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Thesis title: The value of green infrastructure in urban flood risk management, case study: Gernika-Lumo, Spain

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IHS
Making cities work

Institute for Housing and Urban Development Studies of Erasmus University Rotterdam

Summary

Different strategies for water security have been developed during the last decade. Water availability and quality have grabbed the attention of both public and private entities that are looking for strategies to conserve strategic ecosystems, and that provide a wide variety of ecosystem services, including water quantity, quality and sediments regulation among others. This research aims to propose a new methodology to valuate ecosystem services from a disaster risk reduction perspective, by the valuation of the regulation of water as an ecosystem service. To achieve these objectives, a case study in the city of Gernika-Lumo in Spain was selected. The city is located inside the Oka and Golako river basin, where heavy rainfalls have caused frequent urban floods, causing important damages to infrastructure, buildings, and properties.

Green Infrastructure plays an important role in water regulation and has the potential to reduce the quantity of water that causes flooding inside urban areas. This research analyses the effect of different land-use cover scenarios, including the land use trends, focusing on the natural forest as green infrastructure inside the catchment. The land use cover changes were analysed using satellite images and GIS methods. Rainfall scenarios were calculated based on the historic rainfall data of the studied area, producing three storm scenarios for different return periods. Using all this information and the main physical characteristics of the Oka and Golako rivers, a hydrologic and hydraulic model were developed. The resultant flood depth maps were used to calculate the total damage per scenario, using the existing flood damage curves for the city of Gernika-Lumo.

The results of this study reveal the big potential that green infrastructure has in the reduction of flood risk, by reducing the hazardous effect of floods. From 2015 to 2020, the flood modeling results shows that there was an increment in flood damage costs of € 7,016,285 for the worst hydrologic scenario. The conservation scenario shows an avoided damage cost of € 12,786,283 in comparison with the actual scenario for 2021. The conservation scenario consisted of the reforestation and afforestation of 1,595 hectares inside the Oka and Golako river basins. The result for the 500-years return period event shows that in every scenario there is a total avoided damage cost of € 8,000 per hectare of forest. There is an evident direct relationship between the reduction of economic losses and the area of green infrastructure cover that helps in the regulation of flow discharge inside the Oka and the Golako river basins.

Keywords

Green Infrastructure, Urban Flood Risk Management, Ecosystem Services Valuation, Nature-based Solutions, Ecosystem-based disaster risk reduction.

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Abbreviations

IHS	Institute for Housing and Urban Development Studies
NbS	Nature-Based Solutions
EbA	Ecosystem based Adaptation
Eco-DRR	Ecosystem-based disaster risk reduction
FRM	Flood Risk Management
GI	Green Infrastructure
IFRM	Integrated Flood Risk Management
IWRM	Integrated Water Resources Management
HEC-HMS	Hydrologic Engineering Center - Hydrologic Modeling System
HEC-RAS	Hydrologic Engineering Center – River Analysis System
SCS	Soil Conservation Service

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Chapter 1: Introduction

1.1.Background

Flooding is one of the most common and lethal disasters worldwide, they are commonly caused by adverse meteorological conditions, like heavy rainfall with long duration, or high intensity, however, they can be also triggered by other natural hazards, like earthquakes that cause tsunamis and landslides (Samuels et al 2010). But the consequences of flooding are increasing as well, as the vulnerability increases due to the location of more people and economic assets in flood prone areas (Pistrika, 2007). Climate change plays also an important role in the augmentation of flood risk in the near future, as is very likely that its effects can cause an increase in the occurrence of rainfall events and a change in the location of some of them, increasing the vulnerability and exposure of some communities as well (IPCC, 2012). By 2050 is expected that 66% of the world population will live in cities (United Nations, 2015), making this problem even worst for the years to come. To tackle floods, many different kinds of gray infrastructure measures have been applied; dams, dikes, flood gates, river hydraulic optimization, pumping systems, and many others. These solutions were effective at the moment, but today, with the new perspective of climate change, their sustainability and resilience are being highly questioned (Zhang, 2018). On the other hand, there was another concept that emerged to refer to the natural infrastructure, it was used initially to refer to the importance of the wetlands, and afterward to refer to the ecosystems as an infrastructure in urban and rural areas, that supports the regulation of ecosystem services, like water provision and regulation, later on, called as Green Infrastructure (da Silva, 2017). Thus, the concept was added into the wider group, under the umbrella of Nature-based Solutions, to group different terms that were used to express similar ideas and strategies like urban forestry (UF), green and blue infrastructure (GI and BI), ecosystem services (ES), ecosystem-based adaptation (EbA), ecosystem-based disaster risk reduction (Eco-DRR), Sustainable Urban Drainage Systems (SuDs), Low-impact development (LID), among others. Today, Nature-based solutions concept includes and covers the strategic and spatial planning and soft engineering. (European Commission, 2021). During the last decade those concepts have been widely used, we are witnessing a transformation where nature is starting to have an important role in the economy and the development of sustainable and resilient cities (Almenar et al 2021).

Nature-based solutions have been widely proposed to be used for tackling climate change and hydro-meteorological risks, other concepts such as Ecosystem-based Adaptation emerged as a more specific term referring to specific NbS mapped and design to respond to hazards such as floods, storm surges, landslides, debris flow, and droughts. Some research has shown important advancements to date, proving these solutions to be sustainable and cost-effective regarding risk reduction (Ruangpan et al, 2019). On the other hand, Ecosystem-based approaches include the term Ecosystem-based disaster risk reduction or Eco-DRR that refers to the sustainable management, conservation, and restoration of natural ecosystems to reduce disaster risk (Sudmeier-Rieux et al, 2019). This term also has a close and direct relation with Green Infrastructure, which includes all the natural ecosystems as infrastructure that can play a fundamental role in mitigating climate change, societal adaptation, and the delivery of different kinds of ecosystem services like water provision and regulation (da Silva et al, 2017).

1.2. Problem Statement

In 2020 Chausson et al reported the effectiveness of NbS[1] interventions in climate impacts reduction, concluding that freshwater flooding and soil erosion are positively reduced in the majority of the case studies (Chausson et al, 2020). The study evidence the big potential that investments in nature through Green Infrastructure might have in the near future. Nature has an important role in the water cycle and provides multiple ecosystem services to humans, including water regulation which is the main process that maintain river flows (NRCS-USDA 2007). Most of the cities around the world were developed around rivers and water bodies, this makes cities to have a direct relationship with their water catchments and rely on their ecosystem's vitality and service provision. The ecosystem's degradation and the pressure on natural resources has push the necessity to understand which is the value of the services that ecosystems provide. During the last years, ecosystem services valuation has been contributing to the understanding of the importance of nature, and how essential it is for nations economy, where water is undoubtedly one of the most important assets that nature provides and also regulates. Generally, the word flooding is related with disasters, but flooding is also a natural process that was considered sacred by multiple indigenous communities around the world, flooding provides nutrients to the soil through the transportation of sediments and recharge of aquifers, processes that are key for agriculture (Zhang, 2018). Floods are part of the ecosystem health and species adaptation, this is why a change in the paradigm is necessary and is important to understand the role that nature plays, and its value in disaster management and urban planning. This research aims to understand the economic value of the natural capital for cities, proposing a methodology to include nature as an important variable in the integrated flood risk management assessments.

Despite the evident environmental and societal benefits of NbS, and the different complexities that are involve in their analysis, there has been an important question regarding the cost-effectiveness of this solutions, and the real return of investment of its implementation. There is still a lack of evidence regarding its cost-effectiveness, as there are different kind of nature-based solutions that might be addressed depending on the type of hazard and level of risk. In 2019 Ruangpan et al, concluded in the paper titled *"Nature-Based Solutions for hydro-meteorological risk reduction: A state-of-the-art review of the research area"* that it is highly desirable to develop more research on large scale NbS, by including river basins (large scale) and its effects of urban areas (small scale) as there is a lack of studies with that focus (Ruangpan et al, 2019).

Regarding the finance methods for Nature-based Solutions, today there are three main ecosystem services markets that are getting popular and have caught the attention of investors; GHG Emissions or, Carbon Markets, Habitat and Species banking and water funds, the last focused on nature investment to improve water availability and quality. But there isn't yet an open market for Eco-DRR, Green Infrastructure and its benefits regarding the proven water regulation benefit and its contribution to flood risk reduction and economical and life losses. The combination of the implementation of Green Infrastructure, flood risk management, and economic valuation strategies may help to address this problem. This research proposes a methodology with a case study that includes the variable of Green Infrastructure, throughout

[1] The term Green Infrastructure falls under the umbrella concept of Nature-based Solutions, which means that for the purpose of this research, both terms are used interchangeably, referring in general to the natural forest ecosystem.

the analysis of a protected forest area, and its effects into a flood risk assessment for the urban area of Gernika-Lumo in Spain. Thus, incorporate the benefit provided by nature in the economic analysis, taking into account the avoided damage cost calculated using flood damage curves developed specifically for the city.

The Case Study is located in the city of Gernika-Lumo, an important city inside the Basque Country in Spain. The location was selected based on its geographical characteristics, the city of Gernika-Lumo is in the middle of the Urdaibai biosphere reserve protected area. The area covers an important part of the water basin that drains the superficial water into the rivers that drain into the city. The main rivers that drain water into the city are, the rivers Oka and Golako, these rivers cause the main freshwater floods in the region, likely to continue happening due to a significant increase in the region precipitation (Abadie L.M et al, 2017). In January 2018, an uncommon meteorological phenomenon caused an extremely heavy rainfall event, precipitations of 70 l/m2 in 24 hours with intensities of 25 l/m2 per hour and 10 minutes intensities greater than 8 l/m2 during the winter season (Egaña at el, 2018), this rainfall flooded an important part of the city of Gernika, causing important damages to the inhabitants and the economy of the city.

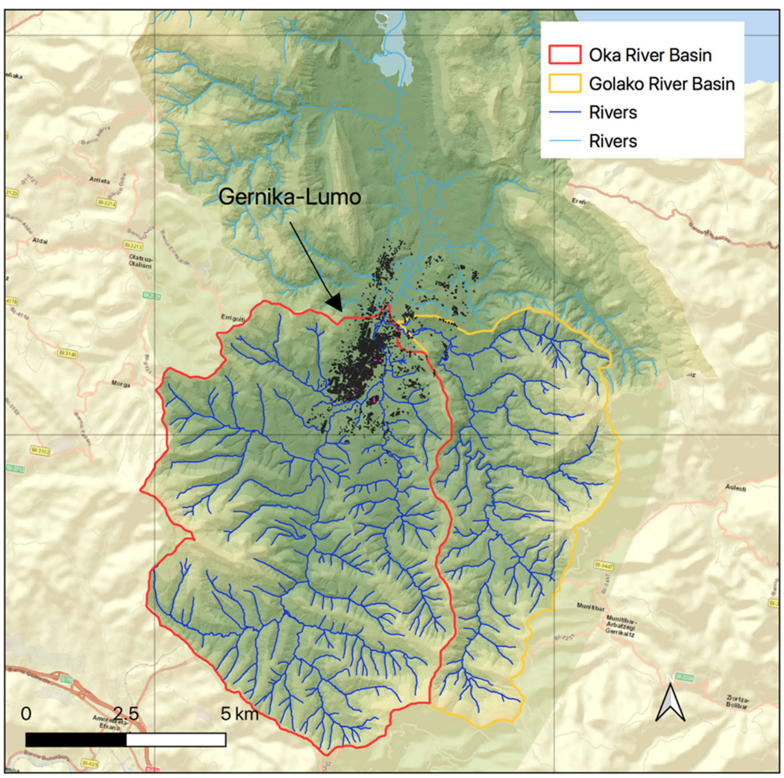

Figure 1 Case Study Area, Gernika-Lumo, Basque Country, Spain. Source: Author maps compilation.

The research is focused on the economic value of green infrastructure in flood risk management, it proposes a methodology to include nature water regulation in the flood risk assessments proposing an economic valuation of ecosystem services. The methodology analyses the probability of the event through its frequency of occurrence and its effect on the flood damage cost, understanding the economic benefit that green infrastructure provides to the urban area based on the avoided cost analysis. This methodology will also help to understand the change in the functionality of a system applying a project on Green Infrastructure and also the value associated with the conservation of nature. The research includes the variable of nature into the vulnerability analysis of a traditional flood risk assessment, widening the analysis and opening the possibility to develop an investment portfolio in nature. New market perspective might be open based on the results of the analysis, as new ecosystem-based disaster risk reduction investment portfolios can be created, where public and private sector can invest in nature willing to receive a positive benefit in terms of water regulation and avoided cost. The results of this analysis may be used as an start point to develop a business case in the city of Gernika-Lumo and the Urdaibai area.

1.3.Research objectives

The objective of this study is to assess the economic value of the ecosystem service of water regulation and the reduction of flood risk provided by the green infrastructure inside the protected area of Urdaibai, and the benefit related to the avoided cost for the city of Gernika-Lumo in Spain.

Sub-objectives:

- Understand in what extent the forest (GI) can reduce the runoff in the catchment of the river Oka, helping in the retention of water and regulating the flow of the river.
- Quantify the reduction of flood damages under five different scenarios, conserved forest, degraded forest, actual scenario 2021, previous years scenarios 2015 and 2017.
- Assess the economic benefits in terms of avoided cost that provides the forest (GI) ecosystem service of water regulation to the city of Gernika-Lumo.

a. Research question

To what extent do Green Infrastructure reduce the economic costs related to flood risk in the urban area of Gernika-Lumo?

b. Research sub-questions

- How does Green Infrastructure in the protected area of Urdaibai contributes to the reduction of the flood risk in Gernika-Lumo?
- How does Green Infrastructure in the protected area of Urdaibai contributes to the reduction of economic losses related to flooding in Gernika-Lumo?
- Is Green Infrastructure cost-effective in terms flood damages avoided cost?

Chapter 2: Literature Review and Conceptual Framework

2.1. Green Infrastructure and Nature-based Solutions

The term Green infrastructure has been used for many different purposes and by different authors and organizations. The definition also varies depending on the place where is used, in the case of the United States, Green Infrastructure terminology has been used to talk about natural assets, but also to refer to man-made infrastructure that uses nature characteristics on it, while in Europe is focused on the natural infrastructure and ecosystems (da Silva & Wheeler, 2017). The origins of the term first appeared during the last decades of the 21st century, when biologist and ecologist started to refer to landscape as an ecological infrastructure that could be used in the humanized landscape, suggesting that nature should be used to obtain not only economic benefits but also preserve biodiversity (Yu, 2011). In 1997, some authors presented the concept of ecosystem services valuation and defined the term natural capital starting from the general idea of capital as a stock of material or information that provides services and benefits (Constanza et al, 1997). In the United States, the term Green Infrastructure was first used to refer to the interconnected natural systems related to cities, that have to be conserved and managed in the same manner as to build infrastructure. But after 2007 the U.S Environmental protection agency (EPA) used the term Green Infrastructure to refer to urban strategies for managing the excess of runoff in cities (da Silva & Wheeler, 2017). It was also the same concept given to the term in the New York City Infrastructure Plan developed in 2010, developed by the City of New York, where they define Green Infrastructure as a strategy to optimize the existing drainage system with green strategies as swales and green roofs to improve water and air quality and increase flood protection (PLANYC, 2010).

On the other hand, Europe developed a different but broader concept of Green Infrastructure defined by the European Commission as, *"a strategically planned network of natural and semi-natural areas with other environmental features designed and managed to deliver a wide range of ecosystem services. It incorporates green spaces (or blue if aquatic ecosystems are concerned) and other physical features in terrestrial (including coastal) and marine areas. On land, GI is present in rural and urban settings."* (European Commission, 2013, p 3). To develop a unified concept, da Silva & Wheeler 2017, suggested the following definition: *"a network of natural semi-natural and restored areas designed and managed at different spatial scales (from local to global), that encompasses all major types of ecosystems (marine, terrestrial, and freshwater), and that aims to conserve biodiversity, mitigate emissions of greenhouse gases, enable societal adaptation to climate change, and deliver a wide range of other ecosystem services"* (da Silva & Wheeler, 2017. p 33). Based on the European Commission, Nature based-solutions are solutions that are *"inspired and supported by nature, which are cost-effective, simultaneously provide environmental, social and economic benefits and help build resilience. Such solutions bring more, and more divers, nature and natural features and processes into cities, landscapes and seascapes, through locally adapted, resource-efficient and systemic interventions"* (European Environmental Agency, 2021, p 17). NbS cover a wide range of strategies, and actions that aim to protect and restore natural or intervened ecosystems helping to address societal, sustainability and adaptation challenges, supporting the provision of human and nature wellbeing (European Commission, 2021). For this research the concept of NbS will be focus on disaster risk reduction and used as a group concept where Green Infrastructure is part of it. Thus, NbS as an umbrella concept is divided into four different dimensions, the strategic dimension that includes the Ecosystem-based

Adaptation (EbA) and Ecosystem-based Disaster Risk Reduction (Eco-DRR) strategies. The spatial planning dimension that includes Green Infrastructure (GI), Blue Infrastructure (BI), Green-blue Infrastructure (GBI) and Urban forestry (UF). The soft engineering dimension that included the Sustainable urban Drainage Systems (SuDS), Ecological Engineering (EE), Best Management practices (BMP), Low-impact design (LID), Water-sensitive urban design (WSUD). And the performance dimension focused on the assessment of Ecosystem Services (ESS) (European Commission 2021). Green Infrastructure considered as a protected forest ecosystem can be considered a Nature-based solution, covered under the spatial planning dimensions of NbS. This type of GI might help to lessen the runoff produced by a strong rainfall, by intercepting the rainfall through its leaves and roots of the trees, regulating the runoff and reducing floods (European Commission 2021). The protection of forest in mountainous areas (GI) plays an important role in climate adaptation and disaster risk reduction, helping in the reduction of vulnerability to risk and supporting local economy and communities (European Commission, 2013).

