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River restoration: not only for the sake of nature but also for saving money while addressing flood risk. A decision-making framework applied to the Chiese River (Po basin, Italy)

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Abstract

One of the key ideas of river restoration is that restoring rivers to a more natural status is desirable not only for pure environmental reasons but also to combat flood and geomorphic risk. This paper investigates whether this can be true even in a Mediterranean context, quite different from that of Northern Europe where European river restoration was born. Specifically, we evaluate whether the savings obtained from not implementing new protection works and from maintenance costs not spent – because of elimination of several existing works – exceed the likely increment of flooding and hydromorphological risk. Different conceptual approaches to the decision problem of flood control are synthesised within an integrated, three-level, evaluation framework. The proposed evaluation framework is applied to a case study on the Chiese River (Po River basin, Italy). Results for this case study are presented. Finally, findings, limitations and potential for application are discussed, concluding that river restoration offers a viable pathway for improving the river environment while not incurring additional economic costs associated with classic flood risk management.

Rationale and scope

The birth and spread of the river restoration concept and practice (see for instance http://www.ecrr.org) was initially centred on river ecosystems in terms of biotic components. Ensuring suitable river habitats for leisure fishing in United Kingdom and commercial fishing in the USA and Canada was one of the main objectives. Today, however, the requirement introduced in Europe by the Water Framework Directive (WFD, Dir.2000/60/CE) to achieve a good *ecological status* in a few years (2015) and those introduced by the Floods Directive (FD, Dir.2007/60/CE) raise a real challenge: river restoration provides most of the answers sought by the WFD, but it has now to demonstrate whether it can provide significant answers to address flood management issues as well. All over the world, the actions against risk have so far been driven by the paradigm of 'putting the territory into safe conditions'. This implies hard interventions, like canalisation, levees, weirs and retention tanks connected by artificial input-output works. Inevitably, more works imply increasing and never-ending costs of operation, maintenance and replacement (OMR), while public administrations suffer more and more from lack of funds (Cellerino, 2004 showed how such costs are steadily increasing in Italy).

More works, while land is getting more and more urbanised, not only accelerate the trend towards a progressive worsening of the ecosystems quality but also increase the risk of failure (residual risk) because of a more artificialised system. The concept of river restoration takes us instead very far from such hard interventions; its current key challenge is probably to demonstrate that more natural rivers and compatible land use are rewarding and socially desirable not only for purely environmental reasons but also because they are the only economically and financially sustainable answer against the risk problem (ECRR, 2008).

A broad-view river–restoration project (see for instance the Sustainable Development of Floodplains of river Rhine at http://www.ecrr.org/sdfproject/sdfproject.htm) would consider dismantling some levees, weirs and bank protection works; it would also try to give space back to the river by

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purchasing land and/or by establishing working agreements with land owners so that their environmental services can be recognised and remunerated (in particular, reduce flood damage somewhere else by bearing part of the damage locally).

Before undertaking, however, any of such actions, carrying out a thorough evaluation of pros and cons, including risk issues, is a must, although something not easy to do. This paper presents an integrated framework to address a flood decision problem with an open perspective and to carry out such an evaluation. In addition, we present a case study on the Chiese River that basically addresses the difficult question, ‘Is it worthwhile to carry out works on this river to achieve the “safe condition” of the layout? Or is more extensive restoration of the river preferable? How can this be evaluated?’

A similar problem has already been addressed by Frans *et al.* (2004) in their thorough study of the Netherlands ‘room to rivers’ national policy. The case presented here is definitely on a much smaller scale but with higher detail; furthermore, it adds value as it addresses a Mediterranean situation, where topography, climate, land use and river behaviour, and particularly management are definitely very different from Northern Europe.

Another type of interesting evaluation of a river restoration project is related to the Skjerne (Dubgaard *et al.*, 2002); but, there – as in many other similar studies or guidelines (e.g. TEEB, 2009) – the emphasis was on the monetisation of environmental services related mainly to water quality and recreation rather than on the role of flood risk and of protection works. Although not referring to river restoration, the European Union (EU) project FloodSite (http://www.floodsite.net; Meyer and Messner, 2005) reviewed the approaches of several countries in Europe to flood risk management, with an evaluation generally based on a cost-benefit analysis (CBA) framework; their findings are key in the discussion that follows.

Conceptual framework and methodology

Let us consider a river at the corridor scale (tens of kilometres), with its current (modified) morphology and geometry (planform pattern; long profile; depth, width and cross-sectional shape of bankfull channel; sediments), all its existing defence and exploitation works, and the current river management practice (i.e. periodic vegetation clearing, sediments removal, . . .). We refer to this set of elements as ‘river setting’.

We consider a set of alternative river settings (*ALTernatives*, in what follows), which include the definition of a new morphology (for instance, because of cross-sectional reshaping to reconnect the bankfull channel with the floodplain or following removal of some levees), of a new set of defence and exploitation works (e.g. with some weirs or longitudinal defences removed or, on the contrary, added), as well as administrative-financial dispositions.

According to a broadly applicable Decision Analysis framework (Loucks *et al.*, 1981; French, 1988), we want to compare different *ALTernatives*, under the same *Scenarios* in order to generate useful information for decision making. We recall that an alternative course of action (here denoted *ALTernative*) can be preferred to another and hence selected by making a decision, while a *Scenario* includes all that can affect the performance of the system (in terms of evaluation indices), which cannot be controlled through decisions within the decision-making-sphere involved in the problem addressed. Furthermore, *Scenario*’s variables are characterised by uncertain outcomes (some examples are given later on). All *ALTernatives* for the sake of a meaningful comparison need to be analysed under the same *Scenario*. However, the analysis can then be repeated for other *Scenarios*, and an overall conclusion can be drawn based on some empirical criteria, like typically the worst case (‘min-max’) or the ‘minimum regret’ optimisation (this latter issue of multiple *Scenarios* is not addressed explicitly in this paper, although it can be still supported by the same framework proposed, just complicating the analysis).

The EU Directive (Dir.2007/60/CE; FD in what follows) requires member States to elaborate *risk maps*; when, however, for planners and decision makers who have to emit land-use regulations and face stakeholders, the key tool rather is the *hazard map*. It is in fact in the areas where a potential harming event may occur – even if today, no exposed value is present (i.e. null risk) – that care has to be taken and land use regulated (see also Hagemeier-Klose and Wagner, 2009 on this topic). The important point, anyway, is that in the end, maps do not solve the decision-making problem; planners should rather compare risk maps associated with the future situations corresponding to alternative courses of actions in order to select the preferred one. Comparing maps is however not easy [e.g. Beinat and Nijkamp (1998) gave some interesting general hints, although not related to flood problems specifically; Malczewski (1999, 2006) provides an overview of spatial analysis issues] and moreover may not capture the full range of relevant aspects, as it is humanly impossible to keep in mind so much information at the same time. Multiple, structured, resuming indices are needed, possibly accompanied by informing maps [Nardini (2004) discusses advantages and risks of using synthesising indices]. This is the driving idea of the whole discussion that follows.

Addressing a flood risk problem: alternative approaches

In what follows, we refer to ‘risk’ as the expected value of damages associated with the stochastic occurrence of (rare)

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flood events (in agreement with EU FD[1]). In principle, it is a multi-attribute vector (direct and indirect economic losses, suffering because of material and psychological stress, diseases or loss of lives, . . . ; see for instance, Meyer and Messner, 2005), but we will refer specifically to its tangible economic component ('technical-economic' reduced view) because the framework presented later on is essentially multicriteria – so that other components are dealt with separately (see the different *Stages i*, *ii*, *iii* of *Approach d* in the following section) – and we want to provide sound information that can convince 'practical' decision makers who are used to think in terms of tangible things.

In what follows basic objectives are introduced (identified by capital letters *R*, *N*, *C*, *S* and variants). They will be discussed in detail later on, as what counts now is just their general meaning, independently on the particular formalisation chosen for them.

Schematising, one can choose among the following alternative approaches to deal with risk management (in the following, **bold** characters denote vectors while *italics* denote sets):

Approach a: 'safety against reference event'

This 'classical engineering' approach is based on the paradigm of 'putting the territory into safe conditions with respect to a reference event' (for the Po River basin, the 200 years recurrence time flood – $Q_{Tr=200}$) while minimising the cost $C(\mathbf{u})$ of intervention decisions $\mathbf{u}$ (given by the sum of investment plus capitalised future OMR costs of new and existing, but maintained, works).[2] This position implies, by definition, nullifying the risk $R_{ref}(\mathbf{u})$ associated with all events more probable (and less severe) than the reference one ('ref'), and with the same decisions vector $\mathbf{u}$. Synthetically,

$$\min_{\mathbf{u}}[C(\mathbf{u})] \quad \textit{subject to} \quad R_{ref}(\mathbf{u})=0 \qquad \mathbf{u}\in\mathbf{U} \tag{1}$$

with $\mathbf{U}$ being the set of feasible decisions (typically engineering interventions, i.e. works) and each particular choice $\mathbf{u}^k$ of $\mathbf{u}$ defines indeed the *k*th *ALTernative* in the sense specified above. Although semantically attractive, this approach is paradoxically counterproductive and eventually dangerous because it fosters in practice further urbanisation of new 'safe' zones with an eventual increase of total risk (because of lower probability of damaging events harsher than the reference one but much higher exposed asset value).

Approach b: 'minimise total risk'

Here the 'total risk' $R_\infty(\mathbf{u})$ includes the risk component $R_T(\mathbf{u}) \geq R_{\text{ref}}(\mathbf{u})$ that takes into account also more severe events (but less probable) than the reference one, as well as the residual risk $R_{failure}(\mathbf{u})$, associated with some failure of the defence system. Synthetically, the decision problem is hence set as

$$\begin{aligned}&\min_{\mathbf{u}}[R_\infty(\mathbf{u})\equiv R_T(\mathbf{u})+R_{failure}(\mathbf{u})]\\ &\quad \textit{subject to} \quad C(\mathbf{u})\leq C_{\max} \qquad \mathbf{u}\in\mathbf{U}\end{aligned} \tag{2}$$

In this case the total cost *C* is limited by a maximum allowed cost $C_{\max}$.

Approach c: 'maximise the net social benefit-[extended cost benefit analysis (ECBA)]'

The CBA approach is very well known, although applied to varying degrees in different countries but now reconsidered by the EU Flood and WFDs. Its environmentally extended evolutions [ECBA, with its techniques well resumed in Dixon and Hufschmidt (1986)] have been applied within river restoration projects (Dubgaard *et al.*, 2002). When a reduced technical-economic perspective is taken, this is equivalent to minimising the total cost, i.e. $R(\mathbf{u})$ (in one of its versions) plus defence expenditures $C(\mathbf{u})$, as the sought benefit is indeed the risk avoided.

$$\min_{\mathbf{u}}[R_\infty(\mathbf{u})+C(\mathbf{u})] \quad \textit{subject to} \quad C(\mathbf{u})\leq C_{\max} \qquad \mathbf{u}\in\mathbf{U}^* \tag{3}$$

where $\mathbf{U}^*$ is an enlarged set of feasible decisions that include in particular the legal-administrative-financial measures needed to redistribute benefits and costs among affected social groups. A broader tool-box $\mathbf{U}^*$ of decisions is here conceptually necessary because the optimal solution will generally correspond to a higher level of partial risk than approaches *a* and *b*, while greater economic savings are generated, and hence redistribution mechanisms are key.

