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RIVER REHABILITATION FOR FLOOD PROTECTION: A SUSTAINABLE SOLUTION (VOMANO RIVER'S MOUTH CASE STUDY, CENTRAL ITALY)

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ABSTRACT: Rivers are highly sensitive to long-term and intensive human activities on their floodplains, which usually lead to fundamental transformations of fluvial morphology and changes in the character and intensity of flood events. In the last years it has been registered a growing interest at both strategic and operational levels amongst river managers in Europe in developing wetland rehabilitation schemes for flood risk mitigation and biodiversity protection.

The paper illustrates a sustainable flood mitigation plan in urban context through destroyed floodplain rehabilitation, based on a geomorphic approach, for the Vomano River's mouth, central Italy: an example on how the analysis of historical information can be a useful tool for identifying a preliminary guiding image for the rehabilitation process, to be then verified by means of hydraulic modeling.

Keywords: River rehabilitation, Flood protection, River morphology, Geomorphic approach.

1. INTRODUCTION

It's a common idea that rivers are dynamic evolving systems, which are the expression of their watershed, climatology and geomorphic history; in this way, rivers have a natural tendency to modify their shape and ecology, in function of the different physical processes that sustain it. But this naturalness and ecological integrity has been gradually altered by human interventions on river floodplains during the last centuries (Smits *et al*., 2000; Maltby and Blackwell, 2005): unplanned urban growth for agricultural production and human settlements on river corridors, intensified land use, large changes in land cover and increasing of impervious surfaces, pollution, over-exploitation of riverine resources and ineffective management (Werritty, 2006; Nachtnebel, 2007) led to the total or partial disruption of natural fluvial environments and to the loss of the genetic function of the floodplains. Eslamian (1995) has outlined that measurements could be done after flood event.

But when the uncontrolled urbanisation has faced with the natural evolution and migration of rivers across the floodplains, resulting in large flood risk areas, a global culture of river confinement has developed, with embankments construction, canalisation, straightening and recalibration interventions, and in doing so, river evolution has been restricted.

However, the impact of these changes on fluvial environments has increased the potential for flood damages, because riverine systems are no longer able to evolve as in the past and to reach a new equilibrium with the modified conditions (Werritty, 2006).

As flood hazard is becoming a growing concern all over the world, it's clear that preventing actions are necessary and that the social and political context must be involved in the decision-making process for selecting flood risk mitigation procedures.

Traditionally, flood risk management is based on flood control for preventing inundation with structural measures (e.g. embankments or storage areas) and/or flood alleviation for reducing flood impacts by non-structural measures (e.g. flood-adapted spatial planning, flood-resilient buildings, development of early warning systems, insurance, awareness campaigns).

Since the 1980s the international scientific community has made huge advances in understanding of how rivers work and how they interact with their natural floodplains. But only recent floods in Central Europe (1993, 1995, 1997, 2002, 2006, 2010) have provoked an important shift in problem-solving approach (Merz *et al*., 2010; and "lessons learned", e.g. in Petrow *et al*., 2006; Nachtnebel, 2007) towards a sustainable river environment management and a growing recognition of the fact that action is required to change the way river corridors are managed.

In this new perspective, it has been recognised that a combination of flood risk management plans with restoration or rehabilitation measures, which are considered environment-friendly and commonly accepted by the public opinion (Kundzewicz and Menzel, 2006), can be more effective and more sustainable than just implementing structural and stand-alone measures. So, wetland rehabilitation can be an efficient solution for restoring the basic and ancient functions of river corridors, i.e. holding floodwaters, improving water quality and supporting biodiversity. In this sense, the implementation of the Flood Risk Directive (European Union (EU), 2007) with the Water Framework Directive (EU, 2000) means a chance for many European countries to combine flood protection measures with those necessary to reach a good ecological status.