2.2. Economic Valuation of Ecosystem Services

Biodiversity is the variability of living organisms that inhabit the land, the ocean, and other aquatic ecosystems, the quality, and quantity of diversity of species and ecosystems is fundamental to ensure human well-being. Ecosystems like forest and coral reefs are important components of the natural capital and important sources of a huge variety of benefits (TEED, 2010).

The concept of Ecosystem Services describes the link between nature and economy, throughout the flows of value to human society. The Millennium Ecosystem Assessment in 2005 defined four types of services that nature provides to society:

- **Provisioning Services:** that are the goods that society take from nature, like fresh water, wood, crops, plant-delivered medicines, among others.
- **Regulating Services:** nature regulates water cycle, carbon storage, nutrient cycle, pollination and many other natural phenomena that impact the life on earth.
- **Cultural Services:** this are the services related with recreation, spirituality, aesthetic values and education.
- **Supporting Services:** this are the support of main natural processes like photosynthesis, nutrient cycle and soil formation.

From the view of the economy, all these services are a kind of “dividend” that humans receive from the natural capital, so in this sense, maintaining a healthy stock of natural capital ensures a sustained provision of ecosystem services for the present and the future well-being of humanity (TEED, 2010).

The TEEB'S approach (TEED, 2010) for evaluating ecosystem services, is a compound of three main steps. The first one is recognizing the value in ecosystems, species, biodiversity, and landscapes. Many times, this value is related to cultural intangible values, where it is impossible to give any kind of monetary valuation to the service, for example, a heritage a patrimony, or any other place that shares a cultural and social value. The second step is demonstrating value, which consists of calculating the costs and benefits of the proposed use of an ecosystem. For example, to calculate the cost and benefits of wetlands in improving water quality and flood protection, compared to traditional grey infrastructures like wastewater treatment plants and flood protection infrastructure like levees and dams. The third is capturing value, this involves the mechanisms that incorporate the value of ecosystem services into decision making through incentives, for example, payments for ecosystem services, tax reduction for conserving the environment, or the creation of new markets, like carbon and green markets (TEED, 2010).

In 2015, the National Oceanic and Atmospheric Administration (NOAA) released a guide to assessing green infrastructure costs and benefits for flood reduction. The guide is compound by six steps including flood risk assessment, scenarios including green infrastructure, identifying flood reduction, estimating a cost-benefit analysis, and the communication of the desired green infrastructure strategy. For the estimation of benefits and costs, the methodology suggests the first estimate a unit cost of each green infrastructure option, and after that determine the total cost of the strategy. The second task is to estimate the benefits, in this case, to consider the avoided damage caused by the Green Infrastructure strategy, also to consider the co-benefits related to ecosystem services. Due to the fact that floods occur few times per year, as a third task, it is important to consider annual benefits and cost for a long period of time, only doing this it is possible to calculate the "break even" or the moment in time when the benefits equal the costs. (NOAA, 2015)

2.3. Flood Risk

The definition of flood risk was well defined by the EU Directive on the assessment and management of flood risks in 2007. The EU Directive suggested the following definition:
"flood risk means the combination of the probability of a flood event and the potential adverse consequences for human health, the environment, cultural heritage and economic activity associated with a flood event." (CEC 2007, p 29)
The term flood risk might be analyzed from the main concept of risk, which is usually understood as the combination of the probability of occurrence of an event and its consequences. (Samuels et al, 2010).

$$Risk = probability * consequences$$

In the case of flood risk, probability refers to the probability of occurrence of a flood with an estimated frequency in a period of time. Flood hazard is the combination of frequency and magnitude of the flood event. The hazard will depend on its source, which might be a heavy rainfall event, a storm surge, a hurricane, or any other kind of hydrometeorological event. And a pathway, that is the route where the water will flow over, usually the main rivers, drainage systems, to finally reach the flood-prone areas, where the receptors of the flood are settled. (Samuels et al, 2010).

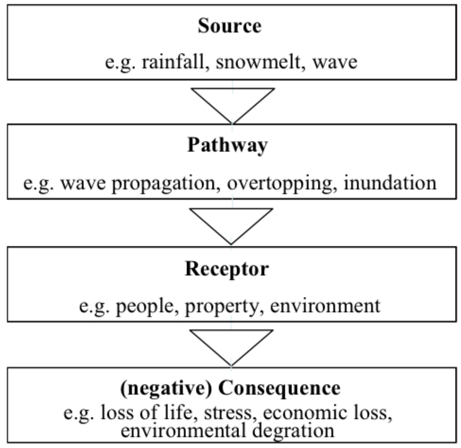

Figure 2 Source-Pathway-Receptor-Consequence Concept. Source: (Schanze 2009, p 4)

The consequences of the flood depend on the vulnerability and exposure in flood-prone areas, where vulnerability is the conditions and processes of a territory, that are the result of social, environmental, economic, and physical factors that increase the susceptibility of a community (Pistrika et al, 2007). Exposure is the quantification of those receptors that may be affected by the flood. Receptors might be "static" like building and urban infrastructure, while other receptors may be "dynamic", as people and vehicles, that can move and reorganized during a flood, reducing the consequences of it (Samuels et al, 2010). Later, the concept of flood risk was expanded to a more integrated view by including the risk analysis, risk evaluation, and risk management, also by including the scope of the integration of interventions in space, actions in time, and across sectors and actors, to define a broader concept called Integrated Flood Risk Management or IFRM. The integration notion also calls for the need for cross-disciplinary communication and interaction between a variety of knowledge disciplines that are involved in the aspects related to floods (Samuels et al, 2010). IFRM is closely related to Integrated Water Resources Management (IWRM), according to the Global Water Partnership, IWRM is a process that enhances the coordinated management of water, land, and other resources to increase the economic and social benefits in an equitable manner taking care of the vital ecosystems to ensure sustainability. To assess sustainability and effective management, it is necessary to include a holistic approach that links social, economic development, environmental, and natural ecosystem protection through the appropriate management of water and land (WMO, 2009). Base on this, IFRM integrates water and land through the proper development of the river basin, within the IWRM concept, to maximize the benefits and reduce the risk of flooding, economical costs, and the loss of life. (WMO, 2009)

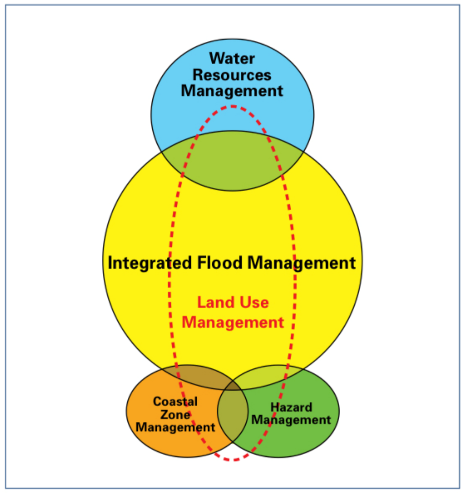

Figure 3 Integrated Flood Management Model. Source: (WMO 2009, p14)

2.4. Hydrologic and Hydraulic Modelling

The concept of the hydrologic cycle is key to understand the role of nature in the regulation of water. It happens inside the hydrosphere, where water circulates through the air, the surface, and the soil. The process doesn't have a start or an end, but it can be said that it begins with the evaporation of the ocean and the water on the surface, and it moves as water vapor in the atmosphere, until it is condensed and falls as rain. This process is called precipitation that is intercepted by the vegetation or other complex structures on the surface of the land. Some of the water infiltrates into the soil, continuing flowing as baseflow, and some other portion of it runs over the surface as runoff. Some of the water that is intercepted by the vegetation, and that ends up on the surface evaporates, returning into the atmosphere once again. The rest of the water flows as baseflow and runoff till it reaches the ocean, closing the water cycle (Chow, 1988). The conceptualization of the hydrologic cycle is necessary to understand and simulate its processes, even though the process is extremely complex, it is possible to simplify it as a system concept. Figure 4 shows a system concept, which is a simplification of the hydrological cycle, relating all the complexities and interactions that might happen inside a water basin. The diagram illustrates the interaction between precipitation, land, vegetation, and the soil that happens, where double direction interaction might also happen. For this research study, the interaction is more limited, as in a storm event evaporation and transpiration do not have much time to happen as the event happens in a matter of hours (Feldman, 2000). What plays an important role in a storm event is the vegetation and the soil, which intercepts and infiltrates the water, contributing to its regulation.

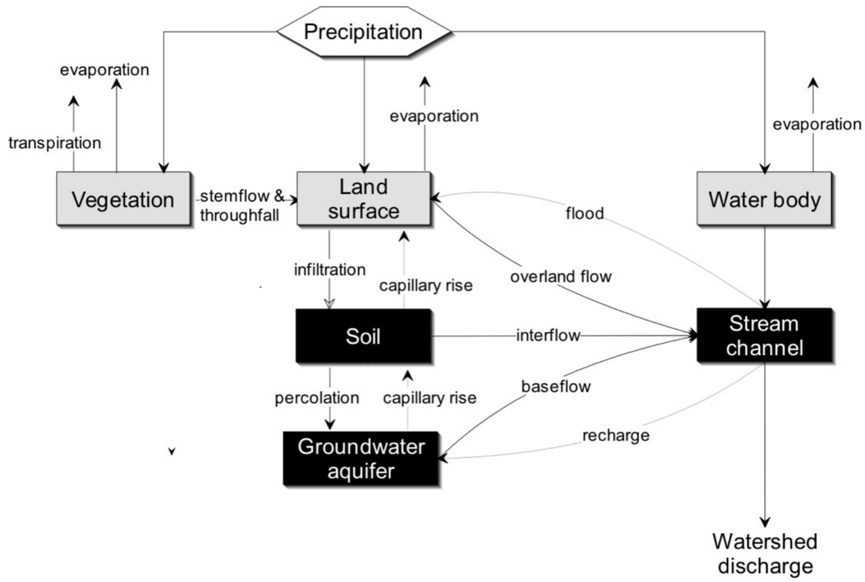

Figure 4 System concept of the runoff process. Source: (Feldman, 2000, p10)

Hydrological models are classified into two big groups, physical models and abstract models. Physical models represent systems, as scale models do, they are design to simulate a real system and its behaviour under specific conditions. Abstract models are mathematic interpretations of systems, simulating the process using some inputs to generate outputs through a defined mathematical operator. The input and output variables can be probabilistic, random or specific in space and time. Thus, the abstract models are classified into deterministic and stochastic models. The deterministic model does not consider randomness, as is the case of this research. However, the rainfall data was calculated through a probabilistic function, the hydrologic model uses three defined storm events, with different probability of occurrence. On the hand the stochastic models are partially random, its input and output variables involve randomness in its calculation processes. The deterministic models can be lumped or distributed, a lumped model spatially averaged, as in this research. The distributed model takes into account the spatial variations in the calculations. For this research, the precipitation was calculated based on rain gauge stations and added to the model as a single storm event. The deterministic model can be classified in steady-flow and unsteady-flow, the steady-flow represents a flow that doesn't change in time, unsteady-flow does change in time. The model of this research can be classified into deterministic, lumped, and steady flow model (Chow, 1988).

The main calculation of the hydrologic model is the computation of runoff models, by simulating the physical relationship between the precipitation, the interception, infiltration, storage and evapotranspiration of the simulated system. There are plenty of different model methods to calculate this relationship, for this research the Soil Conservation Service (SCS) Curve Number (CN) loss method was selected. The method calculates the precipitation excess as:

$$P_e = \frac{(P - I_a)^2}{P - I_a + S} \quad (Feldman, 2000, P\ 37)$$

Where:

P_e = Accumulated precipitation excess at time t.
P = accumulated rainfall depth at time t
I_a= initial abstraction
S = potential maximum retention

Based on different experimental watersheds, the Soil Conservation Service proposes a empirical relationship between I_a and S.

$$I_a = 0.2\,S \quad (Feldman, 2000, P\ 37)$$

Based on this the accumulated precipitation excess is:

$$P_e = \frac{(P - 0.2\,S)^2}{P + 0.8\,S} \quad (Feldman, 2000, P\ 37)$$

The potential maximum retention depends on the characteristics of the catchment, these are given by the Curve Number (CN) developed by the SCS as follow.

$$S = \left\{\frac{25400 - 254\,CN}{CN}\right\} \quad (Feldman, 2000, P\ 38)$$

The values of the Curve Numbers can be found on the published tables of the SCS. For this research the tables used are the ones published by the United States Department of Agriculture, Natural Resources Conservation Service (2004). On the Chapter 9: Hydrologic Soil-Cover Complexes. To find the curve number it is necessary to define the land use and the soil type. The land use is based on the land use cover maps and the soil on the soil texture data, this is defined by the characterization of the percentage of clay, sand and silt (USDA, 2004).

The composite CN of the entire catchments is calculated as:

$$CN_{composite} = \frac{\sum A_i CN_i}{\sum A_i} \quad (Feldman, 2000, P\ 38)$$

Where, CN_i is the Curve Number value for each subdivision of land use and soil type, and A_i is the area of the subdivision.

The mathematical theory for describing the physical behaviour of a river is the same used to describe an open channel, it is classified inside the same group of free surface channels. Storm sewers are also classified as open channels as they maintain a free surface as well. The free surface flow is classified into different types based on the variation of time and space with respect to the water depth. In a channel, a flow is considered steady if its depth does not change in time. On the other hand, a flow is unsteady if the depth changes within time. The discharge in a channel is given by the continuity equation, that relates the velocity of the flow and the area of the section as follows:

$$Q = V * A$$

Where Q is the discharge, V the velocity of the flow and A the area of the channel section (Chow, 1959).

The free surface flow can be described as the movement of water on a surface at atmospheric pressure due to gravity. The weight of water causes the acceleration of the flow, if the slope is positive) and the friction a resistance against that acceleration. The sum of all forces will end up in an acceleration or the deacceleration of the flow. As the hydraulic model developed for this research is based on a steady and one-dimensional flow, the theoretical framework discussed next is only based on this kind of flow. In one dimensional flow there are no effects due two secondary currents in the flow, and the resistance on the surface is considered uniform. For this kind of flow in 1769 the French engineer Antoine Chezy developed the first uniform flow formula:

$$V = C\sqrt{RS} \quad \text{(Chow, 1959, P 93)}$$

Where V is the velocity of the flow, R is the hydraulic radius, S the slope of the channel and C is the Chezy's factor (Chow, 1959). Later on in 1889 the Irish engineer Robert Manning proposed a today's widely used formula:

$$V = \frac{1}{n} R^{2/3} S^{1/2} \; (Chaudhry, 2008, P\ 94)$$

Where n is the roughness coefficient, or Manning's n coefficient. This coefficient is difficult to determine, as there isn't a specific methodology for its definition. In order to find the most appropriate Manning's coefficient, there are tables with typical values for different kind of surfaces (Chow, 1959). For this research, the definition of the Manning's coefficients was already included in the shared model. The computing methodology of the software HEC-RAS is based on the solution of one-dimension Saint-Venant equations, the evaluation of the Manning's formula and contraction and expansion of the flow. Other kind of equations like the momentum equation is also used when water surface profile is rapidly varied. HEC-RAS takes into account the effect of structures that might affect the flow, like bridges and building. The steady flow model is design for flood plan management applications (Brunner, 2021).

2.5. Flood damage curves

Flood damage refers to all the types of harm caused by flooding, including harmful effects on health, and their belongings, buildings, public infrastructure, industry, ecosystems, cultural heritage, and other kind of damages that might affect the economy. There are two main categories for of flood damages, direct or indirect damage, the direct damage refers to all the damages related to the physical contact and consequence of flood like harm that may cause like loss of life, health effects, damage to property and infrastructure. The indirect flood damages refer to damages that are consequence of disruption of the economy and the infrastructure that might cause loss of industrial production, traffic disruptions and loss of ecological goods among others. Some direct and indirect damages are measurable and other aren't, also depending on the possibility to translate the damage into monetary terms. The damages that are easily quantify, and economically valuated are called tangible damages, and the ones that are more difficult to valuate economically are called intangible, but this does not mean there aren't methods for an approximated valuation (Messner et al, 2007). This research is focused on the tangible direct effects related to the damage of buildings, other kind of indirect damages and intangible measures were not considered. The calculation of the flood damage is a combination of the inundation area and depth over the affected territory. This can be calculated by using specialized quantitative and spatially model methodologies and software. For this research a HEC-RAS one-dimension hydraulic model was developed, calculating the extend and depth of the flood for different probabilistic scenarios.

