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Economic appraisal of flood protection projects

Abstract. A model of the economic appraisal of flood protection projects using the NPV indicator is presented with a recent enlargements concerning economic valuation of casualties and psychological losses in victims' well-being. This year's series of big floods in Poland has made this topic come back to public attention.

Key words: flood, casualties, losses, economic appraisal.

Introduction

This year's (2010) series of big floods in Poland has turned the public attention again to the issue of flood protection, its costs, effectiveness and the losses in case it is insufficient. The frequency of big floods in this country seems to rise, we experienced big events of the kind in 1997, 2001 and this year. Żuławy is a region in Poland where smaller or bigger floods happen every year. The model presented below was constructed originally for use in appraisal of flood protection measures taken in this region after a big flood of 1983 [Manteuffel 1986 & 1987]. It has also partly taken advantage of a feasibility study of another flood protection project conceived after another flood in 2009 [Studium… 2010]. Both applications have dealt in most part with floods in rural areas which gives grounds for publishing this paper in an agricultural economic journal.

Model

The standard NPV (Net Present Value) method is the most suitable for an economic appraisal of long lasting projects like those sacrificed to flood protection. The general formula for calculating an NPV indicator runs as follows

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$$NPV = \sum_{t=0}^{T} \frac{1}{(1+R)^t} * (B_t - C_t)$$

where:

NPV – indicator of project's economic efficiency being an algebraic sum of benefits (+ sign) and costs (- sign) occurring in individual years of projects lifetime, beginning with the start of investments and ending with the last anticipated effects of its functioning, all discounted to the present moment of making a decision on its execution

B_t – benefits obtained thanks to the project's execution in year t

C_t – costs borne (represented by both investments and operation & maintenance outlays) within the project in year t

R – discount rate

T – time horizon of the calculation, which means the last year the benefits and costs will occur

t – current index meaning year's number.

Both benefits and costs are inserted in form of money flows or economic values of outputs and inputs at the time of their occurence.

The NPV indicator tells us what is the present value of net effects brought by the project over its whole economic lifetime, i.e. what the project is worth at present. A positive value of NPV (> 0) signifies the project is economically efficient and worth execution.

Flood protection projects have as a rule multiple beneficiaries and are financed from multiple, mostly public funds. Therefore their appraisal usually requires a cost-benefit analysis from both microeconomic (from the perspective of individual stakeholders) and macroeconomic (from the general social perspective, regardless of who bears the costs and who enjoys the benefits) point of view. The first case is nowadays usually called financial, the other economic analysis, in particular in the feasibility studies supplementing the applications for the EU subsidies [Guide… 2003]. Both types are in fact economic analyses, but the first one has first of all the aim of exploring the project's financial feasibility for the main investor. Flows of economic values caused by a project (traditionally called cash or money flows, though in the social analysis they have frequently non-monetary character) in many cases differ significantly between a social and an individual perspective. A standard procedure is to begin with a financial analysis and then to revalue individual flows to their social value, moreover with adding some non-monetary flows [Guide… 2003; Studium… 2010]. This paper will not deal with multiple ensuing, sometimes complicated, problems arising from this double valuation.

If a project covers a vast protected area, it can be usually divided into a series of sub-projects which are aimed at protecting only some subdivisions of the whole area, though in many cases depending on functioning of some structures or installations common to the whole project. However, the other sub-projects do not depend on existence of a particular sub-project and can do without it. Therefore some investment and operational outlays which are connected with only one individual subdivision of the total area are treated separately in the model, in order to make possible their elimination in case of a need to curtail the project.

Benefits can usually be easily assigned to individual subdivisions of the total protected area.

In the light of above said the general formula should be extended to a form of

$$NPV = \sum_{t=0}^{T} \frac{1}{(1+R)^t} * (B_{it} - \sum_i C_{it} - CC_t)$$

where:

i – index number denoting the serial number of an individual subdivision of the project

C_{it} – costs which can be assigned only to the i-th subdivision of the project, in year t

CC_t – costs which can be assigned only to the project as a whole, in year t.

There are many types of floods which may occur on the area to be protected[3]. Each of them has a certain probability of occurrence which is a function of a specific water level.

The probability function of occurrence of different water levels can be approximated by a matrix representation in which the function values are discretised for certain water levels singled out (or rather singled out intervals of water level) and it can be estimated basing on historical hydrological data.

