TWO BIRDS WITH ONE STONE: IMPROVING ECOLOGICAL QUALITY AND FLOOD PROTECTION THROUGH RIVER RESTORATION IN NORTHERN ITALY

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1. Focus of the study

Traditional flood protection approaches rely on the construction of artificial infrastructures (dykes, weirs, concrete walls etc) aimed at containing the flood expected on a sufficiently long return time (TR), usually 200 years.

This approach has many shortcomings. First of all, the economic cost entailed by infrastructure (which is not simply the construction cost, but also ordinary maintenance and the reconstruction after flood events). Although technologies are well known and costs can be easily standardized, a critical issue for assessing the magnitude of such costs is the assumption to be made about their economic life, which depends on the frequency of events and may thence vary due to climate change.

Second, it implies a substantial loss in terms of environmental quality and attitude to provide ecosystem services. An indirect assessment of the magnitude of such losses can be argued from many studies that have quantified the ecological benefits of restoring rivers close to their pristine state (Lüderitz et al., 2011; O'Hanley, 2011)

Third, it encourages a risk-prone attitude of land users: since areas previously subject to periodical flooding are more protected, new opportunities for economic development arise, with the consequence that land use planning is eventually tempted to allow high value-added activities to take place in these areas (Green et al., 2011).

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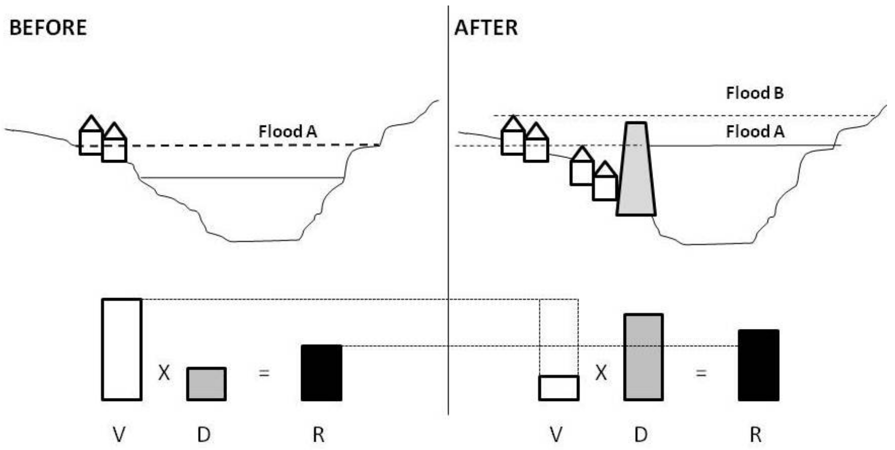
Figure 1 - Residual risk and demand-driven vulnerability (V = frequency of the event; D = exposed value; R = vulnerability index)



Source: adapted from Nardini and Pavan, 2011

Paradoxically, vulnerability could thence *increase* after adopting safety measures. Even if a probability of a disruptive flood is very low (TR>200), in case of its occurrence the economic value that is exposed (D) is much higher: even if the probability of the event, V, is much lower, the resulting expected damage R may also be higher (fig. 1).

Climate change represents a challenge with this respect, since one of the expected outcomes in tempered-climate regions is precisely the increase of the frequency of extreme events (EEA, 2012). The actual annual damage of 5,5 billion € (for the whole Europe) could turn to 53-98 billion by 2080, respectively in an inertial "do nothing" scenario and one that entails adaptation measures (Rojas et al., 2013).

In more recent years, the traditional approach has been increasingly questioned, on the evidence of increasing marginal costs of protection corresponded by comparatively modest economic return (Cuny, 1991; Samuels et al., 2005).

A competing approach has been proposed and increasingly adopted, especially in the US and Northern and Central Europe (Restore, 2012). This relies on the opposite philosophy of river morphology restoration and restitution of adequate spaces for river digression. Rather than an impossible return to pristine situation – which is actually unfeasible given the unfeasibility of reversing anthropic development trends consolidated along time – this approach implies a controlled and planned reduction of the intensity of economic development in floodplain areas. This often means that some high-value added land uses would have to turn to low-value added ones (particularly in the case of agriculture); some dwellings and settlements ought to be relocated; some water uses associated to the defense infrastructure might be given up (e.g. irrigation, hydropower generation). In the present time, the opportunity is provided by an overall reduction of the economic pressure on land – at least on marginal land; this is also favored by de-intensification processes that characterize agricultural (but also industrial) development.

So far, however, this innovative approach has not encountered a comparable success in Southern Europe. An argument often brought forward concerns the relatively higher intensity of development in the (relatively) smaller floodplains that characterize Mediterranean regions and the (relatively) higher variability and irregularity of river outflows.

However, this statement generally owes to conventional wisdom; to our knowledge, no serious attempt has been made with the aim of validating it through a more rigorous assessment method. The study illustrated in this paper represents a first step in this direction. It concerns the basin of the river Chiese– a sub-tributary of the Po basin – with the aim of exploring the degrees of freedom that still survive in a typical Northern Italian location.

The opportunity for the study has been offered by the ongoing elaboration of the Flood Protection Plan by the Po River Basin Authority, which has already issued a feasibility study of an action plan (hereafter RBAFS), which is mainly inspired by the “traditional” philosophy, following on the streamline of the strategies adopted until now for more than one century. This is based on the comprehensive protection against a TR200 event.

Our study compares the expected outcome of the actions foreseen in the feasibility study (RBAFS) with alternative actions that are inspired by a river restoration approach. We have considered different scenarios, with a progressive relaxation of protection targets and a gradual return to natural conditions. However, due to budget constraints, an in-depth analysis was feasible for one alternative scenario only.

We have developed a simplified integrated assessment framework, combining economic indicators (concerning whatever the study has been able to monetize in a reliable way) with physical indicators, following thence a multi-criteria approach. The results are partial, but encouraging: at least the less radical restoration scenario dominates the RBAFS either with respect to ecosystem value or to economic cost-benefit. Despite being superior from an overall social perspective, such an approach entails direct and immediate losses for some stakeholders. We argue therefore that a wisely designed set of economic policy instruments (EPI) could highly improve the outcome of the proposed alternative action plan and enhance the potential of acceptability.

