ECONOMIC EFFICIENCY OF FLOOD PROTECTION MEASURES

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ABSTRACT

The paper presents the results of long-term development of the methodology oriented on the flood protection measures economic efficiency evaluation carried out within the team of researchers from the Brno University of Technology, Faculty of Civil Engineering, Department of Structural Economy and Management and Department of Water Structures. The results consist in the complete methodology of the Territorial Property Index assessment, determination of potential damages caused by flood using the damage curves and in the identification of the approach for the economic efficiency calculation.

ИКОНОМИЧЕСКА ЕФЕКТИВНОСТ НА МЕРКИТЕ ЗА ЗАЩИТА ОТ НАВОДНЕНИЯ

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РЕЗЮМЕ

Докладът представя резултатите от дългосрочното развитие на методиката, ориентирана към оценка на икономическата ефективност на мерките за защита от наводнения, която е разработена от екип от изследователи от Техническия университет Бърно, Строителен факултет, Департамент по Икономика на строителството и

управление и Департамент по Хидротехнически съоръжения. Резултатите се състоят в цялостна методика за оценка на Индекса на собствеността на територията (Territorial Property Index), определяне на потенциалните щети от наводнението чрез използването на криви на щетите и идентифициране на подхода за изчисляване на икономическата ефективност.

1   Introduction

By the realization of suitable flood protection measure it is possible to avoid a part of potential losses connected with flood damages in the territory afflicted with the flood. However not in all cases the realization of suitable flood protection measure is easy and inexpensive matter. From this reason it is necessary just before the own realization of the project to proof its potential benefit for the territory. Very important part of the decision making process about realization of flood protection measure it is the analysis of the economic efficiency of their realization in the area threatened by the flood.

During the valuation of the economic efficiency of flood protection measures there are compared investment costs for their realization with total benefits that the realization of the projects brings in the future. Benefits of projects of flood protection measures realization occur mainly in the form of avoiding or at least decreasing of flood losses in the territory. If it is possible to find out the value of the property in the territory and the expected seriousness of damaging of the property by the flood with certain intensity, then it is possible to assign the expected loss caused by the flood with certain intensity. Depending on the lifetime of realized flood protection measures it is then possible based on the prediction of the frequency of floods causing the loss to predict the total loss that will be by the realized anti-flood operations avoided. For the flood protection measures´ realization total economic efficiency assessment it is next possible to use standard methods of the projects' efficiency valuation regarding the time value of expected benefits of the project.

2   Flood protection

According to the philosophy of the flood protection it is possible the flood protection measures characterize as:

- nonstructural flood protection measures
- structural flood protection measures

Nonstructural flood protection measures

- definition of flooding areas
- legislative assurance of flooding areas
- forecasting system
- early warning systems
- information of public

Structural flood protection measures

- retention
- increasing of watercourses capacity
- protection walls
- stabilization of watercourses
- regulation of forestry
- regulation of activities in agriculture

Next information to the classification and description of flood protection measures are available in following groundwork. [1] or [6]

2.1   Measures against the impact of water in the territory of drainage area

First group of measures can be in the form of regulation of forestry. It concerns mainly about the regulation of the range, kind and age structure of forests. The importance of these measures is in the area of retention, but only for floods with shorter time of repetition, more for better time spread of current precipitation flow off. Impact of these measures expresses

itself consequently and slowly and it is quite hard to prove higher effect of these measures on the retention. Next group of measures consists in the regulation of agricultural activity. As in the case of previous group has this group of measures also the maximal effect in the case of floods with lower period of repetition. Basic principle of these measures consists in avoiding of erosion mainly by increasing of the rate of permanent grass stand. The impact is faster than in the case of previous group, already in the second vegetative period.

The last group of measures in the territory of drainage area involves non-managed retention measures and measures against the erosion. These measures are effectual mainly in lower drainage areas and they can eminently decrease the impact of floods with low probability of appearance. Among non-managed retention measures belongs e.g. increasing of the retention space of ponds, dry dam reservoirs without manipulation, polders without manipulation, wetlands, ditches etc. [1]

2.2   Measures against the impact of water realized on watercourses

These measures can be divided into managed retention measures, cofferdams, increasing of the watercourse's capacity and the stabilization of the watercourse. Main representatives of managed retention measures are artificial lakes and polders. Artificial lakes allow the decreasing of the water flow under the dam and bring more time for the preparation of operation before the flood culmination. In the case of multipurpose artificial lakes there exists a danger of various priorities of subjects that want to use the lake for specific purposes (the question of differences between priorities of public and private sector).

