A Sustainable Approach to Flood Protection Engineering within the Aniene River Valley Linear Park

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***Abstract*- The Aniene River Valley Park project is focused on flood mitigation, ecological quality restoration, urban, sub-urban and rural areas enhancement. The Aniene River Valley (one-million inhabitants) has archeological, historical, natural potentials including the villas of roman emperors, the springs used for the water supply of the city of Rome and Middle Ages Castles and is undergoing extensive urbanization of its riverine areas. The project strategy is centered to a sustainable river valley development under the different constraints, approaches the various functional, social, esthetic, natural points of view and is focused on structural measures that are used to control the flow of water both outside and within urban settlements, within the context of an integrated approach to urban flood risk management. The expected results of the project are: restoration of river corridor's ecological quality, highlighting specific river potentials and resources, allowing an optimal level of sustainability of the territories involved conjugating, flooding, leisure planning and safeguard of the water supply. The realization of the River Park is an important step towards flood protection because if properly maintained and brought to life it's the limit to improper and widespread land use.**

Keywords- Environmental Engineering Construction; Flood Protection Measures; Green Networks; Linear Park; River Restoration; Soil Conservation Measures; Urban Restoration

I. INTRODUCTION

The city is always more the habitat of contemporary man. More than half the world's population lives in cities. Nowadays Urbanization is accompanied by increasingly larger-scale urban spatial expansion and massive land use. In order to accommodate population increases cities grow outwards and thicken within. Urban expansion alters the natural landscape, land uses and land cover, for example by changing water flows and increasing impermeable areas, thereby adding to the flood hazard problem [1].

High levels of urbanization in river flood plains and other areas of catchments with consequent lack of drainage in an urban area may exacerbate and change the frequency of occurrence of flooding.

River or fluvial floods occur when the surface water runoff exceeds the capacity of natural or artificial channels to accommodate the flow. The excess water overflows the banks of the watercourse and spills out into adjacent, low-lying floodplain areas.

Urban flooding is becoming a serious and growing development challenge. When the flood takes place within the city, it will cause loss of life to its inhabitants, damage to buildings, utility works, housing, household assets, income losses in industries and trade, loss of employment, and interruption to transport systems. Therefore this is a phenomenon, which causes widespread devastation, economic damages and loss of human lives.

The occurrence of floods is the most frequent among all natural disasters globally. In 2010 alone, 178 million people were affected by floods. According to the report [2] published in February by the World Bank and the Global Faculty for Disaster Reduction and Recovery entitled "Cities and Flooding: A Guide to Integrated Urban Flood Risk Management for the 21st Century", "The unprecedented rate of global urbanization in cities and other urban areas implies that exposure and vulnerability is increasing, which will cause loss of life and property unless proactive measures are mainstreamed into urban planning processes [3]. Cities themselves are often blamed for social inequalities, the inadequacy of city governments, authorities and institutions, and environmental degradation [4, 5]".

Urbanization shifts the balance of prevention from individual measures to collective action [6]. Accordingly to this assumption, a locally-specific and integrated response to this environmental hazard and risk is needed to address the flood risk that countries face. The "integrated approach" to urban flood risk management within multiple stakeholders is needed to allow more sustainable development.

The topic of river restoration is now a recurrent leitmotiv in most of strategic declaration that are laid as foundations of plans and projects of last years urban transformations. Too often, however, those policies only redesign the fringe between city and river, and attract interventions aimed at economic revitalization of previously industrial neighborhoods been abandoned. Those policies, in fact, generally do not intervene on urban tissues and much less on river ecosystems and can involve transferring hydraulic risk upstream or downstream.

The river corridor includes areas that are often open and unskilled spaces, with land reclamation problems. Further urban fragmentation has resulted from legacies of infrastructure interventions. In several cases they are relics of the countryside remained undeveloped or monumental sites previously isolated and then incorporated by urban expansion. The waterways are therefore privileged contexts for a new approach to urban and environmental regeneration

policies that provide for the creation or strengthening of new urban public spaces and regional or urban parks connected to soil conservation measures.

II. CASE STUDY

The Aniene River has been chosen as the appropriate case study. The territory studied contains the wide area of the Aniene River Valley (Fig. 1) from the sources to its confluence with the Tiber River.