Approach d: 'multi-objective maximisation inspired to quality of life (QoL)'

Risk and costs are relevant, but probably all of us agree that they do not capture the full picture. In the end, what counts more is improving people's QoL, linked to the discussed interventions $\mathbf{u}$, and whatever be its precise meaning (Ventegodt *et al.*, 2003), we can recognise that QoL is a multi-attribute concept that includes at least some well-known components: the cost of interventions $C(\mathbf{u})$, the total

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[1] This decision criterion is known in decision theory literature as *Laplace's criterion* (French, 1988). A more general formulation would rather adopt the Utility Function concept (Keeney and Raiffa, 1976), and accordingly, the objective to be minimised would be the expected value of the disutility corresponding to damages; in other terms, damages are weighed differently depending on the risk attitude of decision maker. When a probability distribution of the uncertain variable (e.g. hydrology) cannot be defined, a *strict uncertainty* approach should be adopted instead, where typically the decision criterion is *Wald's criterion*, known as 'min-max' – or minimising the worst case negative consequences – or the *minimum regret* criterion (French, 1988; see also Loucks *et al.*, 1981). While the Utility Theory – and its Utility Function concept – is rarely used – both because of its intrinsic complexity and because it loses any link with economic welfare theory – Wald's approach is often implicitly utilised when flood analysis is conducted on the base of a reference flood (typically the highest historical one). The most used approach, even in recent advances, like for instance in Mazzorana *et al.* (2011a, b), is however in essence still Laplace's expected value of damages.

[2] Too often, the OMR component is totally disregarded leading to decisions only seemingly 'optimal'.

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risk $R_\infty(\mathbf{u})$, and the ecological status of river ecosystem represented by a synthetic index $N(\mathbf{u})$ aggregating the chemical-physical, biotic and hydromorphological qualities, and as such depends on the intervention decisions **u** because they affect river status and behaviour; a social disturbance index $S(\mathbf{u})$ can be considered too (e.g. change of land use or delocalisation of some settlements, reduction of hydropower generation because of removal of a weir, etc.). Hence, synthetically, our flood risk problem is to be addressed through a multi-objective approach, inspired somehow to the QoL concept.

$$\max_{\mathbf{u}}[N(\mathbf{u}),-R_\infty(\mathbf{u}),-C(\mathbf{u}),-S(\mathbf{u})] \quad (4)$$
$$\textit{subject to} \quad C(\mathbf{u})\le C_{\max} \qquad \mathbf{u}\in\mathbf{U}^R$$

where the minus in the multi-objective vector is consistent with the maximisation operator and $\mathbf{U}^R$ is a new set of feasible decisions further enlarged with respect to $\mathbf{U}^*$ (i.e. $\mathbf{U}^R \supset \mathbf{U}^*$) that includes all river restoration innovative measures, including those sensitive with respect to N, particularly when of *win-win* type (i.e. improving all objectives).

It is worth noting that choosing one particular approach out of these four (and associated variants) implies obtaining a different solution, i.e. eventually . . . a different river. This 'trip' through different approaches to the risk problem aims at pointing out the superiority of the more elaborated *Approach d: 'multi-objective (QoL)'* as it (i) incorporates the previous approaches that just assign zero weights to some objectives and skip some components within the formulation of the risk index R; (ii) considers people's concern (disturbance S), key in a participatory negotiation framework; and (iii) allows to integrate the two key EU Directives (WFD and FD), as it puts on the same table their relevant objectives (costs C, risk R and particularly the ecological status N).

Adopting a particular approach to address a flood risk problem is however not enough. An extensive literature and everyday reality proved that only through an informed participatory approach, decisions can be made, which are then actually implemented (Ortolano, 1974, 1976; Janssen, 1992; Renn *et al.*, 1993, 1995; Renn, 1995; Soncini-Sessa, 2007a), and a key step within this complex and lengthy process is the evaluation of alternatives ranging from (E)CBA (Dasgupta and Pearce, 1978; Dixon and Hufschmidt, 1986; Meyer and Messner, 2005) and environmental impact assessment (EIA) (Vanclay and Bronstein, 1995) to Decision Theory and its operational tools within the Multicriteria Analysis (MCA) framework (Keeney and Raiffa, 1976; Goicoechea *et al.*, 1982; Keeney, 1992; Meyer *et al.*, 2008). But, in essence, to the aim of achieving results, a too complex procedure is counterproductive, even more when, as usual, the different approaches to evaluation (CBA, EIA, MCA) lead to different outcomes. This is what motivated us to define a simple but integrated and operational procedure, which starts with an appropriate position of the problem according to *Approach d: 'multi-objective (QoL)'* to identify sensible and efficient candidate solution alternatives, and pivots then around an integrated evaluation that tries to compensate the weaknesses of CBA, EIA and MCA while harvesting their strengths, as presented in Nardini (1997). Before resuming the proposed decision-making procedure, an insight is given into how evaluation is structured.

Three-stage evaluation

To constructively support public decision making, an integrated evaluation inspired to *Approach d: 'multi-objective-QoL'* can be usefully articulated in three stages as follows:

Stage i: technical evaluation

This is a 'what-if' where the key objectives N, R, C, S (and possibly others) corresponding to each *ALTernative* are measured as objectively as possible.

Stage ii: conflict management evaluation

Here, the idea is to articulate the constituting objectives according to all stakeholders' views, including to some extent also those who do not have direct voice in the process (because they are too far or not enough organised) as far as somebody is somehow representing them possibly just because of ethical reasons. It is the pivot around which to develop an open discussion and negotiation among them and decision makers. Again, here, QoL – or more practically the satisfaction associated with the consequences of the candidate solution alternatives – is the concern, but now, it is specific to each stakeholder according to his own sensitivity and values [an example on a local flood problem project is presented in Nardini (1997) and Nardini and Bacci (2000); a thorough example related to water resources management is presented in Soncini-Sessa (2007b)]. The indices utilised here are conceptually different from those presented above in the formalisation of *Approach d: 'multi-objective (QoL)'* because here, the aim is to represent stakeholders' satisfaction exactly as they perceive it; hence, for instance, risk can be split in several items, and perceived risk can be different from objective risk (expected value of damages) possibly because the subject is strongly risk-averse (and hence the utility function concept is the appropriate tool[3]).

Stage iii: overall public decision making or strategic evaluation

Here, the spirit is to compare general pros and cons, which can be classified in two classes: (a) QoL strictly speaking

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[3] In the case study developed here, we ignored this distinction, but it can be developed and can be relevant particularly in developing countries where most people are prone to bear moderate flooding rather than accepting more costly solutions or delocalisation, as they are somehow 'used to a certain kind of suffering', while solution to flooding may imply resettlement in a unsuited context where social relationships and cultural identity may be destroyed.

including a summary of the perceived satisfaction of stakeholders more directly involved (*Stage ii*), additional components of the multi-attribute risk objective not captured by its technical-economic formulation (e.g. health and psychological effects, or possible lives loss), together with all that is required to achieve, reach and maintain such QoL level – like financial feasibility and sustainability – and proxies of the 'QoL of the outer world'; and (b) 'justice',[4] e.g. fairness in the allocation of pros and cons among different areas/subjects, as well as environmental sustainability in strict sense for the sake of an ethic of nature and of future generations (maintenance of a natural capital, which is where the WFD is reflected through the index *N* for the ecological status), and so on.

Notice that a key item in the 'quality of life of the outer world' refers to the effects (externalities) that the management choices in the considered river basin may export outside and particularly to the downstream main river basin. In the context of flood risk and river restoration, the main consequences are associated with

- export of higher or lower flood peaks (and their timing)
- alteration of solid flow exported downstream

but also other may count like the export of contaminant/nutrient loads downstream or the impact on fish-stock reproduction because of physical barriers, etc.

These aspects are quite difficult to properly quantify, but ignoring them would be a mistake. Hence, at least, they should just be recorded and assessed in qualitative terms.

A powerful partial proxy of the 'QoL of the inner and outer world' is provided by the social net benefit B_N determined through an ECBA because according to welfare theory (Dasgupta and Pearce, 1978), choosing decisions $\mathbf{u}^B$ that maximise B_N implies producing efficiently (with no wastage) and allocating products according to consumers' preferences, which is assumed to make them better off. B_N cannot substitute all other criteria, but it is a powerful synthesis of part of them and an index to which decision makers are very well used and sensitive. It is particularly meaningful when presented in association with additional indices measuring the components of value not explicitly included.

The same framework, furthermore, may be thought to incorporate the classic three sustainability dimensions (Munasinghe, 1993): **social** in terms for instance of disturbance (*S* in *Stage i*), consensus (likely to be achieved thanks to *Stage ii*) and equity (*Stage iii*); **environmental** (here explicitly within *Stage i*) – ecological status *N*, then indirectly under the *QoL* criteria group in terms of environmental services provided to sustain the benefits, as well as under the *Justice* criteria group as far as environmental asset conservation is concerned); and **economic** as far as the efficient use of resources and the maintenance along time of proposed actions are concerned (both reflected implicitly by higher QoL levels or explicitly by suitable proxy indices).

We are now ready to resume our proposed methodology, where the chosen approach to address a flood risk problem plays a twofold role: on the one hand, it drives from the beginning the identification of candidate (efficient, possibly win-win) solution *ALTernatives*, and, then, on the other hand, it frames their evaluation within a participatory decision-making process.

Methodology to address a flood risk problem incorporating river restoration philosophy

Here are the steps of a rational planning process not even particularly restricted to the flood risk problem. We do not claim the process presented here to be new as even President Franklin's own approach to decision making was very similar (Franklin, 1772); essentially, it is just a matter of common sense, but it is worth to be put once more in clear terms as a reference framework specific to the flood problem [very close proposals are presented in Keeney (1992); Renn *et al.* (1995); Soncini-Sessa (2007a)]. All the steps need to be developed through a sound participatory process (not discussed here; see for instance Connor, 1997; Nardini, 2005):

1. *diagnosis* with identification of problems and opportunities;
2. setting *vision and objectives*;
3. definition of feasible *action lines, decision options* $\mathbf{U}^R$ and *strategy*, i.e. a coordinated set of actions within each action line aiming at achieving the desired objectives, inspired to *Approach d: 'multi-objective (QoL)'*;
4. definition of *ALTernatives*: each one specifies a possible course of actions within the same strategy;
5. *prediction of effects for each ALTernative*: in particular, this has to deal with the geomorphic evolution of the river, i.e. predicting the new morphology corresponding to the new future dynamic equilibrium – this is presented in Nardini and Pavan (2012) – and corresponding eroded and flooded areas under a specified *Scenario*, for several recurrence times T_R (in the case study: 2, 5, 10, 20, 50, 200, 500 years);

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[4] We apologise with readers for the simplified use of this complex concept, but what we need here is just to point out that there is a family of relevant criteria conceptually different from those labelled as 'quality of life' and that has strong links with the justice concept. Justice, in fact, should inspire the whole choice of evaluation criteria in this strategic stage as, according to Vichy Been (http://www.nyu.edu/pages/elc/ej/, visited on November 2009), one should select at least one of the following paradigms: (a) *libertarian*: choice is just if it is the outcome of a free bargaining among individuals (point of view of private project proponents); (b) *utilitarian*: the just choice is the one that assigns the largest benefit to the majority of people (point of view of administrations); and (c) *social*: leaves the minimum burden on the shoulders of the most disadvantaged (point of view of local opponents).