The paper is structured as follows. Par. 2 provides a short review of the relevant applied literature. Par. 3 provides some background information about the case study area. Par. 4 illustrates the general methodology of the whole study, while par. 5 provides more details about the economic assessment tool. The results are outlined in par. 6, while par. 7 tries to derive some policy implications and discusses how our results could be improved by further research.

2. Literature review

Traditional cost-benefit studies in the field of flood protection were typically sector-based and focused in particular on the value of land – driven by socio-economic development patterns, assumed as exogenous elements – and the cost of infrastructure (Green et al., 2011).

In the last 30 years, however, the rise of the "integrated river basin management" (IRBM) paradigm has clarified that water-related issues are deeply interconnected (Millington et al., 2006; Schanze et al., 2008). Integrated management requires more sophisticated assessment tools, which enable to capture the multidimensional outputs and the complex range of externalities that characterize each action.

In the case of flood protection, in the first place, artificial infrastructure aimed at "taming" natural rivers and make their outflowing patterns more predictable interfere dramatically on river ecosystems, generating an overall reduction of the ecological quality and the possible loss of valuable ecosystem services (Birkland et al., 2003)

In the second place, assuming that socio-economic development are exogenous elements neglects the fact that patterns of land use are also influenced by flood protection strategies. Ultimately, land use choices depend on the expectations of landowners about the profitability of alternative destinations, which are obviously influenced by the perception about natural risks, and therefore by land use planning and consolidated approaches to flood protection. Cultural habits, collective memory and social dynamics play a fundamental role in shaping individual behavior (Viglione et al., 2014). Cognitive frames play an essential role in determining ultimately local residents' attitudes towards water management projects (Jacobs and Buijs, 2009)

In the third place, adaptive solutions and mitigation measures may be adopted early in advance, and reduce significantly the expected damage in case a flood occurs. These measures concern, for example, building techniques, adoption of management practices (e.g. avoid to store flood-vulnerable goods in lower levels, early warning, installation of monitoring equipment, insurance). Readiness to adopt mitigation measures has also been recognized as a behavioral issue, which is influenced, by social learning, collective experience and memory (Poussin et al., 2014)

The standard approach to valuation is represented nowadays by integrated multi-disciplinary assessment models (Brouwer and van Ek, 2004; Hansson et al., 2008). These generally consist of numeric hydraulic models predicting outflows, GIS-based models that simulate inundation patterns over land, and economic models that estimate costs and benefits using existing information about land use and socio-economic development.

The latter step consists, in the first place, in the identification of the concerned value dimensions. In principle, the valuation should include both tangible and intangible values, originating either within the flooded area or outside it (table 1).

The difficulty of capturing most of these value dimensions – many of which are typically site-specific implies a very careful calibration. Increasingly, such models adopt a mixed top-down and bottom-up approach, which combines model-led expert assessment and stakeholder-led onsite information. Direct involvement of stakeholders and social learning is regarded as a key ingredient of integrated water resources management, due to the need to capture subtle and indirect cause-effect relations that link the different components water ecosystems, as well as for identifying critical issues and relevant value dimensions for the local community (Mostert et al., 2008).

The recent literature about the assessment of flood management options is unanimous in recognizing that no single strategy (structural vs. non-structural) is to be preferred on absolute; rather, both are complementary and should be examined in their interplay. Mitigation actions and non-structural measures of flood control emerges as a very useful complement to more traditional structural measures, especially where large spaces are still devoted to extensive agriculture or low-value economic uses. However, the optimal mix varies and cannot be assessed once forever.

Table 1 - Different dimensions of flood damages

	TANGIBLE	***INTANGIBLE***
Direct	Residences	Fatalities
	Capital assets and inventory	Injuries
	Business interruption (inside the flooded area	Inconvenience and moral damages
	Agricultural land and cattle	Utilities and communication interruption
	Roads, utility and communication infrastructure	Historical and cultural losses
	Evacuation and rescue operation	Environmental losses
	Reconstruction of flood defenses	
	Cleanup costs	
Indirect	Damages for companies outside the flooded area	Societal disruption
	Adjustments in consumption and production patterns	Psychological traumas
	Temporary housing of evacuees	Undermined trust in public authorities

Source: adapted from Jonkman et al., 2008

Floodplain conservation – namely, the strategy of creating protected areas in the floodplain, thereby reducing development opportunities – is shown as an economically beneficial option in the Missouri basin (Kousky and Walls, 2014) for the US as a whole (Brody and Highfield,2013) and in Canada (De Loe and Wojtanowski, 2001)

In the Netherlands, Brouwer and van Ek (2004) conclude that although traditional flood control policy-building higher and stronger dikes-is a cost-effective option, investment in alternative flood control policy-land use changes and floodplain restoration-can be justified on the basis of both CBA and MCA when including the additional ecological and socio-economic benefits in the long run.

The key importance of stakeholders' perspective emerges from studies conducted in the UK. Dawson et al., 2011, show that non-structural actions allow substantial benefits, whose appraisal is nonetheless sensitive to socio-economic changes and governance arrangements. Kenyon (2007), in a Scottish context, finds that landscape-related dimensions are also very important. Luther and Schanze (2008), focusing on the River Elbe (Germany) emphasize the importance of adopting a long-term perspective in order to understand and overcome the constraints originated by the path-dependence of regional development patterns and the related sunk costs.

A common feature that emerges from these studies is that the economic viability of non-structural measures derives from the combination of three factors. In the first place, the dramatic reduction in the cost needed for building and maintaining flood-control infrastructure, particularly in a very critical phase for public budgets, which also emphasizes the opportunity cost of public funds. In the second place, areas that are eligible for flooding can be managed optimally when the flood policy is accompanied by an appropriate set of adaptive behavior and mitigation measures. In the third place, ecological benefits should also be accounted for.