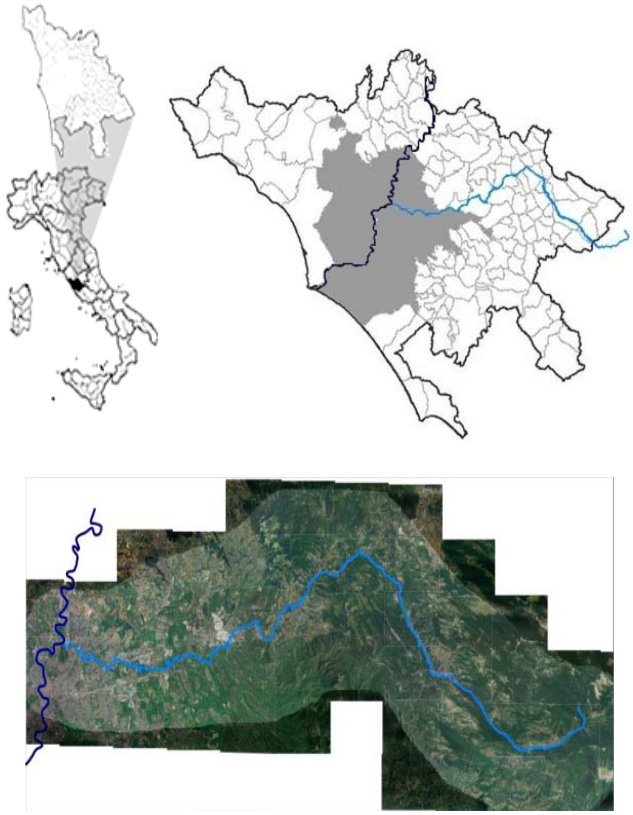

Fig. 1 Italy, Rome's administrative boundary (in grey), the Tiber River (in dark blue) and the Aniene River (in light blue)

A river linear park project is proposed as to involve a widespread environmental rehabilitation combining soil conservation's interventions with the enhancing of places nearby the river corridor.This network approach which involves the territories crossed by the river allows encouraging the use of river resources.

The UN secretary-general Ban Ki-Moon said that the United Nations General Assembly had recognised drinking water and sanitation as human rights. That means that we must ensure the protection of the resource reducing its wastage and pollution.

The Tiber's last major tributary is the Aniene River that contributes with a flow rate of 31%. The river Aniene rises in Simbruini Mountains at an altitude above sea level of about 1,600 m and crosses along its course different landscapes ranging from almost untouched territories at origins in the mountains to highly urbanized areas into the city of Rome where there is the confluence with the Tiber River. The Aniene River's length is about 67 miles (108 km) while its drainage basin is about 569 square miles (1,474 square km).

The mountain section is characterized by:

- steep slopes;
- usually narrow and deep section;
- relevant dimension of the solid material;
- markedly torrential character (strong variability of flow, fast currents).

The stretch valley instead is characterized by:

- bottom slope contained;
- generally broad and shallow section;
- tortuous, often meandering planimetric course;
- size of the solid material smaller than the mountain section.

III. PROJECT'S AIM

The project aims to resolve the River Aniene's problem of ecological and cultural enhancement connected to soil conservation measures. Conceptually, it is to consider the resource both to be protected and to be protected from.

These issues are meant to be realized by a Riverside Park along the Aniene River that results in widespread environmental regeneration providing a better quality of life harmonizing the different requirements according to territorial and administrative interaction going from large to retail scale.

The strict relation between settlement's dynamics and the river, highly shows its importance in territorial development and the design possibility of reconnecting territorial breakdown such as SLOAP - Space Left Over After Planning through a common element that can be the river axis of the linear park.

The project's priority aspects considered for river restoration are:

- planning environmental sustainable flood protection measures for water sensitive urban design;
- using low-impact materials (bioengineering) able to maintain the functionality of the river and encourage environmentally friendly activities (urban gardens);
- handling overflow bands and defending hydraulic high-risk areas;
- recovering degraded river bands and riparian zones and hollowing the creation/preservation of ecological networks longitudinal and transverse to the river;
- protecting the quality of water resources.

