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Result-Based Management Tool for the Assessment of Existing Structural Flood Protection and Future Planning. Case Study in the Strymon River Basin, Greece †

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Abstract: Flood occurrence consequences is inextricably linked to the loss of human life and material damage. The latter has a direct economic impact and requires financial resources for repair or reconstruction, in order to continue to provide protection. In the study area of Strymon River in northern Greece, the implemented flood protection and hydraulic structural works combined with failure repeatability, their initial construction costs and damage/repair costs were thoroughly assessed and correlated. This methodology provided a roadmap to support decision-making procedures to formulate flood protection action plans based on the valuation of current flooding results in established infrastructure.

Keywords: flood protection; management; structural works; economic loss; planning

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1. Introduction

Flood risk management and protection infrastructure does not comprise an exclusively technical subject. The implementation of flood risk management strategies and their societal integration and acceptance necessitate floods governance. The catchment area of the project, Strymon River basin in northern Greece, has suffered numerous flood evets of varying importance the last decades, with consequences on the natural and socioeconomical sector.

At the European Union (EU) scale, the gradually employment of the Water Framework Directive (WFD) (EC 2000) since the early 2000s and the Directive on the Assessment and Management of Flood Risks (EC 2007), commonly known as the Floods Directive (FD), have provided critical legislative framework that led to the development of operational tools such as the Flood Risk Management Plans (FRMPs) [1].

The FRMPs are the first step in compliance to the European Legislation in the hierarchical pyramid of flood management and protection. Their objectives set for flood risk management focus on reducing the potentially negative consequences that floods have on human health, environment, cultural heritage and economic activity and also on initiatives for reducing of flood occurrence. [2] Although they offer a fundamental plan, their macroscopic perspective in terms of scale does not always give precise results when dealing with large-scale areas.

In order to assess the necessity of flood protection infrastructure on local scale, further data shall be introduced. These data include specific information on infrastructure with their site-specific location, structural characteristics, initial cost of construction, performance, their response to flood events and the cost of maintenance and re-construction.

In cases where structural flood protection measures fail to serve flooding inhibition the results may affect different sectors, depending of the intensity and extent of the flood event [3]. Material damage is the most common consequence of infrastructure failures, and it poses a direct economic impact that requires financial resources to be repaired or reconstructed in order to continue to provide the required amount of protection in the future.

2. Materials and Methods

The tools for assessing the financial cost of repairing damage or failure of technical/structural works constructed for flood protection are critical aids in flood project management by governmental authorities and public organizations responsible. These tools can provide spatial data linked to construction and repair costs for identifying problematic spots and areas that repeatedly show structural inability to prevent flooding. The outcome of such a process may lead to a flood risk assessment tool and can record information that supports decision-making procedures in order to formulate action and management plans related to flood planning [4].

This study is part of the project "Evaluation of the performance and interoperability of flood protection intervention measures in the area of the Strymon river basin" that was implemented under the INTERREG V-A European Territorial Cooperation Program "Greece-Bulgaria 2014–2020 "Flood Protection—Cross Border Planning and Infrastructure Measures for Flood Protection" aimed to combine the FRMPs with a thorough and detailed recording and evaluation of the existing situation in terms of flood protection infrastructures, to assess the majority of civil works and already applied measures in order to evince the areas prone to flooding and provide an Action Plan where specific located measures are proposed according to an hierarchical evaluation.

2.1. Study Area

The study was implemented in the catchment area of the Strymon river, with emphasis on the places that show higher flood risk. Strymon is a river of the Balkan Peninsula with a length of 360 km, of which 242 km are in Bulgarian and 118 km in Greek territory. The total hydrological basin has an area of 16,550 km^2, with only 6344 km^2 located in Greece.

The area has suffered numerous flood events, with an increasing tense of occurrence in the last decade. A result-based approach offers a tool for priority-based planning where the initial cost of investment for the construction of flood protection works is related to the potential economic failure consequences and to the repeating cost of maintenance.

Figure 1. Study area and eligible areas of the Interreg program "Greece-Bulgaria") (http://www.interreg.gr).

The methodology developed and the means utilized for this study constitute a comprehensive result, that includes actions in the following critical sectors for flood protection:

- improving, supporting and maintaining existing permanent flood protection infrastructure, in order to either increase their capacity to limit flood waters, or to facilitate better water flow and consequently reduce the risk of flooding,
- supplying of the necessary equipment that will allow managing authorities to immediately react to any impending floods and limit the negative effects on the flooded areas,
- strengthening the cooperation between authorities and countries and their ability to deal with the effects of climate change.