Polders with managed watering and drainage are the compensation for the elimination of inundation areas protected by cofferdams or by the increasing of the watercourse capacity. It concerns about dry lateral dyked reservoirs with watering and drainage objects, the whole volume of reservoirs is intended for the retention. The disadvantage of these measures is the single finality and high requirements on the maintenance of technological parts. These measures decrease water flow under the polder and bring more time for the preparation of operation before the flood culmination.

Cofferdams are low homogenous dikes with the same of different level of the crest of the dike on both shores. Sometimes there arise the problems in the connection with the water

inflow, with drain of the water between dikes and the connection of the sewer network. Sometimes there is the necessity of the pumping of sewerage water, when there the risk of flowage of the protected territory by sewerage waters arises.

Increasing of the watercourse's capacity is the next kind of the flood protection. Until the reaching of supposed watercourse capacity these measures have nearly the same disadvantages, as the previous group of flood protection measures. But after reaching of this state is the protected flood plain with its empty inundation area ready to decrease the final impact of these higher floods, it decreases the impact on lower situated territories.

The last group of technical flood protection measures is connected with the stabilization of the watercourse. Very important activity that must be done for the assurance of operability is the maintenance of watercourses and flood protection measures. Regular maintenance consists mainly in the maintenance of vegetation bank reinforcement (grass, shrub, trees), the removing of sediments and impediments in the flow, maintenance of watercourse's reinforcement and removing of damaged state. Next measures in the frame of stabilization of watercourse belongs to the stabilization of longitudinal profile (weir plants, reinforcement of the bottom), stabilization of shores (vegetation reinforcement, "hard" reinforcement, combined reinforcement) or measures against sedimentation of watercourses (increasing of the water speed, removing of the source of sediments, mining of sediments). [1].

3   Costs and benefits of the flood protection measures realization in settled territories

3.1   Costs connected with flood protection measures

Investment costs

Investment costs are connected with the own project realization during the preparative and realization phase of the project. Investment costs are usually in the form of costs for the realization documentation preparation, costs for supplies of building objects and costs for deliveries of technologies. For the expected investment costs assessment it is needed the technical documentation of building object (drawings, design and technical report). For own evaluation of costs it can be used the price catalogue of building works and price catalogues

of material for valuation of materials in specifications. Other possible way is usage of prices agreed with sub-suppliers.

Appreciable operating costs

Appreciable operating costs of the anti-flood operation are connected with the assurance of utilization of anti-flood operation during its lifetime. The calculation of annual costs is necessary to individually respect the type of anti-flood operation and its location in the territory.

Appreciable costs caused by flood

For the assessment of appreciable costs in the form of potential losses on the property in the territory caused by the flood it is possible to use e.g. Territorial Property Index (TPI). TPI characterizes an average value of the property per the square unit of the territory (e.g. m2). Next tools are damage curves determining the rate of the damage of property representatives in the territory depending up the flood intensity.
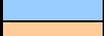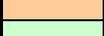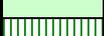
Other impacts

Beside appreciable costs arising during the project's preparation, realization, utilization or liquidation there exist certain number of costs that it is not so easy to express in monetary units. It concerns mainly about costs connected with the detriment of environment caused by the realization of the anti-flood operation, but these non-appreciable costs can arise also from other reasons. The main problem it is the question, how to express these costs in the project's economic efficiency valuation. One possible way is to verbally describe these influences and this description then to take into account during the final decision making. More difficult way is to evaluate these costs and to give them some value expressed in monetary units. This process is not easy, but there exist some methods, with their utilization we are able some non-appreciable costs to evaluate. Methods are based on the evaluation of non-profit goods and it concerns mainly about pricing methods and valuation approaches that will be characterized in following chapters. [4]

3.2 Groundwork the determination of losses caused by flood – territory categories

The basic principle of the expected losses on immovable property caused by flood assessment is the determination of the average value of the property per square unit of the territory and the losses prediction, which will be caused by the flood of the expected intensity. For the possibility of the more objective valuation of the property value it is necessary to divide territory into particular categories characterizing the way of the territory utilization. Particular territory categories come out from the territory planning documentation and their final form is displayed in the table 1.