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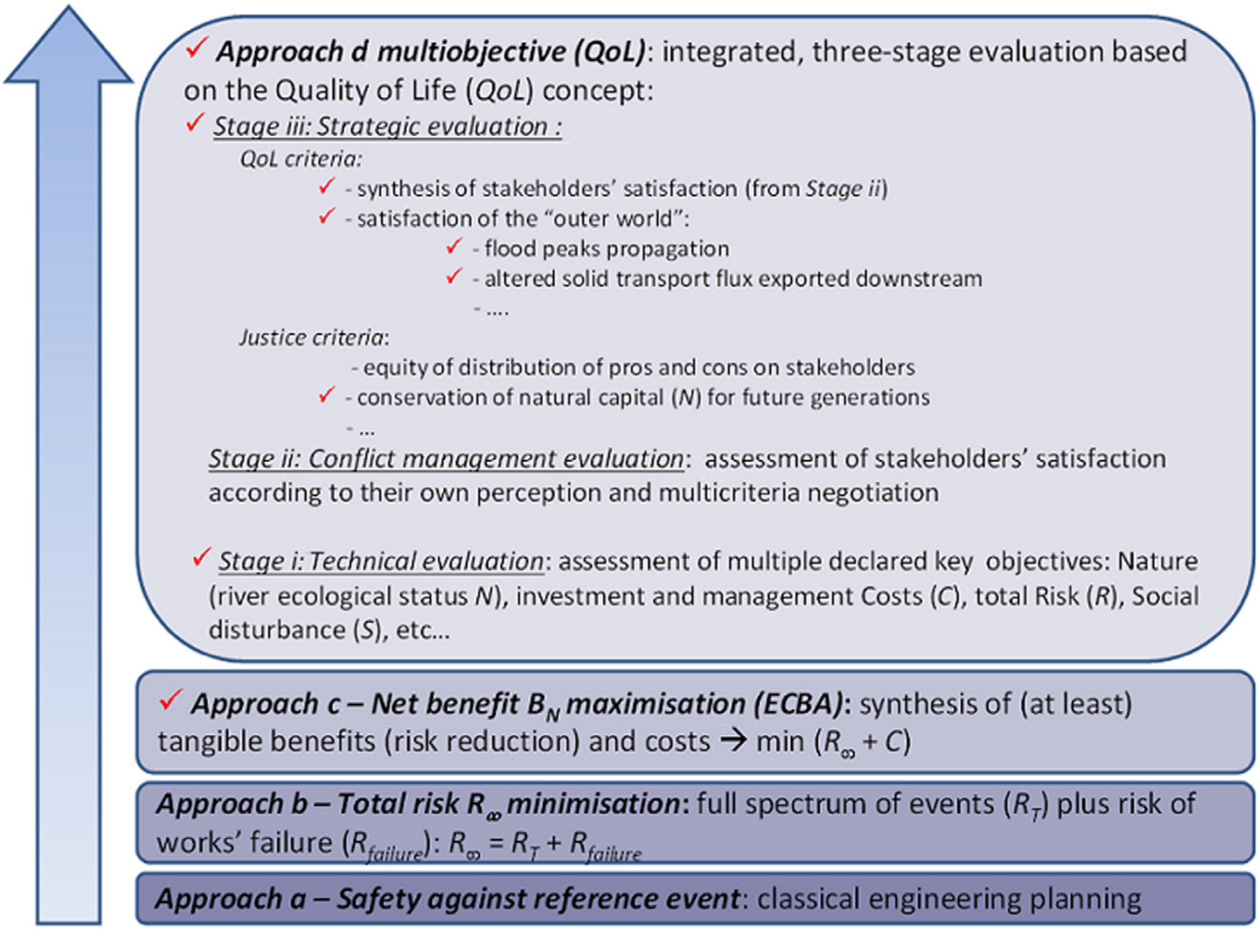

✓ ***Approach d multiobjective (QoL)***: integrated, three-stage evaluation based on the Quality of Life (*QoL*) concept:

✓ *Stage iii: Strategic evaluation :*

QoL criteria:
- ✓ - synthesis of stakeholders' satisfaction (from *Stage ii*)
- ✓ - satisfaction of the "outer world":
  - ✓ - flood peaks propagation
  - ✓ - altered solid transport flux exported downstream
  - - ....

Justice criteria:
- - equity of distribution of pros and cons on stakeholders
- ✓ - conservation of natural capital (*N*) for future generations
- - ...

Stage ii: Conflict management evaluation: assessment of stakeholders' satisfaction according to their own perception and multicriteria negotiation

✓ *Stage i: Technical evaluation*: assessment of multiple declared key objectives: Nature (river ecological status *N*), investment and management Costs (*C*), total Risk (*R*), Social disturbance (*S*), etc...

✓ ***Approach c – Net benefit B_N maximisation (ECBA)***: synthesis of (at least) tangible benefits (risk reduction) and costs → min ($R_\infty + C$)

Approach b – Total risk R_∞ minimisation: full spectrum of events (R_T) plus risk of works' failure ($R_{failure}$): $R_\infty = R_T + R_{failure}$

Approach a – Safety against reference event: classical engineering planning

Figure 1 Four approaches to address a flood risk problem and corresponding evaluation frameworks with increasing level of suitability from bottom-up. Red ticks identify items actually developed in the case study on the Chiese River. ECBA, extended cost-benefit analysis.

6. *integrated comparative evaluation* of the *ALTernatives* as close as possible to the three-stage framework presented earlier through calculation of relevant evaluation indices and due sensitivity analysis;
7. *negotiation and choice*;
8. *specification* with *implementation plan*.

In this paper, just steps 4 and 6 are discussed in detail.

A lot can and should be said about the fundamental step of identifying and proposing *ALTernatives*, but here, we concentrate on the evaluation step because no matter how *ALTernatives* are created, if evaluation is well performed, undesirable courses of actions are identified and can be corrected iteratively. Figure 1 depicts the possible approaches that can be adopted in the evaluation; it includes all the approaches to address flood risk already presented, from which a corresponding evaluation framework is derived. It also points out that the more elaborated *d* or at least *c* are those recommended, while the first classic engineering *Approach a: 'safety against reference event'* should be abandoned. There is however no rigid, univocal definition because each study needs to comply with its own context and resources, and hence, a certain flexibility is necessary. For instance, in our case study on the Chiese River, we could not develop in full *Approach d: 'multi-objective (QoL)'* in three stages, and we centred mainly on *Approach c: 'maximise net social benefit'* with a reduced CBA, with some insight into the former, as marked in Figure 1.

Approach d is the most suited to integrate the two key EU directives (WFD and FD). A somehow acceptable proxy of the QoL criteria within *Stage iii* of *Approach d* is the net benefit B_N accompanied by complementing criteria for the aspects not incorporated within the (extended) CBA scheme that generates it. This is indeed what has been done in our case study on the Chiese River, which was centred on *Approach c*, and developed part of *Approach d*, namely *Stage i*, and in a very rough way also *Stage iii*.

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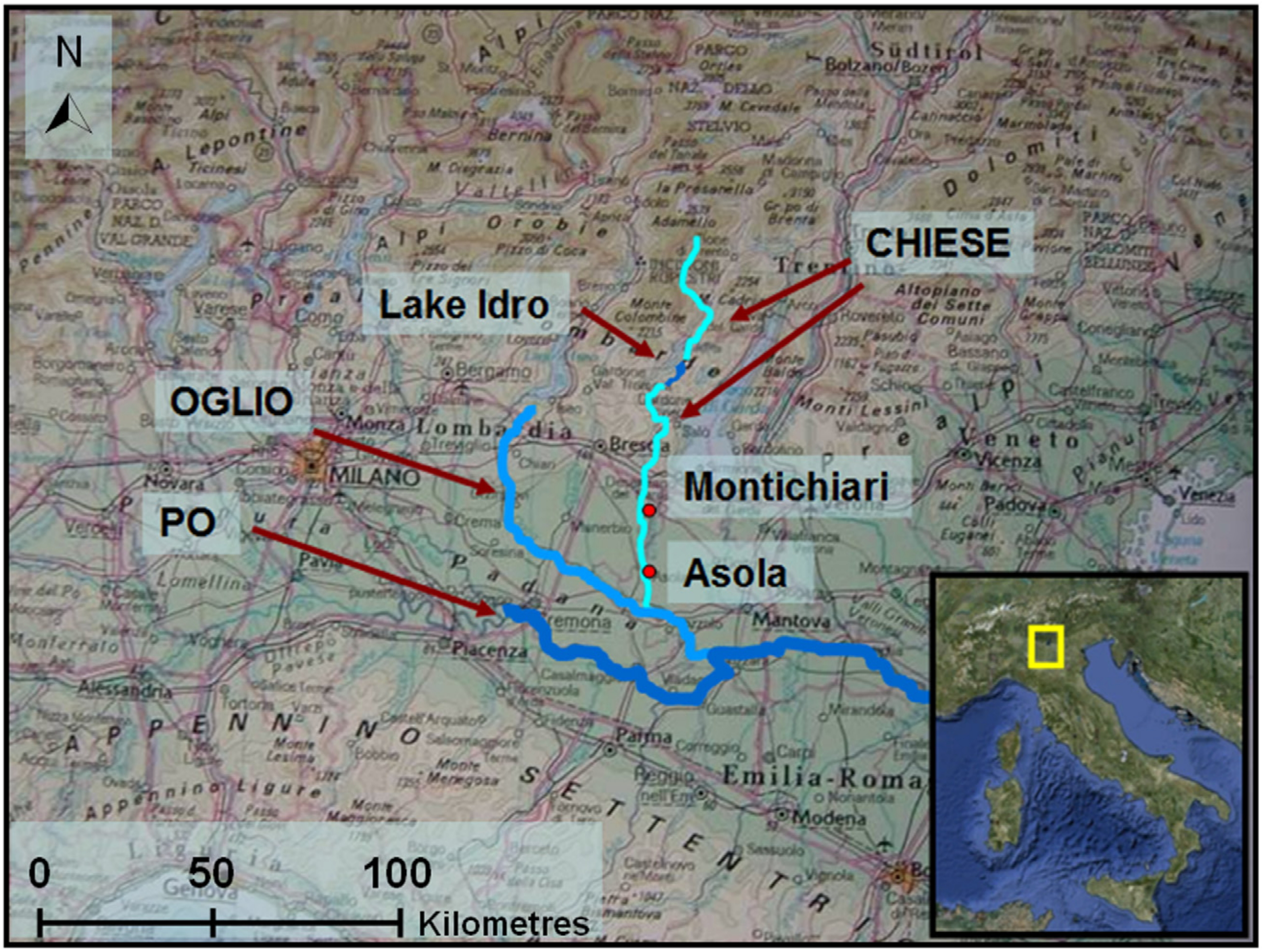

Figure 2 Case study location.

Case study

The methodology was developed and applied to the whole stretch of Chiese River downstream of Lake Idro (one of the piedmont postglacial natural but partially regulated lakes of Northern Italy) until its confluence with river Oglio. Most of the river runs in a semirural area, touching several small towns and rural settlements. Almost all its course is highly artificialised with several big-sized weirs and longitudinal defences, and big, sometimes multiple, levees. Many productive activities are strictly related to the river: agricultural areas served by Chiese River sums up to about 250 km^2; water is abstracted in correspondence of 10 big weirs and distributed by means of a dense irrigation channel net; in all, 15 hydropower plant are located along the river, six of which are associated to the irrigation net; the installed power ranges from 28 000 kW in the upper part, just downstream the Idro Lake, to 335 kW downstream; and the resulting total installed power is about 40 MW. The geographical position is shown in Figure 2, while Figure 3 shows some pictures captured along the case study reach in order to give an idea of the river dimensions and of the kind of engineering works implemented. Table 1 summarises main morphometric and hydrological characteristics.

