Journal of Coastal Research	SI	95	1217–1222	Coconut Creek, Florida	2020

Spreading the Use of Economic Methods in Coastal Risk Management: A Simple but Insightful "Calculator"

www.cerf-jcr.org

Fatima Navas[†‡*], Gonzalo Malvárez[†‡], Edmund C. Penning-Rowsell[§], and Dennis J. Parker[§]

[†]Area of Physical Geography Universidad Pablo de Olavide
Sevilla, Spain

[‡]Coastal Environments Research Group (RNM911) Research and Technological Development Groups of Andalusia, PAIDI, Spain

[§]Flood Hazard Research Centre
Middlesex University
London, UK

www.JCRonline.org

ABSTRACT

Navas, F.; Malvárez, G.; Penning-Rowsell, E., and Parker, D.J., 2020. Spreading the use of economic methods in coastal risk management: A simple but insightful "calculator". *In:* Malvárez, G. and Navas, F. (eds.), *Global Coastal Issues of 2020. Journal of Coastal Research*, Special Issue No. 95, pp. 1217–1222. Coconut Creek (Florida), ISSN 0749-0208.

European Directives, such as the EU Floods Directive (2007/60/EC) require that decision makers include objective methodologies, such as benefit-cost analysis, in their assessments of flood risk reduction measures.

Methodologies to establish a sustainable knowledge framework addressing the costs and benefits of prevention and response to coastal hazards resulting from hydro-meteorological, hydrographic and other natural events and processes (*e.g.* flooding, beach erosion, cliff erosion, sea level rise) are not homogeneously implemented in the European Union. Until now, investment decisions in this field have been made more on local political imperatives than logical economic risk assessments. This paper aims to overcome some these limitations by demonstrating the usefulness of a simplified benefit-cost methodology and its application to a coastal case where a number of alternative flood risk reduction schemes are considered. The method allows the economically optimal scheme to be identified. The method is discussed within the context of generally poorly comprehended aspects; issues presented in coupling benefit-cost methods with vulnerability and related assessments; and key data uncertainties.

ADDITIONAL INDEX WORDS: *Coastal erosion and inundation, coastal flooding, benefit-cost analysis.*

INTRODUCTION

Coastal hazards such as shoreline erosion and flooding are worldwide phenomena. Increased human occupation of the coast, and the intensification of activity there, has necessitated abundant coastal defence and related infrastructure to protect human and natural assets (Navas, Carrero, and Cáceres, 2012; Neumann *et al*., 2015). Most European coastlines have been artificialized and are subject to development in various degrees, with 61% of total land uptake by artificial surfaces due to housing, services and recreation (EEA, 2006). Additionally, the European Union produced in 2007 a Directive on the assessment and management of flood risks (EU, 2007), known as the Floods Directive. This Directive specifies that all coastal hazard and risk management plans should include some degree of action prioritisation, in particular to emphasise areas which need to be studied in more detail, and areas where it is likely that protection and mitigation measures will be necessary.

In terms of coastal flood risks, the EU Floods Directive requires that coastal hazard and risk management plans must be drawn up for areas with a medium likelihood of flooding (at least a 1 in 100-year event) and extreme events or low likelihood events, in which expected water depths should be indicated (EU, 2007). Due to the nature of flooding, Member States have flexibility regarding objectives and measures in line with the European Union's subsidiarity principle. A hazard/risk assessment is the cornerstone of any plan, as it defines the nature of the problem in terms of extent and severity, usually in the form of a risk map. For implementation, prioritisation can be based on benefit-cost analysis, or something simpler at an exploratory stage. Without prioritisation, no coastal hazard and risk management plan is viable in guiding future decisions because available financial resources are rarely, if ever, sufficient to address all risks (Parker, Priest, and Tapsell, 2009). All coastal hazard and risk management plans should identify areas for investment based on priorities leading to a programme of capital spending on appropriate hard and soft structural measures and non-structural strategies, stretching many years into the future, and forming the basis of a bid to central government or other stakeholders for the necessary funds for implementation (Penning-Rowsell *et al*., 2013).

Coastal hazard and risk management is also about preparedness for damaging events exceeding the design standards of known flood defences and the residual risk that this entails (UKEA, 2010). Plans should encompass preparedness strategies, locally implemented, within a knowledge framework that accurately predicts hazard/risk and the communities liable to be vulnerable.