Tab. 1 Territory categories

Color	Marking	Territory Category
	A	**Residential areas**
	B	**Recreational areas**
	C	**Areas of Civil Infrastructures**
	D	**Green Areas**
	E	**Mixed residential areas**
	F	**Transport infrastructure areas**
	G	**Technical infrastructure areas**
	H	**Areas for production and storage**
	I	**Mixed production areas**
	J	**Water and water-management areas**
	K	**Agricultural areas**
	L	**Woodland areas**
	M	**Natural areas**
	N	**Mixed parts of unbuilt-up area**
	O	**Mixed parts of unbuilt-up area**
	P	**Specific areas**

Source: [5], page 21

3.3 Assessment of value of the property in the territory – Territorial Property Index

In the frame of the total value of the property there is taken into account only the value of buildings, not pieces of land. For the calculation of the value of the property there are used reproduction prices of the property. The main reason is that it will be in the next step used for calculation of losses on the property, which are defined as costs necessary for repairs and

reconstructions – construction works. The territory property index expressing the value of the property per the square meter is calculated using following relation:

$$TPI = \frac{VPT}{TRA}$$

where:

TPI   Territorial Property Index,

VPT   Value of Property in Territory,

TRA   Total Residential Area.

The first step is the transformation of lands (built-up area, floor area) of particular building objects from the previous acreage of solved area (104,678 m^2) into hectare (10,000 m^2). The purpose of this step is only the achievement of better transparency. The next step is the expression of the area of particular objects in square meters of built-up area. The reproduction value of particular building objects is consequently assessed using techno-economic indexes in monetary units per square meter of the built-up area. Techno-economic indexes it is necessary to transfer into appropriate price level (2010).

Tab. 2 Representatives in particular categories of the territory

Code	Name of representative	Built-up area (m^2)	Land acreage (m^2)	Techno-economic index (CZK/m2)	Total value (CZK)
803 3	Apartment buildings till 4 floor	120.0	362	77,426	9,293,112
803 5	Apartment buildings over 4 floor	6.2	37	65,604	406,194
803 6	family houses	1,988.6	7,983	31,377	62,397,011
801 1	Buildings for health care and services	17.3	45	120,508	2,087,356
801 2	Buildings for municipal services and hygiene	0.6	4	120,508	77,670
801 3	Buildings for education and training	58.7	646	84,177	4,940,951
801 4	Buildings for science, culture and education	4.5	18	134,833	600,175
801 5	Buildings for physical education	11.5	19	44,239	510,705
801 6	Buildings for administration	4.4	16	79,085	344,717
801 8	Buildings for commerce and public catering	24.5	130	88,282	2,159,358
801 9	Buildings social care	8.3	23	52,948	438,515
812 1	Buildings manufacturing industry, special	0.5	1	90,614	44,114

823 3	Areas for Physical Education uncovered	485.0	485	1,537	745,526
812 6	Additional objects	185.7	186	26,671	4,953,052
822 5	Objects of technical equipment	43.1	45	2,093	90,226
	Totally	**2,959**	**10,000**		**89,088,682**

From the table it is possible to derive result value of the Territory Property Index TPI 8,909 CZK/m^2 (1 EUR is app. 25.8 CZK, TPI = 345 EUR/m^2).

3.4 Groundwork for assessment od expected losses caused by flood – damage curves

The damage of the immovable property it is possible to assess using damage curves displaying percentage damage of property representatives depending on following three flood parameters:

- deepness of water,
- duration of the flood,
- influence of subsoil.