Table 1 Main morphometric and hydrological features of Chiese River

Catchment area	1400 km^2
River length	180 km
Studied stretch	80 km
Average flow	33 m^3/s
Maximum flow ($T_R = 200$ years)	750 m^3/s
Idro Lake volume	747 Mm^3
Idro Lake regulation volume	75.5 Mm^3

For this river, the *Autorità di Bacino del fiume Po* (AdBPo – river basin water authority) had developed a feasibility study (AdBPo, 2004) to define the hydraulic setting, including some interventions of partial restoration (mainly forestation of river corridor and removal of obsolete defences, but also several new defences or adjustments of existing

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Figure 3 Left: reach of the studied Chiese River from Calcinato at the north (top) to the Oglio confluence south (bottom) with typical images. Right:: northern stretch still conserves some seminatural reaches (although water regime and water quality are already altered).

ones, basically adopting the classic engineering *Approach a* discussed above for flood risk management. This important study is referred in what follows as Studio di Fattibilità ('SdF'). We wanted to investigate whether a different solution with 'much less concrete in stream' could imply significant economical savings in terms of works not implemented, and/or OMR avoided, while the risk increase could be kept sufficiently low and the ecological status improved.

The questions, in other words, were: what is the weight of OMR costs in the overall economic balance? Is it worth implementing river restoration from the economic point of view including flood risk?

In this application, as anticipated, we adopted a simplified version of the evaluation framework presented in the previous section (Figure 1). Namely, evaluation has been centred on the reduced CBA (*Approach c*), while only the *technical evaluation Stage i* and a simplified version of the *QoL Stage iii* were developed.

Considered ALTernatives of river setting

We defined a number of different *ALTernatives*, all based on the existing and foreseen settings according to the feasibility study SdF conducted by AdBPo (2004). The set of decisions $\mathbf{U}^R$ actually considered to create new *ALTernatives* included the construction of new defence work (with bio-engineering, any time, this was a sensible option), the dismission of existing defence and exploitation works or their modification (threshold lowering of weirs or enlargement of bridges), the periodic maintenance of the river bed itself (dredging and vegetation clearing, both contributing to OMR costs), as well as the change of land use in some areas or resettlement (which of course generates a social disturbance *S*). Other more advanced options concerning in particular land management (insurance, compensation schemes, . . .) were not considered, given the exploratory character of our study.

In the end, owing to the heavy burden of elaborations required for the whole analysis, only the first three *ALTernatives* were truly developed in full (but some analysis steps were carried out for the other ones as well):

- *ALT_0*: the 'business as usual' alternative, which implies high OMR costs for keeping the current defence and exploitation works system, and some pointwise, urgent interventions that were considered mandatory by AdBPo.
- *ALT_SdF*: this represents the solution proposed in AdBPo (2004) which basically spouses the classic engineering *Approach a* of putting in safe conditions the river corridor (where land use is other than just unexploited natural areas) with respect to the 200 recurrence time T_R flood $Q_{Tr=200}$.
- *ALT_Base*: this is a first trial of restoration that implements the criterion of eliminating as many works as possible while keeping the impact on the anthropogenic system as low as possible. Let us say it is a 'prudent' strategy because it makes a step towards improving the ecological status but without much glamour, as it just tries to increase efficiency through savings
- *ALT_Daring*: similar to *ALT_Base*, with further dismission of existing works even if impacting agricultural land uses but still preserving urban areas. It eliminates also the master levees protecting against back-waters from the receiving Oglio River downstream, which implies flooding sometimes vast areas of the flood plain.

Other two *ALTernatives* were defined with the aim of determining the *Utopia* point but with no claim of real feasibility:

- *ALT_Radical*: this is aiming at estimating how much the community is spending in terms of artificial management of the river system for the sake of permitting all

Table 2 Characteristics defining the considered *ALTernatives* in terms of decisions **u** made about them. Longitudinal works are represented by their cumulative length in kilometres, while punctual works are represented by their total number. The corresponding morphological evolution is not presented here for reasons of space (see Nardini and Pavan, 2012). Corresponding performance indices, like for instance the ecological status *N*, are discussed later on as an effect of adopting each particular *ALTernative*

	ALT_0	*ALT_SdF*	*ALT_Base*	*ALT_Daring*	*ALT_Radical*	*ALT_Extreme*
Existing works						
Levees (km)	66.0	46.6	19.4	1.2	0.5	0.0
Reinforced levees (km)	11.7	9.4	0.9	0.9	0.0	0.0
Concrete walls (km)	1.2	0.7	0.7	0.7	0.7	0.0
Longitudinal vertical protections (km)	5.1	4.9	4.6	4.4	4.4	0.0
Bank protection (km)	16.1	11.6	1.3	0.8	0.8	0.0
Weirs	13	13	13	13	3	0
Modified weirs (lowered)	0	0	1	1	1	0
Check dams and bed sills	10	10	10	10	7	0
By-pass channels	14	14	14	14	1	0
New works planned by SdF						
New Levees (km)		5.4	3.9	2.0	0.6	0.0
Existing levees adjustment (km)		6.0	2.4	2.0	1.1	0.0
New concrete walls (km)		1.1	0.9	0.7	0.4	0.0
Existing concrete walls adjustment (km)		1.9	1.5	1.5	1.5	0.0
New bank protection (km)		6.3	4.2	4.3	1.9	0.0
New works proposed in our study						
New Levees (km)			1.3	0.0	0.0	0.0
New longitudinal protections with bio-engineering (km)			2.7	3.2	0.0	0.0

water uses (irrigation and mini hydropower). It is like *ALT_Daring*, but furthermore also all weirs and withdrawal canals are dismissed, together with the associated longitudinal protection works and levees while changing land use from irrigation to dry agriculture, hence losing the added value of water

- *ALT_Extreme*: in addition to the interventions of *ALT_Radical*, here also all defences now preventing the river from occupying its natural bankfull channel and 'espace de liberté' are dismissed, and land use changes within the corresponding areas. The idea here is not to dismantle the existing urbanised tissue, but rather wondering what is the value that would have been lost if the river corridor were preserved from the beginning in natural status, allowing urbanisation only outside it (and hence giving up some areas that now are exploited for some uses and their associated value).

The definition of an *ALTernative* is an iterative process; indeed, after a preliminary definition is specified, and geomorphic prediction and flood behaviour analysis are carried out, meaningful or necessary modifications can often be easily identified in order to achieve a more efficient performance. For instance, flood analysis may reveal that without a certain levee (that the river restoration approach would have initially eliminated), a too large/sensitive area would be affected; hence, that levee (or a modified, more environmentally friendly version) should be re-introduced, modifying in fact the original *ALTernative*. Therefore, a new prediction exercise has to be carried out and so on. Expertise and common sense drive this process and set its sensible end. We denote *ALT_Base** the *ALTernative* eventually evaluated that is indeed a modification of the one originally defined (it includes the lowering of a weir threshold and keeps in place one levee that we initially foresaw to drop, plus other details).

It has to be noted that currently, most of Chiese River is affected by protection or exploitation works [which are mapped on geographical information system (GIS) shapefile with more than 200 items] and several more are planned in the *SdF* so that defining an *ALTernative* is a tedious and lengthy work that implies a preliminary assessment and a decision for each work, and the compilation of a thorough description.

In the end, considering any particular *ALTernative* means assuming that it is implemented (constructing the new planned works and dismissing those foreseen to be dismissed, etc.) and that the river system will adjust its morphology (geometry, long profile and planform setting) accordingly. As a consequence, eventually, a different river configuration is associated with each *ALTernative*. Subsequent hydraulic analysis (flood simulation) and calculation of synthetic performance indices (*S*, *N*, and both hydraulic and morphological risk indices *R*) correspond to such modified river (this point is further discussed in the Conclusions) (Table 2.).

Figure 4 shows as an example a reach of *ALT_Base**.

For what concerns *Scenarios*, we restricted the analysis to hydraulic and hydrological boundary conditions, i.e. the water elevation of receiving water body downstream, the upstream hydrograph shape associated with any recurrence

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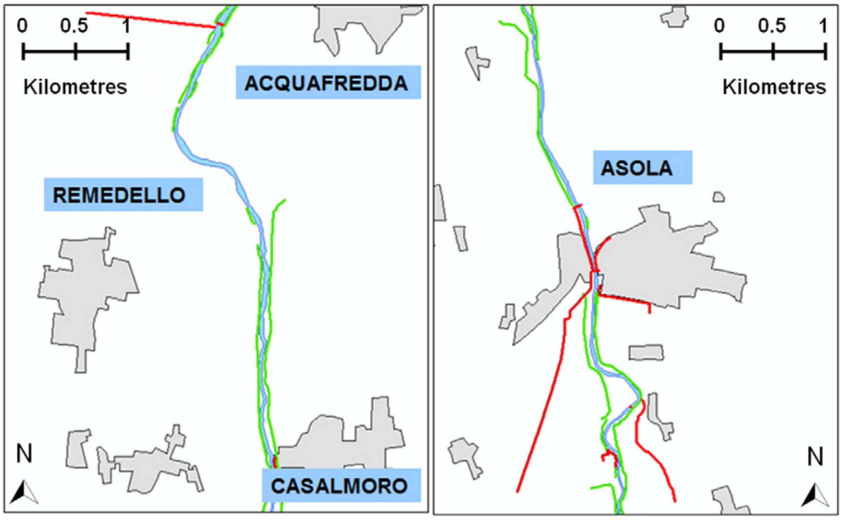

Figure 4 Two reaches of the Chiese River in the *ALT_Base** (left: reach downstream of Acquafredda town; right: following downstream reach). The green lines indicates currently existing works that would be dismissed in such an alternative, while the red ones indicate works (existing or planned by SdF or newly proposed by us) that would exist in such an ALTernative.

time T_R and the water storage of upstream water reservoirs before the flood comes, which determines flood peak reduction. Other important *Scenario* variables – not considered in our case study – include urbanisation patterns (e.g. assuming whether/when areas with pre-scribed potential land use will indeed experience it) or agricultural policies (e.g. the price of some product and hence the value of land and associated damages), and so on.

Evaluation: techniques and indices adopted

This section describes the indices actually utilised in our case study. These are the necessary elements for both *Approach c 'maximise net social benefit'* and *Approach d 'multi-objective (QoL)'* presented above (see Figure 1). Their particular formulation and computation are linked to the case study at hand and as such are less general than the methodological framework presented before, and many variants can be elaborated. For this reason, the description of the indices adopted is located here within the case study. The level of detail of the formalisation is probably suited for several other cases, while the specific techniques (models) adopted can vary greatly.

Insight into risk assessment $R_\infty(u)$

We consider both the flooding risk R^F (associated with actual flooding) and the hydromorphological risk R^M (associated with banks erosion and bankfull channel divagation).

a. Total Flooding risk $\mathbf{R}^F_\infty$ is split in two components: the first, R^F_T, is treated in a risk context with Laplace's perspective, i.e. R^F_T is the expected value of damages associated with possible hydrological events even superior to reference one (this is indicated by the subscript T), but we assumed no levees overtopping can occur (i.e. where there are levees, flood water elevation does not reach their top for any value of the recurrence time T_R considered and no failure can occur[5]); the second component, $R^F_{failure}$, is a qualitative risk index representing the residual risk linked to possible levees failure.[6] In synthesis, we have two indices representing the total flood risk (the dependences are omitted for simplicity except where useful).

$$\mathbf{R}^F_\infty = \left(R^R_T; R^F_{failure}\right) \tag{5}$$

b. The following structure is assumed for the probabilistic flood risk component:[7]

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[5] This assumption implied sometimes modifying the *ALTernative* itself but was considered necessary to keep reliability of the results of the quasi one-dimensional simulation model adopted that we wanted to keep to allow a fair comparison with results already obtained by SdF. Notice that there is no loss of generality because (i) in the specific case, *ALTernatives* were such not to overtop levees for any T_R, and hence the assumption is fulfilled; and (ii) a 2D model can be of course adopted and the limitation dropped (which allows one to explore new, more daring *ALTernatives*).

