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APPROACH TO THE DEVELOPMENT OF INVESTMENT PROGRAMME OF FLOOD PROTECTION ON THE DUNAJEC RIVER INCLUDING ENVIRONMENTAL PROTECTION ASPECTS

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This article discusses an approach applied in the region of the upper Vistula River for the selection of optimum investments in flood protection. It takes into account hydrological, hydraulic, social, environmental, economical and implementation aspects. In order to choose a solution, a multi-criteria analysis was used, which is based on 13 indicators that use the results of mathematical modelling of flood waves for the formulated variants compared to the current state. This method was applied for the main tributaries of the Vistula River and its results were used in the Flood Risk Management Plan for the Vistula River drainage basin, which is being currently developed. In this article, the aforementioned method will be presented on the example of the drainage area of the Dunajec River together with the Poprad River.

KĽÚČOVÉ SLOVÁ: flood, environmental, hydraulic modelling, multi-criteria analysis

PRÍSTUP K VYPRACOVANIU INVESTIČNÉHO PROGRAMU PROTIPOVODŇOVEJ OCHRANY NA RIEKE DUNAJEC S PRIHLIADNUTÍM NA HĽADISKÁ OCHRANY ŽIVOTNÉHO PROSTREDIA. Článok pojednáva o prístup zvolený v oblasti hornej Visly zvoliť optimálny investície povodeň. Zohľadnia stanoviská hydrologického - hydraulické, sociálnych, ekologických a ekonomických - realizácia. Výber riešenia používajú multikriteriálnej analýzy, na základe 13 ukazovateľov, pomocou výsledkov matematického modelovania povodňových vĺn pre formulované varianty v porovnaní so súčasnou situáciou. Táto metóda bola použitá pre hlavné prítoky rieky Visly, a jej výsledky boli využité pri vypracovaní súčasnej povodňového manažmentu plán na Vistula povodia. V článku sa tento spôsob ilustrovaný v príklade povodí Dunajec s Poprad.

KEY WORDS: povodeň, životné prostredie, hydraulický model, multikriteriálna analýza

Introduction

Since 2012, in the upper Vistula River drainage basins, design works concerning the selection of activities (technical and non-technical) decreasing the risk of flooding have been realised. For proper realisation of these analyses, methodical assumptions have been developed by the Regional Water Management Administration (RZGW) in Cracow, stemming from the philosophy of the Floods Directive, analogous to a significant extent to the methodical assumptions for plans of flood risk management. Currently, 15 drainage basin studies, including drainage basin of the Dunajec are being realised.

The basis for analyses of the investment programme, is the evaluation of the condition of flood security in the drainage basin, indicating hazardous areas for buildings and infrastructure, where defined actions should be taken with regard to flood protection on the basis of probable water ranges $Q_{1\%}$ and $(Q)_{0,2\%}$. A folder of technical (reservoirs, embankments, etc.), and non-technical (e.g. relocations) activities has been established. The next step encompasses the generation or updating of hydraulic models for unsteady flow, permitting the analysis of the impact effects of the actions specified within the folder on the course of the flood. From those