Connected with this function is another one which describes the probability of food occurrence when a specific water level occurs. Connection between a water level and flood occurrence can be in many cases treated only in probability terms. A flood need not necessarily come with a certain water level, it may depend on the effectiveness of the anti-flood action or on time a certain level is maintained. This occurrence depends also on the state of existing flood protection structures. This state in turn is usually a function of time. Therefore this matrix (if we approximate the function by its matrix form) has also a time dimension.

The final function of flood occurrence can be represented as a matrix of products of these two probabilities.

If there is such a need, matrices of this type should be prepared for each type of flood separately. Not all types of flood are observed in some neighbourhoods.

The main and generally acknowledged effect of flood protection is a reduction of losses in property situated in protected areas. This property can be divided into relatively homogenous categories and inside these categories into still more homogenous subcategories. The homogeneity refers to relatively similar values of loss coefficients in case of a similar flood events. Depending on the availability of data, these coefficients can have a percentage form, when the property has been evaluated in monetary units, or a monetary form in case the property is given in natural units. A classification like the above usually facilitates the estimation of flood losses. The losses should include not only the loss in property substance, but also the losses due to an interruption of normal functioning of the structures or installations damaged, like an interruption in electric energy supply to households or in production activity, like cow milking.

Since the calculation covers a long time span, changes in the volume and value of protected property can be expected. Therefore a prognosis of these changes is needed. The most popular types of this forecast are a linear model (repeated annual increase by a constant percentage of the initial value) and a geometric (exponential) model (annual increase by a constant percentage of the previous year's value). Stagnation is also possible,

[3] Summer precipitation floods, spring snowmelt floods, winter ice-jam provoked floods, sea storm water compouding floods.

but in normal times people's wealth usually grows. In extreme cases also a decrease in property value may occur, if some other locations become comparatively more attractive for investments.

It can be taken for granted that the growth in property value will be much quicker in case of an increased protection due to the project's implementation, since investors are usually quite risk sensitive.

The savings in flood losses can be calculated as

$$L_{it} = \sum_{jk\,ln} P_{ijk} * (PLC_{ijklm} + ILC_{ijklm}) * (PGCWt_{ijkt} * FPWt_{ilmt} - PGCW_{ijkt} * FPW_{ilmt})$$

where:

L_{it} – expected value of avoided losses in area i in year t

P_{ijk} – initial value (or volume, depending on units the property loss coefficient is measured in) of protected property in category j, subcategory k, situated in area i

PLC_{ijklm} – property loss coefficient in case of flood type m with water level l specific for property in category j and subcategory k situated in area i[4]

ILC_{ijklm} – income loss coefficient in case of flood type m with water level l specific for property in category j and subcategory k, situated in area i, caused by an interruption in normal economic activity attached to this property

$PGCWt_{ijkt}$ – property growth coefficient for property in category j, subcategory k, situated in area i, until year t, in case without project implementation

$PGCW_{ijkt}$ – property growth coefficient for property in category j, subcategory k, situated in area i, until year t, in case with project implementation

$FPWt_{ilmt}$ – occurrence probability for flood type m with water level l, situated in area i, in case without project implementation

FPW_{ilmt} – occurrence probability for flood type m with water level l, situated in area i, in case with project implementation.

[4] In a study of the post 1983 flood project in Żuławy, data from a statistical report on real property situated in individual communes prepared by the Central Statistical Office in 1978 and from local post flood reports were used which have since then probably lost their significance [Manteuffel 1986]. The protected property was in this rural area divided into the following categories, then divided into subcategories:

- roads
- railroads
- energy installations
- telecommunication
- other infrastructure, shops, public utility buildings
- dwelling houses and farm buildings
- centres of big farms (then state or cooperative owned) and agricultural service stations (like tractors and agricultural machinery repair shops)
- livestock
- crop fields as well as irrigation and drainage installations.

The loss coefficients had a form of a flat sum per natural unit for a specific subcategory, e.g. per hectare of a flooded field. They were estimated basing on indemnities paid to the flood victims by a state-owned insurance company. Since it was a winter flood, some losses were noticed only in winter barley and winter raps. The other crops did not yield less than in non-flooded fields.

In the other quoted study, the loss coefficients were taken from insurers' estimates, for multi-family dwelling houses they equaled 5% of building's value and 25% of house equipment [Studium… 2010].

Another vital component of increased flood protection effects can be identified as an additional intensification and development of economic activities in consequence of an increased flood safety in the area. This might be calculated as

$$IEF_{it} = \sum_{jk} P_{ijk} * (PGCW_{ijkt} - PGCWt_{ijkt}) * PR_{ijk}$$

where:

IEF_{it} – intensification effect in area i in year t

PR_{ijk} – net annual productivity of property in category j and subcategory k situated in area i.