There is no such a general methodology for assessing flood damage, nevertheless most of the commonly used methodologies rely on depth-damage curves, they relate the depth of the inundation with the quantification of the damage in an urban area. A general purpose of this curves is to evaluate the cost-efficiency of flood mitigation projects, through the development of different scenarios. Depth damage curves are also known as vulnerability curves, they represent the vulnerability of the tangible elements at risk. They can be classified into three groups, analytical, empirical and synthetic. The analytical curves are assessed through monitoring and laboratory analysis, empirical curves are made using surveys and field collected data, and synthetic curves build from theoretical standard property data, assuming similarities between study areas (Martinez-Gomariz et al, 2020). Due to the different approaches for the construction of the flood damage curves in different countries, the damage assessments cannot be directly compared between each other. To solve this problem a global depth damage curves database has been developed, including normalized damage curves per continent and downscaled to country scale (Huizinga et al, 2017).

2.6. Conceptual Framework

For what concerns the research development, the structure of the research consists of the construction of a hydrological and hydraulic model, which are the main measurers of the effects of natural coverage on the effect of water regulation. The model was developed for five main scenarios, the first using the actual natural cover of the catchment, inside the Oka and Golako river basins, two scenarios of previous years land cover, 2015 and 2017, and two extreme land use cover scenarios. A conservation scenario, where the catchment is afforested and reforested, improving its natural conditions, and a degraded scenario where the catchment keeps degrading with the same rate of the last six years 2015-2021. The resultant discharge hydrographs were used to simulate a flood in the city of Gernika-Lumo in order to get the flood depth maps for each scenario. A vulnerability assessment developed as well, making use of the flood damage curves of the city of Gernika-Lumo, the curves relates the flood depth with the damage costs of each building type. With the hazard and vulnerability analysis, the total damage cost was calculated for each scenario, and with it an economic valuation of the Green Infrastructure based on the avoided damage cost. This analysis will help to understand which is the economic value of Green Infrastructure for the city of Gernika-Lumo and the avoided damage cost related to the protection of the natural capital of the Oka and Golako river water basins.

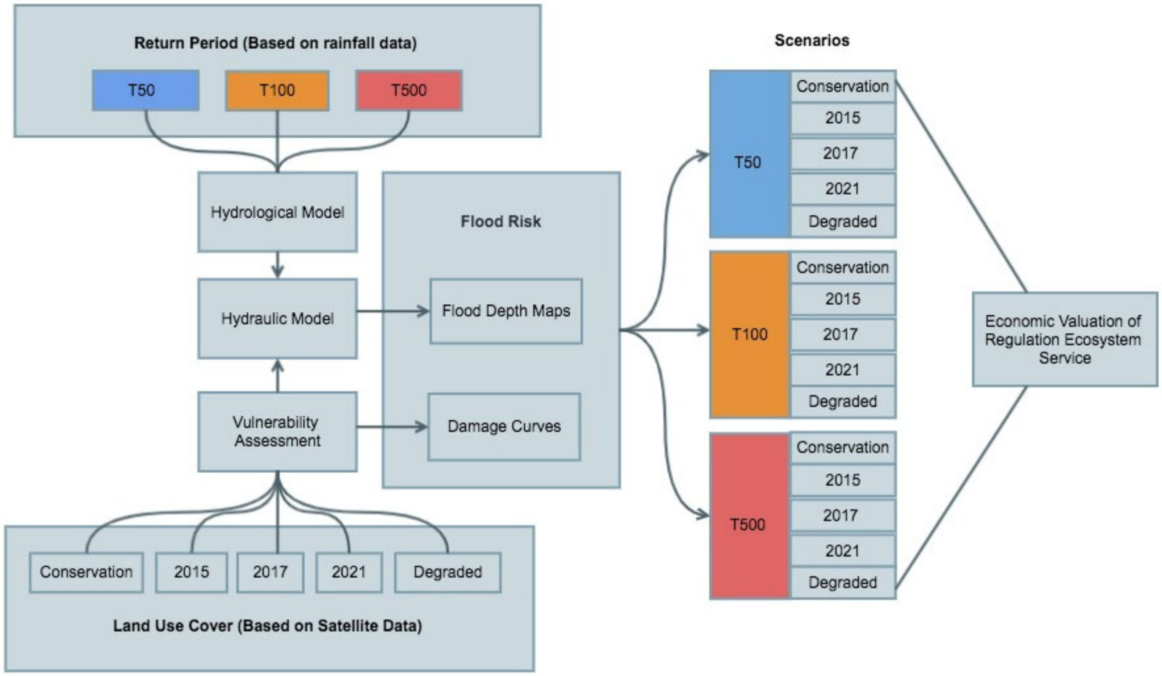

Figure 5 Structure of the research

The research question consists of one independent variable that is the Green Infrastructure, and the dependent variable, that corresponds to the economic valuation of the water regulation service. The Green Infrastructure is included as the land cover scenarios as the natural forest coverage of the Oka and Golako river basin and its effects on the floods in the city of Gernika-Lumo. The economic valuation is based on the analysis of the damage avoided costs when all scenarios are compared. The relationship of both variables is done through the analysis of a flood risk assessment in the urban area, using physically based tools and the analysis of the land use change with satellite images, and the flood damage curves of the urban area.

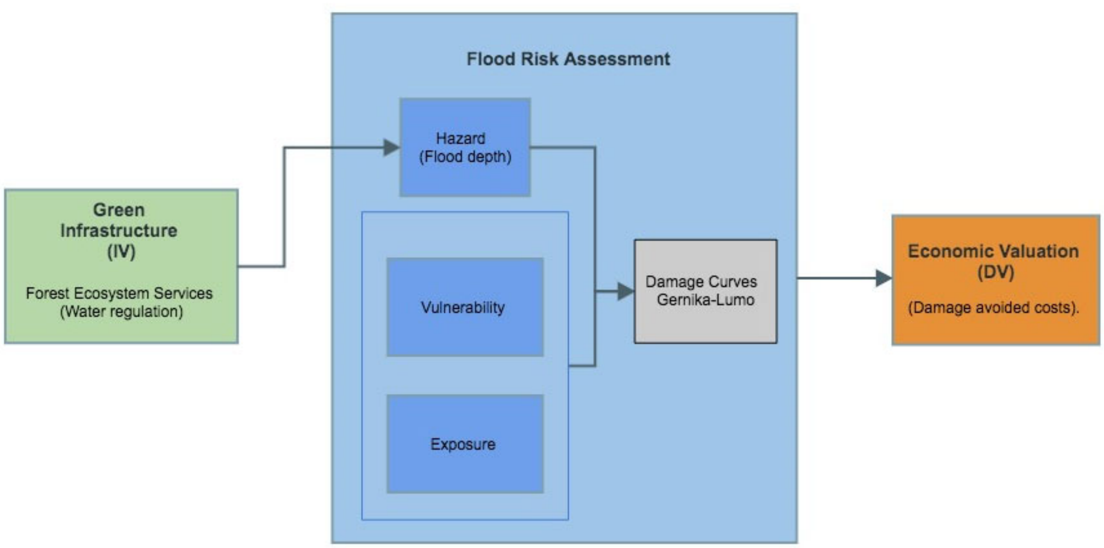

Figure 6 Conceptual Framework

Chapter 3: Research Design and Methods

3.1.Research Strategy

This research aims to contribute to the generation of knowledge regarding the cost-effectiveness of Green Infrastructure in the reduction of flood risk, based on this objective, a Single-Case Study research strategy was selected (Van Thiel, 2014). The Case study research strategy suits the needs of an economic valuation and a flood risk assessment, as it requires technical expertise in the field of water engineering and the development of hydrological and hydraulic mathematical modelling. Based on this, only quantitative, exploratory and testing research strategy is needed, in order to develop the biophysical models, the economic analysis and other numeric kind analysis including the three main phases: data collection, data ordering, and data analysis (Van Thiel, 2014). The research has the objective of assess the economic value of green infrastructure in urban flood risk management, by proposing a methodology to include nature water regulation in the flood risk assessments and in the financial analysis. The methodology will analyse the change on the flood for different return periods, and its effect on the total damage cost, and also including an analysis of the possible investment in nature and its economic benefits, through an avoided cost analysis. This methodology will also help to understand the change in the functionality of a system, by analysing the hydrological behaviour of the green infrastructure inside the water basins, and the flood impacts on the urban area of the city of Gernika-Lumo in Spain. The research aims to include the variable of nature into the traditional flood risk assessment, adding it into the hazard assessment and analysing its impacts on the total damage costs.

The first step of the data collection is be desk research, collecting data that was previously produced by the meteorology, environmental, and housing authorities of the Basque Country, another kind of data is produced using raw data from similar sources. A part of the data will be collected with the assistance of the Naider Project Team that will be the main local partner of the research and that has a direct relationship with some of the public organizations and local authorities. The development of a hydrological model is key, as is the tool that measures the effects of the Green Infrastructure, the independent variable of the research. The hydrological model will be developed using secondary data and making use of the HEC-HMS hydrologic modelling software. HEC-HMS is a widely used hydrological model, that is able to model land use change scenarios (Feldman A, 2000). The hydrological model will be used to construct the peak discharge hydrographs for tree different rainfall scenarios, 50, 100 and 500 years return period, and five land use change scenarios. It is expected that the fifteen scenarios will have significant change in the hydrograph peak. The three resultant hydrographs will be used as inputs of the hydraulic model.

Table 1 Required Input Data

REQUIRED INPUT DATA	**Source (units)**
Hydrological Model	
Precipitation Data	*Basque Water Agency (Daily, hourly)*
Soil Data	*Geo Portal Euskadi (Oka, Berrakondo and Golaki River)*

Land Use Maps	*Supervised Classification of Sentinel-2 Satellite images (researcher developmet)*
Digital Elevation Model	*Copernicus DEM*
Hydraulic Model	
Digital Elevation Model - flood prone area	*Geo Portal Euskadi Lidar*
Bathymetry oof the river	*Geo Portal Euskadi Lidar*
Discharge for different return periods	*Flood Assessment reports*
Flood maps for different return periods	*Flood Assessment reports*
Vulnerability	
Buildings and Roads Maps	*Geo Portal Euskad*
Flood Damage Curves	*Martinez-Gomariz et al, 2020*

The hydraulic model was adapted and modified from the original version developed by the Basque Water Agency and shared by the Naider research group. The model was constructed using a LiDAR hypsometric model of the flood prone area, also available at the online Data Hub of the government. The hydraulic model was developed using the software HEC-RAS, that allows the development of one-dimension steady flow and one and two-dimension unsteady flood models, the software include tools to perform inundation maps, sediment transport and water quality calculations (Brunner et al, 2020). The hydraulic model was used to get the inundation depth inside the urban area for each return period event. This allowed the connection between the expected reduction of discharge due to the Green Infrastructure, and the reduction of the damage cost due to the reduction of the inundation depth. The economic valuation of the ecosystem service that provides the Green Infrastructure is based on the analysis of the difference between the damage costs of each scenario.

3.2. Operationalization

Operationalization is highly recommended when empirical research starting from theory is developed, it helps to understand how the main concepts are going to be analyzed and the relationship between each other, making them measurable (Van Thiel, 2014). Operationalizing variables is important in deductive research as it shows what is going to be studied and measured (Van Thiel, 2014). For this case study, three main concepts will be analyzed: Green Infrastructure, flood risk and economic valuation. The first one refers to all the forest inside protected areas that provide different kinds of ecosystem services, being the water regulation the main service and interest of this research. Green Infrastructure for the case study represents all the natural assets inside the protected area of Urdaibai around the city of Gernika-Lumo, as a second variable of the same concept, the area of protected land describes the magnitude of forest contributing to that regulation. In that sense, it indicates how much area is needed to have an economical benefit from its conservation. The second concept is flood risk management, and its main variables hazard, vulnerability, and exposure (Samuels et al 2010), these variables are derived from the concept of risk, which relates the probability of an event with its consequences. And the third concept, economic valuation, that describes the economic benefit of the reduction of the flood hazard due to the water regulation of the natural forest. The first indicators are related to the flood hazard models where the flooding area and depth are defined for different year return periods. For the vulnerability indicators, damage cost and curves describe the consequences of the flood and are the direct link with the economic analysis. The exposure variable depends on the spatial analysis of buildings and their land use.

Table 2 Operationalization Concepts, variables and indicators.

Concept	**Variable**	**Indicator**	**Source of Data**
1.Green Infrastructure *"Natural and semi-natural areas with other environmental features designed and managed to deliver a wide range of ecosystem services".* (da Silva & Wheeler, 2017. p 33).	1.1 Water Ecosystem Services	1.1.1 Water discharge regulation	Hydrological Model
	1.2 Urdaibai Protected Area (Oka and Golako river basins)	1.2.1 Land use coverage	Sentinel-2 radar images with GIS Analysis.
		1.2.2 Area of Natural coverage	Sentinel-2 radar images with GIS Analysis.
2. Flood Risk *"flood risk means the combination of the probability of a flood event and the potential adverse consequences for human health, the environment, cultural heritage and economic activity associated with a flood event"* (CEC 2007, p 29)	2.1 Hazard *"Hazard is defined as a process, phenomenon or human activity that may cause loss of life, injury or other health impacts, property damage, social and economic disruption or environmental degradation"* (EEA, 2021, p 159)	2.1.1 Flooding Area for different return periods	Modified Hydraulic Model (Basque Water Agency)
		2.1.2 Flood Depth for different return periods	Modified Hydraulic Model (Basque Water Agency)
	2.2 Vulnerability *"Vulnerability is defined in this report as the propensity or predisposition of an individual, a community, assets or systems to be adversely affected by the impacts of hazards."* (EEA, 2021, p 159)	2.2.1 Flood Damage Curves (relationship between flood depth and damage costs)	Martinez-Gomariz et al, 2020
	2.3 Exposure *"Exposure includes the people, infrastructure, housing, production capacities and other tangible*	2.3.1 Affected Buildings (Building type maps)	Geo Portal Euskadi Data Hub

	human assets located in hazard-prone areas.” (EEA, 2021, p 158)		
3.Economic Valuation *“kind of “dividend” that humans receive from the natural capital, so in this sense, maintaining a healthy stock of natural capital ensures a sustained provision of ecosystem services for the present and the future well-being of humanity”* (TEED, 2010).	3.1 Avoided Damage Cost.	3.1.1 Comparison of all the scenarios and its variation on the total damage costs.	Own development using the flood damage curves for Gernika-Lumo

3.3.Reliability and Validity

As a function of accuracy and consistency, reliability is important to determine how certain is the final result and conclusion of research (Van Thiel, 2014). For this research biophysical models were developed, they were done based on hydrological and hydraulic theories and equations that describe the water cycle and the physical principles of hydrodynamics. For this research mathematical modelling was used, the software makes use of equations and theories that have been scientifically accepted and used by many researchers and influent public and private engineering entities. Similar calculations and models have been developed in different parts of the world to understand the relationship between natural covertness and water regulation, the majority showing positive results (Chausson et al, 2020). Regarding the validity of the research, hydrological models can be validated through the process of calibration, this process consist of the small manipulation of the main variables to adjust the results to the on-site discharge gauge stations measurements. Due to the lack of data regarding the discharge of the river, other validation methods were used. The resultant flood maps were compared with the Basque country published official maps, where plenty of similarities were found, the area and depth of the flood were similar for the same return periods, using different input data. This similarities in the results gave reliability to the research results. On the other hand, the results were shared with the Water Basque Agency, a comparison was made between the damage total costs of the study and other damage values from the official Basque Water Agency studies, it was found that the results were very similar between each other. This comparison gave more reliability and validity to the study.

3.4. Challenges and Limitations

The main purpose of the research is to assess the economic benefit of green infrastructure for flood risk reduction, in order to assess that, the development of hydrology and hydraulic analysis is needed. The assessment of these models requires an important amount of data that are be necessary to construct a reliable mathematical model, this is why is important to gather the best and more accurate information as possible. To construct the hydrological model, it is necessary to gather biophysical information about the catchment like precipitation and soil data. For the hydraulic model, it is necessary to count with a well-developed model for the flood risk assessments in the city of Gernika-Lumo, this can only be done with a precise terrain model of the study area, and all the necessary cadastral information about the infrastructure in the flood prone area. This was one of the biggest challenges because this information is usually confidential and is not shared with thirds parties by the municipality or public entities. The same for the economic information regarding the vulnerability assessment. Fortunately, all the information about the precipitation and soil data was available, and a completely developed hydraulic model was shared. Regarding the flood damage curves, they were also shared by the author of an important study about the assessment of many damage curves for Spain.