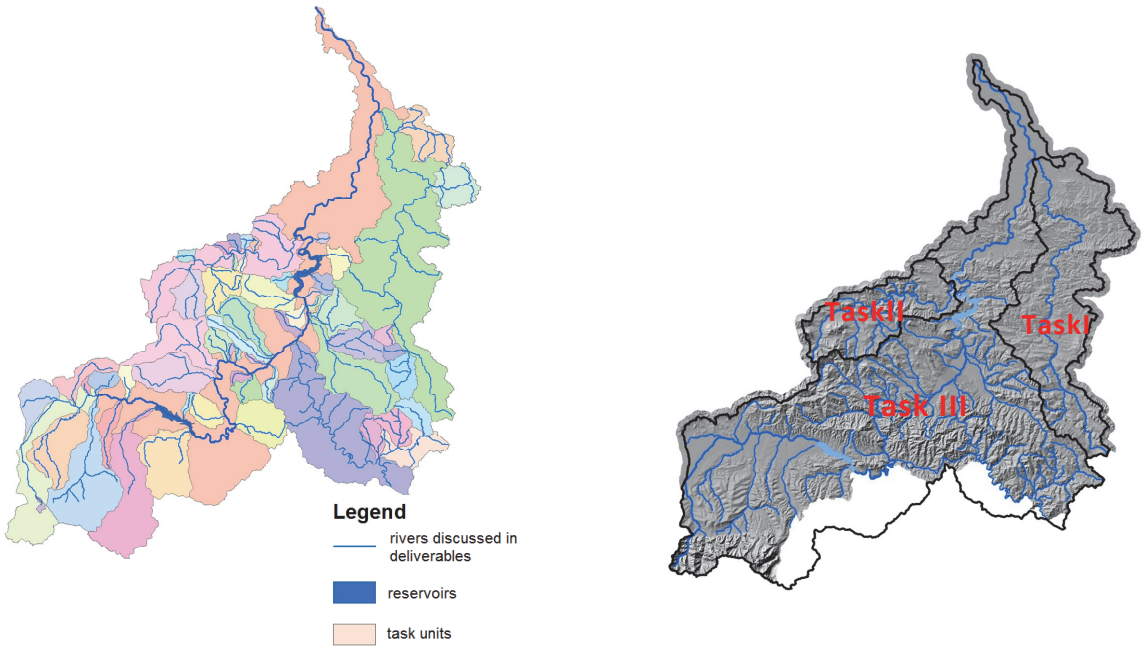


Fig. 1. The division of the Dunajec drainage basin into tasks and task units.
Obr. 1. Rozdelenie povodia Dunajca na jednotlivé úlohy a ich plošné jednotky.

activities variants for different grades of limiting risk of flooding are created for the entire drainage basin, afterwards, based on the results of analyses of the hydraulics, benefits, and environmental and social disadvantages, as well as costs of implementation of each variant, a final, multi-criteria analysis is performed, allowing to indicate the best option.
Project entitled: "Analysis of the investment programme in the basin of the Dunajec River" is carried out by MGGP S.A, in cooperation with the University of Agriculture in Cracow (MGGP, 2013–2015). Analytical works are conducted following the "task unit" model (Fig. 1) broken down into three tasks: I – drainage basin of the Biała Tarnowska, II – drainage basin of the Łososina, III – drainage basin of the Dunajec, excluding the Biała Tarnowska and the Łososina.
The Dunajec drainage basin - total area 5235 km^2, is located in Małopolskie Voivodeship. It encompasses fragments of 7 poviats and 56 communes.

Flood hazard in the Dunajec drainage basin

The level of flood hazard in the Dunajec drainage basin, was estimated on the basis of hydraulic analyses and probable water range specified with the assumptions:

- Contemporary hydrology including the flood of 2010
- Performance of Czorsztyn–Sromowce and Rożnów-Czchów reservoirs with up-to-date instructions and anti-flood reserves.
- Current condition of anti-flood embankments
- Information included in the Database of Topographic Objects (BDOT)
- Land cover according to Corine Land Cover

Risk for areas in particular use classes

Areas in danger of flooding were identified in eight use classes, for individual task drainage basins within flooding ranges $(Q)_{0,2\%}$ and $(Q)_{1\%}$.
Summative hazards for particular use classes of areas within the entire drainage basin constitute Table 1, and the hazards distribution in particular drainage basins, for one-hundred-year-floods is illustrated in Fig. 2.

Enclosed and linear structures

In the designated flood zones for $(Q)_{0.2\%}$ and $(Q)_{1\%}$, a survey of enclosed and linear structures has been conducted, according to the following classes:

- Farm buildings;
- Residential buildings;
- Industrial facilities;
- Public utility buildings;
- Cemeteries;
- Roads;
- Railway lines.

A number of endangered facilities, within the flood risk areas for the abovementioned classes, was established for the first 5 classes and distances for classes: roads and railway lines. The analysis was performed in the system of task drainage basins and main drainage basin. Particular classes of enclosed structures and linear infrastructure have been prepared in the GIS environment.