Among the effects of a flood protection project may also be counted the saved operation & maintenance costs of the existing flood protection structures and installations which will be replaced by new ones in case of project's implementation. Let them be noted as $OMCWt_t$ (O&M costs without the project).

Next effect in a row is saving costs of both anti-flood and flood relief actions. If the frequency of floods is reduced, so are the costs of these actions. The saved costs can be calculated as

$$CFAS_{it} = \sum_{lm} CFA_{ilm} * (FPWt_{ilmt} - FPW_{ilmt})$$

where:

$CFAS_{it}$ – presumptive avoided costs of anti-flood and flood relief actions in area i in year t

CFA_{ilm} – presumptive costs of anti-flood and flood relief action in area I, in case of flood type m with water level l (for the sake of simplification it can be assumed they are independent of the rise in the protected property value).

In a recent study by Liziński, Bukowski and Wróblewska [Studium… 2010], another two effects have been considered, not included in the original model. First of them was the economic value of casualties avoided thanks to the enhanced flood protection.

The economic value of a human life lost has been a frequent topic of research over the last decades. In Poland, a thorough work in this field was done by Giergiczny & team [Giergiczny 2006; Markiewicz 2007]. Estimated by using two methods, the values differed significantly. When the method of compensating wage differentials (increase in wage that induces people to take a job risking a fatal incident) was used, a mean VSL (value of statistical life) was estimated by Giergiczny [2006] at 9.1 million PLN in 2005 prices, or at 4.49 million PLN quoted by Markiewicz [2007]. When a contingent valuation method was used (a survey of a representative sample from population, asking respondents with direct questions) an interval between 0.28 and 4.01 million PLN is quoted by Markiewicz [2007].

The economic value of casualties avoided is no doubt an effect of flood protection. It can possibly be portrayed by an estimation of number of casualties caused by a specific flood multiplied by VSL

$$CCA_{it} = CA_{ilm} * VSL * (FPWt_{ilmt} - FPW_{ilmt})$$

where:

CCA_{it} – social cost of casualties avoided in area i, in year t

CA_{ilm} – casualties in case of a flood of type m with water level l, in area i

VSL – value of statistical life (a simplification, since certainly the social values of life of different individuals differ a lot, and flood casualties can hardly be treated as typical for the whole population).

Another effect considered by Liziński, Bukowski and Wróblewska [Studium… 2010] was the avoided detrimental psychological effect floods cause in the well-being of inhabitants of the flood endangered areas. Their investigation, by means of the contingent valuation method, gave as a result 540 PLN/adult person/year for dwellers and 4 times the material losses for the businessmen whose activity was located in the endangered area [Studium… 2010]. Therefore the total psychological (welfare) effect can be calculated as

$$WE_{it} = DN_{it} * PED_{it} + BN_{it} * PEB_{it}$$

where:

WE_{it} – welfare effect of flood protection in area i and year t

DN_{it} – number of dwellers in area i in year t (the number of dwellers may change with time)

PED_{it} – psychological effect per inhabitant of area i in year t, represented by his/her willingness to pay for avoiding the fear of flood (his/her risk aversion expressed in terms of willingness to pay may change with time)

BN_{it} – number of businessmen in area i in year t (their number may change with time)

PEB_{it} – psychological effect per businessman in area i in year t represented by his willingness to pay for avoiding the fear of flood (his risk aversion expressed in terms of willingness to pay may change with time).

Total effects in area i in year t sum up to

$$B_{it} = L_{it} + IEF_{it} + CFAS_{it} + CCA_{it} + WE_{it}$$

Total effects (benefits) of a flood protection project would then become

$$B_t = \sum_i B_{it} + OMCWt_t$$

The $OMCWt_t$ costs (or, in a NPV calculation rather expenses) can be divided into those assigned to individual protected areas and to the project as a whole.

A more detailed formula for an NPV calculation takes a form of

$$NPV = \sum_{t=0}^{T} \frac{1}{(1+R)^t} *$$
$$[\sum_i (L_{it} + IEF_{it} + CFAS_{it} + CCA_{it} + WE_{it} + OMCWt_{it} - IC_{it} - OMC_{it}) + OMCWt_t - IC_t - OMC_t]$$

where:

IC_{it} – investments which can be assigned only to the area i, in year t

IC_t – investments which can be assigned only to the project as a whole, in year t

OMC_{it} – operation & maintenance costs which can be assigned only to the area i, in year t

OMC_t – operation & maintenance costs which can be assigned only to the project as a whole, in year t

$OMCWt_{it}$ – avoided operation & maintenance costs which can be assigned only to the area i, in year t, in case without project

$OMCWt_t$ – avoided operation & maintenance costs which can be assigned only to the project as a whole, in year t, in case without project.