Other important aspects to be taken into account are:

- reconnecting urban areas and suburbs through the capacity of the river park to weave ties with local landscapes;
- increasing accessibility to resources through the implementation of pedestrian mobility within the park and the surrounding settlement areas;

- conservation and enhancement of local environmental, historical and archaeological values trough new routes, facilities and amenities' realization;
- new facilities' realization or pre-existing one recovering according to compatibility with flood runoff in the way to encourage river's liveability, through sports, nature hikes and environmental education activities;
- different scaled planning instruments harmonization;
- reconstructing ancient territory figurability trough the reconnection of the historic routes' network and historical river crossing;
- guarding the territory and strengthening local identities.

The project foresees a territorial sustainable development approach preserving the quality and quantity of heritage and nature reserves without compromising the ability of future generations to endure the same development.

This form of development of society involves a range of aspects such as environmental, aesthetic, functional, economic and social, which must be made to system.

Current planning instruments explain for that reason as the following points:

- Functional efficiency: qualitative and quantitative adequacy of infrastructure networks and equipments;
- Economic efficiency: locations' supply relative to the demand of economic entities and enterprises;
- Fairness: equal distribution among the inhabitants about territorial heritage and equal benefits and costs of needed actions distribution;
- Beauty and identity: preservation of historical heritage as the depository of cultural identity and aesthetic perception of the morphology of the places;
- Well-being and environmental balance: population livability, health, safety and protection from environmental hazards, and environment protection, conservation and restoration of property and natural resources, including forms of life other than human.

IV. METHOD

The adopted method has provided analysis and project stages. In the first phase of analysis it has studied the river valley according to 3 macro-systems: environmental, relational and settlement. Afterwards another phase of necessary analysis of the case study's area has been the survey of the existing major planning instruments.

The study area was divided into 5 homogeneous spatial sequences according to their characteristics. A "Transect" (Figs. 2 and 3) which was a transversal portion of territory within each sequence was then analyzed in greater detail. In each "Transect" have been proposed strategic redevelopment and enhancement actions. Those actions require to be implemented through the river park also pointing out the specificity of each part and highlighting the similar needed actions. The different requalification projects in urban and not urban areas are assumed as a system that is constituted by the river park.

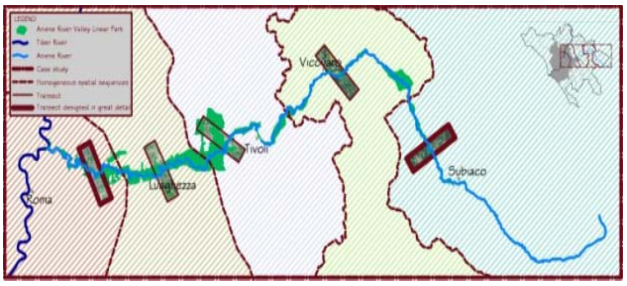

Fig. 2 The Aniene River Valley divided into 5 omogeneous spatial sequences and "Transects"

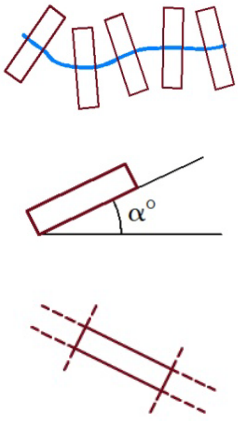

Fig. 3 Transect's location, disposition and size

The "Transects" allow developing the project in more details according to three specific strategies:

- highlight critical issues and resources;
- testing the limit of the river park;
- highlight soil protection measures required.

The transects' location is on particularly significant places within each sequence that offer the possibility to propose interventions that enhance the entire sequence and act as a reference to the territorial scale. The transect's disposition is placed transverse to the river searching the connection between the riverbed and the riverine bands with local landscapes. The transects' size is defined 6 km length to 1, 5km width and remain constant throughout the various crossed territories. These dimensions allow being able to characterize the various parts of territory.