Many authors emphasize the fact that the practical viability and political acceptance of both mitigation and non-structural actions implies a careful consideration of distributional issues (Ledoux et al., 2004)

Distributional issues are the first and most evident. Traditional policies typically socialize the cost of risk mitigation, since infrastructure is realized by state agencies; in turn, after protection is supplied, landowners obtain all benefits. The consolidation of the “traditional approach” over time has reinforced the perception of flood protection as a “social right” which is embedded in the property rights above land. Giving up this scheme implies that the social right (to be financed out of general taxation) turns into an individual duty. In a way, the situation resembles that of social security and welfare state, where a generalized approach to undifferentiated and limitless protection, directly inspired by the idea of “citizenship rights”, evolves toward a more balanced and flexible structure where the social system integrates, and not substitutes, individual self-protection.

A further distributional issue regards a territorial dimension. Non-structural actions typically imply a choice about the areas that are more suitable to retain floods: this is normally lower-value land, which is located in less developed regions, to the advantage of urban and suburban areas. Farmers are quite easily the losers in the game. Compensative payments may indeed help; yet the economic dimension is not the only one to consider, since other and more subtle non-economic factors play a role as well – e.g. the unwillingness to accept a “superior status” of cities and more developed areas (Massarutto, 2012)

In the case of flood protection, a more active role of stakeholders – not anymore confined to a “passive” demand for state funds and for protection measures – becomes necessary by the increasing difficulty to obtain adequate resources from the public budget. Particularly in developing countries – where the right-claiming approach has weaker roots given the lack of tradition of state intervention, spaces for incorporating mitigation and conservation in land use planning are still wide. Yet this is still not sufficient in developed countries, even because land use and regional development trajectories have already implied huge sunk costs, and related barriers to change.

Mori and Perrings (2012) point out that a reason for the sub-optimal policy bias still in favor of structural actions despite evidence of superior outcomes of alternative policies descends from the lack of internalization of protection costs: land values do not incorporate the cost associated to flooding risk. Market-based instruments aimed at internalizing this cost (such as tradable land use permits) are proposed to solve the problem.

More generally, a vast literature has examined the potential role of insurance markets (Filatova, 2014; Burby, 2011). As generally happens in the field of natural disasters, insurance schemes have to cope with the typical market failure that originates from risk correlation (Kunreuther and Michel-Kerjam, 2014). In most countries where such schemes are diffused, the state maintains a central role as the last-resort payer. In France, for example, the "CatNat" scheme fosters the creation of a mutual insurance scheme, whose premia are calculated as land-use taxes with only a weak correlation to risk exposure; funds are managed by insurance companies, but function in fact as a way to mutualize costs (Barraqué, 2014; Barraqué and Grissent, 2005).

A further opportunity is offered by the innovative approach of payments for ecosystem services (PES), namely direct compensations, proportional to social benefits, offered to landowners (particularly in the agricultural sector) in order to foster floodplain conservation, encourage supply of waterlogging and other mitigation strategies. Opportunities in this sense have been illustrated in Hungary (Ungvari and Kis, 2013), in England (Morris et al., 2008) and in France (Erdlenbruch et al., 2009).

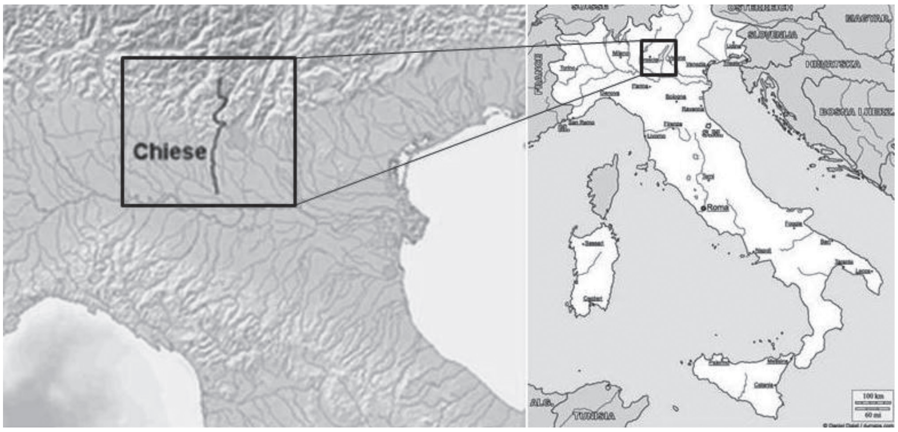
3. The case-study area

The river Chiese is an important tributary of the Oglio, which is on its side one of the most important tributaries of the Po from the left (Alpine) side. The course of Chiese is 180 km long and shared between the two neighboring provinces of Trento and Brescia. Approximately at the half of its course, the Chiese is interrupted by a large natural lake (Idro Lake), which is artificially regulated at its downstream end. This fact allows considering both sections (upstream and downstream of the lake) as independent sections. However, independence is not total, since the artificial regulation of discharges from the lake has to respect certain thresholds (maximum and minimum level of the lake, which also involves a number of upstream reservoirs used for hydropower purposes. Upstream storage capacity therefore may and does intervene to accommodate flood retention requirements, but only up to a certain degree.

The area downstream of the lake, which is the one we actually studied, concerns a length of approx. 80 km with an average outflow of 33 m3/s. The TR200 flood is estimated in 750 m3/s. The storage capacity of lake Idro is 747 million m3, only 10% of which is usable for flood lamination.

The largest abstraction lies in correspondence to the regulation device at the bottom of the lake serves a consortium of users, which includes mostly agriculture, but also industry and hydropower. On top of this larger abstraction, a number of smaller ones displace along the course. The region is characterized by sustained economic development and counts among the richest in the country. Agriculture is mainly integrated in the supply chain of livestock farming for the production of milk and meat; therefore, most irrigated crops are destined as forage.

Figure 2 - The case study area



Source: our elaboration

The chosen case study offers many interesting aspects that allow considering it as somewhat paradigmatic of a typical Northern Italian setting. Lake Idro allows some retention of the flood; consequently, the river flow is at least partially regulated, and this allows some more freedom of action.