[6] This latter is a value function aggregating the following attributes: distance of levee from bankfull, its length and water head – i.e. the difference between bankfull water elevation for T_{R500} and terrain elevation outside the levee. Type of land use was not included among the considered attributes because all the alternatives assume the protection of urban settlements (as such levees already exist), and hence the differential comparative evaluation we developed would not see any difference, while in the rest of the territory potentially affected the land use does not vary significantly. Anyway, the index can of course be made more general by including such an attribute.

[7] This is certainly not the most general formulation one can think of. For instance, the potential damage $D_i^{\circ}(t,c)$ can be made dependent on the specific site (i.e. each corner of a building) rather than on land-use categories $c(s)$. Alternative formulations are however well possible within the same overall methodology framework presented here.

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$$R_T^F(\mathbf{u}/\boldsymbol{\vartheta}) = \sum_{\tau=0}^{T-1} \delta^t \left\{ \int_{\Xi} \left[\int_{S_p} \left(\sum_{i=1}^{I} D_i^F(t,s,\xi;\mathbf{u}/\boldsymbol{\vartheta}) \right) \mathrm{d}s \right] p(\xi;\mathbf{u}/\boldsymbol{\vartheta})\,\mathrm{d}\xi \right\} \tag{6}$$

where:

$$D_i^F(t,s,\xi;\mathbf{u}/\boldsymbol{\vartheta}) = d_i^F(t, c(s,\mathbf{u}), v_i(s,\mathbf{u}), h(s,\xi;\mathbf{u}/\boldsymbol{\vartheta}),\ldots;\mathbf{u}) \tag{7}$$

i.e. total probabilistic flood risk is the summation over the planning horizon T of the discounted yearly risk; this in turn is the expected value (integral over the possible hydrological event ξ weighed on the probability density function p of events) of the total risk over the considered geographical area (integral over space S_p) of the summation on the different damages components i of the flood damage D_i^F itself, depending on the site, age of structures and decisions $\mathbf{u}$ (i.e. the *ALTernative*) under a given overall *Scenario* $\boldsymbol{\vartheta}$. And the ith damage component D_i^F is the product of the exposed asset value d_i^F and its corresponding vulnerability v_i.

In detail, the meaning of symbols used in Eqns (6) and (7) is:

- R_t^F $(\mathbf{u}/\boldsymbol{\vartheta})$: total (with respect to the set Ξ of possible hydrological events) economic risk because of flooding (^{F}), depending on the vector of intervention decisions $\mathbf{u}$, and conditioned to an overall *Scenario* $\boldsymbol{\vartheta}$;
- D_i^F $(t, s, \xi; \mathbf{u}/\boldsymbol{\vartheta})$: ith component ($i = 1, \ldots, \mathrm{I}$) of economic damage because of flooding (^{F}), depending on the vector of intervention decisions $\mathbf{u}$, and conditioned to an overall *Scenario* $\boldsymbol{\vartheta}$;
- $d_i^F(t, c)$: exposed asset value (or potential damage) of ith component ($i = 1, \ldots, \mathrm{I}$) of the ith type of goods at stake (e.g. $i = 1$: physical structure and materials of buildings; $i = 2$: furniture; . . .), depending on the land-use class c and on the age (through current planning time t). This item is further discussed later;
- $v_i(c, h, \ldots; \mathbf{u})$: relative vulnerability, i.e. the fraction of exposed value that is lost in a land-use category c, when the hydraulic field is characterised by depth h (and possibly several other attributes, like flow velocity, time of wave arrival from overflow, duration of flooding, . . .), and management decisions are $\mathbf{u}$;
- $h(s, \xi; \mathbf{u}/\boldsymbol{\vartheta})$: hydraulic hazard, namely the hydraulic field attribute 'water depth' at location s under event ξ, depending on management decisions $\mathbf{u}$ and overall *Scenario* vector $\boldsymbol{\vartheta}$;
- $p(\xi; \mathbf{u}/\boldsymbol{\vartheta})$: probability density function of events ξ, depending on management decisions $\mathbf{u}$ and overall *Scenario* vector $\boldsymbol{\vartheta}$, and assumed independent on previous year hydrology;
- δ: economic discount factor [$\delta = 1/(1 + r)$], where r is the social interest rate, around 5% annual);
- t: annual time index ($t = 0, 1, \ldots, T - 1$), with T the duration of the planning horizon (of the order of 50–100 years);
- s: identifier of spatial site (position) ($s \in S_p$, with S_p being the set of possible sites, covering the whole geographical space of the fluvial and floodplain corridor);
- ξ: identifier of hydrological event ($\xi \in \Xi$, with Ξ being the set of possible events considered)
- $\boldsymbol{\vartheta}$: vector of *Scenario* variables (as discussed, previously, we only considered hydraulic boundary conditions);
- $c(s, \mathbf{u})$: discrete land-use category as a function of the spatial site s and management decisions $\mathbf{u}$;
- $\mathbf{u}$: management decisions with $\mathbf{u} \in \mathbf{U}^R$, where the enlarged set of feasible decisions $\mathbf{U}^R$ includes: defence and exploitation works kept in place or newly built, and their characteristics (position, size, typology, . . .); morphological modifications (e.g. reconnection of bankfull channel with flood plain; re-activation of natural side channels; re-establishment of riparian vegetation; . . .); land-use destination assigned to each zone (zoning); re-settlement (which again modifies the land-use c); legal-administrative-financial mechanisms to compensate environmental services (which modify the vulnerability), etc.

c. For the hydromorphological risk component R^M, we adopted a very simplified deterministic approach. We assumed that from fluvial geomorphic knowledge and considerations, it is possible to predict the strip of future river wandering (or *erodible strip*) for the planning timeframe T considered (Malavoi *et al.*, 1998; Piégay *et al.*, 2005). This land strip area is progressively, linearly eroded by the river bed within T, and the expected damage is the entire value of the land above (for each land use); however, some areas are rescued with a new (lower value) land use ($c^R(s,\mathbf{u})$). Formally:

$$R^M(\mathbf{u}/\boldsymbol{\vartheta}) = \sum_{t=0}^{T-1} \delta^t \left\{ \int_{S_e(t)} \sum_{i=1}^{I} d_i^M(t, c, (s,\mathbf{u}))\mathrm{d}s - \int_{S_R(t)} \sum_{i=1}^{I} d_i^M(t, c^R, (s,\mathbf{u}))\mathrm{d}s \right\} \tag{8}$$

where symbols have already been defined above, except:

- $d_i^M(t, c)$: land value exposed to hydromorphological hazard (already defined above);
- $c^R(s, \mathbf{u})$: newly assigned (lower value) land-use category at site s with decisions $\mathbf{u}$;
- $S_e(t)$: the geographical space lost because of river erosion at year t (not cumulated and occurring only in areas not yet eroded), i.e. $[S_e(t) \in S, \forall\, t]$ and $[U_{t\text{-}1}(S_e(t-1)) \cap S_e(t) = \emptyset, t = 1, \ldots, T - 1]$, where U_τ denotes the multiple union set-operator until time τ;

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- $S_R(t)$: the geographical space rescued at year t among those eroded so far $U_t(S_e(t))$, with a newly assigned (lower value) land-use category $c^R(s, \mathbf{u})$; $[S_R(t) \in U_t(S_e(t)), \forall t]$.

Notice that in what follows the rescued land areas $S_R(t)$ have been assumed always zero, which stands on the side of overestimating damages.

Summarising, the total risk is expressed as flooding risk plus hydromorphological risk (the dependences are omitted for simplicity):

$$\mathbf{R}_\infty = \left[\left(R_T^F, R_{failure}^F\right); R^M\right] \tag{9}$$

where R_T^F and R^M are commensurable as they are expressed in monetary terms.

Many simplifications are possible; we adopted the following:

- asset value (or potential damage): the total value of a land plot includes: (a) intrinsic land value, plus (b) buildings and infrastructures above it, plus (c) economic yield from production. No depreciation was considered because no information on age of building was available. When computing hydromorphological risk (land losses) $d_i^M(t, c)$, components (a) and (b) are taken into account, while (c) is neglected; however, when computing flood risk $d_i^F(t, c)$, only components (b) and (c) (according to vulnerability and hazard) are accounted for, as the land is not lost. In this economic conception of risk, we consider only direct, tangible aspects (value of physical structures directly affected by the event), and partly the indirect, tangible aspects linked to the loss of agricultural and industrial production. Several other components within the tangible-intangible, direct-indirect categories (Meyer and Messner, 2005) could or should be included (e.g. externalities on water quality, improvement of amenity asset, recreation, hazard to human health and lives); some of these have been considered separately and qualitatively in our Multicriteria framework (e.g. the ecosystem status through the objective *N* and the main externalities exported downstream outside the subriver basin boundaries), but others have simply been neglected, while they could play an important role (Dubgaard *et al.*, 2002). Operationally, the estimation of land value has been carried out via three alternative methods depending on the item: corrected market values (for intrinsic land value[8]); productivity (for agricultural land); and engineering estimations (for infrastructures, like roads).
- hydraulic hazard $h(s, \xi; \mathbf{u}/\boldsymbol{\vartheta})$: (i) hydrological events ξ have been discretised ($\xi = 1,2, \ldots 7$) together with the associated probability function computed on the basis of the associated recurrence times T_R, for $T_R = 2,5,10,20,50,200,500$); (ii) $h(s, \xi; \mathbf{u}/\boldsymbol{\vartheta})$ is assumed to be a binary function $h(s, T_R, \mathbf{u}/\boldsymbol{\vartheta})$ (flooded, not flooded); (iii) (once geomorphic prediction is carried out for the considered *ALTernative*), such a function is determined as follows for each T_R: first, given the corresponding flood hydrograph (depending on a set of assumptions $\boldsymbol{\vartheta}_I$ on the upstream Lake Idro management) and the assumed water level $\boldsymbol{\vartheta}_W$ of the downstream receiving water body (Oglio River), a hydraulic simulation is performed with a quasi two-dimensional (2D) unsteady flow model (MIKE 11 – DHI, 2008) with lateral flood channels, able to properly determine water heights within the bankfull channel considering overflows and to establish where these may occur but not to define the water depth on flooded zones nor their extension (see Figure 5). Then, a spatial extrapolation of the maximum water elevations reached along the river is performed so obtaining a water surface (basically, an envelope of the horizontal perpendicular line at each cross section). A GIS spatial intersection is carried out with a Digital Terrain Model to determine the areas indeed potentially flooded. Finally, a manual check and correction are carried out (see Figure 6).
- probability density function $p(\xi; \mathbf{u}/\boldsymbol{\vartheta})$ is assumed independent on previous year hydrology.
- vulnerability is assumed to be a binary function of water depth only, i.e. $v_i(h) = v_i^*$ when $h =$ ‘flooded’ and 0 otherwise, where v_i^* is unity for the case of i being land production value, and a fixed average value associated with average flood duration and depth in the other cases.

Readers will certainly be stimulated by our same curiosity about the extent to which such simplifications may affect results [an interesting analysis is made in Koivumäki *et al.* (2010) who shows how different choices of modelling details, as well as imprecision in the definition of topographic features, can affect uncertainty in flood risk assessment]. The only convincing way to answer is probably to drop them and to carry out a new analysis with the most sophisticated tools available, and compare results. But the effort to conduct our partially simplified analysis is already not trivial (see Table 3 with an overview on the information needed), and we could not afford this further step that certainly deserves attention.

Ecological status (‘Nature’) assessment (N index)

According to *Approach d: ‘multi-objective (QoL)’*, *Stage i: technical evaluation* and *Stage iii: strategic evaluation*, we need to assess the ecological status, with an index denoted as *N*. In principle, this should be the index defined at national level to fulfil the WFD request to classify the ecological river status. However, at the moment of the study, Italy did not count yet with such an integrated index. Moreover, the *ALTernatives* involved in this research mainly affect hydro-

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[8] Conceptually, it should equal the capitalised value of future production benefits.