The inspiring principle of this way of thinking is that urban planning should be carried out "with the water" and "with the river" and not against it, looking for synergy and compromise and not for controversies (Nienhuis and Leuven, 2001). Examples of this new approach versus the traditional practice are the various "Room for the river", "Making space for water", "Living rivers" and "Environmental River Enhancement" programmes in European countries (Klijn *et al*., 2000; Biotec *et al*., 2006; Department for Environment, Food and Rural Affairs, 2005; Samuels *et al*., 2006; Centro Italiano per la riqualificazione fluvial (CIRF), 2006; Potter, 2007; Francés *et al*., 2008; Menke and Nijland, 2008; Autorità di bacino del Fiume Po, 2009).

2. PURPOSE OF THE PAPER

In the last years a growing interest at both strategic and operational levels amongst river managers in Europe in developing wetland restoration schemes, allowing the river to regain its naturalness, is creating favourable conditions for the diffusion of this new vision. In fact this policy can address multiple beneficial hydrological, ecological and socio-economic issues, ranging from flood risk mitigation and biodiversity protection to agricultural restructuring and planned rural development. However, rehabilitation and restoration projects for flood mitigation purpose still remain limited to some test cases and more diffusion is needed among river managers and designers, who continue to prefer the "classical" structural defence measures (CIRF, 2006).

The present paper gives primarily a general review on river restoration philosophy and methodology, with particular emphasis on the use of the geomorphic approach as guiding tool for identifying a preliminary reference image for the restoration efforts: such approach is then applied to Vomano River's mouth rehabilitation case study (central Italy).

3. RIVER RESTORATION AND REHABILITATION

There are extensive discussions in the literature on the use of the term "river restoration" for referring to streamways manipulation allowing the river to regain its naturalness (National Research Council (1992), Brookes and Shields (1996), Federal Interagency Stream Restoration Working Group (1998), Shields *et al.*, (2003a)). But returning a river to its natural state is a challenging, almost impossible, mission.

To "restore", based on the meaning of the word itself, is to bring back to an original condition, which implies that something has been altered or destroyed. The National Research Council (1992) states that restoration is the "return of an ecosystem to a close approximation of its condition prior to disturbance" and that "merely recreating a form without the functions, or the functions in an artificial configuration bearing little resemblance to a natural form, does not constitute restoration". From this perspective, even if the terms "River Restoration" and "River Rehabilitation" are usually intended to have the same meaning and goals, as in this paper, the use of the latter seems to be more suitable as it refers to a partial return to the former function (Shields *et al*., 2003b). Stated this, the remaining question regards what condition we want to restore or, more precisely, how far back in time we should go to reach a "quasi-naturalness", considering at the meantime that the same concept of "naturalness" is probably changed during the centuries.

Nowadays, in fact, the main difficulties in restoring floodplains lie partly in human activities for industrial, agricultural and residential purposes settled on river corridors; in this way, rehabilitation activities affects a wide range of stakeholders and institutions designed to secure a variety of private and public goods associated with water protection, nature conservation, urban and rural development, flood defence and the protection of historical landscapes (Adger and Luttrell, 2000; Adams *et al*.,2004), making it potentially highly controversial. Certainly, a "win-win" strategy, an optimal balance between nature rehabilitation goals and other societal interests, can provide considerable benefits for many actor groups spanning a variety of policy fields.

4. REHABILITATION PRINCIPLES

In planning the rehabilitation project, awareness of the fundamentals of fluvial geomorphology and channel processes allows us to see the relationship between form and process in the landscape. The geomorphic assessment provides the process-based framework to define past and present watershed dynamics, develop integrated solutions and assess the consequences of restoration activities (Koebel, 1995; Galat *et al*., 1998; Baruffi *et al*., 2004). Such study forms the foundation for analysis and design and is therefore an essential first step in the design process. In a certain sense, it gives a "reference image", a sort of picture of a former state of the river that can be used as a target point for the rehabilitation process, in order to define the optimal solution for the river and its floodplains under present conditions; in fact, actual changes can't be ignored and thinking about going back to the XIX century, when the river freely meandered in the floodplains, with no human impact, is just an illusion.