Vulnerable areas are concentrated in the downstream areas, with a clear tradeoff between actions aimed at retaining the flood upstream and damage. The river is intensively used for irrigation and power generation, thence considerations regarding flood interact with land uses that are made possible by the presence of the river itself. The region, and particularly downstream, is characterized by intense economic development, with a complex and integrated agro-industrial system, dominated by dairy and meat production (see table 2). Nonetheless, there is a relatively wide surface, particularly upstream, that is occupied by low value uses and could in principle be sacrificed. The TR > 200 flood could involve high social and economic losses, given the high value of human activities.

In turn, the downstream section of the river is already intensively artificialized; most of the flood protection infrastructure has already been built and most of the work to be done concerns renovation and maintenance rather than new construction. This may reduce the potential benefits of alternative solutions (since savings arising from restoring river morphology would be much lower), and reduces the potential for restoration.

Table 2 - Main soil use categories in the case study area: 22 municipalities in the provinces of Brescia and Mantova

Soil Use Areas	***Area (km2)***
Urban	57
Industry	31
Agriculture	404
Roads & other infrastructures	6
Other	99
Total Area	***597***

Sources: our elaboration on Regione Lombardia (2010)

4. Methodology

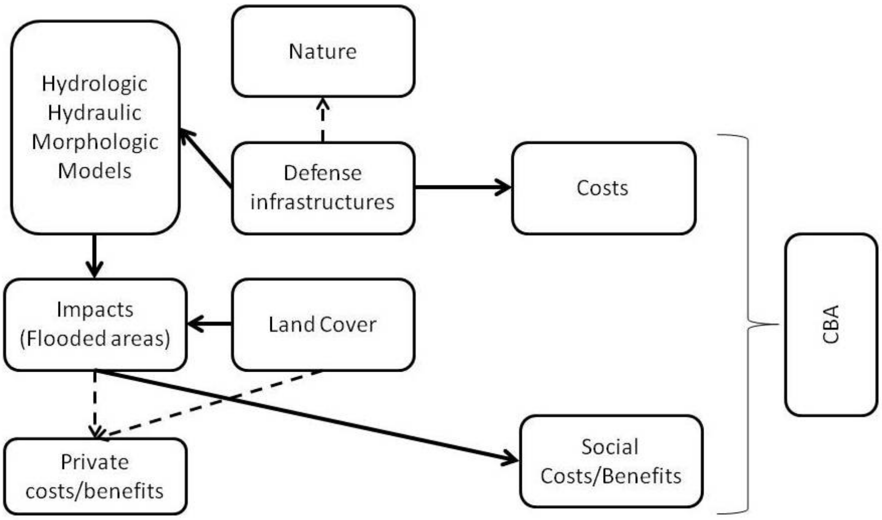
4.1 General overview

The integrated assessment framework consists in a set of coordinated models:

- A GIS model represents the region with a 500 m grid. Each cell of the grid is characterized by elevation on sea level and reports the main categories of land use, economic activities as well as the presence of settlements of any kind, with the related economic values. The GIS uses input data from many sources, mostly institutional ones.

- A hydraulic model of the river, which simulates the outflows consequent to meteorological events, up to a 500 yr statistical occurrence. The model identifies the flooded areas in the GIS and predicts the height reached by water, as a consequence of the size and the location of flood protection artifacts
- An economic assessment tool.

Figure 2b – The conceptual approach of the study



Source: our elaboration

The study considers the state of the art as the baseline. In the present situation, a number of security gaps have been identified (areas whose protection is not guaranteed in case of a TR200 event), while many existing artifacts require maintenance and/or have to be completely rebuilt. As a result, the economic cost associated to the baseline includes the expected damage associated to events (even for TR<200).

The RBAFS identifies a coordinated set of actions aimed at achieving the capacity to retain within the artificialized river corridor the TR200 flood. As a result, flooding risks associated to TR<200 are eliminated. The residual risk arises from TR>200 events and by the probability of collapse of the defense infrastructure.

Alternative scenarios relax some protection targets, assuming that certain categories of land can be flooded. Correspondently, defense infrastructures are adapted to the lower target (e.g. dykes and weirs are lowered, flood expansion areas are designated etc).

The first alternative scenario (ALT-Soft). The next scenarios increase progressively the allowed degree of "disturbance" for human activities. This is obtained by allowing:

i. Alt-SOFT: assumes that only low-value agricultural land is flooded. Only exceptionally a change in land use destination (from high-value to low-value agriculture) is implied
ii. Alt-DARING: systematic flooding of all agricultural land and extensive land-use change;
iii. Alt-RADICAL: elimination of water abstractions and all associated uses (irrigation, industry, hydropower);
iv. Alt-EXTREME: Relocation of residential and industrial areas from the floodplain in case of full restoration of the natural morphology and meandering capacity. This alternative in fact has only been mentioned, but not elaborated.

Table 3 summarizes the main technical indicators that characterize each scenario. As one might expect, the more radical the scenario, the less emphasis is placed on infrastructural works and the more the river is returned to its pristine meandering.

5. The economic assessment tool

For each alternative examined, different criteria (categories) of positive and negative outcomes are considered.

The first categories concern the dimensions for which a reliable economic quantification is feasible. These include:

- Category C (costs): Construction, maintenance and operational costs of flood protection infrastructure.
- Category D (Disturbance): Expected economic damage associated with flood events. These have been further divided in two categories: permanent damages (implying a change in the land use destination, possibly to lower-value activities); and direct damage, associated to the event (loss of crops, disruption of buildings, loss of production due to temporary closure).

