood event when a probabilistic discharge causes the waterlevel of the same probability at Rusne station.

2.4 *Model calibration*

The main goal of model calibration was in matching the flow distribution between Skirvyte, Pakalne, Atmata and right floodplain as well as waterlevel in observations Lietkelprojektas (1982) with the modeling results.

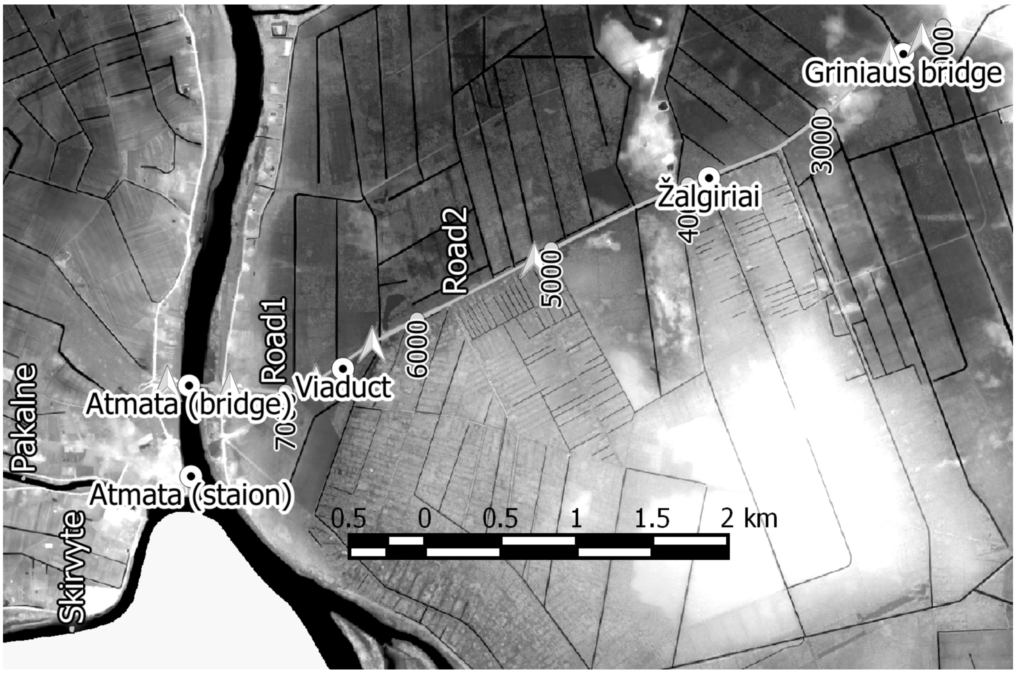

Figure 3. The longitudinal cross section of the Rusne-Šilute road.

The scheme of the dividing of water flows is shown in Fig. 3. It corresponds to requirements of measurements in Lietkelprojektas (1982) and associated with branches of Nemunas and segments of the overflooded road Rusne-Šilute:

a. Skirvyte branch, together with Pakalne branch.
b. Atmata branch, beneath the bridge over Atmata on the Rusne-Šilute road.
c. Road section “Road1” between the bridge over Atmata and projected viaduct.
d. Road section “viaduct” in the place of proposed viaduct.
e. Road section “Road2” between the proposed viaduct and more elevated road section.
f. Road section “Žalgiriai” along the more elevated road section.
g. Flow beneath the Griniaus bridge referred as Slezu bridge in Lietkelprojektas (1982).
h. Sum of discharges in points (c) to (g) is referred as to “floodplain”.

The calibration strategy was as follows: the initial values of the Manning coefficients (surface roughness) was taken according to land cover, Kiselev (1976); the calculations were performed for the [upstream] Nemunas discharge in flood event 1979 (Table 1); the values of Manning coefficients were finetuned and the downstream boundary conditions (waterlevels) adjusted to match the observed and modeled model characteristics.

The calibration results are given in Table 2 and Table 3, 4 (as match of the observed and modeled discharges and waterlevels), Fig.2 (as values of Manning’s N coefficients) and in Table 1 (as downstream boundary conditions – waterlevels in Atmata and Skirvyte).

The achieved fit of observed and modeled discharges should be considered as good; the model overestimates the total discharge in Skirvyte/Pakalne by less than 3%. We may assume that this difference is less than measurement error. The distribution of the flow percentage through Skirvyte (with Pakalne) / Atmata / floodplain is almost a perfect match.