Data for the "Cemeteries" class was taken from BDOT figures, containing land use complexes including cemeteries. Information for the "Roads" and "Railway lines" classes were taken directly from BDOT figures, containing individual communication networks.

Within the whole Dunajec drainage basin, flooding zones have been determined for 1780 km of watercourses. According to the designated zones, these rivers create a large flood threat for people. Ca. 7,146 buildings, 47.5% of which are residential complexes, are endangered by 500-year-floods. Other structures are mostly farm buildings. In addition, 291 industrial facilities and 390 public utility buildings, including numerous offices, public administration departments, a fire department, kindergartens, schools, churches, shopping malls, company offices, hotels, vacation homes and restaurants are located within the flooding areas. For the one-hundred-year-flood areas, the number of endangered buildings drops by more than half, encompassing 1,426 facilities, 41 % of which are residential buildings.

Table 2 compares the number of facilities with a breakdown into individual classes within the flood zones in the case of 500-year-floods and one-hundred-year-floods.

Table 1. Endangered areas in particular use classes, within flooding ranges $Q_{0.2\%}$ and $(Q)_{1\%}$ in the entire drainage basin

Tabuľka 1. Ohrozené územia podľa jednotlivých tried využitia zeme, v rozsahu povodní $Q_{0.2\%}$ a $(Q)_{1\%}$ v celom povodí

No.	Area use class	Class area in the entire Dunajec drainage basin	Class area in the flood zone for $(Q)_{0.2\%}$ [km ^{2}]	Class area in the flood zone for $(Q)_{1\%}$ [km ^{2}]
1	Housing estates	382.57	6.34	2.92
2	Industrial areas	31.92	2.41	0.70
3	Shafts	60.07	1.09	0.53
4	Forests	4071.43	41.54	35.82
5	Green and recreational areas	36.50	0.79	0.35
6	Agricultural areas	3517.72	87.58	69.30
7	Other	59.27	5.68	4.83
8	Waters	174.78	31.09	30.69

Table 2. Enclosed structures and linear infrastructure in the flood zone for $(Q)_{0.2\%}$ and $(Q)_{1\%}$ in the entire drainage basin

Tabuľka 2. Zahrnuté stavby a lineárna infraštruktúra v záplavových územiach pre $(Q)_{0.2\%}$ a $(Q)_{1\%}$ v celom povodí

No.	Class of the facility	Number of facilities in the flood zone for $Q_{0.2\%}$	Number of facilities in the flood zone for $Q_{1\%}$	Unit [pc./km]
1.	Farm buildings	3,066	709	pcs.
2.	Residential buildings	3,399	584	pcs.
3.	Industrial facilities	291	54	pcs.
4.	Public utility buildings	390	79	pcs.
5	Cemeteries	3	1	pcs.
6	Roads	876.99	581.82	km
7	Railway lines	27.60	10.37	km

Endangered inhabitants

Within the whole Dunajec drainage basin, according to the conducted demographic analysis, flooding with the occurrence probability of 1.0% endangers almost 12 thousand people.

Planning Variants

A Planning Variant is a set of activities both technical and non-technical. Each of these activities provides specific results, which in turn provide certain benefits. E.g. reservoir construction is a technical activity, which results in a reduction of the flood extent and stoppage of a specified volume of water. The benefit is limiting the flooding areas and, as a result, reducing losses.
Currently, within the Dunajec drainage basin, a number of hydro-technical facilities are in place, intended to limit potential losses. They constitute both embankments and reservoirs that directly affect the flood extent, and longitudinal and transverse river architecture, counteracting side and bottom erosion of riverbeds. These do not provide complete security against flooding, which is proven by the extent of flood hazard described in the first part of this article. For further studies, this scope of flood protection is **"Variant 0"**, and the size of the present flood hazard shall be a point of reference for subsequent variant formulation.
For the purposes of analysis of the investment programme, information on all planned activities to be executed within the scope in question, has been compiled, as at the date of completion of this study.
A total of 65 activities, which may impact the flood extent, planned for implementation, have been compiled to restrict the flood risk in the Dunajec drainage basin:
These actions include:

- The construction and modernisation of embankments – 8 activities;
- The construction of small reservoirs (including "dry" and "wet" "reservoirs) – 43 activities;
- The modernisation of existing bridges – 10 activities;
- The construction of a pumping station – 2 activities;
- The reconstruction of hydro-technical facilities – 2 activities.