Despite the information was available, there was a limitation with the time frame of the research. The hydraulic model developed for the research was done in one dimension, giving reliable results, however a model in two dimensions can give more detail about the distribution of the flood in space, as it considers the complete behaviour of water over the terrain. A model in two dimensions requires more detail on the input data, time of construction, and a robust computation capacity to solve complex equations. Also, it is recommended to complement this research with a sensibility analysis in order to find the parameters that increase the uncertainty in the results, more specifically the flood depth values that might change the total damage costs of the scenarios results. In order to count with a reliable hydraulic model, it would be necessary to calibrate it, this means to adjust the parameters to make the input data in the model to give the same outputs results, simulating reality. This calibration is only possible by comparing measured data and adjusting the main model variables. In order to assess this, is very important to count with enough measured data that allows the calibration and validation of the model. It was not possible to calibrate the hydraulic model due to the lack of discharge data, the calibration of the model would have given more precision to the results, and modelled scenarios.

Chapter 4: Research Findings

This chapter begins with the explanation of all the data gathering and findings throughout the research. It describes the analysis of the data, the development of two mathematical models, one hydrological and a hydraulic model, and the economic analysis developed using geographical information systems and flood damage curves.

4.1. Description of the case study

As already explained in chapter 1, the case study is located in Basque Country, Spain, in the city of Gernika-Lumo. The city is located close to the coast of the Cantabrian sea in the Bay of Biscay, inside the biosphere reserve of Urdaibai, it has a population of about 17,000 inhabitants. The city has suffered intense floods, there are registers of more than 7th floods during the 20th century, the last one was registered in January 2018, after a strong rainfall with an intensity of 25 liters per square meter[2], rainfall that increased the discharge of the Oka River, flooding the urban area and causing multiple damages to buildings, industries, public and private property. Some of the historical records of flood events in the city of Gernika-Lumo and the Oka river are listed in the next table.

Table 3 Extreme events registered on Gernika-Lumo Urban area (URA, 2018)

Year	Month	Description
1909	September	The Oka river flooded multiple sites of Gernika-Lumo
1915	April	Floods all over Vizcaya province (Gernika-Lumo affected)
1965	N/E	The Oka river flooded Gernika urban area causing important damages
1975	June	Floods all over Vizcaya province (Gernika-Lumo affected)
1977	June	Floods all over Vizcaya province (Gernika-Lumo affected)
1980	December	Floods all over Vizcaya province (Gernika-Lumo affected)
1983	August	Floods all over Vizcaya province (Gernika-Lumo affected)
2002	August	Floods all over Vizcaya province (Gernika-Lumo affected)
2018	January	The Oka river flooded Gernika-Lumo urban area causing important damages

In the Basque region, precipitation can be very intense during the summer, due to the water vapor and warm air that might contain abundant water, precipitations can reach intensities of 30 mm in one hour. On the other hand, intense precipitations are very rare during the winter. However, on the 11th of January 2018 an unexpected event occurred after a warm and a cold air mass encounter, causing a precipitation event of more than 70 l / m2 in 24 hours, intensities of 25 l / m2 in one hour, and 8 l / m2 in 10 minutes, in a wide area of the upper basin of the Oka River, causing several damages and emergency response in the urban area of Gernika-Lumo (Egaña, 2018).

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[2] Base on the Basque EITB newspaper, EITB (2018, January 11). Los bomberos rescatan a los ocupantes de varios vehiculos en Gernika y Muxika. EITB.es: https://www.eitb.eus/es/noticias/sociedad/detalle/5329382/inundaciones-gernika-muxika-11-enero-2018-conductores-rescatados-bomberos/

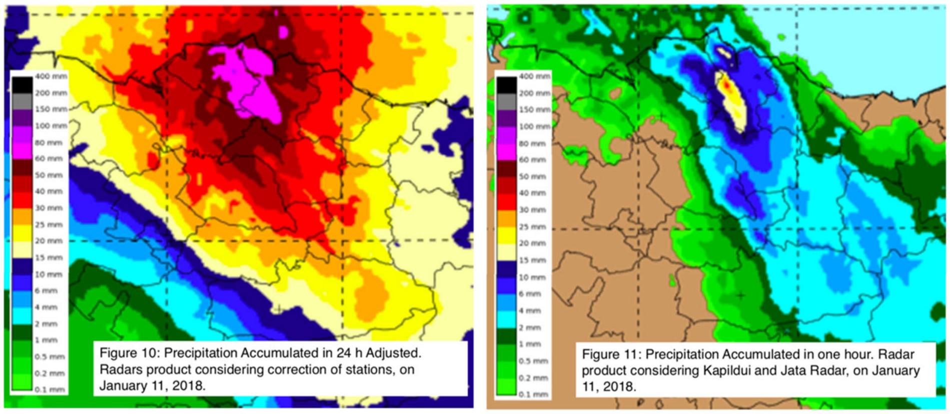


Figure 7 Accumulated Precipitation in 24 and 1 hour. Source: (Egaña, 2018, EMS Annual Meeting)

4.2. Precipitation Data and Analysis

An important part of the analysis is the development of a hydrological model with different rainfall probabilistic scenarios that can be used to generate different flood maps. The first step was the selection of the rainfall gauge stations that were used to construct the synthetic rainfall hydrographs.

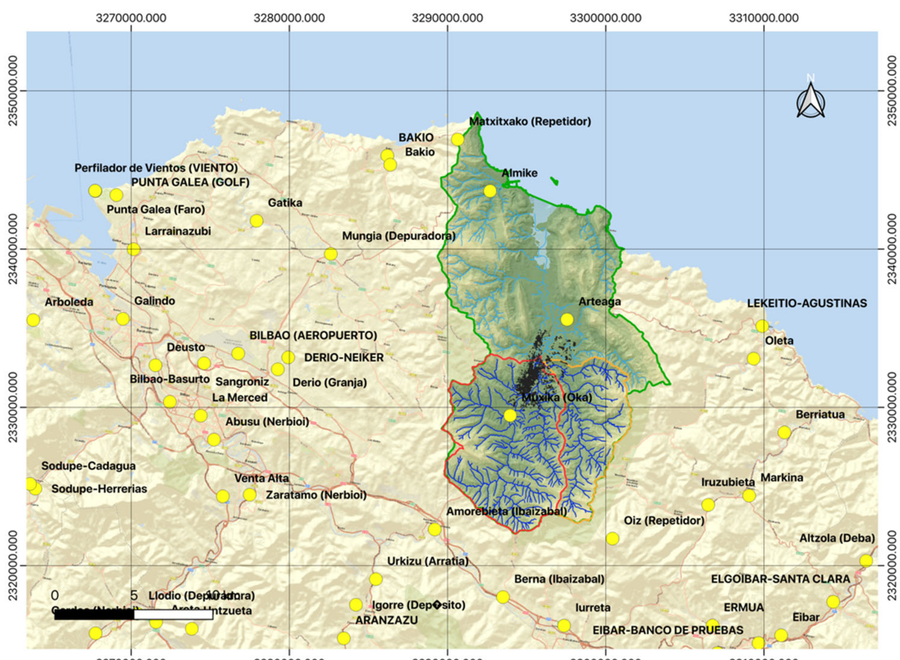


Figure 8 Rain gauge network close to Gernika-Lumo (Own development based on data from: Open Data Euskadi)

Based on the location of the existing rain gauge network, two rain gauge stations were chosen for the analysis and based on the availability and quantity of data. The first one located inside the Oka River catchment, G063-Muxika (Oka) and the second located in the airport of the city of Bilbao, 1082 - Bilbao (Aeropuerto). The rain gauge station G063-Muxika (Oka) has daily recorded data from the year 2002 to 2007 (see Annex 1), and the rain gauge station 1082 - Bilbao (Aeropuerto) daily data from the year 1970 to 2015. Based on the quantity of available data, and the proximity of both rain stations to the area of study, the 1082 - Bilbao (Aeropuerto) station data was selected to develop all the precipitation analysis, including the rainfall event return period calculations and the analysis and the development of Intensity-Duration-frequency (IDF) curves.

$$I = \frac{K \cdot T^m}{t^n} \qquad \text{(Aparicio, 1997)}$$

I = Intensity (mm/h)
t = Rainfall Duration (min)
T = Return Period (years)
K,m,n = Adjust Parameters

Table 4 Rainfall Intensities per Frequency Year - G063-Muxika (Oka)

Rainfall Intensities – Time (Duration)												
Frequency	Duration in Minutes											
Years	5	10	15	20	25	30	35	40	45	50	55	60
2	112.83	73.48	57.17	47.85	41.68	37.23	33.84	31.16	28.97	27.14	25.58	24.24
5	128.61	83.75	65.17	54.54	47.50	42.44	38.57	35.51	33.02	30.93	29.16	27.63
10	142.00	92.47	71.95	60.21	52.45	46.85	42.59	39.21	36.45	34.15	32.20	30.51
25	161.86	105.40	82.01	68.63	59.78	53.40	48.54	44.69	41.55	38.93	36.70	34.78
50	178.70	116.37	90.54	75.78	66.00	58.96	53.60	49.35	45.88	42.98	40.52	38.40
100	197.30	128.48	99.97	83.67	72.87	65.10	59.18	54.48	50.65	47.45	44.74	42.39
500	248.30	161.69	125.81	105.29	91.71	81.93	74.47	68.56	63.74	59.72	56.30	53.35

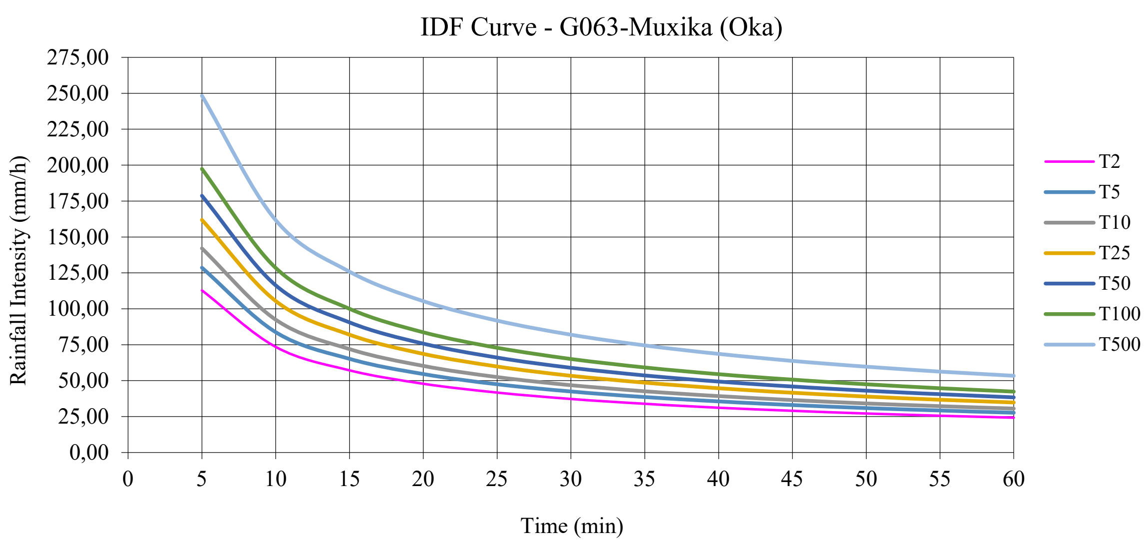


Figure 9 Intensity-Duration-Frequency Curve G063 – Muxika (Oka)

Table 5 Rainfall Intensities per Frequency Year - 1082 - Bilbao (Aeropuerto)

Rainfall Intensities – Time (Duration)												
Frequency	**Duration in Minutes**											
Years	**5**	**10**	**15**	**20**	**25**	**30**	**35**	**40**	**45**	**50**	**55**	**60**
2	114.73	74.71	58.13	48.65	42.37	37.85	34.41	31.68	29.45	27.59	26.01	24.65
5	140.23	91.31	71.05	59.46	51.79	46.27	42.06	38.72	36.00	33.73	31.80	30.13
10	163.22	106.29	82.70	69.21	60.28	53.85	48.95	45.07	41.90	39.26	37.01	35.07
25	199.49	129.91	101.08	84.60	73.68	65.82	59.83	55.09	51.22	47.98	45.23	42.86
50	232.20	151.21	117.65	98.47	85.76	76.61	69.64	64.12	59.61	55.85	52.65	49.89
100	270.27	176.00	136.94	114.61	99.83	89.18	81.06	74.63	69.39	65.01	61.28	58.07
500	384.51	250.39	194.82	163.05	142.02	126.87	115.32	106.18	98.71	92.48	87.18	82.61

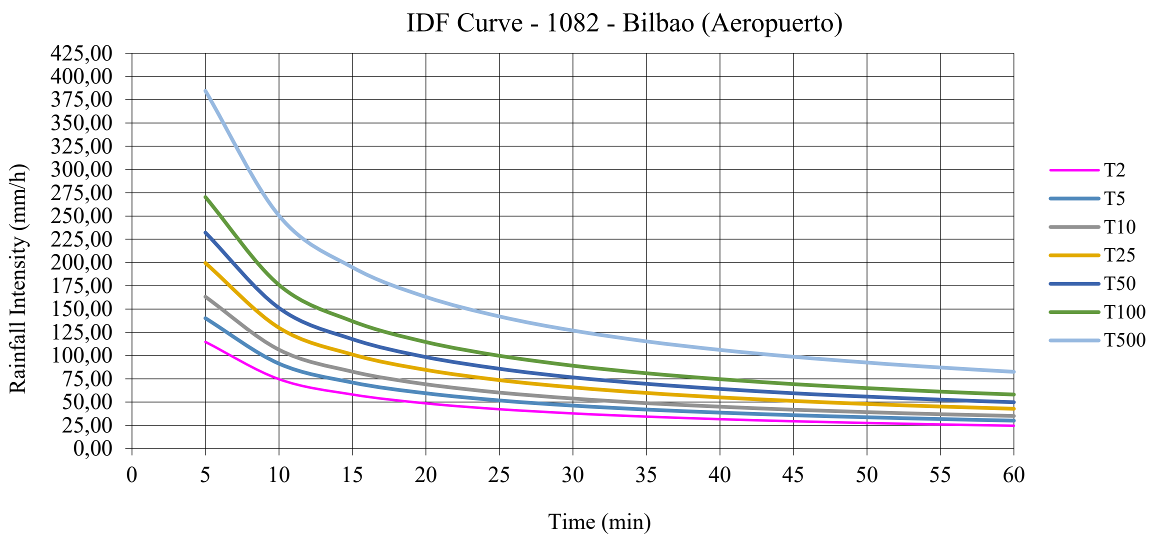


Figure 10 Intensity-Duration-Frequency Curve 1082 – Bilbao (Aeropuerto)

The rainfall intensities of the rainfall station G063-Muxika (Oka) are lower than the calculated for the rainfall station 1082 - Bilbao (Aeropuerto), this might be related to the quantity of data available for both rainfall stations, since the average of maximum rainfall in 24 hours is even greater for the G063-Muxika (Oka) station. Making use of the Intensity-Duration-Frequency curves the hyetographs for different return periods were developed, using the methodology of alternating block method (Chow et al. 1988), the method consists on the distribution of the intensities, based on the time of concentration of the catchment and the logarithmic regression of each IDF curve for each return period. The time of concentration of the catchment was calculated using the Kirpch formula (Kirpichm, 1940), however there are many different empirical approaches for the calculation of the time of concentration as is the Ven te Chow equation (Chow et al, 1988), Williams equation and many others (Perdikaris et al, 2018). Another approximation is highly used in Spain from the Ministry of transport and mobility of the same country (MOPU, 1987). As different results get with each equation, the selection of the equation was based on the final results and its similarity with the area with the official flood maps published by the Basque country government (URA, 2018). These maps were used as the calibration base, as no discharge data was available.

The following physical characteristics of both catchments were calculated using a Digital Elevation Model with 25 meters resolution from the Copernicus data service (Copernicus Sentinel Data, 2021). This were also used for the calculation of the time of concentration of the Oka river and Golako river catchments and the input data of the hydrological models.