This type of analysis can be applied to individual areas separately, by skipping the costs and benefits connected with other areas and the whole of the project, in order to check if including protection of an individual area is worthwhile.

Among many other efficiency indicators basing on the NPV, the most popular are its equal annual equivalent and internal rate of return.

$$EAE = NPV * \frac{R * (1+R)^T}{(1+R)^T - 1}$$

where:

EAE – expected annual equivalent of NPV, denoting an equal every year net effect of the project over its whole lifetime when the discount rate is R.

Internal rate of return (IRR) means a value of the discount rate which drives the NPV down (or upwards in projects with a negative NPV) to zero. The bigger the IRR the better, since it means that the benefits which come naturally later than the costs (investments in particular) must be discounted stronger in order to make them equal with the costs that come earlier. This rate can be compared with the usual rate of interest applying to investor's capital (its opportunity cost). Since the NPV calculations are usually made in constant (fixed) prices, real (and not nominal) values of rates are compared.

Risk analysis

A decision under risk is the one that depends on aleatory values of certain variables whose probability distribution is known to the decision maker.

In the economic analysis of such decisions, a risk analysis is routinely required [Guide… 2003]. A standard procedure in this case is the so called Monte Carlo analysis.

This analysis makes use of the known distributions of external variables influencing the final result, in the present case the NPV indicator. Parameters of these distributions (in case of the most frequent normal distribution it is the mean and the standard deviation) are fed into the computing programme. Then, a long series of runs computing the dependent variable (in this case the NPV, according to the above presented model) is made with different possible values of the external variables generated by an aleatory numbers generator. Such generators are built into many computer applications, including the most popular spreadsheet programs like Excel. The series of results gives a sample distribution of results which is treated as a base for estimating the probability distribution of analysed variable and therefore as a base for estimating the stability of results within certain value brackets and the risk attached to the venture. Risk means in this case the probability of getting an unfavourable result, a negative NPV in particular. For larger models, a number of trial runs above 500 is practically advisable.

In the above presented model, the variables most susceptible to random variation and therefore predestined for a Monte Carlo analysis seem to be [Manteuffel Szoege 2003; Studium… 2010]:

- PLCijklm – property loss coefficient in case of flood type m with water level l, specific for property in category j and subcategory k, situated in area i

- ILC_{ijklm} – income loss coefficient in case of flood type m with water level l, specific for a property in category j and subcategory k, situated in area i, caused by an interruption in normal economic activity attached to this property
- $PGCWt_{ijkt}$ – property growth coefficient for property in category j, subcategory k, situated in area i, until year t, in case without project implementation
- $PGCW_{ijkt}$ – property growth coefficient for property in category j, subcategory k, situated in area i, until year t, in case with project implementation
- $FPWt_{ilmt}$ – occurence probability for flood type m with water level l, situated in area i, in case without project implementation
- FPW_{ilmt} – occurence probability for flood type m with water level l, situated in area i, in case with project implementation
- PR_{ijk} – net annual productivity of property in category j and subcategory k, situated in area i
- CA_{ilm} – number of casualties in case of a flood of type m with water level l, in area i
- PED_{it} – psychological effect per inhabitant of area i in year t, represented by his/her willingness to pay for avoiding the fear of flood
- PEB_{it} – psychological effect per businessman in area i in year t represented by his willingness to pay for avoiding the fear of flood.

Distributions of these variables can be taken for relatively independent, though some parallels might be detected in some cases and therefore parallel values used in individual trial runs.

In a simplified attitude to the risk analysis an analogous determination (using the same randomly generated parameter value) of variable values over the whole time horizon is assumed. This could be treated as generating generally more or less pessimistic or optimistic variants of the future aleatory conditions. A more precise attitude would allow for an independent determination (generation) of a random variable value in each year of the analysis. In a still more sophisticated attitude, a stochastic dependence between values in neighbouring years could be applied. Both would, however, require a lot more sizeable computational effort of a doubtful final usefulness.