Each transect has, therefore, a specificity which is identified a priority and a subsequent planning action. The identified priority ranges from the need to preserving, re-naturalization, safeguarding and restoring to attracting, connecting and mitigating. Fruition centered actions are expected through feasibility river recovery and enhancing existing bridges and viewpoints, including the confluence of the River Aniene's tributaries. It's also pursued the creation of picnic areas and access points to the river as well as riverine bank's re-naturalization and hydraulic defense realization.

A. Analysis

This portion of the Lazio Region as showed by the analysis of the environmental system so determined is extremely rich in particular valued areas. Numerous ANP – Natural Protected Areas, in fact, gravitate near the River Aniene as well as several SIC – Site of Community Importance, both established by the European Community.

The environment of the river corridor according to the analysis of biological quality by the Lazio Region remains unaltered or slightly polluted especially in the upper valley that is upstream of the Municipality of Subiaco, and alters and degrades even significantly in the lower valley and through the city of Rome in which it's affected by the proximity of manufacturing facilities (Fig. 4).

Fig. 4 Diagram of the biological quality of Aniene River [7]

The Aniene River Basin is included within the Tiber River Basin Management Planning (approved by Tiber River Basin Authority in 2009) that is the major planning instrument at a wide scale.

The Tiber River Basin Management Planning includes its objectives Rome's protection and the riverine environmental features' recovery. It also distinguishes hydraulic bands derived from hydraulic model outputs, based on areas subject to flooding: band called "A" with a return period of 50 years and band called "B" with a return period of 200 years. These areas are then highlighted risk areas called "R4" or "R3" that are zones within settlements which require the construction of hydraulic defence works.

The return period or recurrence interval is defined as the average time between events of a given magnitude. The return period of floods of different heights varies from catchment to catchment, depending on various factors (the climate of the region, the width of the floodplain and the size of the channel).

B. Project

The case study examines two sections of the river for which there are proposed two types of soil conservation measures.

In general it is necessary to distinguish between the arrangement of a mountain or valley section of a waterway that have different characteristics.

The first concerns measures which are generally aimed at reducing erosion in the basin and sediment transport in the river bed. The second, regards, however, interventions mainly aimed at reducing the risk of flooding through the realization of special artifacts.

The hydraulic protection of the Aniene Valley seeks to defend those areas identified and labelled according to the magnitude of the risk using the first approach for the "Transect" in the Urban sequence and the second for the one in the Mountain sequence.

There are also two types of approach that need to be taken into account: structural and non-structural measures. An integrated strategy usually requires the use of both structural and non-structural measures.

Structural interventions are those interventions that reduce damage resulting from flooding by changing the characteristics and the effects of floods.

A possible approach to reducing damage is represented by designing an infrastructure that is robust to flooding, and can therefore be sited in the floodplain without increasing risk.

Structural measures can be classified into active defence measures or passive defence measures.

The flood protection through active measures aimed at reducing flood flows at its height, laminating floods by means of reservoirs located upstream of the areas to be protected.

The flood protection through passive measures intended to create conditions that prevent runoff enlargement of areas to be protected by increasing the flow capacity in the river bed with water levels lower than those of flooding.

The arrangement of the streams can be synthetically divided into water drainage measures or accommodation measures. The first tends to change the flow regime of the river and include: embankments, dams, flood control, the diversions and spillways. The second tend to change and/or consolidate the riverbed to achieve a stable horizontal and vertical alignment and include: defence works and stabilization of the banks and of the riverbed, flood longitudinal and transverse defence works, the reshaping of the sections and the re-profiling of the track layout.

The project includes the use of non-structural measures such as the delimitation of the areas of danger and the development of early warning systems. These interventions tend to reduce the damage caused by the flooding without directly intervening on the causes (floods) but using administrative and civil protection measures. Non-structural solutions such as flood warning systems, are also necessary for the protection of the populations already at risk of flood, whether protected by defences or not. Operations and maintenance, greening of urban areas, improved drainage, can minimize the expected damage from flooding.

1) Urban Sequence:

The strategic actions that seek to exploit the potential of urban park connecting the riverine park with other nodes of Rome's ecological network, provide the redevelopment of the river bend with the restoration and enhancement of ancient Mammolo Bridge (Fig. 5).