In this perspective, it's necessary to look for synergism, enter into compromises and meanwhile exploit the structural and functional potentials of restored river habitats, considering, in addition, that the public acceptance of the process of heightening and strengthening of the dikes is strongly decreasing, due to the high environmental impact of these insurmountable river-walls separating urban areas from the river.

Ecological rehabilitation plays a key role in this new policy: the restoration of former floodplains in order to reduce flood risk allows, at the same time, the creation of ecologically robust nature reserves (creating a "new nature" (Drenthen, 2009)) and the improvement of the spatial quality of the river environment.

The inspiring principle of this vision is the "genius of the place" concept (Helmer & Overmars 1998), in which the dominant impact of man in shaping physical habitats is recognized: this means that we shouldn't always leave everything the way it was, but that we should start with a meticulous examination of each particular place. Ideally, natural hydrological and geo-morphological processes should be followed, instead of artificial designs from the drawing-table: "liberate" nature instead of "constructing" nature.

5. A REHABILITATION CASE STUDY

5.1 Study Area

Herein we illustrate a flood mitigation plan through destroyed floodplain rehabilitation for the Vomano River (Central Italy). The investigated area is located in the terminal reach of the Vomano River (central Italy), which originates in the Gran Sasso Massif at 2155 m above sea level (a.s.l.) and it flows 68 km in an eastward direction to the Adriatic Sea, covering a 767 km^2 wide watershed.

A synthetic image of the study area, in its "natural condition" was given by Lorenzetti (1935), who described the river as wandering, composed of one or two branches which moved from bank to bank in function of the hydrological conditions of the moment (Fig. 1(a) and (b)). This description already suggested an evolution trend towards instability, that, during the years and due to human interventions along the river, would have generated serious hydrological problems. In the same report, the author described the disadvantages created by such "hydraulic disorder" in the surrounding cultivated areas during winter floods and suggested, as remedy, water control by embankments construction and canalisation. But the rapid economic development and population growth after the Second World War led to an intensive exploitation of the valley area, in its various aspects, ranging from gravel and sand extraction from the river bed to human settlements for industrial and agricultural purpose on river corridors.

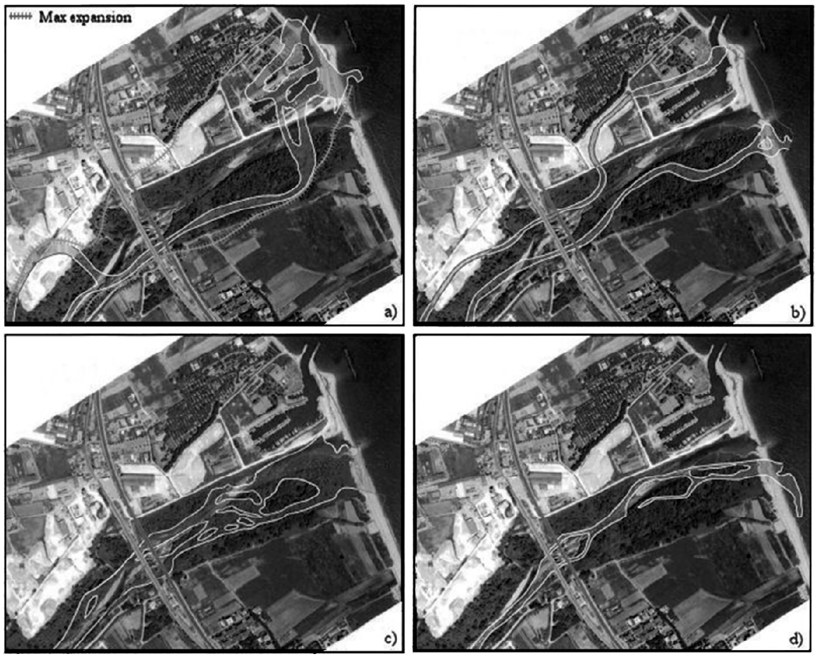

Figure 1: River Pattern Evolution: (a) 1943; (b) 1954; (c) 1976; (d) 1983. The Backdrop Orthophoto Refers to Actual Condition (2007)