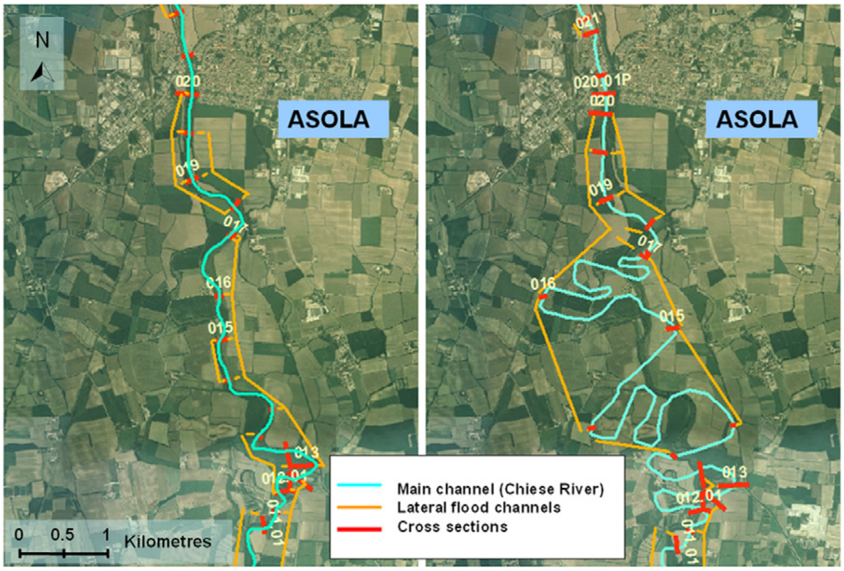

Figure 5 Example of the hydraulic schematisation adopted to apply MIKE11 flood model for a reach (in total, 221 cross sections were introduced). On the left, Chiese River actual axis used for the simulation of *ALT_0* and *ALT_SdF*; on the right, river axis resulting from geomorphological prediction for *ALT_Base*.

morphology, and only marginally biotic and, even less, water quality; although these aspects should and could be included, we concentrated on the former only, disregarding completely *water quality* and *biotic quality* attributes. We only assessed the hydromorphological quality in a very rough way, as our aim was just to be able to rank in a preferential sense the considered *ALTernatives* from the point of view of the *N* objective (the ecological status). Our *N* index is therefore built on 'proxy' indicators, as shown in the following Table 4, by adopting the value function concept (Beinat, 1995; Nardini, 2004).

No one reaches the top (1.00; see Table 5). Possibly, *ALT_Daring* and *ALT_Radical* can be considered 'good status', as required by WFD; *ALT_SdF* basically does not move from current *ALT_0*, which is definitely poor. *ALT_Base** brings a clear improvement, although probably not enough for the WFD request.

Costs assessment (C index)

Both investment cost of new works and OMR costs of all works present in any given *ALTernative* need to be considered.

For the former, a classic technical engineering method was applied. For the OMR costs, we explored two ways: (i) engineering estimate, including the expected life duration of each category of work; and (ii) empirical attempt, based on a 27-year record of expenditures by the main maintenance agency, Agenzia Interregionale per il PO (AIPO), Italy. This latter approach conducted to much lower OMR values than the approach (i), but this result, we believe, is due (a) to the fact that the investigated source, AIPO, is not the only one that can spend money on the river (other subjects, although with a lower institutional status can, and data are not fully traceable) (b) rather than spending to keep works in place, the capital 'works in good status' has been progressively eroded, showing today works in a very bad status . . . which just speaks of likely, future disasters, as shown in Figure 7.

Disturbance assessment (S index)

1 Impact on current agricultural setting (because of removal or lowering of thresholds of existing water withdrawal weirs for irrigation): we assumed that it coincides with the difference of land value between current irrigation agricultural use and dry agricultural use.
2 Impact from land-use change decisions: it is assessed as the difference of land value between current and newly planned ($\mathbf{u}_L$) land use (this impact does not occur, however, in the *ALTernatives* analysed later).
3 Relocation impact: we assumed that the reconstruction cost be equal to the land-value difference between current and no-value land-use category; additional sociopolitical costs are disregarded (notice, however, that in the *ALTernatives* analysed later, this impact does not occur, so again, the results presented are not affected by such an assumption).
4 Impact on hydropower production (because of removal or elimination of withdrawal weirs): an estimate is based on the differential production plus externality cost of equivalent energy amount to be produced by alternative (more greenhouse impacting) means. (Notice, however, that also

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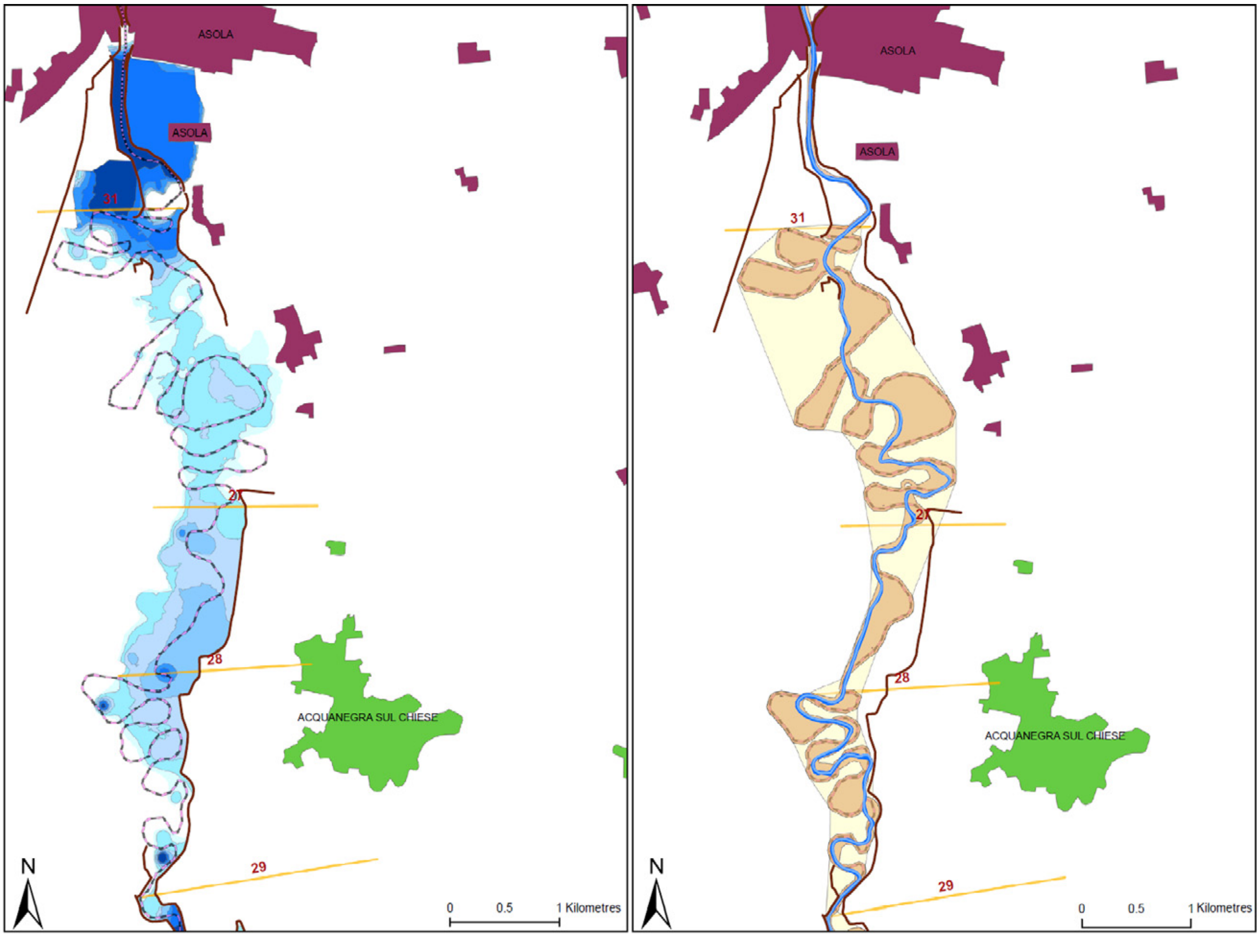

Figure 6 Left: example of obtained flooded areas utilised to compute the flood risk component $R_T^F(\mathbf{u}/\vartheta)$ for *ALT_Base** for each recurrence time T_R (2, 5, 10, 20, 50, 200, 500, with darkest blue for the most frequently flooded and hence deepest areas) around the forecasted bankfull channel axes (dashed thick line); longitudinal defences and levees are visible (dark brown lines). Right: example of the erodible areas in light brown [union of the $Se(t)$, for $t = 1, \ldots, T-1$] obtained from geomorphic prediction exercise and utilised to compute the morphological risk component $R_M(\mathbf{u}/\vartheta)$ (for land-use regulation, the envelope strip in light pink would be considered).

this impact does not occur for the *ALTernatives* analysed later).

In the evaluation section presented later on (particularly, Table 6), we use the symbols $S_{\text{agro-sett}}$ and $S_{\text{water use}}$ to explicitly refer to impacts 1 and 4, respectively.

Evaluation: results

Results are now presented according to the scheme shown in Figure 1, starting with *Approach c* – CBA first.

Approach c: 'maximise net social benefit', reduced CBA (index B_N)

This is a differential CBA, i.e. the items shown report the difference between the value assumed for the considered *ALTernative* (*ALT_Base** in Table 6) and *ALT_0* as a reference (also *ALT_SdF* has been evaluated in an analogous way, although not presented here). Notice that the same item can play a positive or negative role depending on the *ALTernative* considered (except the grey ones because of their very definition).

The analysis says that for *ALT_Base*:

- the OMR savings from reaches no longer 'managed' (whose geomorphic dynamics would then be restored), and from works dismissed sum up to about 185 million Euro (ME)[9];
- investment in new interventions (mainly bioengineering to protect urbanised areas affected by reactivated river dynamics) is significant (about 66 ME) but definitely lower than savings;

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[9] As already noted, the actual, historical expenditure for OMR of works in the past 27 years seems to be much lower, but the reasons already discussed are strong. In any case, sensitivity analysis on OMR costs shows the robustness of the findings.

Table 3 Overview on the information needed to carry out the case study on Chiese River

Category	Info item	Main purpose	Details
Morphological	Topographic cross sections of river	Morphological prediction and hydraulic simulation	About 221 cross sections
	Air photographs in different years	Understand geomorphic behaviour and predict morphology	Available sources: Flight GAI 1954–1957; Flight IGM 1995–1996; Flight 2002
	Historical maps and descriptions from State Archives at Milano, Brescia, Mantova, Venezia	Understand geomorphic behaviour and predict morphology	Qualitative since 1400; georeferenced since 1885
	Granulometry to estimate solid transport	Predict future morphology	Granulometric analysis in 15 cross sections
	Ground pictures	Predict future morphology	At least two in each topographic and sediment cross section (upstream and downstream), plus at least two for each existing work
	Digital Elevation Model of the river basin	Morphologic prediction and determination of flooded areas [hydraulic field $h(s, \xi; \mathbf{u}/\vartheta)$]	Obtained from a set of about 9000 elevation points in a basin area of about 513 km^2
	Set of works of each category, existing and foreseen in each considered *ALTernative*	Predict future morphology; determine hydraulic behaviour in modelling; estimate investment and OMR costs; determine the proxy index of ecological status (N)	About 200 GIS items already existing; 25 categories (e.g. weirs, thresholds, reinforced levees, . . .)
Hydrological	Peak flow-rate Q_{TR} for each recurrence time T_R at three different sections (upstream, middle and confluence), calculated by a rainfall-runoff model by assuming a given hydrograph shape	Morphological prediction and hydraulic simulation	T_R considered: 2, 5, 10, 20, 50, 200, 500
	Behaviour of Idro Lake when floods come (free volume stored to reduce peak)	Morphological prediction and hydraulic simulation	
	Water level of the receiving water body downstream (Oglio River)	Hydraulic simulation	For each considered T_R
	Roughness Manning coefficient n for each reach	Hydraulic simulation	
Socio-economic	Land-use map	Planning interventions; calculating land value and damages	34 categories; scale: 1:10 000
	Value of land	Calculating land value and damages (R, S indices)	For each land-use category, from official agro-economic records
	Correction parameters	Calculating land value and damages (R, S indices)	From economic knowledge and literature
	Parametric investment cost	To compute the investment cost component of the index C for each *ALTernative*	From engineering knowledge and literature
	Parametric OMR cost	To compute the OMR cost component of the index C for each *ALTernative*	From engineering knowledge and literature, and from records of effective expenditures of management agency AIPO
	Vulnerability v_i^*	To calculate damages (R index)	For each land-use category, from literature on previous assessment in the Po basin and elsewhere

AIPO, Agenzia Interregionale per il PO; GIS, geographical information system; OMR, operation, maintenance and replacement.