Fundamental is also the realization of the hydraulic intervention as to defend the ancient building of Casale De

"La Vannina" that is placed in "R4" area.

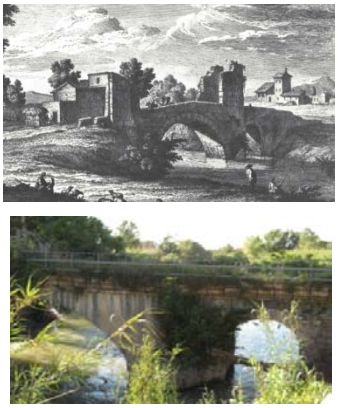

Fig. 5 Ancient Mammolo Bridge in an engraving by Thomas Ashby (1874 – 1931) and in a contemporary picture. In the right engraving's background the Casale De "La Vannina"

The embankment's location that joins the redevelopment of abandoned and degraded areas with the provision of new suitable equipment and new routes addresses the need to minimize the reduction of the rolling surfaces available for the river's flooding. Storage thereby has the effect of attenuating (reducing the peak) of flood flows.

The embankment it though to mend the pedestrian paths' network to the Ancient Mammolo Bridge. It isn't located in direct contact with the water flow but in the floodplain zone to ensure the intervention's sustainability and durability (Figs. 6 and 7).

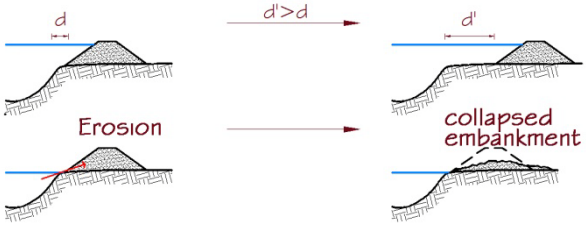

Fig. 6 The embankment location addresses the need to minimize the reduction of the rolling surfaces available for the river's flooding and to ensure the intervention's durability

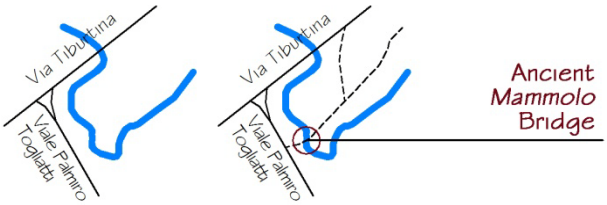

Fig. 7 The diagram shows the redevelopment of abandoned pedestrian paths to the Ancient Mammolo Bridge

The fundamental issue taken into account is combining the flood protection with a flood tolerance approach. As shown in Figs. 6 and 7, the embankment localization is meant to ensure the river bend's optimal dimensions. Safeguarding the rolling surfaces allows the natural but controlled spread of water. Doing so will prevent damages to downstream.

The embankment's design creates a partition between the flood-safe area and the rolling area.

The first area, where are continuously granted some amenities such as an open theatre, a skateboard ramp and children's slides, is enjoyable also during the flooding instead the second area is equipped with a baseball field and gardens that can easily be flooded (Fig. 8).

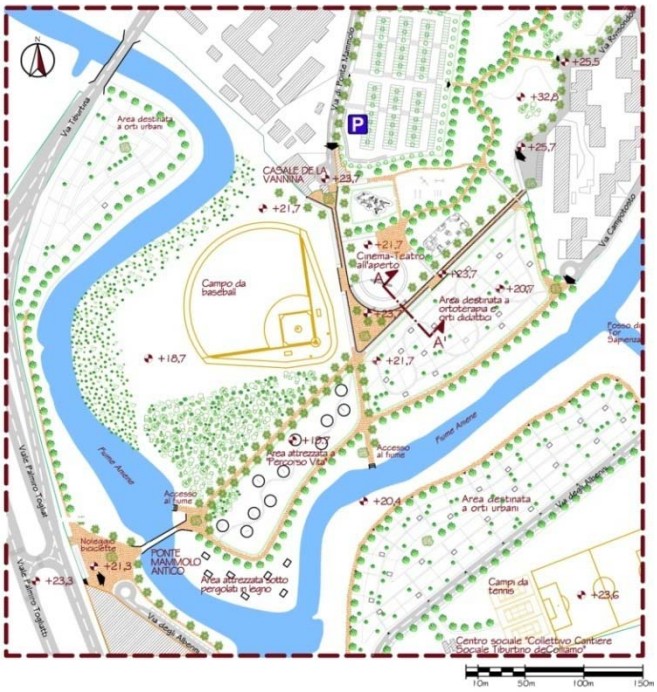

Fig. 8 The Linear Park project in the urban sequence

The embankment is also intended to realize a flood safe area enjoyable during the overflow