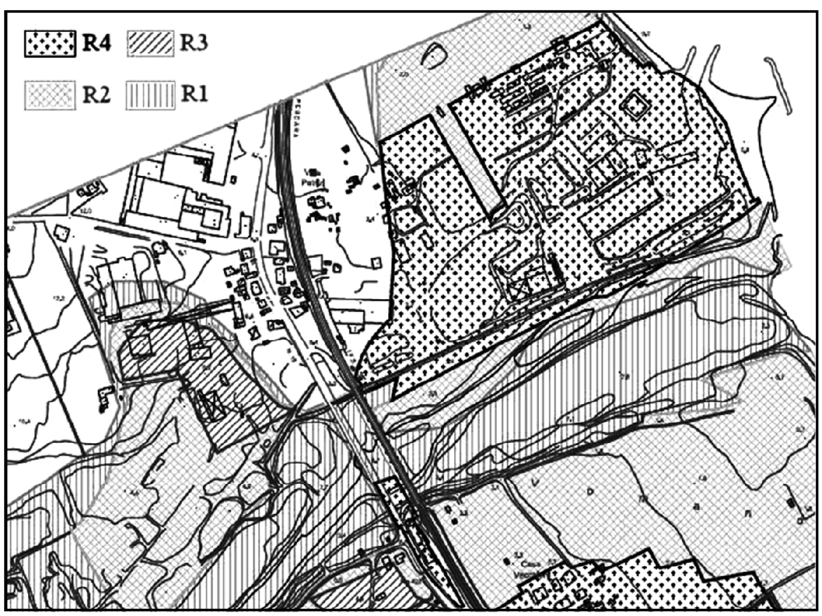

Figure 2: Flood Risk Map: R4: Extreme Risk; R3: High Risk; R2: Medium Risk; R1: Low Risk (Regione Abruzzo, 2007)

Nowadays, the study reach is characterised by critical elements that compromise the hydraulic safety of the surrounding urban areas, as easily visible in the flood risk map (Fig. 2). In addition, recent "average" events, which have caused dike breaks and overflowing, especially in correspondence of the aggregate processing plant, have proved the weakness of the existing defence measures. For example, the 1992 flood caused a dike break just downstream of the bridges, with the river that followed its ancient course with its natural mouth in the north direction, resulting in the consequent inundation of the surrounding areas on the left.

But the problems are not only limited to the hydraulic safety, but also regard the general spatial quality of the entire zone. Here we briefly report the main problems registered:

- Awful state of maintenance for what concerns the embankments and the floodplains in terms of forestry; it's evident the presence of a thick vegetation (trees and shrubs) both in the channel and on the left bank, which prevents the safe flow of water;
- Presence of vegetated gravel deposits in the main channel; some of them are vegetated and take the form of little islands;
- On the left bank, from the bridges to the shipyard, there's a recently built embankment, which as to be intended only as a temporary protection measure for low return-period floods;
- Presence of a large gravel deposit, that works as an obstacle to river flow, in correspondence of the mouth, which modifies its shape and deviate river's outlet in the north or south direction, in function of sea currents;
- Thick vegetation affects the right embankments (characterised by irregular elevations) downstream of the bridges; just upstream of the mouth, there's also a very high vegetated area which, during the time, has retained the material transported by the river, generating a large deposit in shape of an island.
- The area is characterised by a general state of abandon, until the limits of decency, for what refers the cleanliness, with signs of solid urban waste dumping of illegal and uncontrolled nature.

5.2 Methodology

The geomorphic approach is applied in order to obtain evidence of the changes in river morphology produced by human interventions on the floodplains (assessment of stream condition); in this way, a guiding image and an endpoint for the rehabilitation process is identified a priori and then applied to the numerical flood modelling process, in order to obtain, by an iterative process, an optimal solution in terms of hydraulic safety, low environmental impact and in accordance with actual boundary conditions.