In some EU countries, institutions using the results of analyses of costs and benefits prefer them to be performed initially

DOI: 10.2112/SI95-236.1 received 31 March 2019; accepted in revision 13 February 2020.
*Corresponding author: fnavas@upo.es

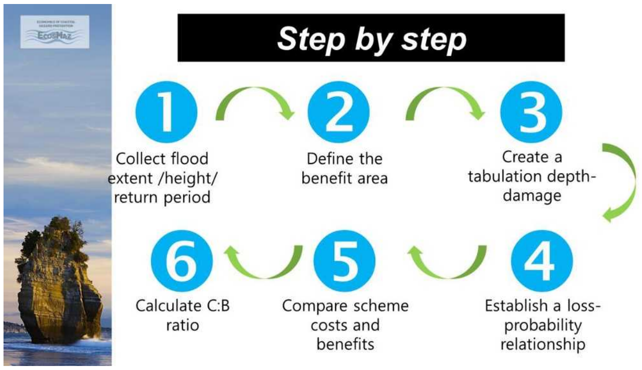

Figure 1. Methodological steps in the calculator.

in a relatively simplified manner and strongly recommend accompanying physical environmental impact assessments (Malvarez *et al*., 2018). Such analyses require specific types of data (*e.g.* potential flood depth, potential flood damages, cliff erosion rates) and knowledge of appropriate analytical procedures (see below) to ensure feasibility and sustainability of application. In order to undertake these analyses a range of potential erosion and/or flood events of different magnitude need to be considered together with a range of measures (*i.e.* different risk management schemes) as some will provide better value for money than others. All coastal hazard and risk management plans should include action prioritisation so that areas requiring investigation in more detail may be identified. This prioritisation may be based initially on exploratory benefit-cost analyses with more detailed analyses for those areas or schemes prioritised in the exploratory analyses (Penning-Rowsell *et al*., 2013; Navas *et al*., 2018).

In this paper, given our previous experience of reviewing EU countries' methods of project appraisal applied to erosion and flood risk management, a "calculator" for coastal risk management is introduced using the results of a coastal case study to illustrate the applicability of the methodology.

METHODS

Here we present a simplified methodology to guide decisions about which of a number of proposed alternative coastal flood risk management schemes is economically optimal. The preferred optimal option is the one in which the difference between benefits and costs is greatest. Benefit-cost ratios are also a useful index.

This method is based on research at the Flood Hazard Research Centre, Middlesex University, London. Simplified, exploratory and more complex benefit-cost analysis tools permit coastal erosion and flood risk management options to be appraised. These tools were developed for both educational purposes and for the Centre and coastal risk management organisations to undertake actual appraisals informing decisions about a wide range of schemes now implemented in the UK, and were also implemented during the EcosHAZ EU project (Navas, Malvarez and Moré, 2017). The analytical tools require inputs of hydraulic/hydrographic, land use and potential damage data as well as other parameters. The tools allow data manipulation to determine the effects on results of changing parameters exploring the effect of data uncertainties.

The methodology, referred to here as the "calculator", includes 6 steps (Figure 1). This calculator is something to be 'played with' prior to exploring the related, more detailed and complex methods. Therefore, the 'calculator' as presented here is not meant as a practical appraisal method: instead it demonstrates the procedures, data and results to be expected in a more serious appraisal. Step 1 is the collection of flood extent, height/depth and return period data. Using these data, step 2 defines the benefit area (*i.e.* the area directly affected by floods). Step 3 creates a table relating the flood depth and potential damage to residential and non-residential properties. To complete this step historical data are ideally required to correlate depth of flooding in properties with damage. Integration of all the data collected previously is entered into a table in step 4 with the probability of each return period flood. In step 5 scheme costs (provided by quantity surveyors and engineers) are compared with the benefits (*i.e.* the potential flood losses avoided) previously computed. In this step, the test discount rate is also applied to correct data in order to correctly compare the future stream of costs and benefits. The final step, 6, is to calculate the difference between the costs and benefits for each scheme and their benefit-cost ratios which will inform decisions about the most suitable scheme to implement.

Step 1. Data collection and calculation of flood return periods and height/depth of flood. The standard approach for estimating flood risk reduction benefits is through investigation of the potential damage avoided in a variety of land uses/properties in the benefit area. It is customary within benefit-cost analysis of flood risk reduction investment to consider only current land use (except where the future flood regime is likely to make current use untenable and property is assumed to be written off or subject to change of use, or when agricultural land becomes suitable only for less productive uses).