Table 6 Oka and Golako river basin physical characteristics

Oka River

River Lenght (km)	13
Slope (m/m)	0.0117
Area (km2)	65.85

Time of concentration (h)	2.63

Golako River

River Lenght (km)	13.5
Slope (m/m)	0.018
Area (km2)	33.71

Time of concentration (h)	2.29

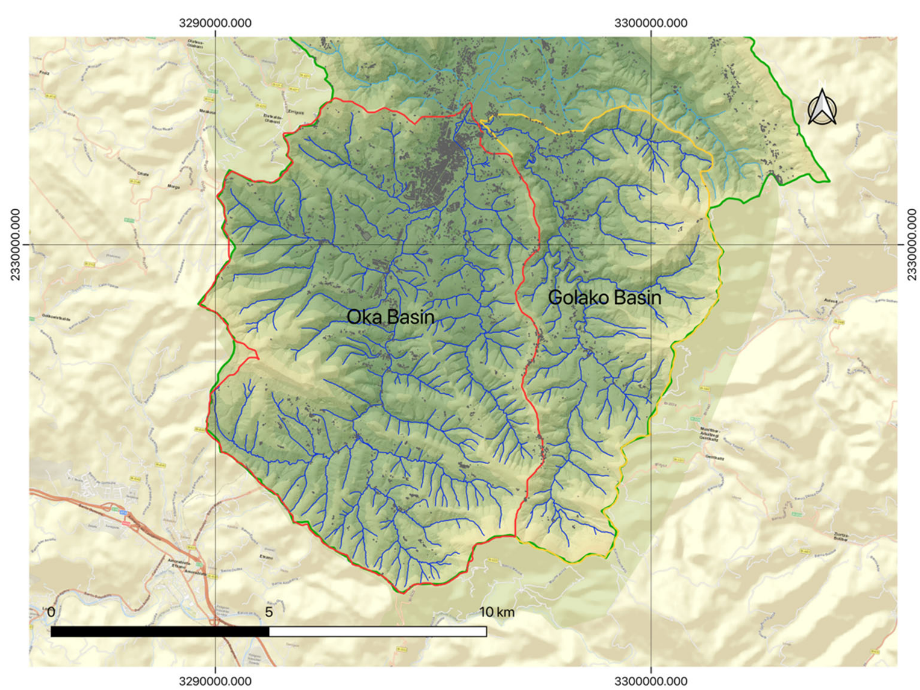


Figure 11 Oka and Golako River Basins

The hyetograph is the representation of a storm event for a specific probability of occurrence. Hyetographs were developed for three different return periods, 50 years, 100 years and 500 years. The return period represents the probability of occurrence of an event, for example, a 100 years return period event have a probability of 1% to happen once in a year. The duration of the storm is equal to the time of concentration of the catchment, based on the general recommendations of applied hydrology design (Chow et al. 1988). These hyetographs are used to calculate the storm hydrograph that describes the behaviour of the river discharge in time.

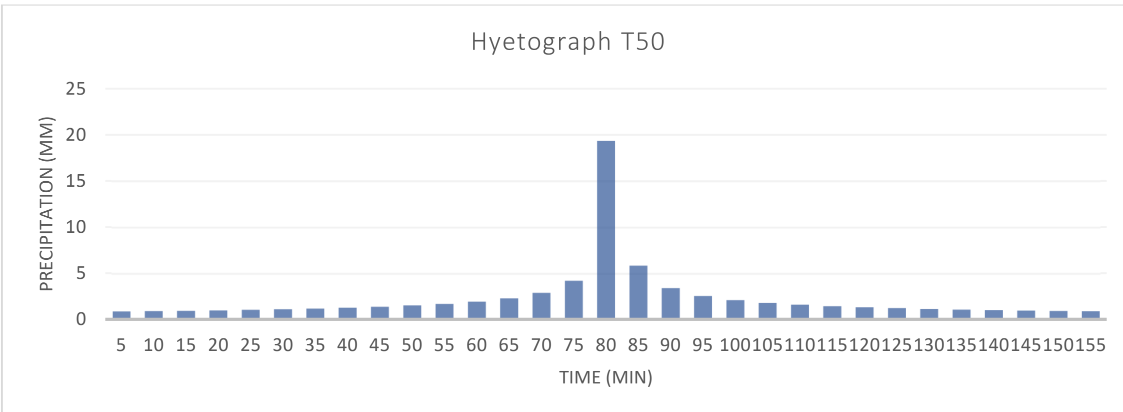


Figure 12 Hyetograph T50

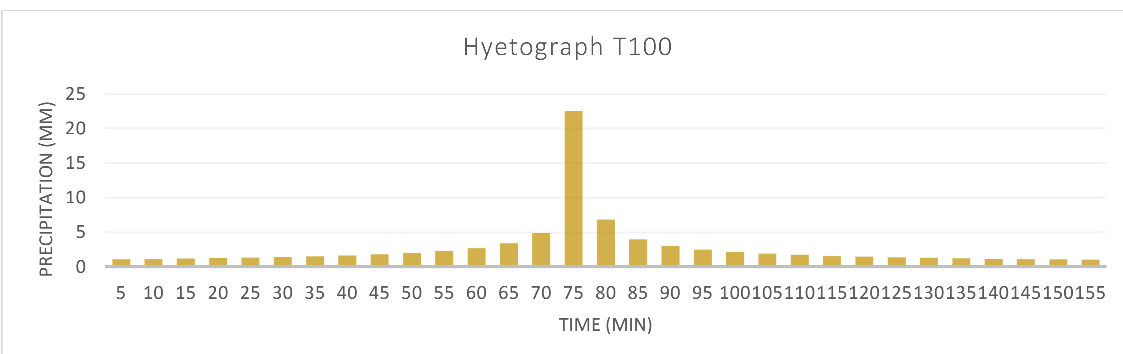


Figure 13 Hyetograph T100

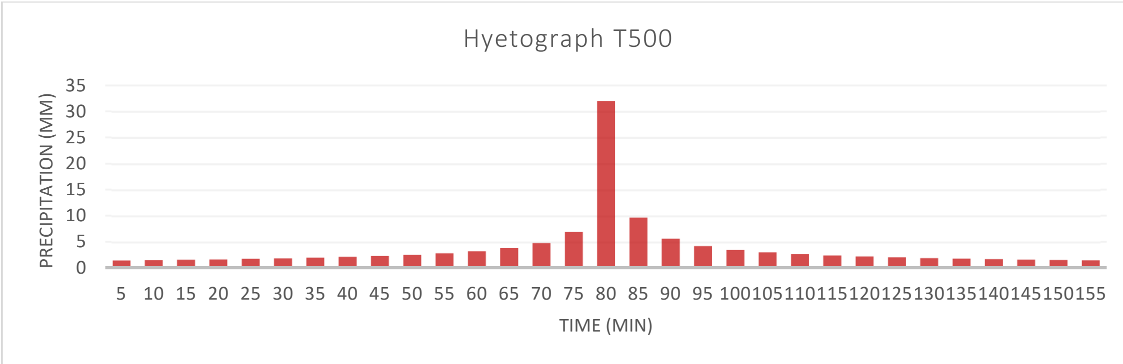


Figure 14 Hyetograph T500

4.3.Land Use Cover Analysis.

The land use cover of the catchments of the Oka and Golako river were developed using satellite images from the Sentinel Satellite Data Hub (Copernicus Sentinel Data, 2021). The satellite images were analysed and processed using the supervised classification technique from ArcGIS classification algorithm plugin. To analyse the land use change in the Oka and Golako river basins three different years were selected, based also on the availability and the good quality of the images from the years 2021, 2017 and 2015. The following image corresponds to the actual scenario, the year 2021.

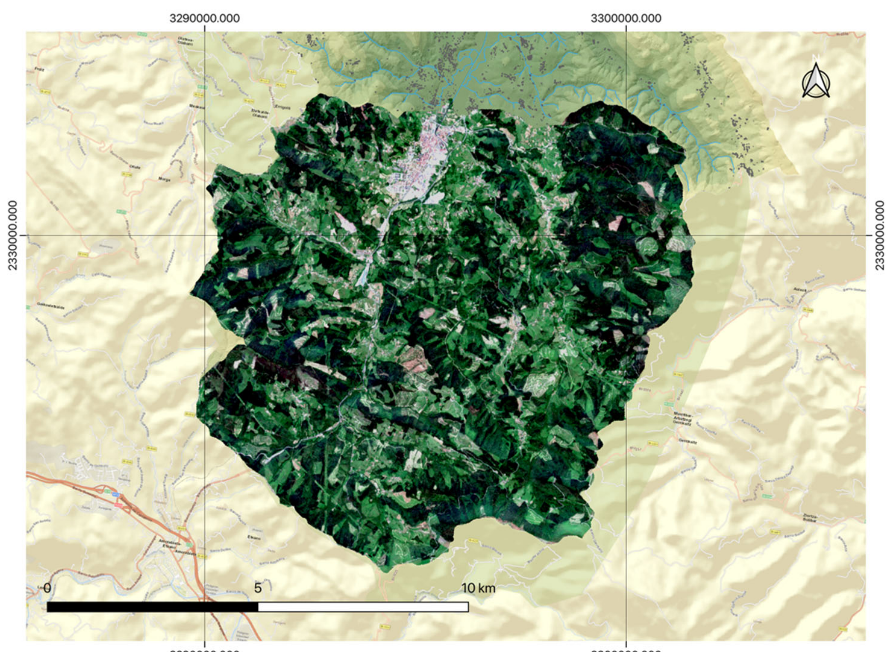


Figure 15 Satellite image: Sentinel-2A, June 6 2021. Bands Combination B2,B3 and B4.

The image was classified in five classes, Forest, Urban, Open Land, Agriculture & Grass and Roads. The supervised classification plug in is included in the toolbox of the Spatial Analyst extension of the software ArcGIS. The methodology consists of the identification of different land use areas using specific training samples from a satellite image, the samples contains information of a known land use, and it is classified in one of the five named classes. As a part of the recognition of the study area and definition of the training samples, an analysis of Normalized Difference Vegetation Index (NDVI) was developed. The NDVI is a simple calculation between the values of two different bands (light wavelengths) of the satellite image, the index uses the visible light (Band 4) and the near-infrared light (Band 8) to calculate the health of the green vegetation based on the absorption and reflexion of light (Kamble et al, 2013).

$$NDVI = \frac{B8 - B4}{B8 + B4}$$

The values of the NDVI varies between -1 and 1, a negative value corresponds to water or an urban area, streets buildings, rock sand or snow, while positive values and values that are close to 1 represents green vegetation areas. For the case study catchment, areas with healthy forest are shown with green and dark green areas while bare soil, roads and urban areas are shown in light green and grey.

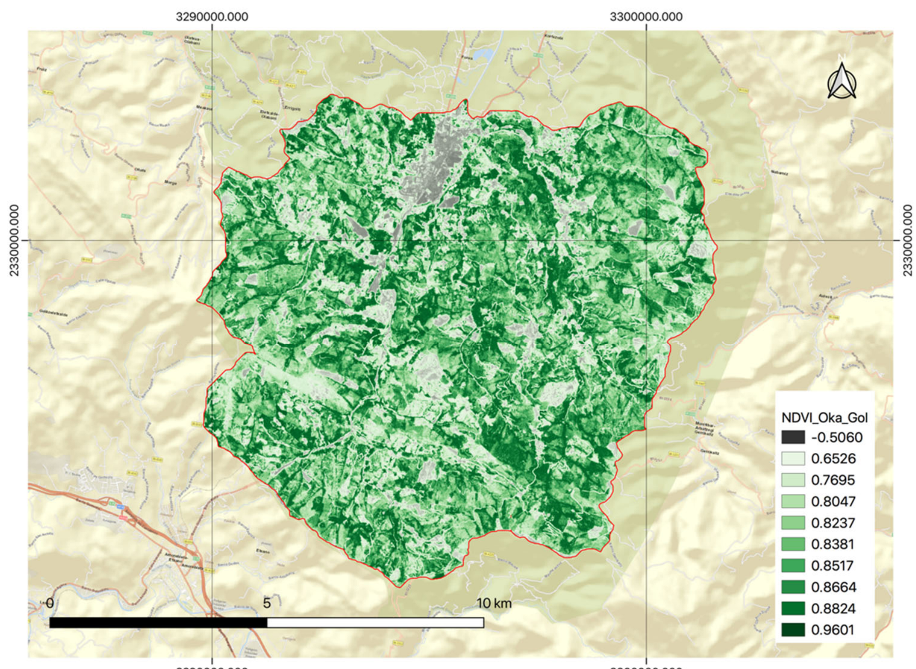


Figure 16 Normalized Difference Vegetation Index (NDVI), Sentinel-2A, June 6 2021. Bands Combination (B8-B4/B8+B4).

After defining the training samples, based on the real color image and the NDVI, the image was classified into five classes that were used in the hydrological model. The next image shows the classification for the year 2021.

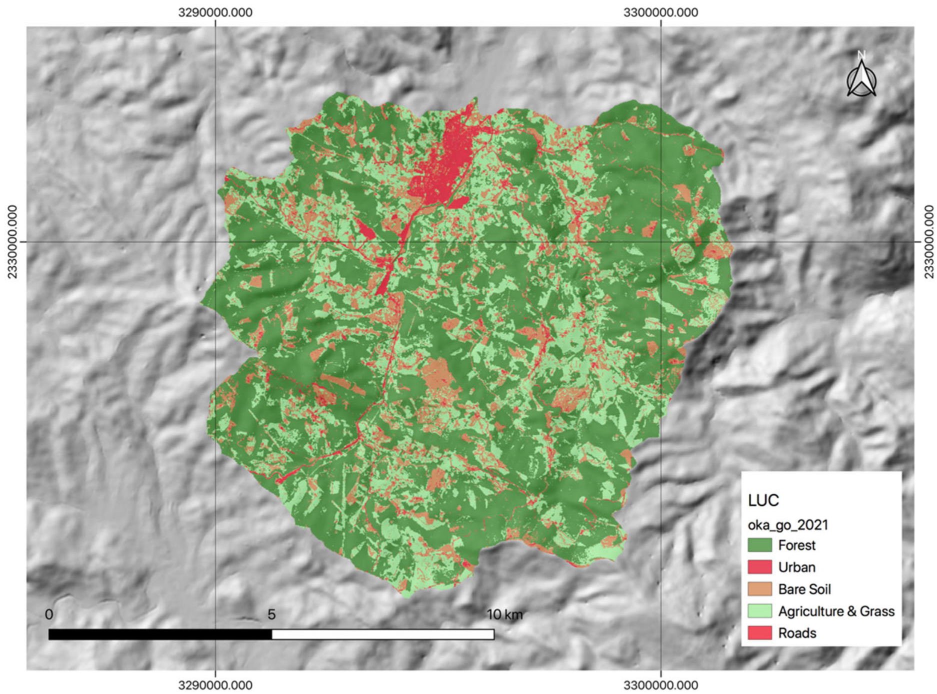


Figure 17 Supervised Classification for the Satellite Image June 2021.

The same process was developed for images of the year 2015 (August 21) and for the year 2017 (April 9). The main objective of the analysis of previous satellite images was to find the rate of degradation of the catchment. At first on the research, it was supposed that the catchment was well preserved as it is part of an important protected area of Spain, the Urdaibai Biosphere Reserve, declared as it by UNESCO in 1984 to conserve its high environmental value. But during the analysis process of this research, it was found that the catchment has been losing an important part of its preserved forest, due to industrial interventions and timbering. It is not clear if some of the forest areas are used for timber crops, that are cut a certain number of years, anyhow the catchment has been losing an important amount of forest cover, and replacing that areas with bare soil, grass and agriculture fields areas. The change of the land cover from the year 2015 to 2021 becomes evident with the Supervised classification analysis.

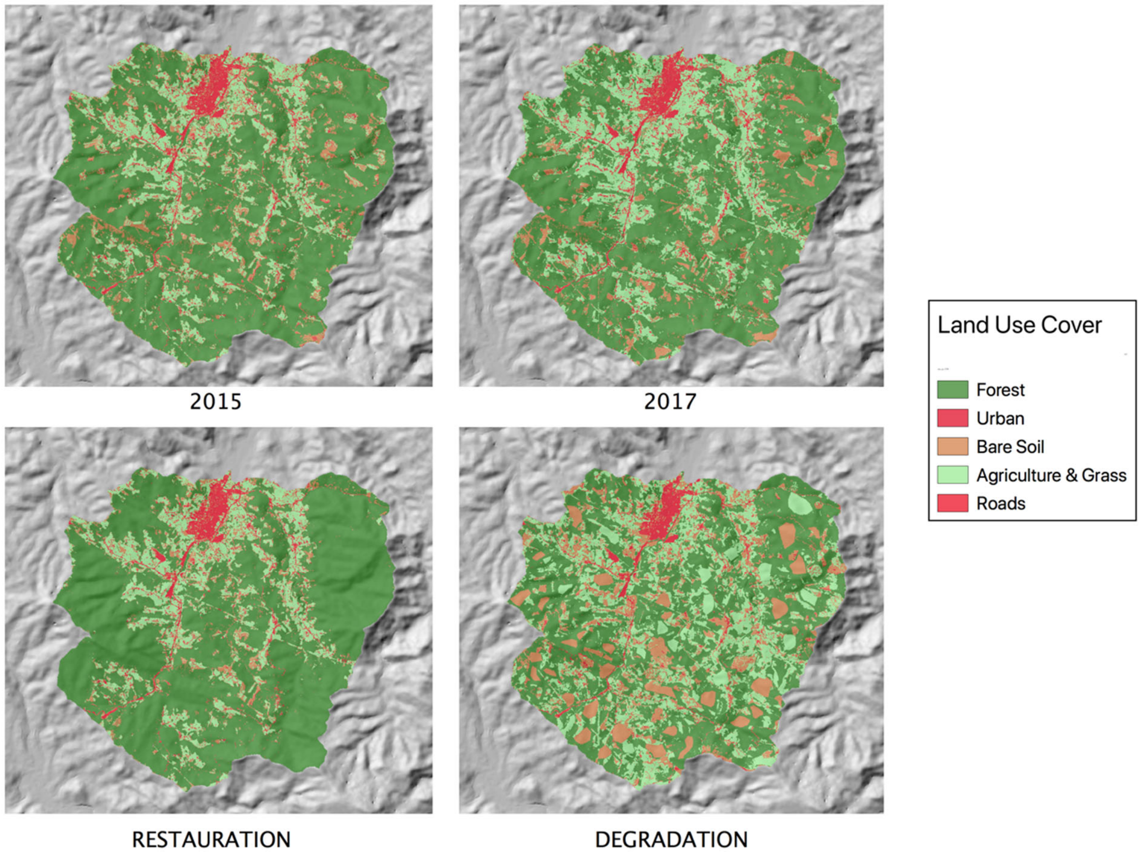


Figure 18 Land Use Cover maps for the four main scenarios.