These actions constitute **"Variant I"** adopted in further planning analyses, showing the possible degree of reduction of flood risk in the drainage basin, provided all planned investments are carried out by watercourse administrators and local government authorities.
Each subsequent Planning Variant has been defined as a collection of activities, both technical and non-technical. Technical activities constitute the creation of additional artificial retention in the drainage basin through the construction of "dry" and wet" reservoirs and polders, and modernisation as well as construction of embankments. The main non-technical activity, directly limiting potential losses, may be relocation of inhabitants and transfer of business operations and public utility buildings from the flood areas. Non-technical activities may also encompass increasing the flood reserve (in relation to its current size) on the Rożnów reservoir, and possible revisions in control instructions.
Priority was given to constructing homogeneous, and to some extent extreme, variants, by defining e.g.

- **"Variant IIA"** – as the maximum use of actual artificial retention in the drainage basin,
- **"Variant IIB"** – as artificial retention on the main watercourse, and embankment protection of endangered areas,
- **"Variant IIC"** - as maximum embankment protection of endangered areas,

and, subsequently, mixed variants.

Due to the defined hydrographical system of task drainage basins, a decision was made to:

- seek a preferred variant individually in each of the task drainage basins,
- seek a preferred variant for the Dunajec drainage basin as a whole.

As part of the process of creating and anti-flooding effect evaluation of subsequent variants, an important stage is the hydraulic calculations model for areas of particular elementary units. They provide the basis for comparative studies in relation to the existing condition (for "Variant 0"). The comparison covered the flood extent and ordinates of water surface, for areas in danger of flooding in individual classes of architecture and infrastructure, population for endangered areas for $(Q)_{1\%}$ and $(Q)_{0.2\%}$. Also, economic benefits were compared, resulting from the designated, by way of modelling, restrictions of flooded areas for $(Q)_{1\%}$ and for water $(Q)_{0.2\%}$.

Hydraulic Modelling

For hydraulic calculations the MIKE 11 (2009) model was used. For the basic hydrographical system of task drainage basins, models have been delivered by the Regional Water Management Board (RZGW) Cracow, for part of the so-called "additional watercourses", which were specified as required for modelling, due to the location of technical activities (additional artificial retention, embankments), models of the same standard were prepared by MGGP and the Agricultural University in Cracow.
The Stages of model generation: I) analysis of the river system, along with interpretation of the digital terrain model and orthophotomaps, II) geodetic surveys

including the riverbed and engineering structures, III) identification of roughness indexes, IV) hydrological calculations of flows constituting boundary conditions. The resulting model undergoes a check procedure – for calibration and verification (Książek et.al., 2010a). For uncontrolled drainage basins, calibration and verification are conducted by experts. For controlled drainage basins, model evaluation is conducted by comparison of calculation results of, inter alia: flow rate, water surface level, flood volume with past floods (Książek et.al., 2010b).
The constructed model takes account of updated field data, side tributaries to the main watercourse, the course of inflows, soil humidity in the river valley and the type of land use. The results of the modelling process, are the flow conditions for the entire drainage basin, dynamic water surface system, forecast of flood passage in each profile, flood duration, maximum fillings and flows, specification of embankment flow capacity, indicating places not ensuring the required flow capacity.
The Dunajec model was supplemented with the model of reservoirs in Czorsztyn–Sromowce and Rożnów-Czchów, integrating those far separate models for individual parts of the Dunajec drainage basin.
The model assumption for the direct Dunajec drainage basin, due to it being the recipient for all other drainage basins, adopted while seeking a preferred variant, was that all entrances for tributaries concentrated in the hydraulic model will be introduced as:

- inflow hydrographs, resulting from simulations of "Variant 0" – if we analyse Dunajec individually,
- inflow hydrographs, resulting from preferred variant simulations, in every task drainage basin, where a variant analysis was conducted, and for other drainage basin resulting from simulations of "Variant 0" – if we analyse the Dunajec drainage basin as a whole
- inflow hydrographs, resulting from secondary variants simulations, for every task drainage basin, where a variant analysis was conducted, but providing a maximum reduction in flood extent, and for other drainage basins, resulting from simulations of "Variant 0" – if we analyse the Dunajec drainage basin as a whole, and at the same time we wish to check the maximum impact extent on the Vistula River.