5.3 Geomorphic Analysis

The analysis of historical maps and aerial photographs (Fig. 1) with a diachronic approach clearly highlights how river morphology has changed during the last century. Figure 3 shows

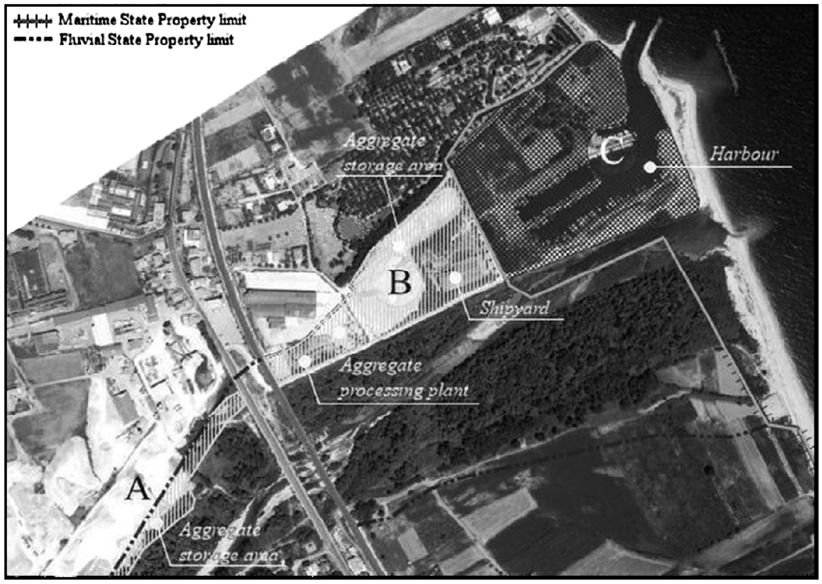

Figure 3: Occupied Areas in the Left Floodplain

that the actual river pattern is the result of the progressive antropization of the original mouth and floodplains: in particular, man-made structures can be noted on the left bank, including an aggregate storage area, a shipyard, an aggregate processing plant ($B \approx 32.000$ m^2) and a small harbour ($C \approx 66.000$ m^2), located in the original Fluvial State Property lands. There's also another aggregate storage area ($A \approx 10.000$ m^2) on the left bank which effectively halves the run-off cross-section of the river: this area is protected by temporary and discontinuous embankments, which invade the floodplain for a total length of 350 m.

The progressive occupation of these areas for human activities is responsible of the left bank migration towards the river, which has resulted in cross-sections narrowing and in an unnatural deviation of the river in southward direction.

5.4 Proposed Interventions

The geomorphic analysis is used as reference point for the concept of "stream-way" or "freedom space", in order to maintain a "functional flooding area" (Malavoi *et al*., 1998), hence to restore a sufficient channel capacity.

Based on the observation that the impossibility of achieving the minimum safety requirements can be easily ascribed to the occupation of the ancient floodplains and that the restoration "in toto" of the original state is a very impractical solution, the hydraulic risk mitigation, i.e. avoid flooding events in the perifluvial zones, seems the fundamental and the most realistically achievable goal, trying to preserve, at the same time, natural river characteristics and its relationship with the environmental and urban context.

The interventions aiming at flood risk mitigation and geological and environmental rehabilitation of the study area should be first inspired by the basic guidelines for the basin plans, in particular:

- Maintain those existing flood defences strictly useful for the hydraulic safety;
- Limit new works to the areas of real risk, while promoting, as far as possible, actions of bioengineering;
- Exclude canalisation and impermeabilisation of the main channel and river banks;
- Ensure the conservation of the floodplains and the conditions for the free digression of the river;
- Tend to the original cross-sections;
- Rehabilitate the destroyed parts of the river, through appropriate bioengineering techniques;
- Recover the floodplains, allowing the natural expansion of the river under extreme conditions, including, where possible, the demolition and/or the relocation of human activities.

Specifically, the identified works should include:

- The construction of a new embankment on the left bank, downstream of the bridges, located in Fluvial and Maritime State Property;
- The construction of a new embankment on the right bank, downstream of the bridges, located at the limit of the Fluvial State Property;
- The lowering of both the overbanks downstream of the bridges, the regularization of the low-flow channel, mainly located in State Property areas, and adjustment of the embankment on the right bank.