The following Sankey diagram shows the change of the land cover during the analysed years, 2015, 2017, and 2021. The diagram was developed using the three land-use change scenarios and a code in R that compares the land cover of each year and identifies the conversion of each pixel into another land use cover. The Sankey diagram analysis shows clearly the conversion of forest into bare soil and agriculture and grass between the years 2015 and 2017, and a very similar behaviour between the years 2017 and 2021. The diagram also shows a clear trade-off between the forest and agriculture and grass areas, this might be explained by the dynamic timber industry that happens in the Golako river basin, and that it seems it is growing in the region. Anyhow, the overall behaviour of the catchment is the loss of forest and vegetation.

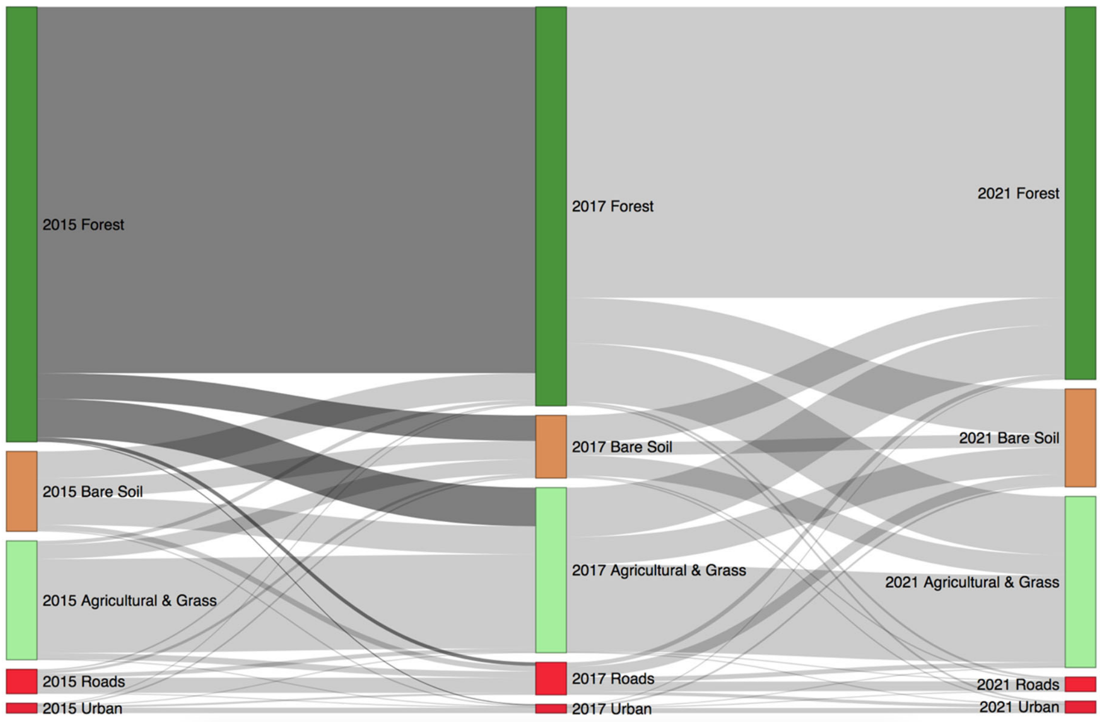
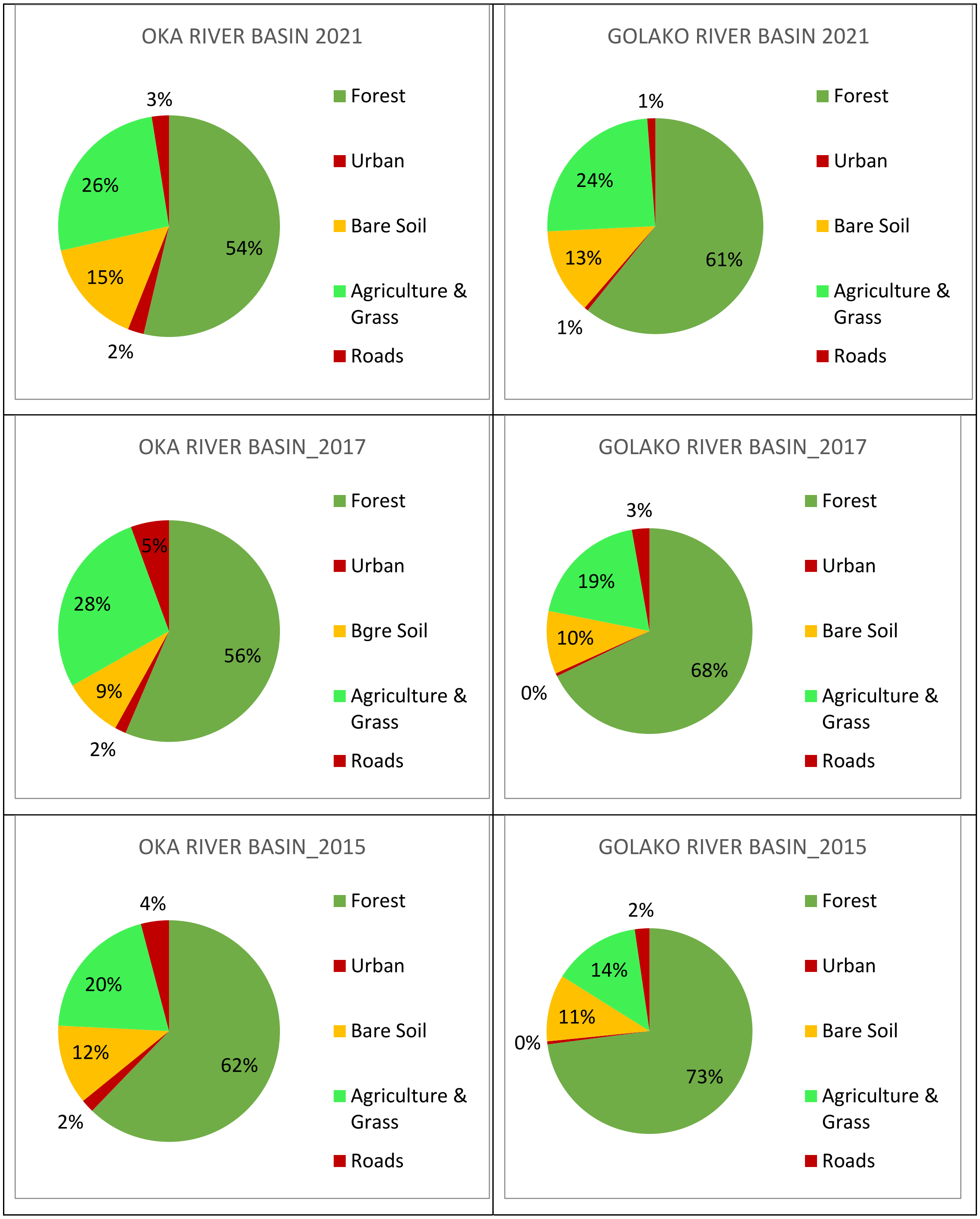


Figure 19 Land Use Change Sankey Diagram, years 2015 , 2017 and 2021 for the Oka and Golako river basin.

Due to the unexpected change in the forest cover from 2015 to 2021, three other scenarios were created in order to compare extremes, one of the scenarios consists of the afforestation of an important part of the catchment, an increase of the forest cover area, in the Oka river basin from the 54% to 67% and in the Golako river basin from 61% to 82%. On the other hand, another scenario where the catchment is degraded, and keeps losing an important part of its natural cover with a similar trend. In this scenario the Oka river basin reduces its forest cover from 54% to 46% and the Golako river basin from 61% to 52%. Both scenarios of land restauration and degradation were developed manually, changing the land cover based on the observed trend between the years 2015, 2017 and 2021.


OKA RIVER BASIN 2021
3%
26%
54%
15%
2%
Forest
Urban
Bare Soil
Agriculture & Grass
Roads
GOLAKO RIVER BASIN 2021
1%
24%
13%
61%
1%
Forest
Urban
Bare Soil
Agriculture & Grass
Roads
OKA RIVER BASIN_2017
5%
28%
56%
9%
2%
Forest
Urban
Bgre Soil
Agriculture & Grass
Roads
GOLAKO RIVER BASIN_2017
3%
19%
10%
0%
68%
Forest
Urban
Bare Soil
Agriculture & Grass
Roads
OKA RIVER BASIN_2015
4%
20%
12%
62%
2%
Forest
Urban
Bare Soil
Agriculture & Grass
Roads
GOLAKO RIVER BASIN_2015
2%
14%
11%
0%
73%
Forest
Urban
Bare Soil
Agriculture & Grass
Roads

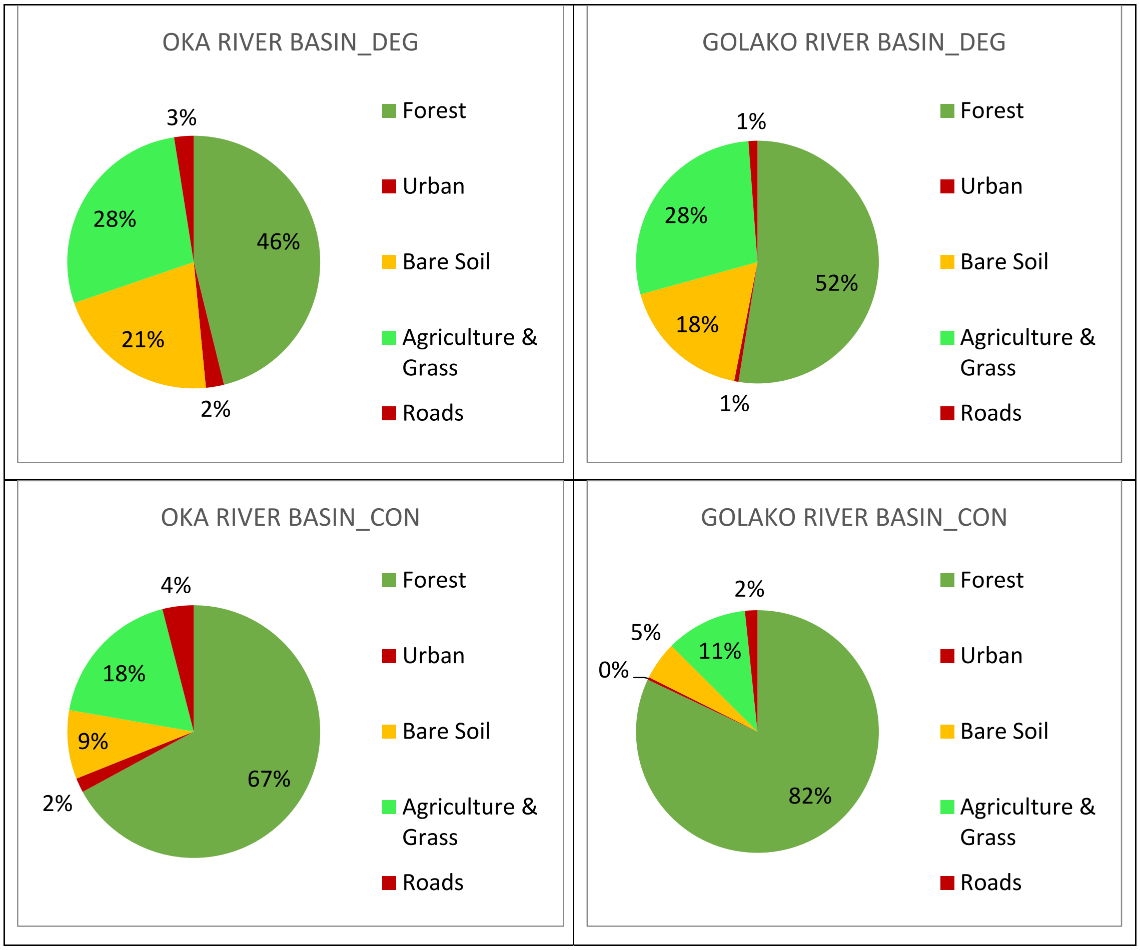


Figure 20 Percentage of each land use class for all the scenarios for the Oka and Golako river basins.

4.4. Hydrologic Model.

The hydrologic model was one of the most important parts of the analysis, as is the main connexion between the flood depth maps and damages with the effects of the land use change, through the calculation of the hydrological response of the catchment and the production of discharge caused by heavy rainfall with different probabilities of occurrence. The model gives the scientific base to the analysis and determines the magnitude of the flood based on the water catchment characteristics. The development of the hydrological model requires specific information about the water catchment, bio-physical characteristics that combine the hydrologic soil group and the land use cover classes, this combination is called soil-cover complex (USDA, 2004). The soil cover complex might be described by the Curve Number (CN), this indicates the runoff potential of a river catchment or system.

To define the CNs of each soil-cover complex it is necessary to describe the soil characteristics of the catchment. The information of the catchment's soil was downloaded from the GeoEuskadi Data Hub (Eusko Jaurlaritza, 2021), and it is available for the entire Basque Country. The available maps contain information about the lithology and the characteristics of the soil, characteristics that are very important in the determination of the hydrologic response of a water catchment (Gómez-Sanz et al, 2019). Making use of that information, the soil characteristic was classified into the four hydrologic soil types defined by the United States Department of Agriculture. The groups are, Group A – are soils with a los runoff generation potential, these soils are very permeable, and contain a big percentage of sand and rock fragments. Group B – are classified as soils with a moderate low runoff potential, they are still permeable. Group C – are soils with a moderately high runoff capacity, are soils with an important amount of clay and less than 50 percent of sands. Group D – soils with a high runoff generation potential, this are very impermeable soils with usually more than 40 percent of clay (USDA, 2007). The next map contains all the classification for the catchment of the river Oka and Golako.

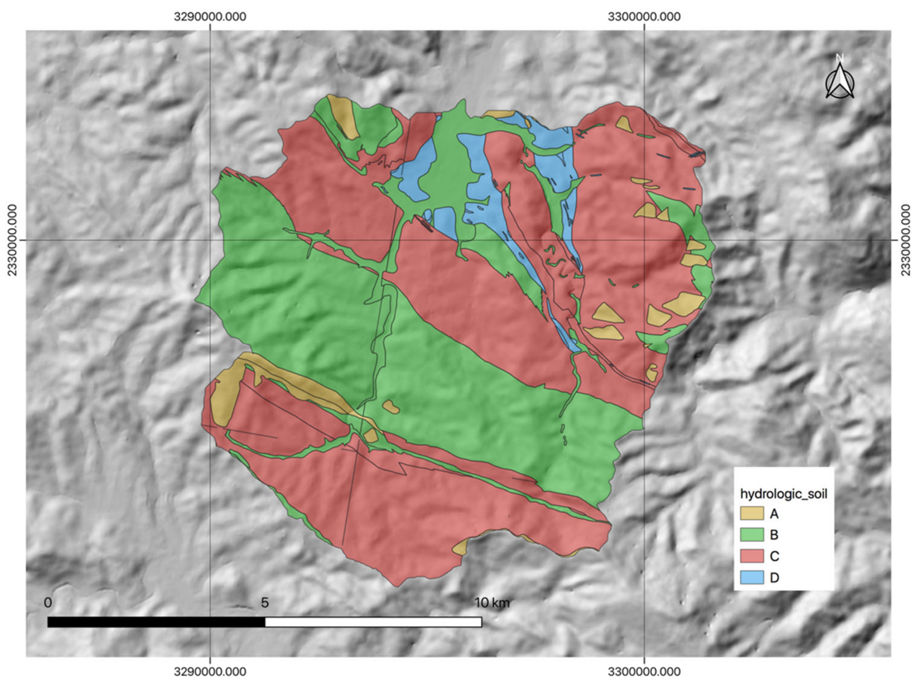


Figure 21 Hydrologic Soil Group for the Oka and Golako River Basins.