Multi-criteria analysis

Every analysis for variant selection, regardless of whether it was conducted within each drainage basin separately, or for the Dunajec drainage basin as a whole, was subject to specific rules adopted in the procedure for multi-criteria analysis.
The subject of the multiple-criteria analysis, are the benefits resulting from introducing the proposed planning variants. One of the vital matters in the multi-criteria analysis, is to choose the method of selection of the best, or rather most satisfactory variant. It should meet several conditions:

- "cope" with assessments expressed in different scales (quantitative and qualitative)
- enable performance of analyses for changing criteria of assessment and weight factor values
- must be transparent to enable the decision-makers to learn in the course of analyses.

The assessment of variants of activities undertaken at the drainage basin level, for limiting flooding effects, was comprised of marking out groups of criteria to be assessed, defining, for each examined partial criteria groups, measures and assumptions for the variant classification procedure, and determining weights between criteria groups.
4 groups of issues have been defined, and within these, the following criteria were considered:

Flooding Criteria

- Reduction in values of potential losses within the flood area 1% [PLN]
- Reduction of direct hazard for people in the flood area 1% (depth> 0.5 m) [number of inhabitants]
- Reduction in flood extent (flow reduction in the estuary-cross-section of a given drainage basin for flow $Q_{1\%}$) [%]

Social Criteria

- Occupancy for the whole variant (total surface of investment areas) [ha]
- The number of resettlements related to the variant execution (persons to be relocated in connection with the investment execution) [number of inhabitants]
- Sum total of water-protected public utility facilities for $(Q)_{0,2\%}$ [pcs.]

Environmental Criteria

- Impact on protected areas other than Natura 2000
- Impact on the areas of Natura 2000
- Scale of natural compensation
- Compliance with requirements of the WFD

Within this group of unquantifiable criteria, expert evaluations were carried out by a specialist in nature protection provided with information on the beneficial impact resulting from certain actions adopted in a given planning variant. Under these evaluations, planning variants were arranged in sequence from worst to best, on the scale of 0 – 10, where the expert has independently (subjectively) set scale boundaries.

Economical-Implementation Criteria

- The value of investment outlays [PLN]
- The value of annual average maintenance costs [PLN]
- Technical difficulty level of realisation

The assumption for cost analyses of planning variants, was that the costs would be analysed for a specified time-frame, and take into account both investment and operating costs. To ensure cost comparability of technical structures, a document has been prepared, containing unit prices of technical structure construction, and select non-technical activities (MGGP, 2013). The assumption was made, that the estimated operating costs shall be calculated as a specified percent of investment costs for a given activity. The last criterion is unquantifiable and requires expert assessment.
For each criterion, points of reference on a scale of 0 – 10 pts have been determined. The scale for numerical data is normalised according to the principle that 0 is assigned to the worst variant and 10 to the best, while the expert assessment scale is determined by the expert. After assigning point grades to each planning variant, under each criterion, calculations of the final variant assessment are conducted. This can be done in two ways by:

- totalling the grades obtained by a variant for each criterion, or
- assigning internal weights to the concerned criteria within a group of issues, and calculating the weighted average.

The preferred variant in each group of issues is the one with the highest point assessment.

The preferred variant may then be examined with regard to sensitivity to weights assigned to individual criteria groups.