Step 2. The benefit area is the starting point for assessing the benefits. - it is the maximum area directly affected by flooding. In practice, floods often have indirect impacts within and beyond the benefit area and so indirect losses may also be incorporated. Risk maps already produced in accordance with EU Directive, showing the benefit area, will be the maximum known or modelled extent of flooding. Different land uses affected by the risk are presented in different colours.

Step 3. Within the benefit area, the altitude of the threshold of flooding at properties and their ground floor size in square meters (if the property is non-residential) are entered into a table relating flood depth with potential damage. A fully comprehensive assessment of benefits will be necessary to determine the geo-reference of each property (the grid reference). Field surveys may be used to identify land uses/properties for which data sets are currently unavailable. Otherwise, national databases are the first source of data that should be consulted (*e.g.* the Cadastre and SIOSE databases in Spain).

Step 4. Annual average flood damages are calculated from the loss-probability curve which is the relationship between flood event damages and flood exceedance probability (*i.e.* the reciprocal of return period) and are represented by the area beneath the curve. Once determined, the annual average values need to be accumulated over the anticipated lifetime of any scheme (*i.e.* annual average times the number of years of scheme life, such as 50 or 100 years). Future values need to be discounted to give the present values of damages (PVD). Discounting is a complex subject but a necessary one that makes all costs and benefits comparable, whenever they occur in time.

Figure 2. The benefit area – the likely flood extent in the northern UK town of Hartlepool. The dark shade is the 100-year return period outline; the lighter shade the 1,000 year return period.

Step 5. Comparing the scheme costs with the scheme benefits to compute the differences between them: the scheme for which the difference in costs and benefits is greatest is preferred.

Step 6. Computation of the BCR. The highest value will generally be the optimal value according to the Step 5 analysis.

RESULTS

The calculator is a simple device allowing coastal planners to obtain a quick assessment of the economics of evaluating reductions in flood risk at a particular location. It is not meant to be used at the detailed appraisal and design stages but can be used to include or exclude different policy options at a feasibility or pre-feasibility study stage.

We illustrate here its likely application, for our research purposes only, to a flood problem in Hartlepool, in northern England (Figure 2).

Several options are likely being considered, from the very basic interventions to reduce the risk of flooding from the sea, to schemes that are progressively more ambitious. The most basic scheme (Table 1) would only reduce the risk of flooding to some 15 properties (14 of which are residential buildings), perhaps with a series of small walls or bunds to protect individual properties. The cost would be c. €2,000,000 (€133,000 per property). The most ambitious scheme would be for a high standard sea wall protecting the large part of the lower part of the town, and reduce the risk of flooding there to approximately 125 properties (7 of which are non-residential shops and offices) in the majority of the area now shown to be at risk (see Figure 2), some of which are likely to flood very rarely. The cost for this scheme would be approximately €10,000,000. An intermediate scheme (No. 3 in Table 1) involves enhanced beach nourishment to the foreshore so as to reduce the force of the waves attacking the existing (rather dilapidated) sea wall (capital costs €3.5m and €87,500 per property).

The calculator rapidly assesses these several possible interventions. What Figures 3 and 4 show is that the least ambitious scheme is far from worthwhile; the costs far exceed the likely benefits (with a BCR below 0.7). The £10m scheme for a new sea wall is also economically poor, with a BCR of 0.73 and a value for benefits minus costs of €2.73m (this is the measure economists prefer in this situation, as the return on investment). Scheme no. 4 is the preferred one on both measures, with a benefit minus costs figure (or "profit") of €1.82m. The flexibility of the calculator allows one to explore very rapidly "what if" situations.

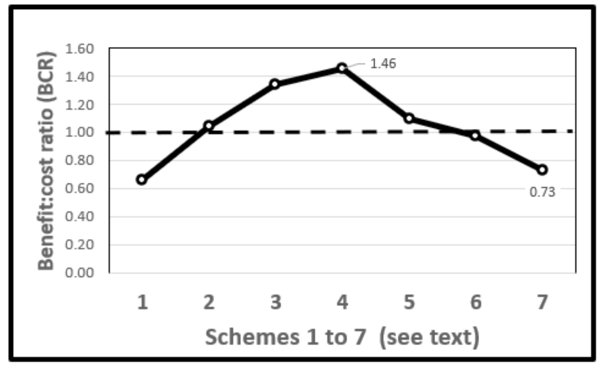

Figure 3. Benefit-cost ratios for each scheme.