The Curve Number is the most important hydrologic modelling parameter, this number contains the information of the runoff potential of each part of the catchment. It is the parameter that changes the final output of the hydrologic model, based on the land use cover of the catchment. The curve number is the result of the combined analysis of the Land use and the hydrological soil, what is called the soil-cover complex. For this research the CN methodology of the United States Department of Agriculture was used (USAD, 2004), and the selection of the hydrologic condition the following assumptions where done; for the forest LUC (woods), a good hydrologic condition was selected, this means that "*woods are protected from grazing, and litter and brush adequately cover soil"* (USAD, 2004, Chapter 9 pag 3). For the Bare Soil a fallow cover (crop residue cover) type with a good hydrologic condition was selected. The Agriculture & Grass land use cover corresponds to the Pasture, grassland covert type with a poor hydrologic condition this means that less than the "*50% it is ground cover or heavily grazed with no mulch"* (USAD, 2004, Chapter 9 pag 3). For roads a CN of impervious areas including paved streets and roads was selected, as the natural soil is covered with impermeable pavement, the curve number is 98, same for every hydrologic soil group (USAD, 2004, Chapter 9 pag 9)

Cover description: cover type	treatment [2/]	hydrologic condition [3/]	CN for hydrologic soil group: A	B	C	D
Pasture, grassland, or range-continuous forage for grazing [4/]		Poor	68	79	86	89
		Fair	49	69	79	84
		Good	39	61	74	80
Meadow-continuous grass, protected from grazing and generally mowed for hay		Good	30	58	71	78
Brush-brush-forbs-grass mixture with brush the major element [5/]		Poor	48	67	77	83
		Fair	35	56	70	77
		Good	30 [6/]	48	65	73
Woods-grass combination (orchard or tree farm) [7/]		Poor	57	73	82	86
		Fair	43	65	76	82
		Good	32	58	72	79
Woods [8/]		Poor	45	66	77	83
		Fair	36	60	73	79
		Good	30	55	70	77
Farmstead–buildings, lanes, driveways, and surrounding lots		---	59	74	82	86
Roads (including right-of-way):						
Dirt		---	72	82	87	89
Gravel		---	76	85	89	91

Figure 22 Runoff curve numbers for different land use covers (USAD, 2004, Chapter 9 p 3).

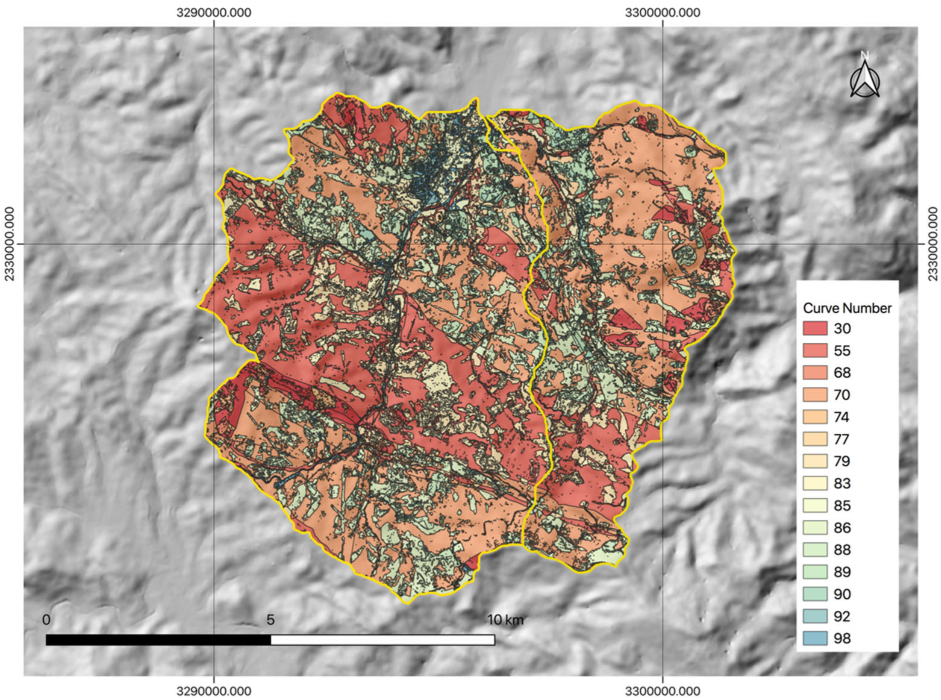


Figure 23 Curve Numbers (2021) for the Oka and Golako River Basins.

A high Curve Number indicates a high runoff generation potential, while a low Curve Number indicate a low runoff potential, this also means a high infiltration potential. In the case of the Oka and Golako river basin the soils at the upper and middle basin are soils with a low runoff potential, as in some parts its Curve Number is between 30 and 55. As the lower basin of the Oka and Golako river basins are degraded, higher values of CN can be found, between 85 and 98. The Figure 10 shows the soil cover complex (CN values) of the complete catchment for the year 2021.The same process was used for all the different scenarios, the hydrologic model requires a composite CN, that is the weighted average of each CN found in the catchment. The composite Curve Number per scenario was calculated as follows.

$$CN_{composite} = \frac{\sum A_i \, CN_i}{\sum A_i} \quad (Feldman, 2000, p\ 38)$$

Where A is the area of each polygon and CN is the Curve Number of the same polygon. The following table contains the composite CN for each scenario.

Table 7 Composite Curve Numbers for all the scenarios.

	CN(composite)		
Scenario	**Oka**	**Golako**	**Total**
2021	72.12	72.65	72.32
2017	71.75	71.47	71.74
2015	70.58	70.45	70.58
Restauration	69.24	68.19	68.92
Degradation	73.84	74.37	74.02

The hydrologic model was developed using the software HEC-HMS, this software uses hydrologic mathematical methods to transform the rainfall into runoff by using loss methods that are able to estimate the amount of precipitation that infiltrates into the soil and calculates how much discharge is produced in the process (Feldman, 2000). Because the model was developed for flood routing porpoises, the evapotranspiration was not considered, as it doesn't have a significant effect in the generation of discharge during a strong rainfall event with a short duration.

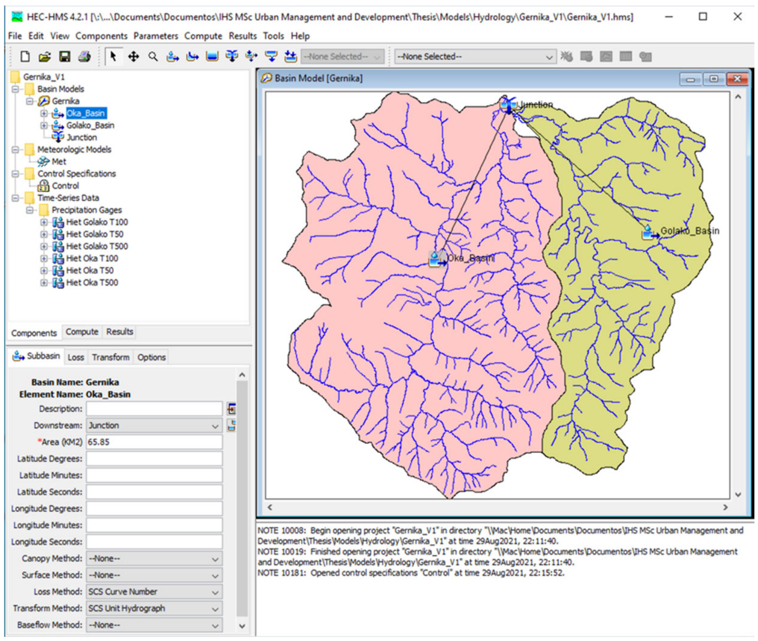


Figure 24 HEC-HMS model.

The model was divided into two basins, one for the Oka river and another for the Golako river, each basin with its own physical characteristics, and curve numbers. The hyetograph is the same for both basins, assuming the rain will occur at both hydrological units at the same time. The model simulates each land use cover scenario for the three hyetographs for the previously calculated returned periods, T50, T100 and T500. The output of the model is the resultant hydrograph for each river basin, and the combination of both hydrographs results in the total hydrograph that reaches the urban area of Gernika-Lumo during and after the designed storm.

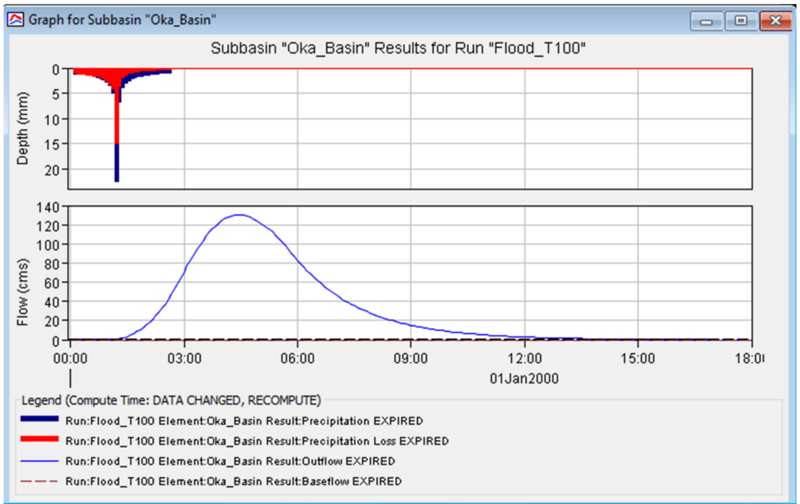


Figure 25 HEC-HMS Oka river model results T100, 2021 Scenario.

For the actual scenario 2021, and for a return period of 100 years, the Oka river reaches a discharge of 130.4 m3/s and the Golako river a discharge of 69.4 m3/s. For the extremist scenario, a returned period of 500 years, the Oka river reaches a total discharge of 248.7 m3/s and the Golako river a discharge of 137.5 m3/s.

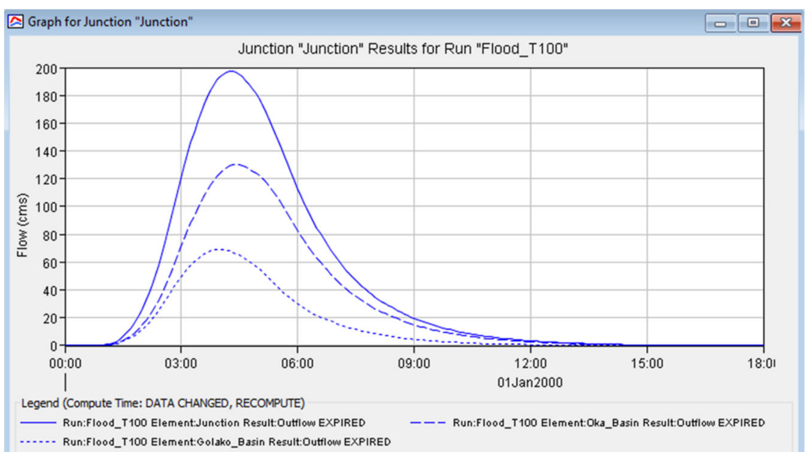


Figure 26 HEC-HMS Oka and Golako model results T100, 2021 Scenario.

Table 8 Peak discharges for the scenario 2021.

Scenario	**2021**	T50	T100	T500	T50	T100	T500
River Basin	Area (KM2)	Peak Discharge (m3/s)	Peak Discharge (m3/s)	Peak Discharge (m3/s)	Volume (1000 M3)	Volume (1000 M3)	Volume (1000 M3)
Oka_Basin	65.85	96.9	130.4	248.7	1395.2	1885	3570.6

Golako_Basin	33.71	51.1	69.4	137.5	661.4	897.3	1786
Junction	99.56	145.6	197.2	382.3	2056.6	2782.3	5356.7

For the other scenarios peak discharge results see Annex 1: Data tables.

4.5.Hydraulic Model.

The hydraulic model was developed in base of an existing hydraulic model provided by the Basque Water Agency and created in the software HEC-RAS, a software developed by the U.S Army Corps of Engineers and that is widely used for river modelling and open channel flow simulation, sediment transport and water quality modelling (Brunner et al. 2021). The original model was analysed by the author, and modified in order to fit the hydrological model, developed during the same research. The original model contained the physical characteristics of the Oka river starting from the upstream and including some other tributary rivers that end up draining in the urban area of Gernika-Lumo. The model was modified for simplification purposes but contains the same information included originally on each profile, like bridges and buildings. The model was run for steady flow, which is based on the solution of one-dimensional energy equations. The energy losses are calculated based on the Manning's equation for friction. This kind of methodology is recommended for the analysis of flood plain management and flood insurance studies (Brunner et al. 2021).

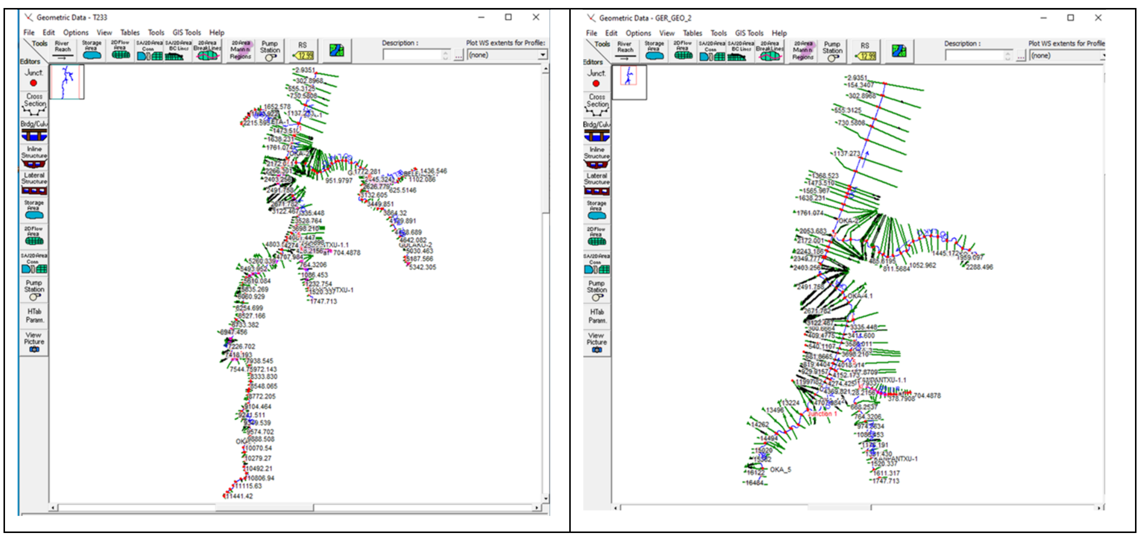


Figure 27 HEC-RAS model. (Agencia Vasca del Agua, 2021)

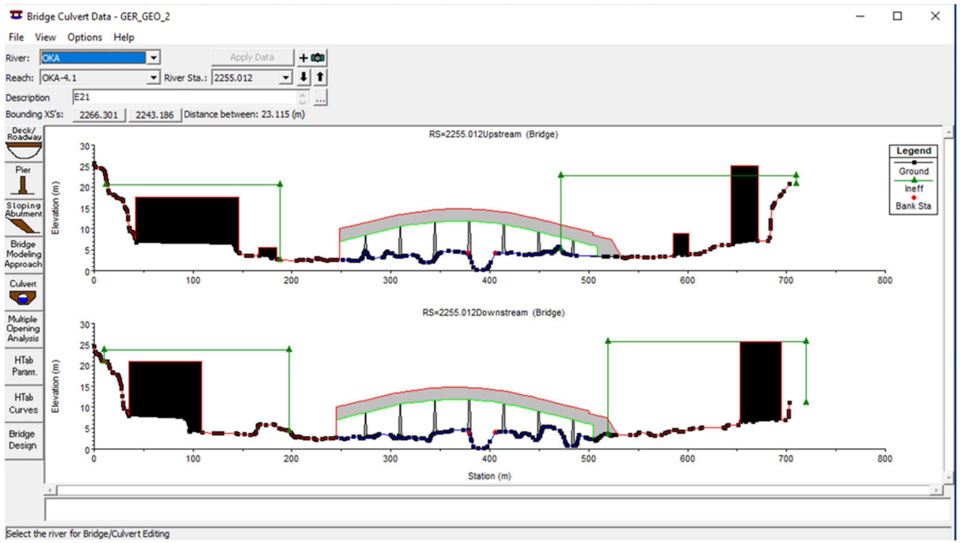
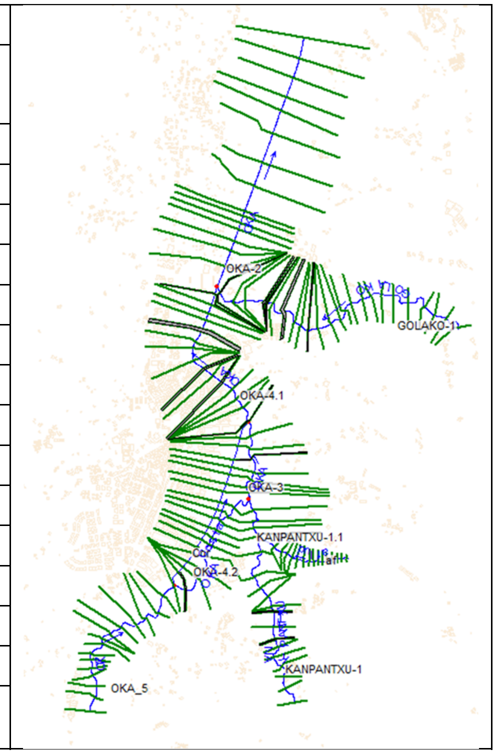


Figure 28 HEC-RAS model profile sample. (Agencia Vasca del Agua, 2021)

Once the model typology was ready, the distribution of the discharges was done based on the location of each reach and the size of each basin. For the Oka river, the discharge was divided into two, 75% of the total discharge was assigned to the reach OKA_5, while the rest was assigned to the Kanpantxu reach. The Oka-2 reach represents the union of the total discharge of the river. The reach of the Golako river includes all the calculated discharge of the complete Golako river basin. Notice that the total discharge that end up in the urban area is the sum of both, the Oka and Golako river basins. For other peak discharge distribution scenarios see Annex 1: Data tables.