Example for the selected task drainage basin, – Z34Kamienica Nawojowska

Planning variants in accordance with Table 3 were considered for the drainage basin.
Hydraulic simulations of modelling variants and analysis of flooding area resulting from activities contained therein, allowed for defining the effects of these variants, in the basin, for criteria expressed numerically, while experts – a naturalist and hydraulic engineer stated their subjective evaluations for other criteria. This is shown in Table 4.
Additionally, in order to illustrate the extent of the possible impact of the planning variants on the receiver, i.e. the Dunajec River, Fig. 2 shows hydrographs of flooding with the probability of 1% in Kamienica Nowojowska estuary-cross-section. It shows the flooding reduction size and the degree of its of delay in relation to the natural flooding $(Q)_{1\%}$.
Subsequent Tables 5 and 6 show the results conducted of a multi-criteria analysis aiming at indicating the variant preferred for task drainage basin Z34 (MGGP, 2014). This analysis was executed for 4 groups of issues on the basis of the calculated assessments of normalised values $\mathbf{OZ_{i,j}}$ and 3 weights variants adopted $\mathbf{WZ_j}$**.** Those weights were arbitrarily approved, for the purposes of this example, to examine their significance for the selection of the preferred variant.
As can be concluded from Table 6, the preferred variant in the Kamienica Nawojowska basin is the "WIIB" variant, which assumes building embankments in crucial points of the drainage basin. The selection process in this case is not dependant on the diversity of the weight system for criteria groups.

Table 3. Description of variants in the Kamienica Nawojowska basin
Tabuľka 3. Opis jednotlivých variantov v povodí Kamienica Nawojowska

Variant Name	Variant Description
Variant "W0"	Present state
Variant WI"	Variant "W0"unchanged – no investments planned
Variant "WIIA"	Construction of a dry reservoir, capacity: 15.5 million m3
Variant "WIIB"	Construction of 4 and modernisation of 6 embankment sections
Variant "WIIC"	Construction of 3 and modernisation of 6 embankment sections, and construction of a dry reservoir, capacity: 1.2 million m3

Table 4. Absolute effects r_i of planning variants in the Kamienica Nawojowska basin
Tabuľka 4. Absolútne efekty plánovacích variantov v povodí Kamienica Nawojowska

Variant	WI	WIIA	WIIB	WIIC
FLOOD CRITERIA GROUP				
Reduction in flood extent $Q_{1\%}$ expressed in value of protected land [mio PLN]	0	7,351	7,237	9,206
Reduction of danger to human life in the area $(Q)_{1\%}$ (depth > 0.5 m)	0	183	215	228
Reduction of flooding for $Q_{1\%}$ [%]	0	47%	0%	1%
SOCIAL CRITERIA GROUP				
Total land occupancy for the whole variant [ha]	0	120.60	1.85	33.78
Number of resettlements related to the variant implementation [number of inhabitants]	0	113	0	0
Total protected public utility facilities of particular significance for $Q_{0.2\%}$	0	61	49	4
ENVIRONMENTAL CRITERIA GROUP				
Impact on protected areas other than Natura 2000	10	7	10	8
Impact on the areas of Natura 2000	10	6	10	8
Possibility of natural compensation	10	7	10	8
Compliance with the WFD	10	8	10	8
ECONOMICAL-REALIZATION CRITERIA GROUP				
Costs of technical activities (construction costs, area buyouts [mio PLN]	0	65,697	17,099	28,804
The value of average annual maintenance costs [mio PLN]	0	1,340	0,269	0.512
Technical difficulty level of realisation	0	7	9	8

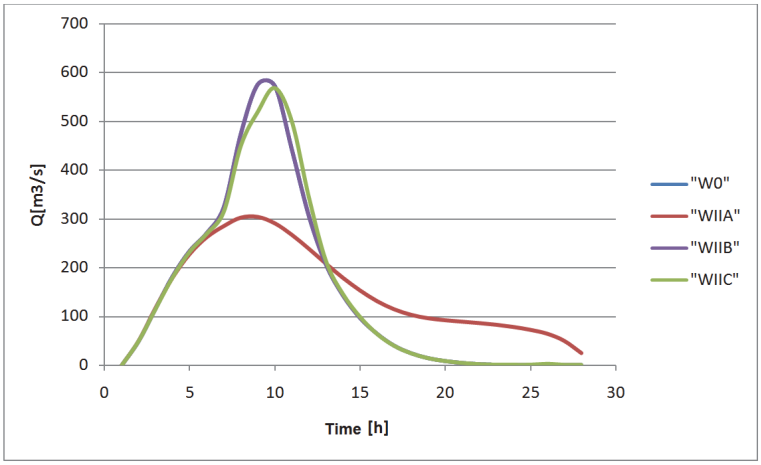


Fig. 2. The flooding size reduction and flooding shift on the Kamienica Nowojowska estuary-cross-section as a result of activities of planning variants.
Obr. 2. Redukcia veľkosti povodne a jej transformácia v čase v dôsledku plánovaných variantov v ústí rieky Kamienica Nowojowska.