In this way, the existing deviation point in correspondence of the bridges is eliminated, thus giving the river an easier and straighter access to the sea, similar to the ancient course, and preserving, in the meanwhile, the existing large and densely wooded island located in proximity of the right bank.

5.5 Hydraulic Modeling

The effectiveness of the identified interventions is then analysed by means of a 1D steady-state model (HEC-RAS). Starting from the *ex-ante* configuration and keeping in mind the target image defined by the geomorphic analysis and the actual boundary conditions, adjustments to river's geometry are made in order to obtain, by an iterative process, the most suitable solution in terms of hydraulic safety and environmental impact. In particular the analysis is made for the 200-years return period flood Q_{200} = 1568 m^3/s.

In the spirit of 1D modeling, the reach is described as a series of 14 cross-sections, located at an average distance of 85 m, for a total length of 1200 m; the cross-sections, defined between

Figure 4: Vomano River. View in Correspondence of the Shipyard Looking Upstream

the left and right embankments, in the *ex-ante* configuration are ≈ 200 m wide. Figure 4 shows the actual configuration of the river (under high flow condition): it's recognizable the left embankment, part of the left floodplain and the dense wood on the right.

Roughness coefficients were estimated for each interval based on the characteristics of the channel and experience from previous studies; in particular a constant value of $n = 0.05\ m^{-1/3}s$ is attributed to the low-flow channel, whilst the overbanks are differentiated as follows:

- For the right overbank: from 0 m to 600 m, $n = 0.3\ m^{-1/3}s$ (densely wooded area); from 600 m to 660 m, $n = 0.075\ m^{-1/3}s$ (in correspondence of bridge crossings); from 660 m to 1200 m, $n = 0.15\ m^{-1/3}s$.
- For the left overbank: from 0 m to 600 m, $n = 0.15\ m^{-1/3}s$; from 600 m to 660 m, $n = 0.075\ m^{-1/3}s$; from 660 m to 1200 m, $n = 0.15\ m^{-1/3}s$.

The results of the model for the actual configuration (Fig. 5, solid grey line) show that bridge crossings and cross-sectional areas are insufficient to convey the two-hundred years return period design discharge.

Then, iterative adjustments are made to river's geometry and roughness coefficients (*n*-values are reduced of the 20% respect to the original ones, due to regularization interventions in the main channel and in the overbanks), arriving to the final configuration represented in Fig. 6, which shows the new dike alignments and the rehabilitated areas, indicated as A and B;

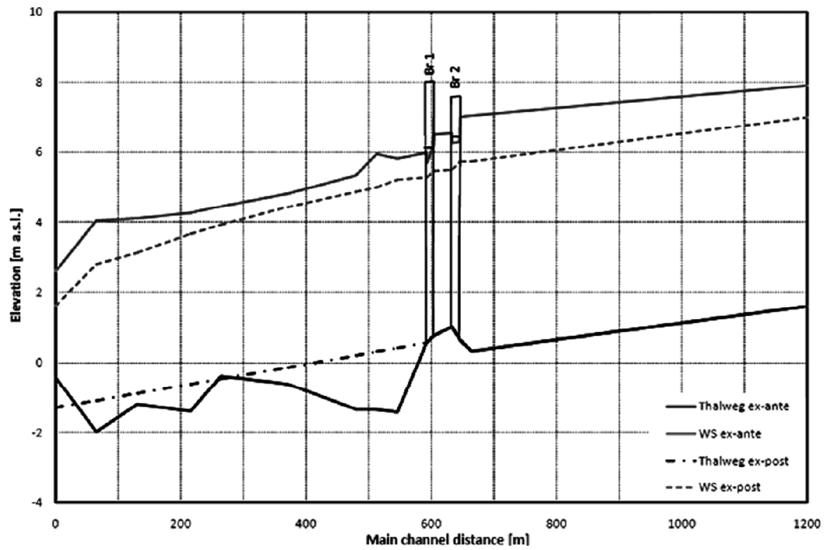

Figure 5: Water Surface (WS) Profiles for *ex-ante* and *ex-post* Configurations (200-Years Return Period flood)