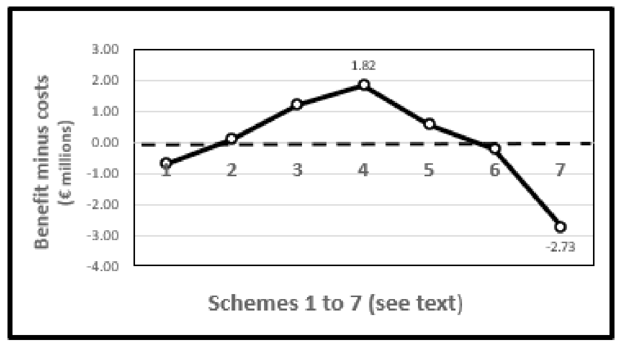

Figure 4. Difference between schemes' benefits and costs.

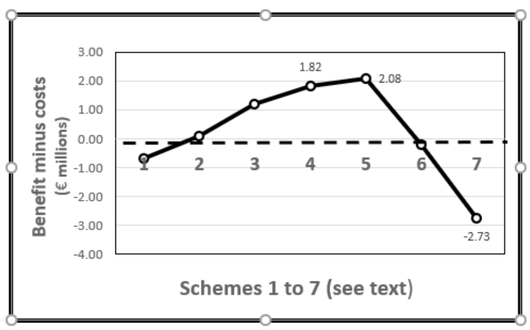

Figure 5. Effect of reducing the cost of scheme 5.

If the costs of option No. 5 (the New sea wall [low standard]) could be reduced to €4.5m from €6.0m, this becomes the preferred

Table 1. *The range of scheme options and their costs.*

Scheme	Properties protected	Scheme cost (€000s)
1. Small bunds round individual properties	15	2,000
2. Larger bunds around communities	30	2,600
3. Beach nourishment (capital costs only)	40	3,500
4. Beach nourishment and larger bunds	50	4,000
5. New sea wall (low standard)	55	6,000
6. New sea wall (medium standard)	100	7,300
7. Higher standard sea wall	125	10,000

option (Figure 5). Endless other situations can easily be explored with the calculator with very little time and effort.

DISCUSSION

At a broad level, the whole issue of adaptation in areas where damages occur as a result of high energy natural events affecting human infrastructure provides the basis for a widespread debate among many academics and decision makers alike. Whilst adaptation is still being discussed at an intellectual level (Craft and Fisher, 2016), significant practical progress can be made by the coupling of economic appraisal and risk mapping/assessment (Ferreira, Plomaritis, and Costas, 2019). Although benefit-cost analyses can integrate intangible impacts of flooding, they do not yet comfortably incorporate or couple with issues and measures of vulnerability and resilience which, in addition to economic efficiency (*i.e.* value for investment), are important dimensions of successful coastal risk management. The search for a solution in which risk, hazard impacts and vulnerability are interlinked in complex ways has been going on for a long time (Wisner *et al*., 1994) and resilience has been added to the equation (Parker, 2019). It is currently feasible to reflect some aspects of vulnerability and resilience in the residential damage values used in cost-benefit analyses, for example by linking these values to socio-economic variations. In this way the residential damages potentially avoided by a scheme (*i.e.* the benefits) may be weighted to take into account low or high damage values associated with homes occupied by the wealthy or the poor. The benefits attributed to poor residential communities may therefore be increased in this way to ensure that they do no lose out in comparison to wealthy communities when it comes to choosing between locations to protect from flooding. However, it may be unrealistic to think that vulnerability can be comprehensively assessed. Methods like the one introduced in this paper, though simplifying the overall issue, offer useful ways of working towards ensuring that scarce resources are allocated in the most economically efficient manner which is usually in the national interest. The method adds to the existing literature searching for such comprehensive appraisal methods (*e.g.* Shreve and Kelman, 2014) and contributes to the overall debate about the adequacy of cost benefit analyses in a disaster risk reduction setting (*e.g.* Garrote *et al*., 2019).