Table 5. Normalised evaluation of the planning variants $OZ_{i,j}$ and variant weights WZ_j for criteria groups in the Z34 Kamienica Nawojowska basin
Tabuľka 5. Normalizované vyhodnotenie plánovaných variantov $OZ_{i,j}$ a váh variantov WZ_j podľa kriteriálnych skupín v povodí Z34 Kamienica Nawojowska

GROUP OF ISSUES	PLANNING VARIANTS OZi,j				WEIGHT VARIANTS WZj		
	WI	WIIA	WIIB	WIIC	Weights I	Weights II	Weights III
FLOODING	0.00	8.67	5.76	6.74	1	3	3
SOCIAL	6.67	3.33	9.29	5.94	1	2	3
ENVIRONMENTAL	10.00	7.00	10.00	8.00	1	1	1
ECONOMICAL	10.00	2.33	8.13	6.60	1	1	1

Table 6. Final weighted sums of normalised assessments SOZ_i in the Z34Kamienica Nawojowska basin
Tabuľka 6. Výsledné vážené sumy normalizovaných vyhodnotení SOZ_i v povodí Z34Kamienica Nawojowska

WEIGHT VARIANTS	PLANNING VARIANTS SOZi			
	WI	WIIA	WIIB	WIIC
Weighted total I	6.67	5.33	8.30	6.82
Weighted total II	4.76	6.00	7.72	6.67
Weighted total III	5.00	5.67	7.91	6.58

Summary

Investment programme for the drainage area of the Dunajec River involves:

- Increase in the anti-flood reserve of the Rożnów reservoir from 50 mio m^3 to **80 mio m^3** and change of control rules for the Czorsztyn reservior.
- Construction of 1 polder with a capacity of **0.048 mio m^3** and dry reservoirs with a total capacity of **3,773 mio m^3**.
- Modernisation of existing embankments at a length of **29.7 km** (23 locations), construction of embankments and promenades on the Dunajec River at a length of **17.5 km** (19 locations) and its tributaries at a length of **42.4 km** (105 locations).
- Construction of **4** pumping stations.
- Alteration of **23** bridges.

As a result of this programme implementation, compared to the current state, we protect against flood 1%:

- 9451 residents, constituting **80%** of people at risk
- 2036 residential buildings, constituting **79%** of buildings at risk
- 1276 farm buildings, constituting **66%** of buildings at risk
- 144 public utility facilities, constituting **68%** of facilities at risk
- 133 industrial facilities, constituting **73%** of facilities at risk.

At the same time, as a result of this programme implementation, flood wave with a probability of 1% at the confluence of the Dunajec River and the Vistula River reduces by 4% (ca. 250 **m^3/s**).
The presented approach complies with the requirements of the Floods Directive and is consistent with the "Methods of development of flood risk management plans for river basins and water areas" adopted in Poland by the National Water Management Authority (KZGW, 2013). The results of drainage basin studies implemented according to the proposed approach were used in the process of development of the flood risk management plans for the water area of the upper Vistula River.

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PRÍSTUP K VYPRACOVANIU INVESTIČNÉHO PROGRAMU PROTIPOVODŇOVEJ OCHRANY NA RIEKE DUNAJEC S PRIHLIADNUTÍM NA HĽADISKÁ OCHRANY ŽIVOTNÉHO PROSTREDIA

Článok pojednáva o prístupe uplatnenom v oblasti hornej Visly pre zvolenie optimálnych protipovodňových investícií na príklade povodia Dunajca.