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Table 4 The adopted, very simplified index ignores water quality and biotic quality attributes but captures the aspects more directly impacted by works. It disregards comparison with reference status (Water Framework Directive) and is based only on proxies determined by existing works; this may introduce a bias. It is assumed that low-flow regime is a function of the accumulative number of upstream withdrawals; therefore, it worsens downstream (hydropower withdrawals with return are not present). Increasing levels of artificialisation are penalised more than proportionally through a nonlinear value function, whose shapes and relative weights have been determined by the project team. The overall index structure is a classic additive value function (Beinat, 1995)

	Attribute	Indicators	Nature	Type	Unit	Range
1 Water quality						
2 Biotic quality						
3 Hydromorphological quality	a) Water regime (minimum flow)	Accumulative number of weirs	Proxy	Quantitative	–	0–∞
	b) Lateral continuity	Average % of left and right banks covered by levees	Proxy	Quantitative	%	0–100
	c) Longitudinal continuity	Number of weirs per unit length	Proxy	Quantitative	km^{-1}	0–∞
	d) Lateral mobility (space)	% of right plus left banks with protection	Proxy	Quantitative	%	0–100

Table 5 The resulting *N* index for each *ALTernative* considered

ALT	*N*
0	0.48
SdF	0.48
*Base**	0.64
Daring	0.69
Radical	0.80

- although planform wandering is generally increased, *ALT_Base** shows a net gain on erosion risk because the other *ALTernatives* evaluated did not consider such a likely phenomenon, being mainly concentrated on flooding and did not foresee ad hoc protection measures, particularly in urbanised areas;
- as expected, there is a significant increase in flood risk because in *ALT_Base**, many levees are no longer present[10];
- the (small) economic loss expressed as land-use change is due to a decision to lower one of the diversion weirs to reduce local upstream overflows;[11] hence part of the current irrigation district has to shift to nonirrigated agriculture with lower productivity.

Similarly, also *ALT_SdF* shows a positive B_N, although much less pronounced.

The overall outcome is that the net benefit B_N is decidedly positive, i.e. implementing *ALT_Base** is economically rewarding with respect to *ALT_0* and more than *ALT_SdF*. In other words, moving towards river restoration is rewarding.

Sensitivity analysis with respect to the planning horizon *T*, the interest rate *r* and the OMR parametric unit costs (once computed as in *SdF* and once according to our computations) shows that this result, although modified, does not change sign. It is also worth noting that this is a basic economic evaluation, where several additional, important aspects are disregarded, which would generally play in favour of river restoration; they are considered in the multi-objective QoL *Approach d* discussed next. And perhaps more important, *ALT_Base** is far from being the best river restoration solution; there is still a whole universe $\mathbf{U}^R$ of solution options to be explored.

This outcome has to be taken with calm happiness because the analysis is hindered by a number of assumptions and limitations (partly presented in the simplifications *section e* of the risk assessment and partly discussed later). However, certainly, it cancels our main doubt that the damage increment could result orders of magnitude larger than the savings in works not implemented and/or dismissed.

According to the proposed framework (see Figure 1), *Approach d: 'multi-objective (QoL)'* starts with *Stage i*, the *technical evaluation*, considering the objectives *R*, *C*, *S* and *N*.

Approach d: 'multi-objective (QoL)', Stage i: technical evaluation

As several indices are commensurable (monetary units), it is possible to plot on a bidimensional plan the multi-objective performance of the *ALTernatives*. We just sum up all indices spontaneously evaluated in economic monetary terms (OMR saving from dismissed works, investment of new ones, differential flood and hydromorphological risk, value gains or losses because of land-use changes) in a single

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[10] The behaviour is indeed further complicated by morphological adjustments: expected bankfull widening implies lower water depth; the increase in length of some stretches, because of naturally recovered sinuosity, increases the overflow threshold length and hence reduces in-stream flood volumes and again water depth. However, morphological adjustment often implies recovering some bed elevation from current incision. . . .

[11] We carried out a historical research in the State Archives and found out, in particular, that exactly there stakeholders were discussing and fighting since Middle Age because farmers wanted water (i.e. a weir), while upstream settlers were periodically flooded. Ironically, once more at the beginning of November 2010 (after our study was just completed with the decision to lower the weir threshold), a new overflow occurred at the same place.

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Figure 7 Longitudinal defence in bad status (foot erosion): historical savings on operation, maintenance and replacement imply future harsh problems.

Table 6 Outcomes of the differential cost-benefit analysis where Δ denotes 'difference with respect to *ALT_0* (keep current conditions all life-long)' (values discounted and capitalised on the planning horizon of 50 years at interest rate of 5%). First column classifies items according to the key objectives introduced (*C*, *R*, *S*); items are calculated as specified in the text, but in differential terms (index measured in *ALT_Base** with respect to the corresponding value obtained for *ALT_0*), and sometimes, they are split into components (e.g. costs *C*). B_N is the net social benefit

			Benefit	Cost
		Item	Million Euro	
C	*Economic*	OMR savings from works to be dismissed (OMR) and (OMR + invest.) of works not being implemented	185.27	
C	*Economic*	Investment and OMR of new works to be made		65.84
C	*Economic*	Δ Maintenance of river bed	17.72	
R_T^F	*Hydraulic*	Δ Flooding risk		22.16
R_M	*Morphological*	D Land loss risk because of erosion and wandering	7.09	
S	*Agro setting*	Δ Land-use value from irrigated to dry agriculture		1.26
S	*Water use change*	Loss from hydropower production because of modification of weirs or river elevation		0.00
		TOT	211.45	89.25
B_N		**122.2 (M Euro)**		

OMR, operation, maintenance and replacement.

index on the horizontal axis, while the fluvial ecosystem status (index *N*) is represented on the vertical axis (Figure 8):

The evaluation of the single economic items (presented in the next paragraph) reveals that *ALT_Base**, i.e. smooth restoration dominates both *ALT_0* and *ALT_SdF* (which show very similar performances); in other words, *ALT_Base** implies lower total expenditures (moves to the left), while improving 'Nature' (moves upward towards the Utopia point U)!

Approach d: 'multi-objective (QoL)', Stage iii: strategic evaluation

Here, a quite simplified attempt to implement *Stage iii* of *Approach d* discussed in the Conceptual framework and Methodology section (see Figure 1) is presented in relation to our case study. Measures already obtained for total (R_T) and residual ($R_{failure}$) risks, and social disturbance (S) are used instead of the subjective satisfaction indices (QoL) to be obtained from *Stage ii: conflict management evaluation* (not developed in this research). For the *outer world's QoL* component, we considered a proxy, rough measure of net social benefit, i.e. the same index B_N already calculated (because it resumes how well objectives are reached compared with the effort required); aside with the required expenses *C* to be borne by the whole community, also qualitative 'measures' of key effects exported outside from our basin are included in this component. No explicit measure representing *Justice*

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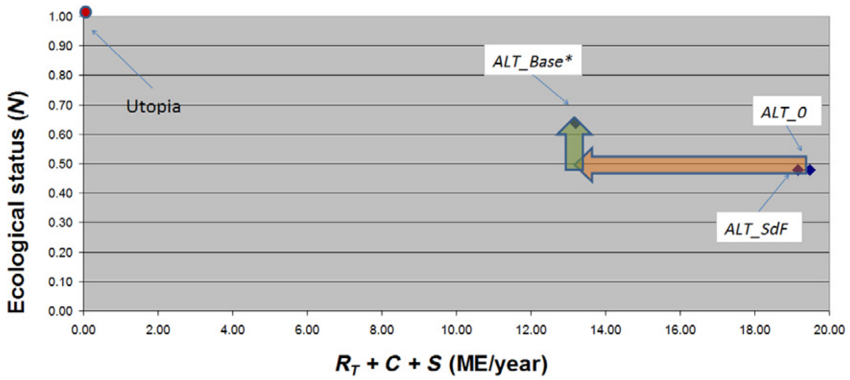

Figure 8 Multi-objective technical evaluation: total equivalent expenditure (R_T, flooding R_T^F plus hydromorphological risk R_M; C, total cost of works, including capitalised OMR; S, social disturbance that, in our case, reduces to just land-use change in an irrigation district) on the horizontal axis; ecosystem status N index on the vertical axis (proxy of the Water Framework Directive ecological status, as synthesised in Table 4). 'Utopia' point corresponds to the ideal, unreachable situation where there are no expenditures, while the ecosystem status is perfect.

Table 7 Summary of *Approach d: 'multi-objective quality of life (QoL)', Stage iii: strategic* evaluation. *ALT_Base** increases, as expected, the hydraulic and morphological risk components, as well as (slightly) the social impact (*S*). It clearly performs better, however, with regard to all other aspects

				ALT_0	*ALT_SdF*	*ALT_Base**
QoL stakeholders	$R_T^F + R_M$	Total RISK (hydraulic R_T^F + morphological R_M)	ME/year	2.52	2.11	3.30
	$R_{failure}^F$	Fragility (residual risk)	–	2.06	1.68	0.85
	$S_{agro\text{-}sett.}$	Social disturbance: land-value loss	ME/year		0.00	0.07
	$S_{water\ use}$	Social disturbance: hydropower loss	ME/year		0.00	0.00
QoL outer	C	Financial sustainability: total cost (invest. + OMR)	ME/year	16.95	17.05	9.83
	B_N	Economic efficiency: net benefit	ME/year		0.33	6.35
		Externalities out of basin	–	3 peak reduction 1 solid flow	1 peak reduction 0 solid flow	3 peak reduction 3 solid flow
Justice	N	Nature conservation (ecosystem status)	–	0.48	0.48	0.64

ME, million Euro; OMR, operation, maintenance and replacement.

component is developed; however, the ecological status index *N* is here considered as representative of nature conservation issue. This latter perspective (resumed in Table 7) clearly shows that *ALT_Base** increments both total risk (hydraulic R_T^F component plus morphological R^M component) and marginally the disturbance *S* (the agro-setting component $S_{agro\text{-}sett.}$) but significantly reduces the residual risk ($R_{failure}^F$). CBA result (B_N) tells us that there is a powerful net gain that benefits the whole community, as, indeed, there is a significant reduction of total cost *C* (investment + OMR of existing and new works from about 17 to about 10 only). Furthermore, there are additional benefits in terms of positive externalities (rough, subjective, qualitative indication where 3 is the best and 0 the worst score): (i) fewer defence works in Chiese basin imply more overflows in it and hence a (small?) reduction of flood peak exported downstream (a benefit!); (ii) again, fewer longitudinal defences imply an increment of solid input from bank erosion and hence a (slightly?) increased solid flow exported downstream (again a benefit, as the rest of the river network is strongly sediment starving). Finally, in *ALT_Base**, the ecological status is significantly improved.