To ensure the stability of the bank, it is chosen a specific arrangement of trees, adapted to climate and site characteristics, disposed at a 4 meters distance from the embankment's foundation as to prevent filtration preferential pathways that can affect the construction's resistance. The chosen trees are used also to strengthen the paths' network: the Aspen and the White Poplar are used respectively to mark the main and the secondary routes.

It is part of the project even the design of areas for urban agriculture, educational and therapeutic gardens (Fig. 9).

Those amenities are intended to be enjoyed by nearby schools, and for the recovery of the most vulnerable groups of population such as elderly, disabled or inmates of the nearby Rebibbia prison.

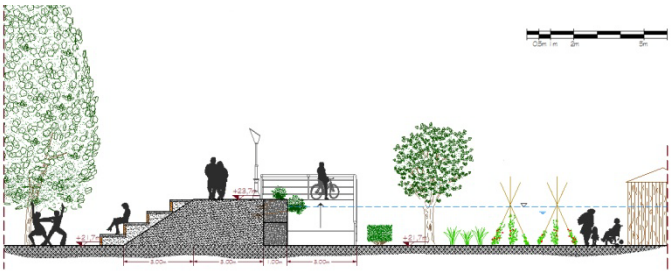

Fig. 9 The embankment section (A-A') showing pathways and educational gardens

2) Mountain sequence:

In the Mountain sequence it's identified an area along

the river that needs hydraulic defence measures. In particular it's necessary an intervention of naturalization that involves environmental engineering which tends to revive the area where an earlier human intercession by ARDIS- Soil Protection Regional Agency has affected the natural habitat (Fig. 10).

It is therefore envisaged the creation of a cycle path that runs parallel to the river bed and planting hardwood cuttings of shrubby willows to grant naturalness to the banks.

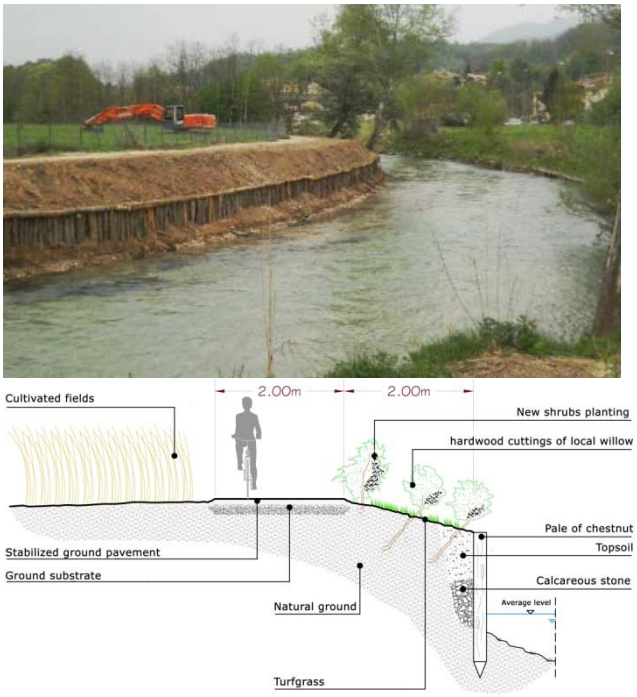

Fig.10 A current picture and the intervention of naturalization proposed

Another intervention is the upstream bank protection. In fact, at this point we are in the presence of a phenomenon of erosion (Fig. 11).

The intervention of accommodation river banks is performed by means of the passive type and placement of metal mesh gabionades with filling of local stone and insertion of cuttings that contribute to the overall stability of the structure and the camouflaged with the development of the aerial parts.