Table 2. Calibration results – downstream boundary conditions for all scenarios

	Upstream discharge , m3/s	Downstream water level, m	
Scenario	Nemunas	Skirvyte, Pakalne	Atmata
1%	5894	2.65	2.25
1979	3502	2.12	1.72
50%	1603	1.57	1.77

The discrepancy between observed and modeled waterlevels is better than 10 cm; it can be assessed as good, especially because the measurements took place during the course of several days.

2.5 *Alternatives of design of Rusne-Silute road*

Alternative "proj1" assumes building a 400 m long viaduct over the lowest stretch of the road. This alternative aims at prevention of the road overtopping during 50% flood. Alternative "proj2" combines the alternative "proj1" with the lowering of the road section beneath the viaduct to the level of surrounding terrain (20 cm a.s.l.). This alternative also aims at prevention of the road overtopping during 50% flood but in the same time enhances the water flow beneath the new structure thus preventing its impact on the water level raise. Alternative "proj3" combines the alternative "proj2" with the raising of the road stretches "road1" and "road2" to the level 220 cm a.s.l. This alternative guarantees the defense against the floods which exceed 50% probability for the most vulnerable stretches of the road. Alternative "proj4" combines the alternative "proj3" with the raising of the whole road Rusne-Šilute to the 4 m level. This alternative is aimed for the prevention of the road overflow during the 1% flood situations. Alternative "proj5" is a variation of alternative "proj4" with prolonged viaduct (700 m instead of 400 m). Such an alternative is considered to facilitate a discharge of water at low probability floods through the viaduct.

3 CALCULATION RESULTS

Five modifications of the digital terrain model and calculation mesh were performed according to the alternative configurations / parameters of the proposed viaduct (Section 3.2). For each of the design alternatives the calculations of 50% flood, spring flood 1979 and 1% flood was done. The results of these calculations are presented as discharge values through Nemunas branches and different segments of the Rusne-Šilute road for all scenarios and cases in Table 3, water levels and flow velocities (Table 4) at different locations – under Atmata bridge, under the proposed viaduct and the Griniaus bridge, longitudinal profile of Rusne-Šilute road with waterlevels and flow velocities for all design cases and all flood scenarios, see Fig. 4.

There are some common features during any of flood events. The Nemunas flow concentrated in the riverbeds is partly isolated form the flow in the floodplain by the dams. The flow concentrated in the floodplain northeast from the Žalgiriai originates from the main Nemunas flow upstream the Leite confluence and flows towards sea through the Griniaus bridge. The flow concentrated in the floodplain southwest from the Žalgiriai originates from the main Nemunas flow downstream the Leite confluence and flows towards sea over the lowest stretch of the Rusne-Šilute road.

The alternative "proj1" solves the most important problem of exploitation of the road Rusne-Šilute – protection of the lowest road section. The water level near the viaduct rises by approximately 5 cm (Table 4). It does not prevent overtopping of the road stretches "road1" (by 30 cm) and "road2" (by 20 cm) during the 10% floods. The construction only slightly changes the water balance reducing the floodplain share of overall Nemunas flow by 1.5% (Table 3). The water velocity changes insignificantly both in Atmata under the main bridge (by 2 to 8 cm/s) and under the Grinius bridge (by 5 cm/s), see Table 4. The water velocity under the viaduct may reach 2.6 m/s during the 10% flood.

The alternative "proj2" is aimed to facilitate the water flow beneath the new viaduct. The water level near the viaduct is almost the same as in "proj1" (Table 4). The water balance is restored to reference situation for 50% flood; reduction of the floodplain share of overall Nemunas flow for this scenario is only 0.4% (Table 3). The water velocity under the viaduct is reduced to 1.25 m/s during the 10% flood (Table

4). The total discharge through the viaduct is restored to almost the same discharge as over that road stretch in the reference situation (Table 3).