2.2. Methodology

The methodological approach constituted of the elaboration of the following actions-activities:

1. Development of a geospatial system containing base information by all the necessary data [5] (backgrounds, networks, structures, flood events, flood zones etc.)
2. Recording of the existing legal and institutional framework and its integration into the geospatial system [5] (protected areas, land uses, special zones, special infrastructures etc.)
3. Introduction of the areas-zones potentially at high risk of flooding according to FRMPs
4. Determination of TWI (Topographic Wetness Index)
5. Recording of existing measures from the regional and local action and flood protection management plans
6. Recording of historical flooding phenomena and their damage assessment data
7. Recording of the results of existing measures, interventions and infrastructure depending on their efficiency in flood events
8. Determination of positive and negative effects of measures on the anthropogenic, natural, and economic environment
9. Future projection of the operational capacity of the protection and intervention measures
10. Cost estimation of protection/intervention measures and prioritization

All data were introduced in a web-GIS (Geographic Information System) for visualization and analysis.

3. Results and Discussion

In cases where past construction data are needed, the main obstacle is the scattered records among public authorities responsible and the lack of service files. Despite the difficulty of the venture, there were 652 structural flood protection measures and civil works recorded in total, through field survey and file search, constituting to the first effort of such scale in the Greek territory.

These structures were further divided into 21 sub-categories according to the type of structure and the frequency they occur in the river basin. The occurrence frequency is indicative of the structural type mostly preferred and constructed in the area. Figure 2 illustrates all categories of structural measures, their types and occurrence frequencies in the study area.

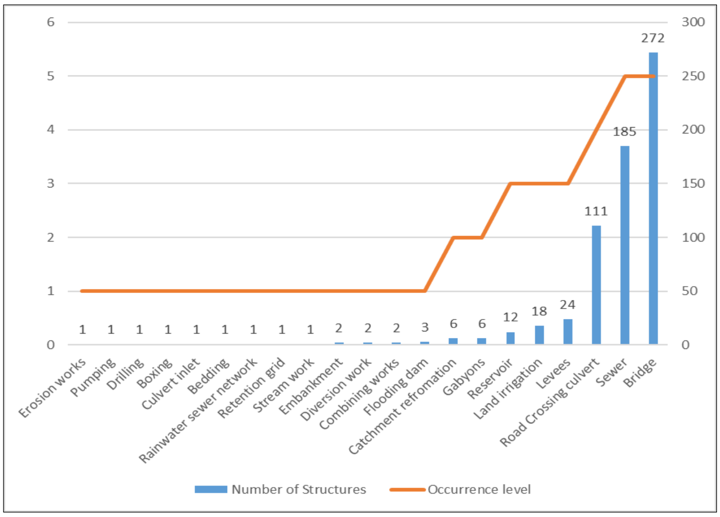


Figure 2. Protection infrastructure according to structure type and occurrence frequency.

All aforementioned data were mapped in QGIS while the geodatabase was populated with information relative to each structure such as construction date, cost, maintenance frequency, failure, damage, repair cost and interoperability with other structures. Figure 3a–c show the mapping outcome of structure data and their reclassification in six main categories: (i)restoration works, (ii) urgent projects (iii) dredging works, (iv)cleaning works & works on technical islets (in rivers), (v) alluvial removal works, according to the type of maintenance necessary throughout a time period of 5 years. Maintenance works include any kind of intervention needed once, while the repeatability of maintenance in a specific structure/location was also recorded, providing thus an index of vulnerability and poor resilience of each structure to flooding events (Table 1).

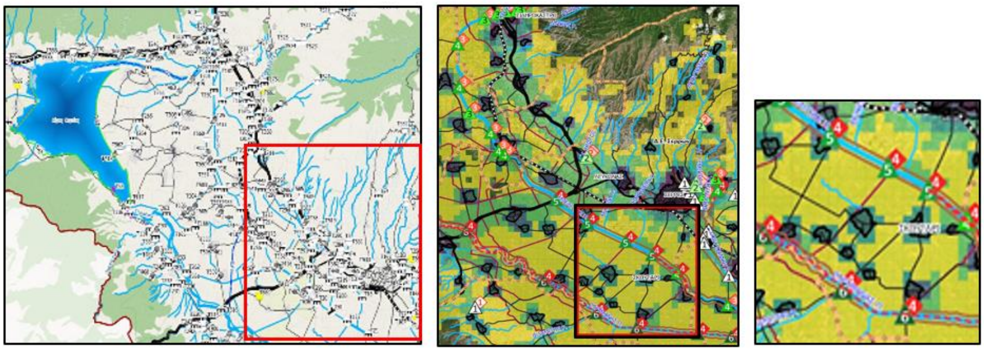
Table 1. Flood protection infrastructure and maintenance interventions.