A sensitivity analysis makes another part of risk analysis frequently applied. It simulates the behaviour of final result as a consequence of a certain probable change in value of a parameter vital for the calculation. Changes of a significant and rounded magnitude are usually tried, like 10%, 20% or 50%. In the presented case, varying the $PGCWt_{ijkt}$ and $PGCW_{ijkt}$ parameters, most probably with uniform variation for all t years, seems to be worth trying. The sensitivity analysis may concern also some external economic parameters, like the wages growth, energy prices growth and services prices growth, all in real terms, which would influence future costs of the project, both borne and avoided [Studium… 2010].

Flood damages

Natural conditions in our country are favourable for human settlement, also from the perspective of flood dangers. Big floods, however, occur in Poland with a frequency of several years and this frequency seems to have risen in the last decades. The material losses naturally also rise together with the growing, in peaceful times, national wealth. These losses depend on the intensity of human activities in the endangered areas. Therefore one of the principles of flood protection is to avoid locating valuable investments in these areas and to construct protective structures in the second order [Johnson 1976; Lind 1967]. Potential losses should be in advance calculated as a part of hardly evitable costs in the feasibility studies for investments located in the endangered sites [Stedinger 1983]. Steadily progressing urbanization of natural lands makes a great difference in the precipitation water outflow because of hardening the ground surface, from a ratio surface/underground outflow of 10%/90% to a ratio of 60-90%/40-10%.

Table 1 displays very rough estimates of flood losses in our country in the last decades, in years of big floods.

Table 1. Estimates of flood damages subsequent to big floods of national scale in Poland

Type of damage	Year											
	1934[5]	1958	1970	1977	1979	1980	1981	1982	1983	1997	2001	2010[6]
Flooded area, thousand hectare	250	352	156	215	470	1745	80	111	14	521	402	400
Destroyed and damaged buildings, thousand	22.0	27.0	23.0	10.0	17.7	26.0	7.5	6.6	1.0	72.39	25.9	2
Damaged and destroyed bridges	102	1207	1400	612	147	135	29	617	47	4048	2254	1469
Destroyed and damaged state roads, km	100	596	751	2321	478	348	68	618	140	14432	56343	81160
Destroyed and damaged flood dams, km	100	330	100	38	118	14	47	94	29	721	450	185
Number of person evacuated, thousand	0.1	55.6	35.0	20.0	33.2	4.0	1.3	16.0	2.0	150.0	20	23
Casualties	x	x	x	x	x	x	x	x	x	54	18	9
Losses, million PLN, price level 2009	979	1201	1587	2670	1877	5384	589	879	438	21108	4108	10000

x means data not available to the authors

Source: own calculations and [Borowski 1984; Powódź 2010 będzie… 2010; Już… 2010; Ochrona… 1995-2009 passim; Środki… 2010; Mazik… 2010].

Once the property is reckoned to be worth protecting, the adequate structures should be built and well maintained. Unfortunately this is not the case in our country.

5 Losses of 1934 recalculated to the 1999 price level by dividing the losses by the exchange rate to the USD in 1934 (5.3 zloty/USD), multiplied by the average rate in 1999 (3.98 PLN/USD) and by the USD inflator in years 1934-1999 equal to 12.42 [U.S. Department… 2003]. Other losses recalculated with the Polish consumer price index.

6 Losses recorded and reported for the period up to July 22nd 2010, not final data, price level 2010.

The probably most known example are dry polders in the outskirts of Wrocław built in German times and after the war inconsiderately converted into residential quarters of the city. For some reasons a flood dam there has never been constructed [Powódź 2010: można… 2010]. Governmental plans of construction or reconstruction of a series of flood dams and flood water reservoirs conceived in 2007 were nullified after a change in power next year.

Before the flood of 1997, 25% of existing flood dams in Poland needed an urgent reconstruction, the same applied to 20 out of 240 flood water reservoirs [Ambrożewski 1997]. This seems to be a permanent state, since the budgetary allotment for construction and reconstruction of flood dams in the 80ies covered only between 20% and 30% of the needs [Bartoszek 1997]. In March 2010, the Chief Controlling Chamber stated that a half of flood dams in the Małopolska region (worst flooded in May and June) did not guarantee safety because of their state [Znowu… 2010].

The permanent deficits in public finances cause big delays in payments to the construction firms for the reconstruction works on flood dams, sometimes driving them to the brink of insolvency [Szczygielski 2002]. Meanwhile their work does count, e.g. the flood of 2001 destroyed 10% (in value terms) of the main water regulating structures in the country [Kaca, Lipiński & Mosiej 2002].

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