Základom pre analýzy investičného programu je posúdenie stavu protipovodövej ochrany v povodí, ukazujúce na rizikové oblasti pre výstavbu a infraštruktúru, v ktorých by sa mali prijať určité opatrenia v oblasti ochrany pred povodňami, na základe rozsahu pravdepodobností $Q_{1\%}$ a $Q_{0,2\%}$. V celom povodí Dunajca je podľa vykonanej demografickej analýzy rizikom záplavy s pravdepodobnosťou 1,0% ohrozených takmer 12 tisíc ľudí. V záplavovej zóne pre prietoky $Q_{0,2\%}$ a $Q_{1\%}$ boli identifikované oblasti povodňového ohrozenia v ôsmich triedach využívania (obytné sídliská, priemyselné oblasti, doprava, lesy, zelené plochy a športové zariadenia, poľnohospodárska pôda, iné pôdy, vody), uzavreté konštrukcie (hospodárske budovy, bytové domy, priemyselné stavby, verejné budovy, cintoríny) a lineárne objekty (cesty, železnice).

Pre hydraulický výpočet bol použitý model MIKE 11. Zostavený model zohľadňuje aktuálne terénne údaje, postranné prítoky do hlavného toku, priebeh povodňových vĺn, vlhkosť pôd v údolí rieky a druh využívania pozemkov. Výsledkom modelovania sú podmienky prúdenia podzemných vôd pre celé povodie, dynamický systém hladiny vody, prognóza priechodu povodňovej vlny v každom prerieze, trvanie vrcholu vlny, maximálne objemy a prietoky, stanovenie priepustnosti pásma nábreží, označenie miest, ktoré nezaručujú potrebnú priepustnosť.

Do modelu Dunajca bol začlenený model nádrží Czorsztyn - Sromowce a Rožnów - Czchów, čím sa dosiahla integrácia existujúcich samostatných modelov fungujúcich pre každú časť povodia Dunajca.

Vytvorený bol katalóg technických (nádrže, nábrežia, atď) a netechnických činností (napr. vysídlenie). Sú vytvárané varianty obmedzujúce v rôznom stupni riziko povodní v celom povodí a následne na základe výsledkov hydraulických analýz, výhody a nevýhody v oblasti životného prostredia a v sociálnej oblasti, ako aj náklady na realizáciu variantov. Vykonáva sa finálna multikriteriálna analýza umožňujúca určiť preferovaný variant (v článku je príklad pre povodie riečky Kamienica Nawojowska). Analýza zahŕňala 13 kritérií definovaných v 4 skupínách (povodňové, sociálne, environmentálne a ekonomicko- realizačné).

Investičný program pre povodie Dunajca nakoniec predpokladá 186 činností, vrátane: zvýšenia povodňových rezerv nádrže Rožnów a zmeny pravidiel riadenia na nádrži Czorsztyn, výstavby poldra a suchých nádrží, modernizácie existujúcich hrádzí a budovania nových hrádzí a brehov, výstavby vodnej čerpacej stanice, rekonštrukcie mostov.

V dôsledku implementácie programu vo vzťahu k existujúcemu stavu chránime pred vodou 1%:

- 9451 obyvateľov, čo predstavuje **80%** ľudí v ohrození
- 2036 obytných budov, čo predstavuje **79%** ohrozených budov
- 1276 hospodárskych budov, čo predstavuje **66%** ohrozených budov
- 144 verejných budov, čo predstavuje **68%** ohrozených objektov
- 133 priemyselných zariadení, čo predstavuje **73%** ohrozených objektov.

Zároveň v dôsledku implementácie programu sa povodňová vlna s pravdepodobnosťou 1% pri ústí Dunajca do Visly zníži o 4% (asi 250 m^3/s).

Prezentovaný prístup spĺňa požiadavky Smernice o povodniach, a je v súlade s „Metodikou vypracovania

plánov riadenia povodňových rizík pre povodia a vodné oblasti", prijatou v Poľsku Národnou správou vodného hospodárstva. Výsledky analýz uskutočnených pre povodia podľa navrhovaného prístupu boli použité pri procese vytvorenia plánu riadenia povodňových rizík pre toky oblasti hornej Visly.

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