Fig. 11 A current picture of a needed bank protection intervention

A further intervention relates to the project of a floodgate (Fig.12) needed to prevent rising water in a secondary channel.

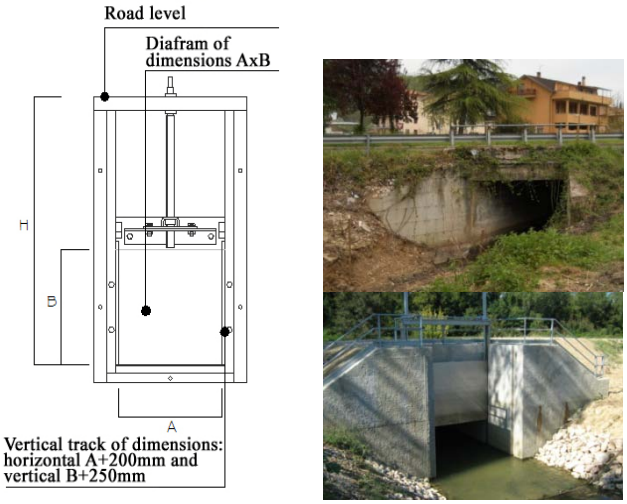

Fig. 12 Floodgate's scheme on the left side and the channel before and after the works with the floodgate on the right side

The floodgate is a passive structural measure that stops water from flowing towards buildings placed in "R4" area.

V. ENGINEERING CHALLENGES

The adopted method has faced some difficulties. Firstly, it has been arduous to determine the hypothetical park boundaries due to the different planning instruments and to the directives of regulatory constraints. In fact, the above-mentioned Tiber River Basin Management Planning tool outlines a river corridor that ends downstream to the city of Tivoli because of the administrative boundaries. With an approach of supra-municipal level and thus preventing the park boundary was constrained by administrative boundaries it has been outlined then an entity that would take account of local vocations, researching old and new relations with the surrounding territory and introducing connections longitudinal and transverse the river.

Another challenge brought as a result by the project has been the fundamental issue of combining the flood protection with a flood tolerance approach. This hydraulic engineering problem has been overcome through an integrate approach noticeable in the choice of measures adopted. In the "Urban Transect", for example, the embankment's localization, dimensions, shape and distance from the arrangement of trees is determined by the need to ensure this combining approach.

The added value is that environmental, aesthetic, functional, economic and social issues are then assured as provided by a sustainable design and so that the different stakeholders can take part into the integrated process. Such concept is crucial in the time we are living in. The last economic crisis in Italy, in fact, as opposed to several other European countries and other countries in the world such as the U.S. and China has seen the decline of investment in the construction of public works. This decline prompts to react and oppose to it through creativity, searching for alternative

integrated solutions able to answer to the sustainable principles required. The research of a more economic solution thus leaves space for bioengineering works.

VI. CONCLUSIONS

The project contributes to achieve a good level of sustainability in the territories involved while respecting the specificity of each "*Transect*". A special team of interdisciplinary professionals was necessary to derive integrated solutions. The interventions, given their bioengineering content, require a more accurate construction care and a constant future maintenance (either by public or private actors). The process's efficiency allows the redevelopment of the river corridor and of its surroundings.

The creation of green spaces such as riverside corridors, parks and tree-lined streets also assists in responding to climate change and could indirectly further reduce flooding in urban areas. It has also been observed [8] that with a higher percentage of green space and green infrastructure, post-flood human psychological pressures are reduced as they create a healthier urban environment and promote recreation. This preservation of streams in their original state prohibiting unsustainable use of the land allows the biodiversity's preservation in term of compatible use ensures, as well, the maintenance of the necessary flooding-free buffer thinking in terms of reducing risks for the population.

It's also important to underline that flood-adapted design can be employed at a lower cost during the planning phase than would be the case if retrofitted intervention such us demolition. The increase in vulnerability of cities to flood disasters arises, in fact, predominantly from the following factors [9]: degradation of natural ecosystems; increased urban migration; unplanned occupation and unsustainable planning and building practices.

Unveiling, safeguarding and enhancing riverine landscape's unique hidden potentials can be the way to boost a better environment sustainability and human wellbeing ensuring human safety.

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