Table 3 - Characterization of scenarios: main infrastructural works foreseen (km)

	Baseline	***RBAFS***	***Alt-SOFT***	***Alt-DARING***	***Alt-RADICAL***
Existing works					
Levees	66	46,6	19,4	1,2	0,5
Reinforced levees	11,7	9,4	0,9	0,9	0
Concrete walls	1,2	0,7	0,7	0,7	0,7
Longitudinal vertical protections	5,1	4,9	4,6	4,4	4,4
Bank protections	16,1	11,6	1,3	0,8	0,8
Weirs	13	13	13	13	3
Modified weirs (lowered)	0	0	1	1	1
Check dams and bed sills	10	10	10	10	7
Bypass channels	14	14	14	14	1
New works planned by RBAFS					
New levees		5,4	3,9	2	0,6
Existing levees adjustment		6	2,4	2	1,1
New concrete walls		1,1	0,9	0,7	0,4
Existing concrete walls adjustment		1,9	1,5	1,5	1,5
New bank protection		6,3	4,2	4,3	1,9
New works proposed in our alternatives					
New levees			1,3	0	0
New longitudinal protections with bio-engineering			2,7	3,2	0

Source: Autorità di Bacino del Po, 2004 (Baseline and RBAFS); our elaboration (Alt)

OMR costs have been quantified through a detailed parametric cost function based on interviews with engineers and experts. Since the magnitude of costs of defense infrastructure could affect the results of the cost-benefit analysis, the engineering cost model has been calibrated integrating two further sources of information:

- Historical expenses for flood defense in the case study area, based on a 27-years time series; these are reported in the annual accounts of the competent authority, the Interregional Agency for River Po (AIPO). These however include construction but not management and maintenance costs
- Expected costs from RBAFS (AdB Po, 2004); this study reports first time overnight spending for investments and estimated annual operational costs, including maintenance. For some items, these data have been verified and integrated via expert-based engineering models

Annual full cost have been calculated in accordance with the WATECO Guidance Documents of the EU (European Commission, 2003); the annual full cost results from the sum of operational and management costs (O&M) and the annual capital expenditure, calculated by dividing the total overnight investment per the expected economic life (equation 1)

$$Annual\ Full\ Cost\ =\ \frac{Investment}{Economic\ life} +\ O\&M\ cost \qquad [1]$$

Table 4 shows the results obtained by applying the formula in equation 1 to the main infrastructural typologies. The chosen approach (full cost estimated with an expert-based model) leads to significantly higher costs than the ones arising from historical experience (which however omits maintenance). For this reason, we have tested this variable with a sensitivity.

Concerning damage associated to floods (category D), three components of value have been identified for each class of land use:

- Land
- Infrastructures
- Production

In all cases, we refer to a formulation of the exposed value (or maximum potential loss) defined by equation 2:

$$D(c)\ =\ V(c)\ \cdot fc \cdot [1 + k(c)] \qquad [2]$$

Where:

- D(c): damage per unit area of type c (generally expressed in €/m^2 or €/ha);

Table 4 - Normalized OMR yearly cost of flood protection infrastructure

		Full Costs		
		Capital	***O&M***	***Total***
Longitudinal vertical protections	€/m	139	137	276
Bank protections	€/m	56	76	132
Concrete walls	€/m	139	137	276
Reinforced Levees	€/m	39	124	163
Levees	€/m	31	85	116
Diversions	€/piece	7.000	7.954	14.954
Check dams and bed sills	€/piece	8.000	10.335	18.335
Weirs	€/piece	15.000	7.954	22.954
By-pass channels	€/piece	5.000	7.954	12.954
Bridges	€/piece	40.000	1.125	41.125
Bio-engineering works	€/m	4		4
River bed maintenance	€/m		94	94

Source: Our elaboration based on AdB Po (2004), integrated by desktop estimates supported by engineering models

- V(c): value for category c expressed in €/m^2 or €/ha (not to be confused with the vulnerability described below and which is represented by the symbol V);
- f_c: correction factor value, incorporating expectations about future development;
- k (c): parameter that define the value of the contents of the buildings in the class c of land use.
- The total value is obtained by multiplying the specific value for the coverage area of the given class of land use, properly corrected (equation 3)

$$DT(c) = D(c) \cdot A(c) \cdot \alpha(c) \qquad [3]$$

Where:
- DT (c): total exposed value (expressed in €);
- D (c): the specific value for each area, resulting from the previous

expression;

- A (c): surface for each class of soil use;
- a (c): correction factor to identify the real urbanization in a specific land use category.

The concerned indirect economic losses in the case of agriculture result from the sum of the following items:

- value of land (calculated on the base of data obtained from public registers and Chambers of Commerce inventories, and affected only in case of erosion);
- value of man-made infrastructure and economic goods (valorized on a cost base, and affected entirely in case of erosion and partially in case of flooding);
- Net value of agricultural production (calculated on the base of average rents emerging from the official agricultural accounting database (RICA), integrated by data on crop market (ISMEA).

The economic value at risk depends thence on the actualized value of the profit margins associated to economic activities (obtained from a detailed netback analysis).

A critical assumption concerns the impact of structural modifications of land use. Since our model did not consider any relocation of urban settlements, land use modifications concern in particular the agricultural sector, with two possible variants: shift from intensive to extensive cultivation and from irrigated to non-irrigated crops. In case the land is not anymore suitable for intensive production integrated with the dairy industry (that is, production of forage), it is assumed that only a fraction can be converted to high-value productions (greenhouses, horticulture etc), while the remaining part will be dedicated to carbon-fixing cultivations and set-aside.

The model assumes that farmers optimize cropping choice always choosing the best available alternative. In case the probability of being flooded is higher than a certain threshold, developers may consider a change in the use destination. Downgraded land is expected to earn the same net income as comparable land in the present situation (i.e. we imagine that profitability of each choice remains the same as today, without considering scale effects). This assumption is justifiable since the concerned area is small enough, but is probably critical if the analysis is extended at a macro level.

The damage on real estate, sport facilities, road infrastructure is estimated through parametric functions obtained from a detailed meta-analysis of technical literature, adjusted with on-site interviews.