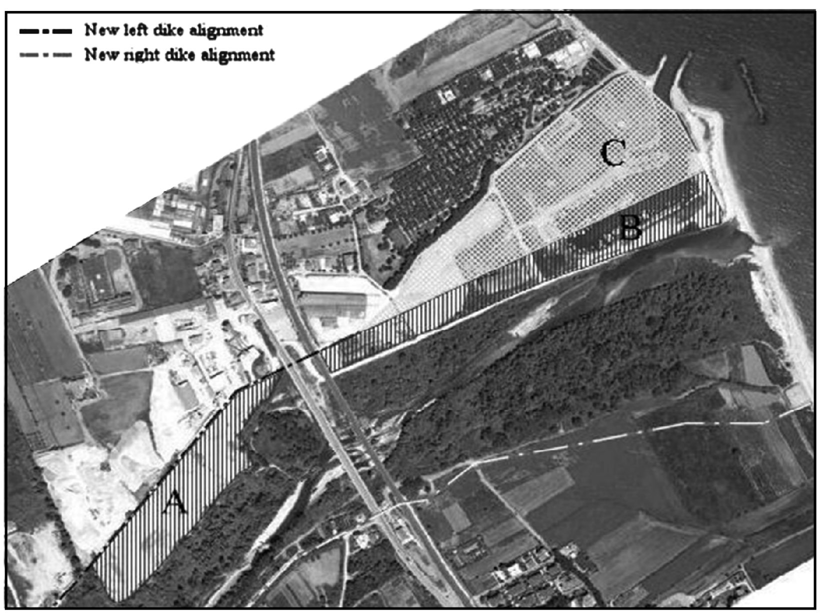

Figure 6: Final River Recalibration

C is obviously an area once occupied by the river, but its restoration actually seems a very impracticable solution, as now in use by major human activities.

Thus, the proposed solution consists in channel's regularization and recalibration, i.e. in giving river more room, through the rehabilitation of those areas, mainly located on the left bank and occupied by minor human activities, strictly necessary to the transit of the maximum probable design flow.

The results of the hydraulic simulation for this new configuration are shown in Fig. 5 (dashed grey line): it's evident the important reduction in water depth values, ranging in the order of one meter for the total length of the reach under investigation.

In addition, the proposed enhancement of river conveyance by adjusting cross-sectional profiles and by relocating and reinforcing the embankments also prevents problems in correspondence of bridge crossings, allowing the recovery of four bridge spans, actually not available as flow area.

Concluding, this rehabilitated pattern seems to be an optimal solution for the study area, as it is in accordance both with the man-made environment and with the natural processes, which are in operation when the river is allowed to take more space.

6. CONCLUSIONS

Increasingly, there's a growing shift from hard and stand-alone structural engineering solutions to more nature friendly restoration activities, in order to reduce flood risk and to improve the quality of degraded rivers. However, such interventions are still limited to some test cases, so a larger diffusion among river managers and engineers, who continue to prefer the "classical" structural defence measures, is desirable.

It's essential to recognize that there can be no universally applicable restoration endpoints, given the regional differences in climate, geomorphology and land-use history. Instead, many approaches exist for establishing a guiding image for restoration efforts.

The study presented in this paper wants to be an example of how a geomorphic approach, based on the analysis of historical information, as aerial photographs and maps, can provide valuable insights on river evolution during the years due to human disturbances and then it can be a useful preliminary tool for designing a sustainable rehabilitation project. This guiding image may be influenced, as in this case study, by irreversible changes to river morphology and by permanent infrastructures on the floodplains; the idea is to follow a pragmatic approach in which the restoration goal should be to move the river towards the least degraded and the most effective and environmental friendly state possible, given the local context.

It should be noted that the main objective of the rehabilitation activity reported in this paper concerned the mitigation of the hydraulic risk; so, other important factors related to fluvial environment like impacts on water quality, fish habitats, vegetation species, etc. were not taken into account in the analysis. Such aspects may be object of future work.

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