Summarising, *ALT_Base** is in principle a well-rewarding solution but implies some tangible drawbacks to some stakeholders (residents, farmers, . . .): a bit more frequent flood damages; progressive land loss because of erosion; and some production loss from no longer irrigated agricultural areas. Hence, such a project may not be a

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socially desirable solution, at least not in a straightforward way.

Conclusions

Findings and innovations of the methodological framework

Our research provides – we think – a logical, systematic and operational framework to address a flood risk management problem that enables to link the requirements of the two key EU directives (WFD and FD). Perhaps, an innovative content of what we propose mainly lies in identifying and labelling different key approaches to flood risk management and in structuring the associated evaluation methodology by, hence, providing a useful, compact guideline. Indeed, it just pulls together several pieces of approaches and methodologies already existing but yet not enough integrated: hydrology and hydraulic engineering, fluvial geomorphology, mathematical modelling, land use and river basin planning, environmental economics and conflict management, together with several different types of evaluation, from EIA to strategic environmental assessment, social CBA, decision analysis.

Meyer *et al.* (2007) provide a wide review related to flood risk and multicriteria decision making that is a very useful base; it shows that several authors have considered economic, social and environmental criteria to evaluate *ALTernatives*, yet an underlying structure of the kind here proposed, as well as the integration with CBA, is lacking.[12] On the other hand, even the most CBA-oriented guidelines on flood risk project appraisal (Penning-Rowsell *et al.*, 2003) mention the existence of multicriteria approach, but it is seen as a separate, different and essentially marginal approach. Other authors (e.g. Scolobig *et al.*, 2008) explicitly address the participatory dimension but perhaps miss the *technical* level and the overall *strategic* view relevant to public decision making. In some sense, all of them consider the key objectives: risk reduction, ecosystem status improvement, and costs and social impacts minimisation; but perhaps not as explicitly and simply as in our *Stage i* evaluation, a challenging requirement planners have to address to respond to the EU WFD and FD directives. Indeed, there is a serious 'meta-risk' that in order to solve flood problems, the ecological status of rivers be seriously further degraded as too common structural engineering measures consist of (concrete) works that clearly do not favour environmental quality, as required instead by the WFD. Existing flood risk assessment approaches do not really support the serious consideration of restoration options within the set of feasible decisions and the integrated evaluation of their consequences (one relevant experience offers, however, an important exception to this statement; it was developed in the NofDP EU INTERREG III/B project at http://www.nofdp.net/, visited in June 2011; Hübner *et al.*, 2008).

On this regard, it seems worth noting that the framework proposed here can play an important role to bridge the two key Directives (WFD and FD). Indeed, the WFD shows an important weakness as far as the hydromorphological quality component of the fluvial ecosystem is concerned (Nardini *et al.*, 2008). Practically speaking, it leaves a door open to further worsening of hydromorphological quality because such component –according to WFD – has to be evaluated in the classification process only when quality is 'elevated'; hence, it is practically disregarded in most cases (good conditions or, more often, less than good), where likely increments of artificiality would not be directly recorded. In principle, they should be reflected through the biotic quality component, but this is far from being real as the adopted biotic indicators are too loose or too local to perceive a generalised morphological worsening. This fact may lead to add further concrete in rivers to fight against risk without directly recording ecosystem worsening, while we are all aware that morphology (together with water quality) lies at the basis of rivers' good health. The ability to distinguish the changes of hydromorphological quality (index N) within an integrated evaluation of alternative settings is hence a key issue to ensure consistency between the two directives.

Finally, a note on heavily modified water bodies (HMWB), as foreseen again by the WFD: if one considers only the impacts that river restoration would induce on current activities that led to the loss of hydromorphological quality, many rivers would be labelled HMWB; if instead one includes in the evaluation also the benefits that river restoration itself could lead to, particularly in terms of reduction of total expenditures concerning the control of risk, possibly, the label assigned would change. Chiese River is at first sight beyond doubt a HMWB, but the outcomes from the integrated evaluation say something quite different.

Assumptions and limitations

An integrated evaluation as the one presented here requires many assumptions and simplifications; assumptions are not intrinsically bad but must not be forgotten when results are interpreted. Main ones are as follows:

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[12] In turn, the spatial dimension of risk is emphasised, see for instance Meyer *et al.* (2008) or Yang (2011). This is however not in contrast at all with what is proposed in our paper, as spatial analysis provides just an instrumental information used to build final evaluation indices like the total risk R_T or R^M [or alternative forms that can be obtained with what is called 'disjunctive approach' in Meyer *et al.* (2008)], and equity measures to be used under the *Justice* group, within *Stage iii, Approach d*. On the other hand, nothing prevents one to associate geographical maps to facilitate the comprehension of the values of the indices adopted.

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- Effects are evaluated for the future new geomorphological equilibrium of the river (assuming it will sooner or later reach one) according to each *ALTernative* considered; hence, we disregard the transition process from current setting to future equilibrium, a process that in reality may imply undesirable intermediate situations and which may last several years or decades, or more.
- Dismission of existing works is no cost; this appears very simplistic and definitely needs to be investigated further. The idea is that the project just gives an initial input (like breaking locally at some points a longitudinal defence or a levee; a local reconnection of incised bankfull channel with its now too high flood plain) and then lets the river continue the dismantling job naturally. In this process, it is possible that dangerous situations occur (e.g. damaging bridges foundations because of broken concrete blocks transported by current); this means that implementation must be closely accompanied by monitoring and management, hence not costless.
- Our CBA captures only some of the relevant value components (direct tangible and some indirect tangible) and looks just at the subriver basin considered.
- There is no rescue of land once the bankfull channel moves to another zone (while in reality, rescue occurs all the time, although slowly, so diminishing drawbacks from geomorphic river divagation).
- The hydrological *Scenario* $\boldsymbol{\vartheta}$ assumes a significant free storage available in upstream Idro Lake, available to smooth the flood peak (same assumption present in *SdF*); the water level of the downstream receiving water body (Oglio River) corresponds to a flood with the same recurrence time *T* as the one considered for the event on Chiese River [simultaneity of events, what is not necessarily true and an approach like the one of Lamb *et al.* (2010) could help better represent].

There are also technical limitations:

- Hydraulic prediction (the quasi-2D simulation model adopted) can be certainly improved specifically to determine flooded areas (see Koivumäki *et al*., 2010 for a thorough discussion of this type of uncertainty).
- The prediction of the future river geomorphology corresponding to each *ALTernative* (not discussed in this paper, see Nardini and Pavan, 2012) is a challenging task definitely affected by high uncertainty.
- Vulnerability is certainly quite rough and should be refined.

Findings on the application

As many assumptions and simplifications have been introduced and high uncertainties are definitely present, we can just conclude that an additional building block has been laid down to develop and implement the driving idea that rivers in more natural conditions, together with a more compatible land use and suitable management, may really offer very good opportunities to fight flood and hydromorphological risk. Our initial doubt – that possibly, the risk increase in our Mediterranean context would overcome by orders of magnitude the OMR savings – has been cancelled.

These findings cannot be considered however as representative of the extremely diverse situations one can find in the Mediterranean context; furthermore, they hold for a semirural context where nonurbanised space is still available, contrary to many urban situations. Indeed, our *ALT-_Base** foresees the protection of urban settlements at 'the expenses' of the rural land. In other situations, the driving policy (**u**) may rather focus on reducing vulnerability (http://www.floodprobe.eu/) through real-time flood forecasting and alert and contingency plans, and structural and management adjustments of buildings and infrastructures, options still belonging to the enlarged decision set $\mathbf{U}^R$. In both cases, anyway, the underlying philosophy is one of learning how to 'live with the risk' in a more sustainable fashion.

A wide research space is open to ascertain the role of assumptions, simplifications and uncertainties, and certainly, results can change and become less attractive. But on the other hand, some important aspects, which have been disregarded or considered just superficially, can play further in favour of river restoration even in the very economic core (B_N index), as for instance the externalities[13] exported to the downstream basin, the very important residual risk (failure of defence works[14]) or the environmental services provided by a better ecosystem status (leisure, amenities, . . .; see for instance Dubgaard *et al*., 2002), definitely not a secondary issue, as it inspires the whole WFD or the consideration of the option of land rescue after river wandering.

Finally, it has to be reminded that the explored *ALT_Base** is far from being the most attractive river restoration solution one can think of: a whole universe $\mathbf{U}^R$ is open and waiting to be explored.

Concerning the fact that in the end, *ALT_Base** increases the risk, two key points need to be considered:

- In general, letting a river wander and overflow in its broad corridor certainly contributes to reducing downstream hazard, as possibly also risk, depending on the distribution of value assets (usually more concentrated in

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[13] Such externalities are perhaps not computable but certainly not negligible when the same concept is going to be applied to all tributaries of a large basin.

[14] This could be incorporated within the very same framework of quantitative assessment of risk, provided a suitable 2D modelling were adopted at least for the cases of levees overtopping and/or failure, and the whole process were inserted within a Montecarlo simulation of possible failure locations (that would be possible only by counting with a suitable Decisions Support System to carry out the whole calculation process).

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flat areas downstream). In our Chiese case study, this effect does exist but is marginal. In general, therefore, a river restoration project could even lead to net risk reduction (typically increased upstream and reduced downstream), even more when externalities to the rest of the main basin are considered and if residual risk is taken into account (as it occurs for our *ALT_Base**).

- In any case, some stakeholders are generally negatively affected. However, if – as in the Chiese case – the net benefit B_N is positive (provided other aspects play positively for river restoration *ALTernatives*), it means that with the net savings, it is in principle possible to extra compensate negative effects. Therefore, social desirability can be reached, provided a thorough negotiation is carried out and new broad-minded variants of the project (new *ALTernatives*, indeed) are identified. It is here that *Stage ii* of the evaluation framework plays a key role.

In essence, the problem becomes one of how to translate the net gain into a *socially desirable solution*. Aside from the fundamental information to people to increase awareness, there are several operational actions that can be undertaken (e.g. http://www.loirenature.org) Perhaps, the most straightforward ones are:

- purchasing affected land;
- establishing clear agreements and a working mechanism for assessing and rescuing assets each time a damage occurs (indemnities) or, more elegantly, by remunerating environmental services provided by those who suffer the private consequences of a process (flooding, land loss.) directed to the common good (recovering geomorphological dynamic processes, protecting high value assets elsewhere) while redirecting land use to more compatible activities (e.g. multiple aim forestation, including CO_2 fixing and biomasses for energy generation rather than traditional monocrop agriculture);
- applying a mandatory or voluntary insurance coverage capable to respond operationally and able to differentiate the various areas according to hazard (all accompanied by a policy to encourage people in the wrong places to move out but supported by a solidarity mechanism for those who have no other chances or who were not sufficiently informed when they settled, etc.).

These costly solutions can be totally or partially financed by future OMR savings of dismissed works or expected avoided damages (benefits) of those whose risk has been diminished.

But this type of solution options (belonging to the enlarged decision set $\mathbf{U}^R$) need to be supported, on the one side, by a clear national policy and strong institutional coordination, and, on the other side, by a thorough participatory, negotiation process developed around evaluation *Stage ii: conflict management evaluation*. The idea is that through this evaluation, planners – supported by skilled analysts – be able to identify *ALTernatives* that, in the end, leave affected stakeholders in a better-off condition (*win-win* solutions) according to their own subjective judgment or at least with the convincement that the chosen one is a fair option (Keeney, 1992).

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