As basic parameters for the construction of particular curves were used deepness of water and the duration of the flood, separately for particular building objects on bearable and unbearable subsoil. Damage curves were carried out for many building object, the example for family house sis displayed in picture 1.
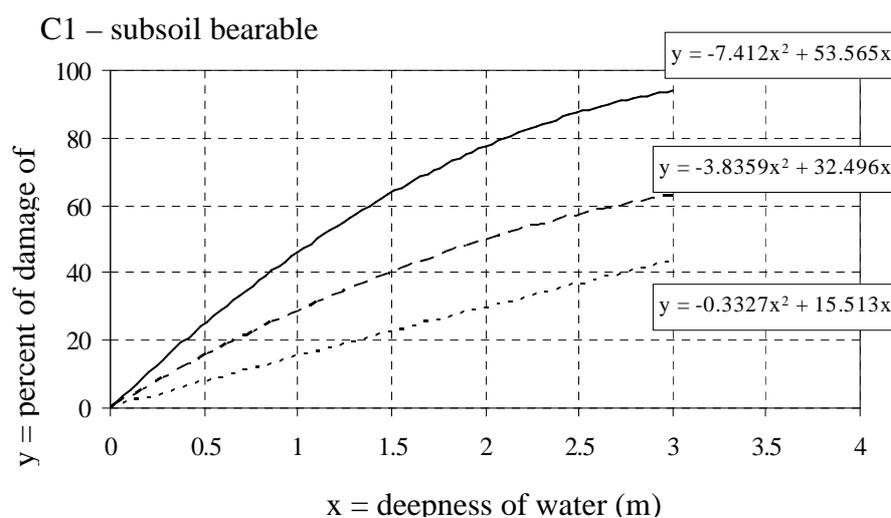

C1 – subsoil bearable

$y = -7.412x^2 + 53.565x$

$y = -3.8359x^2 + 32.496x$

$y = -0.3327x^2 + 15.513x$

y = percent of damage of

x = deepness of water (m)

Fig. 1 Damage curves for separate one-flat family houses (source [5]. str. 91)

Detailed information about the damage curves and their detailed overview is listed in sources [5], str. 84 - 103, a [8].

3.5 Flood losses prediction

The prediction of flood losses is based on the financial evaluation of damages caused by flood. The losses assessment is in this case limited on losses in the territory category A – Residential areas. Groundwork for the prediction of losses is in the form of reproduction values of particular representatives of the property per square unit of the territory of the category A. For defined parameters of the flood (quality of subsoil, duration of flood and deepness of water) there are consequently using regression analysis derived loss curves characterizing dependence of the total loss on the deepness of water by defined quality of the subsoil and the duration of flooding. For derivation it is possible to carry out following steps:

- the assessment of the damage (in %) for particular property representatives in dependence on quality of subsoil, duration of flood and deepness of water,
- the assessment of the loss on particular representatives caused by flood,
- the derivation of the dependence of the total loss on property in the territory on the quality of subsoil, duration of the flood and the deepness of water.

3.5.1 The assessment of the percent of damage for particular representatives of the property and the assessment of the loss on particular representatives

The percent of the damage of particular representatives of the property it is possible to derive using damage curves, which are for solved property representatives described in source [5], page 84 – 103. These curves express dependence of the percent of damage of specific representative on the deepness of water and they are constructed for particular types of the subsoil and the duration of the flood. Consequent calculations are carried out for bearable subsoil and for duration of the flood till 1 day, from 2 till 7 days and more than 7 days. The example of the calculation of the damage and losses on representatives of the property in residential areas is in the following table.

Tab. 3 Scenario 1 (duration of the flood till 1 day, deepness of water 4 m)

Name of representative	Damage %	Reproduction price CZK/ha	Loss totally CZK/ha
Apartment buildings till 4 floor	17,0192	9 293 112	1 581 613
Apartment buildings over 4 floor	17,0192	406 194	69 131
family houses	56,7288	62 397 011	35 397 076
Buildings for health care and services	51,5440	2 087 356	1 075 907
Buildings for municipal services and hygiene	51,5440	77 670	40 034
Buildings for education and training	51,5440	4 940 951	2 546 764
Buildings for science, culture and education	51,5440	600 175	309 354
Buildings for physical education	51,5440	510 705	263 238
Buildings for administration	51,5440	344 717	177 681
Buildings for commerce and public ery	51,5440	2 159 358	1 113 020
Buildings social care	51,5440	438 515	226 028
Buildings manufacturing industry, special	59,4568	44 114	26 229
Areas for Physical Education uncovered	29,1792	745 526	217 538
Additional objects	59,4568	4 953 052	2 944 926
Objects of technical equipment	50,7528	90 226	45 792
Total loss of territory representative			**46 034 331**

The calculations were carried out only for one variant of deepness separately for each property representative.