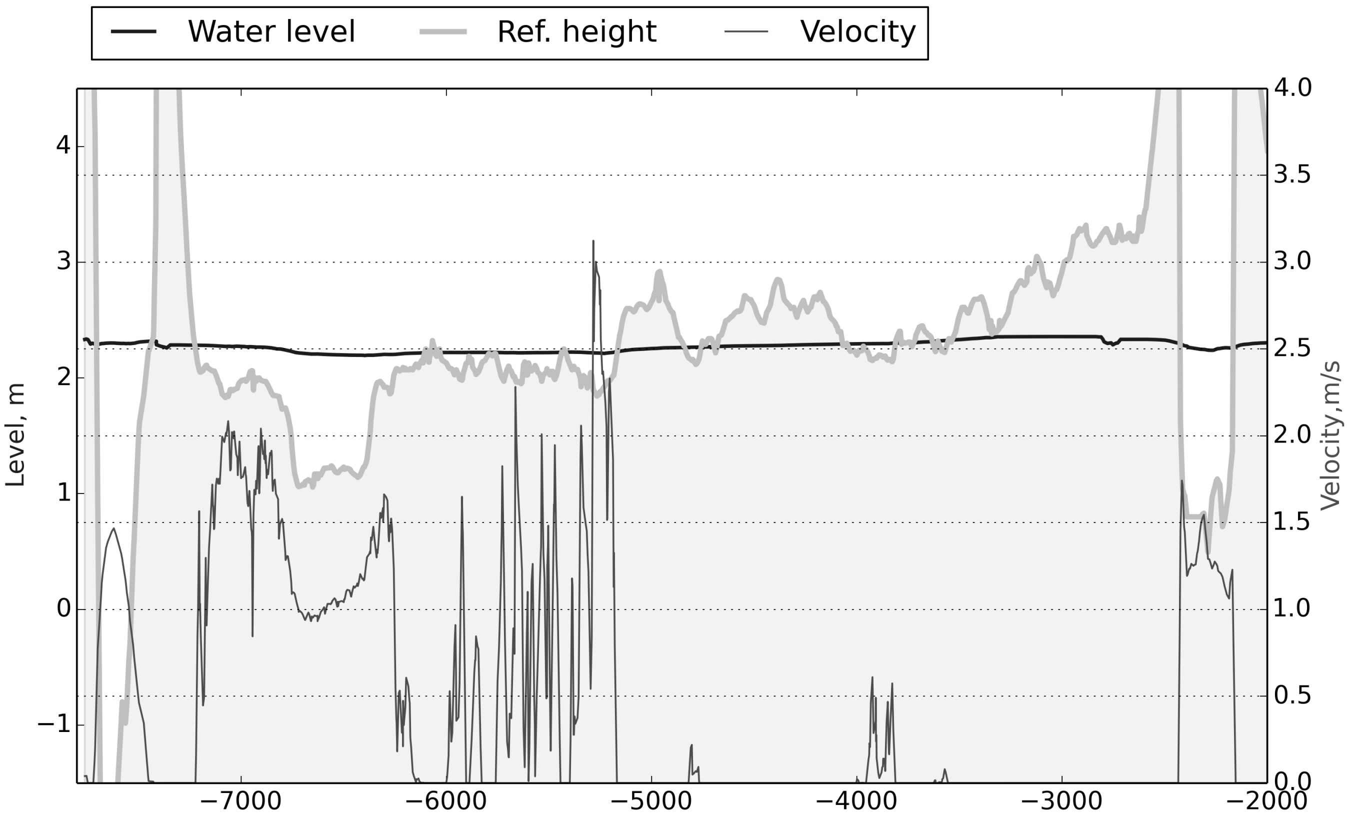

Figure 4. Road profile, waterlevel and flow velocity. 1979 year flood, reference case.

The alternative "proj3" is aimed for improving the situation in the most vulnerable stretches of Rusne-Šilute road protecting them for the floods of probability below 50%. This alternative does not change the situation (in comparison with "proj2") for 50% flood. The situation changes most significantly for medium (10%) floods; the depth of overtopping of the road in this case is below 20 cm. The overall flow through the floodplain reduces by 3.3% of total Nemunas discharge in comparison with the reference situation (Table 3). The water level and velocity elsewhere changes negligibly (Tables 4).

Table 3. Discharges through different river branches and road sections for calculation cases.