The river also fuels an intensive hydropower production, which is situated along canals and millstreams deriving water flows from the main watercourse. At present, 14 run-of-river hydropower stations are active, with an installed capacity of 14 MW and an average annual production of 102 GWh/yr. The total economic value of this production, resulting from the mere multiplication of this production per the market price[1], can be quantified in 7,7 M€/yr. From a private perspective, the price also includes incentives and subsidies to renewable energy that should be omitted in a social cost-benefit perspective, leading to a total value of 16 M€/yr. In case this production is lost (this happens in the more radical scenarios, in which existing abstractions from the watercourse have to be given up), we also measured a social cost of replacement (SCR) as the difference between the production cost and the external cost of the best available alternative and the same values for the hydroelectric production:

$$SCR = \left(C_p + EC\right)_{BAA} - \left(C_p + EC\right)_{Hydro} \qquad [4]$$

Where:

- Cp is the electricity production cost for the different power plants. In this case, the best available alternative (BAA) for the run-of-river plant is a Combined Cycle *Gas* Turbine (CCGT). We estimated these values adapting the values of De Paoli *et al. (*1999) and Lorenzoni *et al.* (2007).
- EC is the external costs for the different power plants (adapted from European Commission, 1999)

The social cost of replacement was estimated in 1,2 M€/yr.

We consider vulnerability both of activities based in the concerned areas and of downstream areas, (the latter measured as the variation of the likelihood of downstream overflows as a function of the flood wave transmitted. The simplifying assumption here concerns the damage function, which we assume as a linear function of the water draught and/or the duration of submersion. Figure 3 illustrates some examples of the functions adopted

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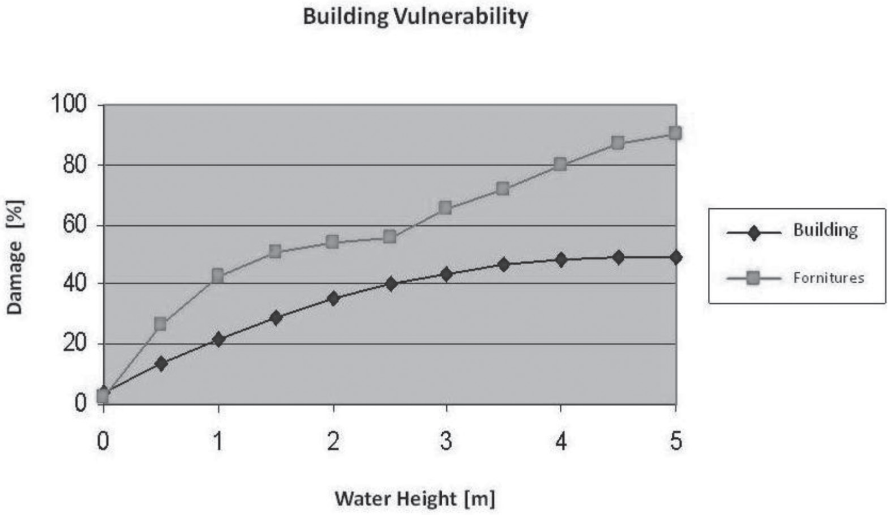
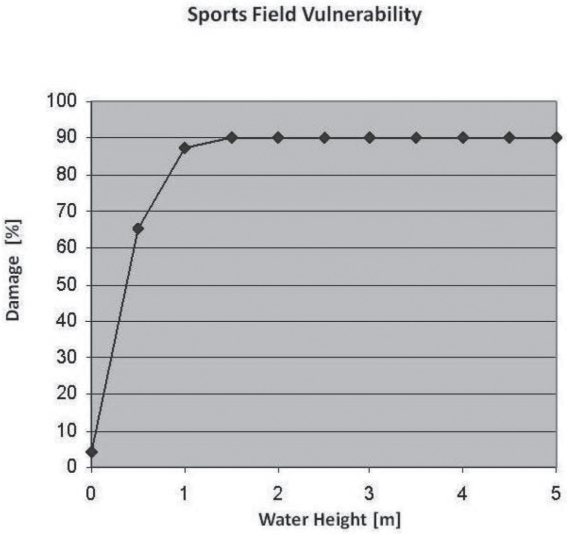
[1] For the run-of-river hydroelectric plants, the market price is the national average price (PUN) of Electricity Stock Exchange price (Source: www.gse.it).

Figure 3a – Vulnerability functions for buildings



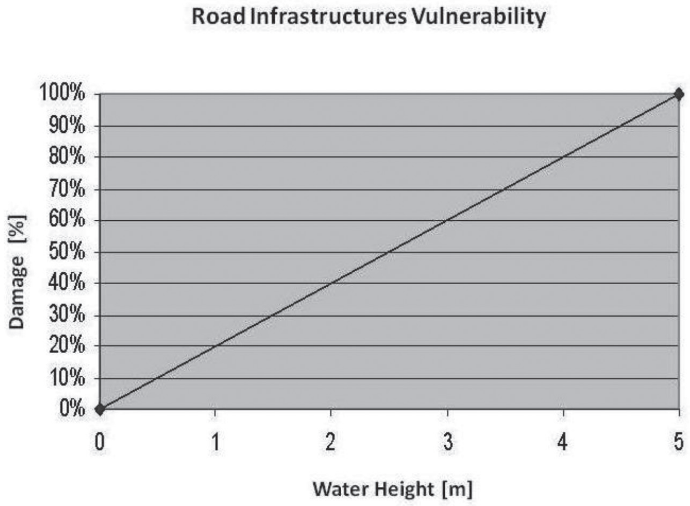
Source: AdB Po (2009)

Figure 3b – Vulnerability function for sport facilities



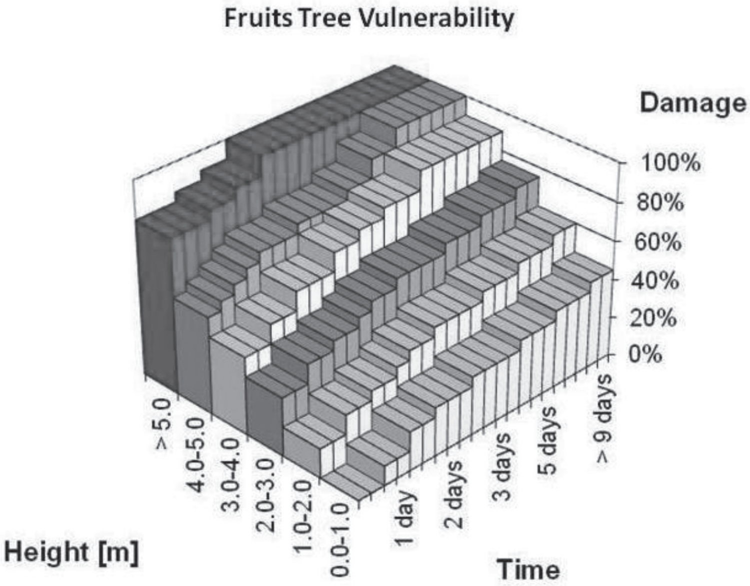
Source: AdB Po (2009)