One key element of the method that is often poorly comprehended is the need to discount scheme costs and benefits. This is done by selecting the appropriate discount rate, which is generally the one used by central government at any point in time, and then applying the relevant discount value according to which year in the future life of a chosen scheme each cost and the annual average benefits are expected to occur. So, if the life of a scheme is determined, say, as 50 years, then we can expect floods – and the benefits of avoiding them – to occur only in some of those years. On the other hand, capital costs of a scheme usually occur in the early life of a scheme followed by regular but intermittent maintenance costs. Discounting is the process of **determining the present value of a stream of costs and benefits that occur in the future life of a scheme.** Given the time value of money, a Euro is worth more today than it would be worth tomorrow. The key point however is to recognize that, in any decision, we are making a judgement which compares impacts now to impacts in some point in the future. If costs and benefits are not discounted, then they cannot be correctly compared. Although this is so, discounting often causes some discomfort because it implies, for example, that we should be prepared to spend less to reduce the risk of a death from flooding occurring in 50 years' time than to reduce the risk of a death by this cause tomorrow.

The "opportunity cost of capital" should be carefully considered by decision-makers when selecting a flood risk reduction scheme. If we invest public capital in a scheme, we forgo the opportunity to invest it in another scheme, whether this is another flood risk reduction scheme or, say, a new hospital. If, after undertaking a benefit-cost appraisal of alternative flood risk reduction schemes, decision-makers opt for a coastal scheme which is less optimally economic efficient than another, then opportunities will be forgone to invest elsewhere.

There are also a number of important considerations regarding data. Flood return periods are key hydrological/hydrographic data inputs into the calculator methodology as they significantly affect the calculation of annual average flood damages. The reliability of flood frequency data grows with the length of the flood frequency-magnitude record but sometimes this record may be short. It is vital therefore that the effect of uncertainties surrounding these data on the calculation of average annual flood damage is assessed by exploring 'What if?' questions. Exploration of the effect of data uncertainties of this kind is referred to as 'sensitivity analysis' which is a key part of benefit-cost analyses. There may well also be uncertainties surrounding the flood damage data used in the analyses. For example, in the Flood Hazard Research Centre's (FHRC) manuals (*e.g.* Penning-Rowsell *et al*., 2013) potential property damages from a range of severities of flooding are estimated, resulting from different depths of flood waters within the property. Only by employing such data will the shape of the key loss-probability curve be determined. Much of the flood damage data available from the literature, including the FHRC's data, are "synthetic" (*i.e.* from a synthesis of many data items). They are, therefore, often not directly derived from an analysis of properties which have been flooded in the recent past, not least because evidence suggests that often post-flood surveys of damage can be very inaccurate. An alternative is to choose to use flood damage data derived from post-flood surveys (Merz et al., 2010; Merz and Kreibich, 2013), or at least to calibrate synthetic flood damage data by relating them more closely to data gathered in post-flood surveys.

In national economic efficiency benefit-cost analyses, only economic damage/loss values are to be used. These values are different to the values assessed by the insurance industry which uses 'financial' values which are almost always higher. In a national economic efficiency analysis the damage to property components (*i.e.* inventory items), is based on their depreciated value - rather than the cost of their replacement with new items at current market prices which insurers often use. Also any taxation element within potential flood damages losses must be subtracted, because these are transfer payments within the economy rather than real resource costs. Therefore, for example, Value Added Tax (VAT) elements in repair costs are not counted as part of the damage value and so any taxes in flood damages or erosion losses values must be netted out. Similarly, any taxation elements within the estimated costs of flood risk reduction schemes should be netted out to make all amounts comparable. For indirect flood losses, it is also necessary to separate financial and economic losses by not including, for example, the loss of income in one particular retail shop if the trade this represents is likely to be deferred in time or transferred to another retail outlet that is not flooded.

CONCLUSIONS

This paper introduces a methodology to help decide which flood risk reduction option is economically optimal in a context of the assessment of risk of coastal flooding. The design of the method is implemented as a simple "calculator" (not meant for practical use on its own but to demonstrate the method) presented in a spreadsheet that allows for estimates of the costs and benefits of a number of alternative schemes. The method allows comparisons of suitability in the selection process to identify the optimum one, as understood to be the one where the value of benefits minus costs is maximised. The methodology is explained in 6 simple steps and then implemented in a simulated scenario that replicates the flooding situation for a municipality exposed to risks at various return periods. The results represent a simplified coastal case in which 7 flood risk reduction schemes, with realistic costings based on true cases of engineering works against flooding, are investigated leading to the identification of the preferred scheme in terms of both the benefits minus costs measure and the benefit-cost ratio. Key data input issues are discussed in the context of uncertainty and sensitivity analysis. The methodology is also discussed in the context of some of the principal issues affecting benefit-cost analyses in risk assessment and economic appraisal and within the wider context of vulnerability, resilience and risk assessment.