		A		A		R1		v		R2		Ž		GB		FP		Total
	case	m^3/s	%	m^3/s	%	m^3/s	%	m^3/s	%	m^3/s	%	m^3/s	%	m^3/s	%	m^3/s	%	m^3/s
1%	ref.	2067	35.1	1190	20.2	445	7.6	469	8.0	498	8.5	578	9.8	646	11.0	2637	44.7	5894
	proj1	2119	35.9	1222	20.7	405	6.9	371	6.3	533	9.0	587	10.0	656	11.1	2553	43.3	5894
	proj2	2112	35.8	1217	20.7	382	6.5	444	7.5	505	8.6	578	9.8	655	11.1	2565	43.5	5894
	proj3	2123	36.0	1189	20.2	315	5.3	475	8.1	508	8.6	638	10.8	646	11.0	2582	43.8	5894
	proj4	2515	42.7	1361	23.1	0	0.0	985	16.7	0	0.0	2	0.0	1031	17.5	2018	34.2	5894
	proj5	2404	40.8	1305	22.1	0	0.0	1212	20.6	0	0.0	2	0.0	971	16.5	2184	37.1	5894
1979	observ.	1363	38.9	947	27.0							0	0.0	305	8.7	1192	34.0	3502
	calibr.	1403	40.1	942	26.9	177	5.1	408	11.7	149	4.2	6	0.2	417	11.9	1157	33.0	3502
	proj1	1438	41.0	960	27.4	168	4.8	321	9.2	172	4.9	15	0.4	429	12.3	1105	31.6	3502
	proj2	1427	40.8	954	27.3	143	4.1	399	11.4	143	4.1	10	0.3	426	12.2	1120	32.0	3502
	proj3	1468	41.9	993	28.4	28	0.8	511	14.6	23	0.7	15	0.4	463	13.2	1041	29.7	3502
	proj4	1461	41.7	971	27.7	0	0.0	572	16.3	0	0.0	1	0.0	498	14.2	1071	30.6	3502
	proj5	1433	40.9	950	27.1	0	0.0	641	18.3	0	0.0	1	0.0	478	13.6	1120	32.0	3502
50%	ref.	753	47.0	565	35.2	0	0.0	171	10.7	0	0.0	0	0.0	114	7.1	285.1	17.8	1603
	proj1	769	48.0	574	35.8	0	0.0	135	8.4	0	0.0	0	0.0	125	7.8	259.9	16.2	1603
	proj2	757	47.2	567	35.4	0	0.0	163	10.1	0	0.0	0	0.0	116	7.2	278.7	17.4	1603
	proj3	755	47.1	570	35.5	0	0.0	161	10.0	0	0.0	0	0.0	117	7.3	277.9	17.3	1603
	proj4	757	47.2	567	35.4	0	0.0	163	10.2	0	0.0	0	0.0	116	7.2	278.9	17.4	1603
	proj5	755	47.1	562	35.0	0	0.0	171	10.7	0	0.0	0	0.0	115	7.2	287	17.9	1603

where following notations is used: A stand for Atmata, S – Skirvyte, Ž - Žalgiriai, v - viaduct, GB - Griniaus Bridge, R1 - Road1, R2 – Road2, FP - Floodplain.

The alternative "proj4" is aimed for the protection of overtopping of the road "Silute-Rusne" during 1% flood events. Blocking the road overtopping leads to change of the floodplain flow volume in 1% floods (Table 3). The flow through the floodplain is reduced by 10.5% of the total Nemunas flow. This volume is diverted to Skirvyte (above 70%) and Atmata (below 30%). The discharge through the viaduct more than doubles but through Griniaus bridge increases by more than 50% for 1% flood (Table 3).As a consequence of above the flow velocity under the constructions increases significantly comparing to reference cases (Table 4) during 1% flood: (a) from 1.6-1.7 m/s to 1.9 m/s beneath the main Atmata bridge; (b) from 1.1-1.2 m/s to 2.3 m/s under the viaduct; (c) from 1.8-1.9 m/s to 3 m/s under the Grinius bridge. These velocities may be critical for the constructions. The water level in 1% event rises by 15 cm at the viaduct, by 56 cm in Zalgiriai and by 27 cm at the Griniaus bridge (Table 4).