Figure 3c – Vulnerability functions for buildings



Source: Kok (2001)

Figure 3d – Vulnerability function for fruits tree



Source: Frank et al., 2004

The second group of categories include non-monetized items, represented by a set of a-dimensional qualitative indicators:

- Category E (Externalities to downstream areas): these are simply represented by a score that captures the flood wave that is transmitted (the highest wave, the poorest score) and sediment transportation. These indicators are once more normalized in a qualitative assessment ranging from 0 (very bad) to 3 (very good).
- Category N (River ecological status): it is measured adapting the FLEA indicator proposed by Cirf, 2006. It combines in a simplified way a set of biochemical, hydrological and morphological attributes. This indicator has been chosen for simplicity of calculation and because it has already been tested in a number of applied case studies in Italy. The indicator varies between 0 (very bad: complete artificialization, total loss of ecological functions) and 1 (very good: close to pristine state, 100% of ecological functions are guaranteed)
- Category F (Fragility): it is defined as the probability that the existing infrastructure collapses, failing to provide the desired function even in case of TR<200 (this is proxied by the gap between actual investment and real depreciation.

Since the limited budget did not allow for a systematic involvement of stakeholders, we decided to refrain from value judgments: the integrated assessment adopts therefore a non-weighted multicriteria framework. Indicators had to be calculated through a desktop expert evaluation. This inevitably introduces an element of discretional evaluation, which can be considered an acceptable compromise given the purpose of the study. In order to refine the evaluation, more precise cause-effect relations should be investigated, and more sophisticated assessment techniques should be applied (e.g. Delphi interviews to experts, direct monetary or non-monetary evaluation etc).

6. Main results

Table 5 breaks down the financial costs for operation, maintenance and replacement (OMR) of the alternative scenarios. The mere reproduction of the status quo implies a total expenditure of 323 M€. Assuming a 5% interest rate and a 50 yr time horizon, this is equivalent to an annual expenditure of 16,95 M€. The RBAFS foresees the elimination of some older works and their replacement with new and more effective facilities, also completing the infrastructure in order to eliminate existing gaps with respect to the TR200 event. As a result, the total cost remains more or less the same, with a very slight increase. The alternative scenarios imply a progressive dismantling of higher portions of the existing system and here and then replacement with green engineering works. Costs reduce dramatically: -35% in the "Soft" alternative, -58,5% in the "Daring" and -72,5% in the "Radical".

Table 5 - OMR costs of flood protection measures implied by each scenario (over the next 50 years)

		Baseline	***Scenarios***			
			RBAFS	***Alt-Soft***	***Alt-Daring***	***Alt-Radical***
Existing	M€	273	209	91	48	34
New – FS	M€		69	50	50	38
New - Alternatives	M€			12	12	12
River maintenance	M€	50	50	32	23	6
Total	***M€***	***323***	***328***	***185***	***134***	***90***
Normalized annual expenditure	M€/ yr	16,95	17,05	9,83	6,89	4,17
Δ vs Baseline	%		+1,7%	-35,4%	-58,5%	-72,1%

Source: our elaboration

The ecological indicator N, as expected, exhibits a stable and continuous improvement from the baseline to the alternative scenarios. Since the ecological quality of the river is already in line with the good ecological status required by the EU Water Framework Directive, the different scores are entirely attributable to morphological aspects. The RBASF performs substantially similar to the baseline (N = 0,48). The first two alternatives (soft and daring) do not differ too much from each other, but mark a significant step forward with respect to baseline (N = 0,64 and 0,69 respectively). The Radical scenario reaches the highest score (0,80).

The externality indicator reaches the worst score with RBAFS – precisely because this scenario is based on an effective removal of the peaks associated to all floods TR<200, which are entirely transferred downstream. Both the baseline and the alternative scenarios, in turn, imply some flood retention in the Chiese basin: the former in an uncontrolled way and due to the existing gaps, the latter, to the opposite, in a planned and deliberate way. It has also to be noted that sediment transport is greatly enhanced in the alternative scenarios, and seriously limited both in the baseline and RBAFS.

Unfortunately, due to budget constraints, it was not possible to explore the full impact of the Daring and Radical scenarios in terms of flooded areas and land use destination change. For sure, the Radical alternative would imply the elimination of existing dams and artificial embankments, thence impeding both the supply of water for irrigation and associated hydropower production. Only the latter amounts to 1,4 M€/yr.

A detailed breakdown for the three first scenarios is shown in table 6, where data are presented as a total for the whole period considered (50 years), and calculated as differential values with respect to baseline.

The soft scenario, while requiring the periodical flooding of some marginal land, particularly in the upstream part of the case study area, does not imply a too radical change in the land use destination. Only a modest surface will have to consider a transformation of cropping choices from high-value to low-value ones, with an expected cost of 1,26 M€.

The normalized annual differential cost of inundation – entirely referred to agricultural land – amounts in the Soft alternative to 22 M€, which is only partially compensated by benefits due to reduced erosion (7 M€). The RBAFS with this respect obtains a better performance (4,66 and 3,33 M€ of benefits respectively due to reduced inundation and erosion). However, differences in OMR cost are fare higher than this gain.

In order to provide at least a rough estimate of the cost/benefit ratio, we have assumed:

- OMR costs using the higher engineering cost function
- r = 5%
- time horizon = 50 yr

As is shown in table 6, the RBAFS allows a positive, but modest improvement with respect to baseline (6,02 M€ of net benefit, corresponding to 0,33 M€/yr). The Soft alternative performs rather better, allowing a net benefit of 122 M€, or 6,35 M€/yr).