3.5.2 Derivation of the dependence of the total loss on the property in the territory in the quality of subsoil, the duration and the deepness of the flood

In the previous part there is assessed the loss on property for particular property representatives. The sum of partial losses is the total loss on the property in the territory for defined quality of the subsoil, the duration and the deepness of the flood. The goal of the chapter is to determine general relation, which expresses the unit price (related to m^2) in valuated territory in dependence on the deepness of flooding. There will be used the regression analysis, regression curve is the polynomial of the second degree. In the following table there are displayed inputs for the regression analysis, which are derived using repeating calculations in previous table.

Tab. 4 Inputs for regression analysis

Duration of the flood till 1 day		Duration of the flood from 2 till 7 days		Duration of the flood more than 7 days	
Deepness	Loss CZK/m2	Deepness	Loss CZK/m2	Deepness	Loss CZK/m2
x	y	x	y	x	y
0,0	0	0,0	0	0,0	0
0,5	640	0,5	1239	0,5	2035
1,0	1261	1,0	2340	1,0	3806
1,5	1864	1,5	3303	1,5	5312
2,0	2449	2,0	4129	2,0	6555
2,5	3015	2,5	4816	2,5	7534
3,0	3563	3,0	5365	3,0	8246
3,5	4092	3,5	5776	3,5	8700
4,0	4063	4,0	6049	4,0	8887

The results of the regression analysis are relations (loss curves) expressing the dependence of the unit loss (in CZK/m^2) in category of territory A – Residential areas on the deepness of flooding, and this for specified quality of the subsoil and the duration of flooding.

3.5.3 Overview of assessed loss curves for category territory A – Residential areas

Quality of subsoil:	bearable subsoil
Duration of the flood:	till 1 day
Loss curve:	$y = -89{,}668x^2 + 1423{,}6x$
The value of reliability:	$R^2 = 0{,}994$

Quality of subsoil:	bearable subsoil
Duration of the flood:	2 - 7 days
Loss curve:	$y = -276x^2 + 2616{,}3x$
The value of reliability:	$R^2 = 1$

Quality of subsoil:	bearable subsoil
Duration of the flood:	more than 7 days
Loss curve:	$y = -527{,}87x^2 + 4333{,}1x$

The value of reliability: $R^2 = 1$

The graphic expression of the dependence is in following graph.

Flood longer then 7 days
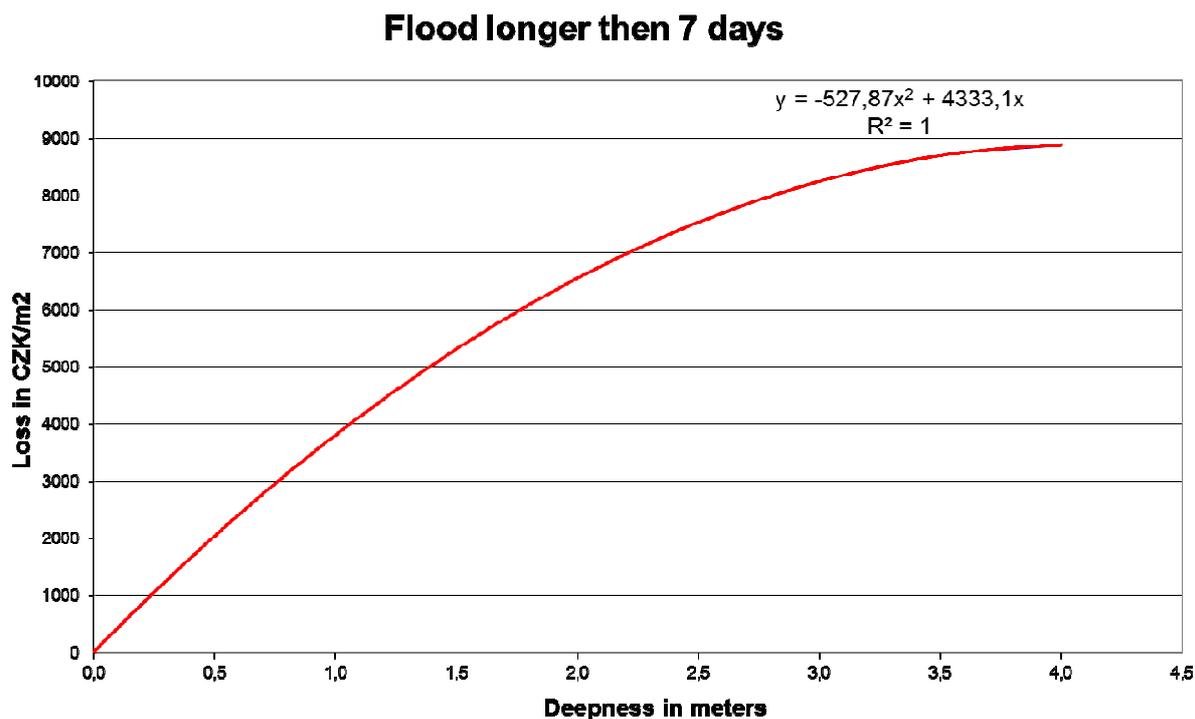
Fig. 2 The dependence of the loss value on the immovable property in category territory A on the deepness of the flood