Type of Structure/Work	Structures Works	Maintenance Works	Maintenance (Including Repeatability)
Stream bottom slope alteration/depth	27	4	10
Restoration work	10	16	17
Islets	4	19	19
Excavations	8	21	44
Removal of alluvium	1	27	75
Technical projects (inlets/culverts)	330	28	96
Bridges	272	138	431
TOTAL	**652**	**253**	**692**

In total, all 652 recorded flood protection structures showed a repetitive need of intervention actions to be taken, due to possible failure or unsuccessful operation with an approximate rate of 1:3, while in most cases maintenance works ought to be repeated with the reverse rate 3:1. The two categories proving to be of more vulnerability and less ability to perform well in potential flooding are: (a) restoration works in critical flood protection infrastructure and (b) bridges and stream crossings.

The above were introduced to the GIS model in order to determine the spatial distribution of the data and to have a visual outcome that will emerge critical locations, subject to further study, since these locations show increased vulnerability in flooding event, as the data demonstrate.

Figure 2a–c present the mapping outcome of infrastructure data visualization and their reclassification, with the repeatability of maintenance marked for each structural work.



(a) (b) (c)

Figure 3. Infrastructure mapping and maintenance/intervention repeatability in the Strymon river basin.

Another important dataset/information collected was the initial cost of infrastructure and the maintenance cost. While initial cost was not always available due to the construction in rather past years, the maintenance costs for the last decade were easier to obtain.

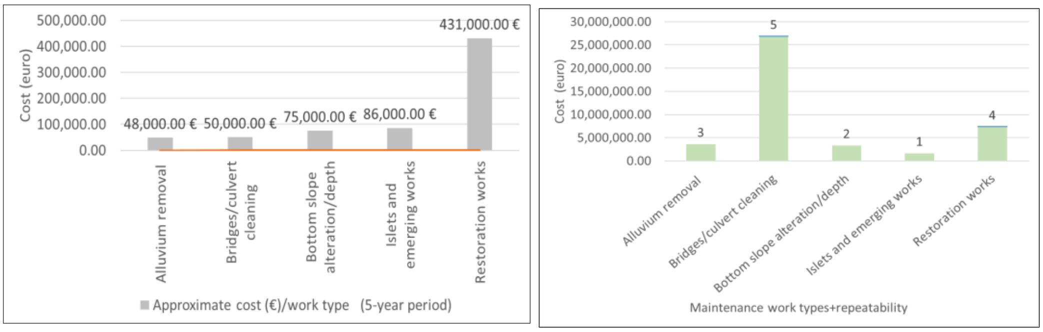


Figure 3. Task repeatability ranking by approximate labor cost (euro).

During the first time a flood protection task is implemented, the restoration works show a significantly higher cost of 431,000.00 € while the repetition of the work/intervention measures places the interventions in bridges and culvers in the first place and with a significant difference. The works on the islets shows the lowest cost as implying that it has not been necessary yet to modify them (based on repeatability). The total approximate cost for maintenance of flood work only, rises to 42,711,000 € in a 5-year time period.

The significance of the structural works and the prioritization of the needs in new flood protection infrastructure was also correlated to the FRMPs where all data were overlayed with the food risk zones to spatially determine most vulnerable infrastructure [6] so as to hierarchize potential interventions.

4. Conclusions

Flood events (major of minor) are inevitable, regardless the amount of existing protection. Flood protection is critical, yet the financial cost of maintaining high levels of protection can prove rather excessive. In major flood events, failures occur and often at different locations each time and depending on the spatial distribution and evolution of the phenomenon. However, it is possible to take into account the parameters that highlight the weaknesses and the problematic or insufficient flood protection design so that rational and reliable alternative proposals and solutions emerge.

From the correlations and analysis of the data in this study, it is derived that an important element for the spatial determination of the new measures is the infrastructure already developed for flood protection. The study showed that, despite the existence of multiple structural measures/works, many of them show poor efficiency, as shown by the high rate of repeatability of maintenance and its cost.

The methodology followed in this study, was based on the results of the performance of existing flood protection measures, their characteristics, and their spatial correlation. The evaluation of structural measures, by assessing their vulnerability via their yearly maintenance, implements the economic loss and the financial impact flooding events might have on infrastructure. The new measures should be related to the cost of construction and maintenance each time, applying the rule of cost-benefit [7] and life cycle analysis, where infrastructure that costs more to maintain, should be replaced.

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Data Availability Statement: All data, models, or code that support the findings of this study are available from the corresponding author upon reasonable request.

Conflicts of Interest: The authors declare no conflict of interest.

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