ACKNOWLEDGMENTS

The authors thank the ECOSHAZ Project consortia (project supported by the European Union within EU Civil Protection Financial Instrument. Ref. ECHO/SUB/2014/693711). Also acknowledge the support of the Coastal Environments Research Group (RNM911), Research and Technological Development Groups of Andalusia, PAIDI, Spain.

LITERATURE CITED

EEA (European Environment Agency), 2006. *The changing faces of Europe's coastal areas*. No. 6. Office for Official Publications of the European Communities. ISBN: 92-9167-842-2.

EU (European Union), 2007. *Directive 2007/60/EC of the European Parliament and of the Council of 23 October 2007 on the assessment and management of flood risks.*

Craft, B. and Fisher, S., 2016. *Measuring effective and adequate adaptation*. International Institute for Environment and Development.

Ferreira, Ó.; Plomaritis, T.A., and Costas, S., 2019. Effectiveness assessment of risk reduction measures at coastal areas using a decision support system: Findings from Emma storm. *Science of the Total Environment*, 657, 124-135.

Garrote, J.; Bernal, N.; Díez-Herrero, A.; Martins, L.R., and Bodoque, J.M., 2019. Civil engineering works versus self-protection measures for the mitigation of floods economic risk. A case study from a new classification criterion for cost-benefit analysis. *International journal of disaster risk reduction*, 37, 101-157.

Malvárez, G.; Navas, F.; Parker, D.J., and Penning-Rowsell, E., 2018. The Need for Coastal Hazard Prevention and its Valuation Methodologies in Europe. *Journal of Coastal Research*, SI 85, 926-930.

Merz, B.; Kreibich, H.; Shwarze, R., and Thieken, A., 2010. Review article. Assessment of economic flood damage, *Nat. Hazards Earth Syst. Sci.*, 10, 1697-1724

Merz, B. and Kreibich, H., 2013. Non-linear and non-parametric modeling of flood damage, *In*: Klijn, F. and Schweckendiek, T. (eds), *Comprehensive Flood Risk Management*, 599-602, Taylor and Francis Group, London, ISBN 978-0-415- 62144-1.

Navas, F.; Carrero, R., and Cáceres, F., 2012. A new approach to Future Scenarios for the EU COASTANCE Project. *Ministry of the Environment of the Regional Government of Andalusia Technical Report*, 119.

Navas, F.; Malvárez, G., and Moré, G., (eds.), 2017. *Coastal Hazard Prevention: A methodology for Cost-Benefit Analysis*. Seville: EU & ECOSHAZ, ISBN: 978-84-09-01172-8, 239.

Navas, F.; Malvárez, G.; Penning-Rowsell, E., and Parker, D.J., 2018. Flood Hazard Prevention Appraisal in Europe: Training Key Stakeholders on the Benefits and Costs of Efficient Protection and Response. *Journal of Coastal Research*, SI85, 1546-1550.

Neumann, B.; Vafeidis, A.T.; Zimmermann, J., and Nicholls, R. J., 2015. Future coastal population growth and exposure to sea-level rise and coastal flooding-a global assessment. *PloS one*, 10(3), e0118571. https://doi.org/10.1371/journal.pone.0118571.

Parker, D.J., 2019. Disaster resilience – a challenged science. *Environmental Hazards,* 19(1), 1-9.

Parker, D.J.; Priest, S.J., and Tapsell, S.M., 2009. Understanding and enhancing the public's behavioural response to flood warning information. *Meteorological Applications: A journal of forecasting, practical applications, training techniques and modelling*, *16*(1), 103-114.

Penning-Rowsell, E.C.; Priest, S.; Parker, D.; Morris, J.; Tunstall, S.; Viavattene, C.; Chatterton, J., and Owen, D., 2013. *Flood*

and Coastal Erosion Risk Management: A Manual for Economic Appraisal, London and New York, Routledge, 448.
UKEA (United Kingdom Environment Agency), 2010. *Flood and coastal erosion risk management appraisal guidance (FCERM-AG)*. Environment Agency, Bristol. 310p.
Shreve, C. M. and Kelman, I., 2014. Does mitigation save? Reviewing cost-benefit analyses of disaster risk reduction. *International journal of disaster risk reduction*, 10, 213-235.
Wisner, B.; Blaikie, P.; Cannon, T., and Davis, I., 1994. At risk: natural hazards, people's vulnerability and disasters. London, Routledge, 124.