4   Economic efficiency of the flood protection

The assessment of the economic efficiency of the investment project provides information, which economic impact on the society the project will have. Generally it concerns about the comparison of in monetary units expressed benefits and costs of the project. If the benefits and costs are spread into time, it is necessary to respect their time value. In the case of projects of the flood protection the costs and benefit can be characterized as investment costs, operation costs, savings of costs in the form of avoiding of losses and other impacts not primarily expressed in monetary units. The result efficiency it is possible to assess according to the following relation.

$$NPV_E = \sum_{i=1}^{n} \frac{B - C}{(1+r)^i}$$

where:

NPV$_E$ Economic Net Present Value,

B   in monetary units expressed benefits of the project,

C   in monetary units expressed costs of the project,

r   discount rate,

n   lifetime of the project, the duration of the valuated period in years.

Mainly in the case of savings of costs connected with the avoiding of losses on property caused by flood it is necessary to respect the fact that flood losses do not arise regularly each year, but randomly with certain rate of probability, which it is necessary in the calculation of the economic efficiency to take into account.

The result of the comparison and the main index of the investment project economic efficiency it is the Economic Net Present Value (NPVE), which it is possible to calculate with the help of following relation:

$$NPV_E = \sum_{i=1}^{n} \frac{1}{(1+r)^i} \left[\sum_{j=1}^{m} p_j \left(C_{ij}^0 - C_{ij}^I \right) \right] - IC$$

where

NPV$_E$ Economic Net Present Value

IC   Investment costs

C$_{0ij}$ j - kind of costs in zero option in i - time period

C$_{Iij}$ j - kind of costs in investment option in i - time period

r   Discount rate

n   Life time of the investment project, event. duration of the valuated project's time period (in years)

m   Number of costs identified in the frame of the projects

p$_j$ Probability of j - cost, it must be $\Sigma pj = 1$

Practical use of defined relation consists in the identification of particular states of the world characterized by certain intensity of the flood (and also by the loss that the flood causes), that can turn up during one year, and in assigning of probabilities of the occurrence of particular states of the world. This identification must be realized for particular years of the valuated period. The characteristic of particular states of the world and the identification of their probabilities must be realized regarding the local conditions of the solved territory. For the assessment of potential losses on the property in the territory caused by the flood it is possible to use e.g. Territorial Property Index characterizing an average value of the property per the square unit of the territory (e.g. m2) and damage curves determining the rate of the damage of property representatives in the territory depending up the flood intensity. More detailed information about the flood protection measures efficiency determination is available e.g. in [2], [3] or [7].

5   Conclusions

The realization of suitable flood protection measures in the territory threatened by flood can be in many cases quite difficult for financing. This is the main reason, why it is very important objectively to valuate the economic efficiency of these operations and directly to determine the total economic impact of these operations on the territory. This paper in the first part describes the basic principle of the economic efficiency of flood protection measures´ valuation. There are also described particular kinds of costs that can arise together with the realization of these projects.

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