The alternative "proj5" is aimed for the protection of overtopping of the road "Silute-Rusne" during 1% flood events and in the same time reducing the adverse effects of "proj4". It assumes increase of the viaduct length from 400 to 700 m to facilitate the discharge through it. Change of the floodplain flow volume in 1% floods (Table 3) is reduced by 7.5% of the total Nemunas flow (10.5% for "proj4"). The discharge through the viaduct almost triples in comparison with "proj2" and raises by 50% in comparison with "proj4" for 1% flood (Table 3). The increase of flow velocity under the constructions still increases significantly comparing to reference cases (Table 4) during 1% flood: (a) from 1.6-1.7 m/s to 1.8 m/s beneath the main Atmata bridge; (b) from 1.1-1.2 m/s to 1.9 m/s under the viaduct; (c) from 1.8-1.9 m/s to 2.8 m/s under the Griniaus bridge. The water level in 1% event is lower than in "proj4": by 2 cm at the viaduct, by 6 cm in Žalgiriai. The increase of the waterlevel (50 cm) in comparison with reference case is still significant for Žalgiriai settlement.

Table 4. Water levels and water velocities at different locations (incl. road sections) for calculation cases.

		Water level, m					Water velocity, m/s			
	case	A(s)	A(b)	v	Ž	GB	A(b)	R1	v	GB
1%	reference	2.98	2.83	2.72	2.62	2.76	1.61	1.52	1.00	1.81
	proj1	2.98	2.82	2.77	2.62	2.76	1.69	2.34	1.52	1.85
	proj2	2.98	2.82	2.76	2.62	2.76	1.69	2.19	1.09	1.85
	proj3	2.98	2.82	2.76	2.62	2.76	1.71	2.42	1.21	1.88
	proj4	3.03	2.84	2.91	3.18	2.93	1.88	0.00	2.31	2.95
	proj5	3.02	2.84	2.89	3.12	2.89	1.82	0.00	1.86	2.83
1979	observed	2.40	-	2.23	2.20	2.18	1.46	0.83	0.78	1.03
	calibr.	2.44	2.30	2.19	2.29	2.25	1.47	2.08	1.15	1.74
	proj1	2.45	2.31	2.25	2.30	2.25	1.53	3.21	2.26	1.79
	proj2	2.45	2.31	2.23	2.30	2.25	1.51	2.87	1.25	1.78
	proj3	2.45	2.31	2.25	2.30	2.26	1.52	1.51	1.45	1.84
	proj4	2.46	2.32	2.28	2.45	2.30	1.55	0.00	1.71	2.04
	proj5	2.46	2.31	2.26	2.43	2.29	1.52	0.00	1.17	1.99
50%	reference	1.93	1.85	1.75	1.78	1.76	1.01	0.00	1.00	0.74
	proj1	1.93	1.85	1.79	1.80	1.77	1.03	0.00	1.89	0.79
	proj2	1.93	1.85	1.76	1.79	1.76	1.05	0.00	0.66	0.76
	proj3	1.93	1.85	1.76	1.79	1.76	1.05	0.00	0.65	0.76
	proj4	1.93	1.85	1.76	1.79	1.76	1.05	0.00	0.67	0.76
	proj5	1.93	1.85	1.76	1.77	1.76	1.05	0.00	0.47	0.76

where following notations is used: A(s) stand for Atmata (station), A(b) - Atmata (bridge)

4 CONCLUSIONS

The hydrodynamical modeling provides the evaluation of the consequences and effects of different solutions aiding and supporting the decision-making.

Basically the defence of road against frequent (50%) floods can be done without disturbing hydrodynamical regime of Nemunas in vicinity of Rusne. It may be achieved by realizing alternative "proj2". The building of viaduct should be accompanied with removing of the "old" road beneath the viaduct (leveling it with the surrounding terrain) and eliminating the trees along this old road stretch.

The longitudinal profile of the road suggests a further step – "proj3", or slight elevating to 220 cm of the most vulnerable road stretches. This alternative only insignificantly changes the hydrodynamical conditions both at frequent (50%, road overtops in neither case) and in infrequent (1%, road overtops anyway) floods.

The increase of the road surface above the level of 1% flood significantly changes the hydrodynamics of floodplain during the low probability flood events. This causes several consequences which may be considered as dangerous: (a) essential reduction of the flow over floodplain and increase of flow in the main river channels, (b) significant increase of the water velocities beneath the existing (Atmata bridge, Griņius bridge) and proposed (viaduct) constructions, (c) the significant increase of the waterlevels in Žalgiriai settlement. These adverse consequences cannot be eliminating by reasonable increasing of the length of the proposed viaduct.

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