Three sensitivity tests have been provided. In the first one, we have used the lower OMR parametric cost function (derived from actualized historical cost). This result in a lower magnitude of cost savings, yet the difference remains remarkably high. The second and third assume a longer time horizon (100 yr) or a lower interest rate (2,55%). The effect of the former is to reduce the gap, but once again, the result is overwhelmingly confirmed. Reducing the interest rate, in turn, further increases the gap.

Table 6 - Breakdown of cost and benefits over the next 50 years (differential from baseline)

	Soft		***RBASF***	
	Benefits	***Costs***	***Benefits***	***Costs***
OMR savings	182		64	
OMR - new works		62		69
Maintenance of river bed	50	32	50	50
Flooding risk		22,16	4,63	
Land loss risk (erosion, wandering)	7,09		3,33	
Land value losses (agriculture)		1,26		
Loss from hydropower production				
Total	***239***	***118***	***122***	***119***
Net benefit	***121,45***		***2,56***	
Sensitivity 1 (OMR = RBASF)	82,1			
Sensitivity 2 (T = 100; r = 5%)	91,3			
Sensitivity 3 (T = 100; r = 2,55%)	188,1			

Source: our elaboration

Table 7 resumes the multicriteria evaluation scores, with a breakdown for the different categories. Limiting the discussion to the first three scenarios, we can note that the Soft alternative dominates both the baseline and the RBAFS, since its scores are systematically better. However, this is true only if D and C are considered together (as net benefits). In fact, the combined score derives, as already seen, from a huge saving of C, compensated by some increase of D.

This result confirms a typical outcome that also appears from the case studies discussed in par. 2, namely the clear trade-off between cost-benefits in a social perspective and the distribution of costs, which happen to be concentrated on a specific sector (agriculture) and arguably on specific areas and subjects.

Table 7 - Summary of results for all scenarios - annualized (NA: dimensions not yet analyzed)

Categories	**Item**		**Baseline**	**RBASF**	**Soft**	**Daring**	**Radical**
C	*OMR costs*	M€/y	16,95	17,05	9,83	6,89	4,17
D	*Expected damage*	M€/y	2,52	2,11	3,3	NA	NA
	Loss of agricultural land value	M€/y	-	-	0,07	NA	NA
	Hydropower production loss	M€/y	-	-	-	-	1,4
C -D	*Net benefit (Δ w/ baseline)*	M€/y		0,33	6,35	NA	NA
E							
	Flood peak TR 500, height	m3/s	603	641	578		
	Flood peaks, a-dimensional (1 = bad, 3 = good)		2	1	3	3	3
	Sediments transport (a-dimensional)		1	0	3	3	3
N	*Ecological status (a-dimensional)*		0,48	0,48	0,64	0,69	0,80
F	*Fragility*		2,06	1,68	0,85		

Source: our elaboration

7. Conclusions and policy implications

The study we have conducted had a mere explorative aim; budget and time constraints have forced us to limit the scope of the analysis. The case study area offered only a limited set of river restoration opportunities; scenarios that are more radical would imply a much wider and far-reaching reconversion of land use, whose actual feasibility is hampered by a number of reasons ranging from social and political acceptance to the obvious path dependence of regional development trajectories that cannot be easily inverted.

We have therefore deliberately concentrated the analysis on a less radical scenario (the Alt-Soft), which in practice can be seen as an acceptable compromise, in the sense that it is based on the maximum restoration that is feasible, once a “reasonable” level of disturbance to the actual patterns of social and economic development is provoked. These could be effectively managed – as in other analogous situations in Europe and elsewhere – through an attentive strategy oriented to affected stakeholders. Compensative payment schemes – such as payment for ecosystem services, mutual insurance and similar could be easily designed in order to cope with distributional issues.

An analysis that implies a more radical change of the patterns of land use could be nonetheless useful. In the first place, it would cast a light over the actual feasibility of non-structural measures and of the degrees of freedom that are still open in this direction. Second, it would allow appreciating the order of magnitude of the social cost of the rather chaotic and weakly regulated pattern of spatial development that has characterized Italy especially in the period following World War 2.

Another limitation of the present study is its microeconomic dimension. River restoration is assumed not to generate effects at the macro level: this is a reasonable assumption if Chiese would remain the only river adopting the new approach: but not anymore, if a similar approach would be generalized to the rest of Italian rivers. In this case, the cumulative effects of land use change would probably imply scale and systemic effects that need to be more carefully investigated.

Despite these limitations, however, we believe that results are encouraging enough to sustain the hint that an approach based on the philosophy of river morphology restoration – which is increasingly becoming the reference standard in Northern Europe – might have useful and promising applications also in a rather different context as the Italian one, at least in the North. The decisive aspect that qualifies an area as suitable for river restoration projects is clearly represented – as in many other studies in the literature – by the availability of low value land, particularly upstream of the larger urbanized areas.

While it seems that on a social base this philosophy allows to achieve better results (lower expected costs and better ecological quality), it also emerges clearly that the economic advantage accrues to the nation as a whole (reduced pubic expenses), while losses are concentrated on landowners and developers. At present, the legal opportunities for compensating the sacrificed activities are rather poor and unreliable. There is clearly an opportunity for using economic instruments for improving the acceptability of such measures; for example:

- Payment for ecosystem services (PES) schemes for compensating areas exposed to regular flooding
- Insurance schemes for covering residual damage (TR > 200)

- Environmental taxes on property (calculated with an inverse relation to the exposure to regular flooding) aimed at funding a compensation schemes for damages
- Flat-rate land ownership taxes aimed at funding maintenance and operation of infrastructure
- More generally, an attitude to live together with risk, which cannot be eliminated nor exorcised, but requires instead a fundamental investment in social learning, aimed at improving resilience and capacity to manage risk as an event of ordinary life rather than an abrupt and unpredictable catastrophe.

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