Table 9 Distribution of peak discharges for the scenario 2021.

2021	T50	T100	T500
Reach	Q (m/s)	Q (m/s)	Q (m/s)
aflud	12.1	16.3	31.1
Corta	5.0	5.0	5.0
GOLAKO-1	51.1	69.4	137.5
KANPANTXU-1	12.1	16.3	31.1
KANPANTXU-1.1	24.2	32.6	62.2
OKA_5	72.7	97.8	186.5
OKA-4.2	72.7	97.8	186.5
OKA-3	96.9	130.4	248.7
OKA-4.1	96.9	130.4	248.7
OKA-2	145.6	197.2	382.3
OKA-2	145.6	197.2	382.3
Oka Peak	96.9	130.4	248.7
Golako Peak	51.1	69.4	137.5
Total Peak	145.6	197.2	382.3



The hydraulic model was run for each land use scenario and for the three different return periods, T50, T100 and T500. Every scenario has a different flood map output, showing different extension and depth of the flood. The Figure 28 shows the comparison between the official flood map (GeoEuskadi, 2021) and the research result flood map for the return period T500 and the 2021 Scenario. There is an important similarity between both flood maps in terms of area, which is a good indicator of the reliability of the study. The final result of both studies is very similar, using author's methods and developed using different raw data as input.

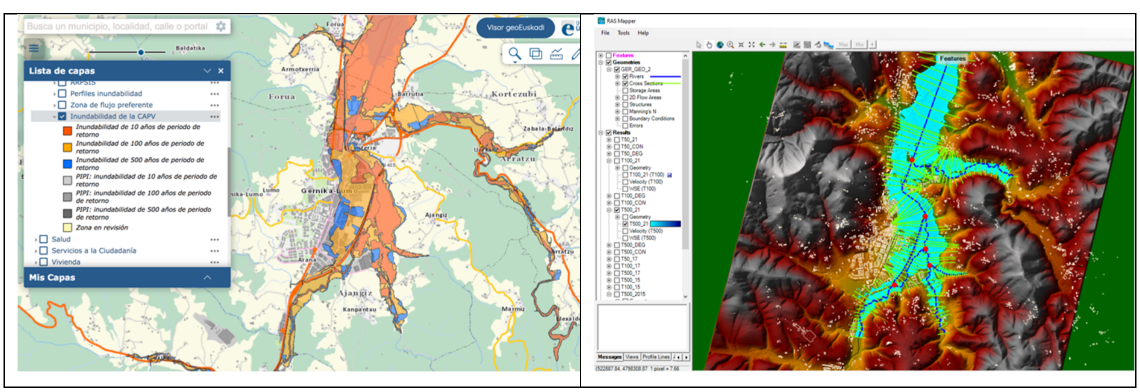


Figure 29 HEC-RAS Official flood maps (GeoEuskadi, 2021), 2021 Scenario, T100 Result

As a final result 15 different flood depth maps were developed, the maps shows a progressive increment of the flood hazard from the years 2015, 2017 and 2021, and a considerable increment with the degradation scenario. The flood depth changes considerably between the return periods scenarios, showing a very extreme flood event for the 500 years return period and more similar flood areas for 50 and 100 years return period, for the scenario 2021. On the other hand, there is a notable reduction of the flood depth for the restauration scenario compared to the 2021 and the degradation scenario, showing a worst event for the degradation scenario and a less hazardous one for the conservation scenario, compared with the 2021 scenario. The flooded area doesn't change much, but the flood depth does it, showing considerably deeper depths for the degradation scenario.

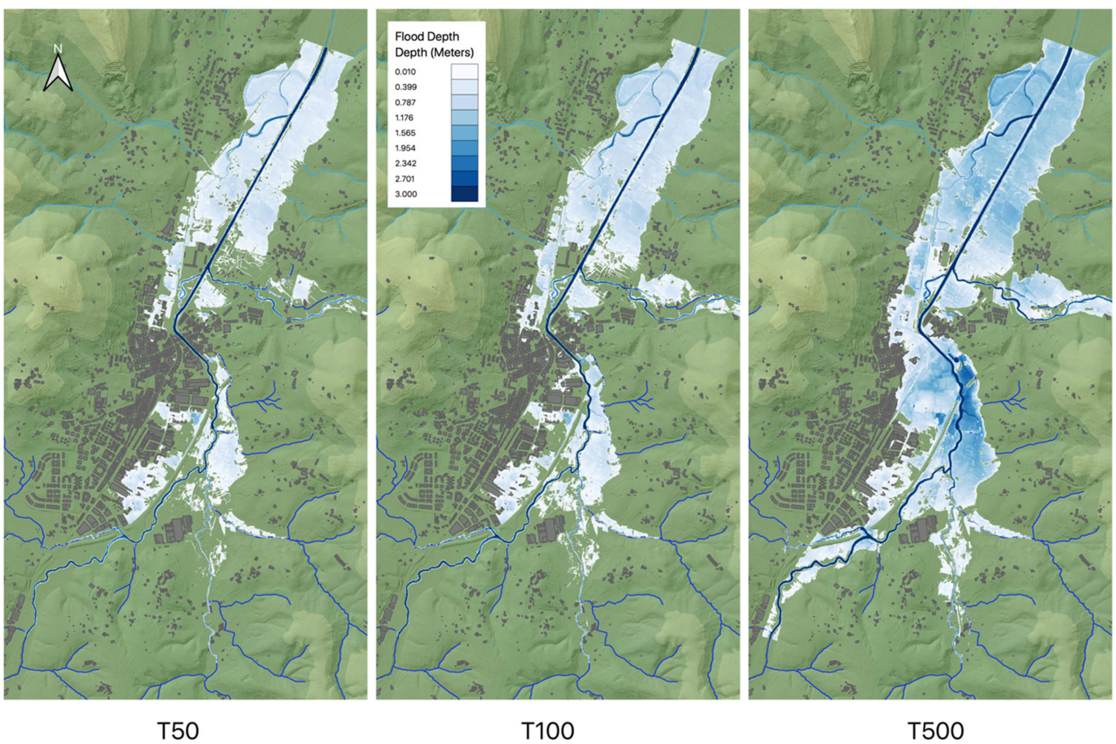


Figure 30 Flood maps for the scenario 2021, for different return periods.

During a strong rainfall related event with 50 years return period and the actual conditions of the catchment, it would be expected to have some flood damages with flood depths of less than one meter at the eastern area of the urban area of Gernika-Lumo. The vast majority of the flood will happen at the downstream at the river Oka flood plain, affecting some buildings that are settled inside of it.

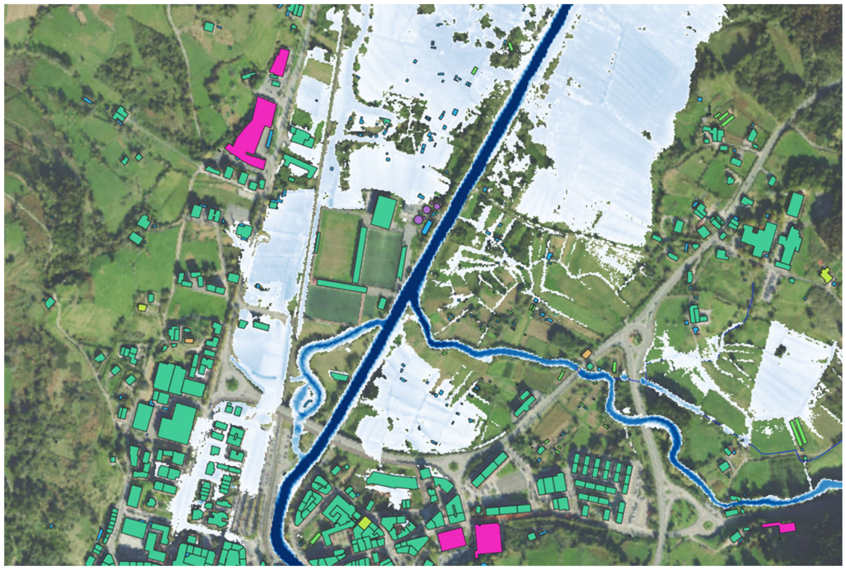


Figure 31 Detail of the flood map for the 2021 scenario and 50 years return period.

For an event of 100 years return period, the flood area is slightly bigger, increasing also the depth of the flood, and affecting more buildings. For this event the downstream floodplain is also flooded, increasing the damage cost in some of the buildings. For an event of 500 years return period, the flood area is bigger, and an important part of the eastern side of the city is flooded, affecting some industrial buildings and increasing the damage costs.

Figure 32 Detail of the flood map for the 2021 scenario and 500 years return period.

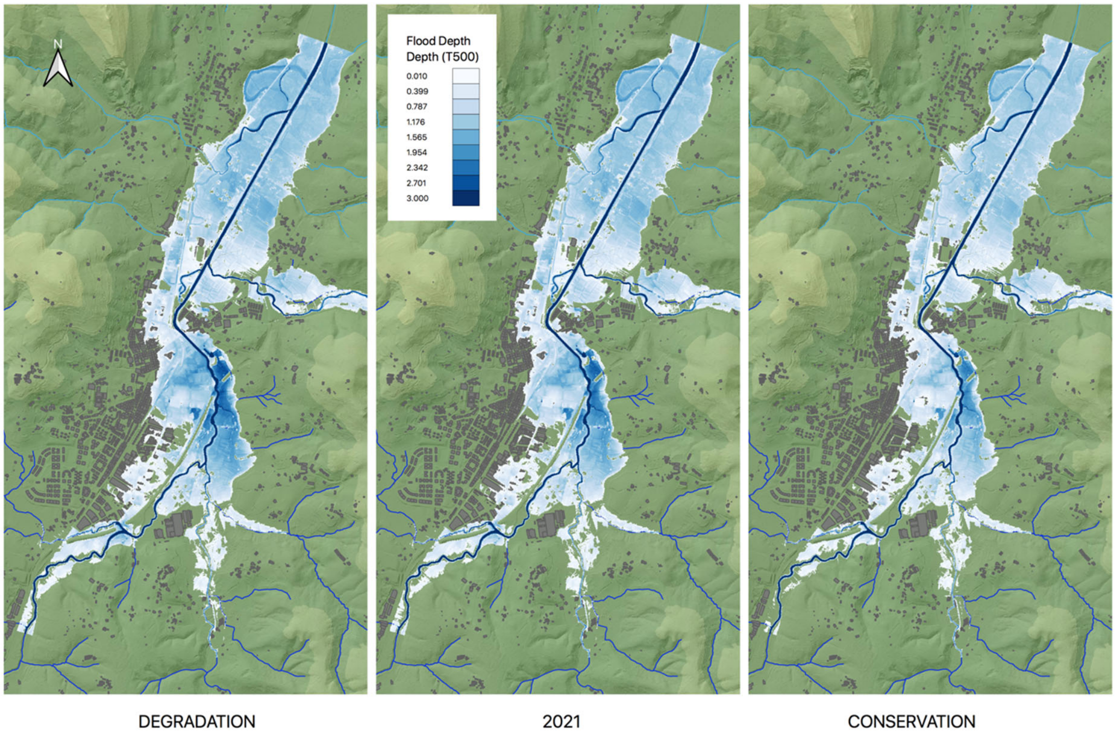


Figure 33 Flood maps for the degradation, 2021 and conservation scenario, for a return period of 500 years.

4.6. Damage Cost Analysis.

The total damage cost caused by all the 15 flood scenarios was analysed using each of the calculated flood depth maps developed during the analysis, in combination with the building's shapefile available in the GeoEuskadi Hub (GeoEuskadi, 2021). The buildings shapefile contains all the buildings and its type classification. In total there are eight different building types inside the urban area: warehouses, ruins, dwelling, workshops, churches, singular building, greenhouses and industry. The urban area of Gernika-Lumo is divided by the train railway into two main areas, in the west the old city center, composed of dwellings, churches, commercial and health building types, and the east of the city urbanized mostly by industrial buildings and a strong commercial activity. At the north of the city, and inside the flood prone area of the Oka river there are also greenhouses and some other agro-industrial activity that might be affected by a flood event.

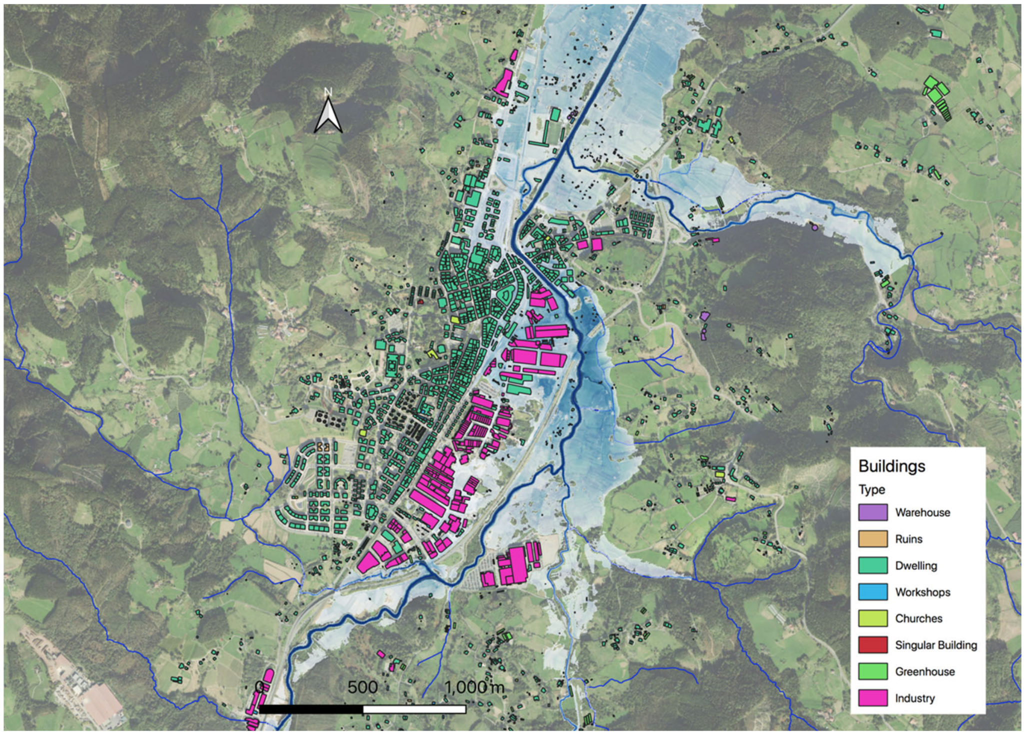


Figure 34 Buildings type and T500 Flood Map 2021 Scenario

The total building damage is the combination of the flood raster map and the buildings shapefile, by using Geographical Information Systems software it was possible to relate both by assigning the corresponding depth to each building and defining the direct affection on the city infrastructure. For this research, the only affected infrastructure that was analyzed were the buildings, other kinds of infrastructure, like roads, vehicles, and damages to public services were not included in the analysis due to time restrictions. The depth of each building was calculated as the mean depth inside the building polygon, those water depths were calculated for each of the 15 scenarios including only the buildings that fall inside the flood map area. For the affected buildings, especially the industrial area, the flood depth can reach between 1 and 3 meters for the actual scenario 2021. For all the scenarios the depth has small increments or decreases, however it changes the total damage cost considerably. This is one important limitation of this methodology, due to the accumulated uncertainty in the hydrological model due to some changes in the selection of empirical parameters, that can have an impact on the final flood depth in the model and hence an impact in the building damage. In order to understand does uncertainties, it is recommended to develop a sensibility analysis. The next figure shows the actual 2021 scenario, and the 500 years return period flood event, the affected buildings are shown in a red color scale, based on the flood depth of the building.

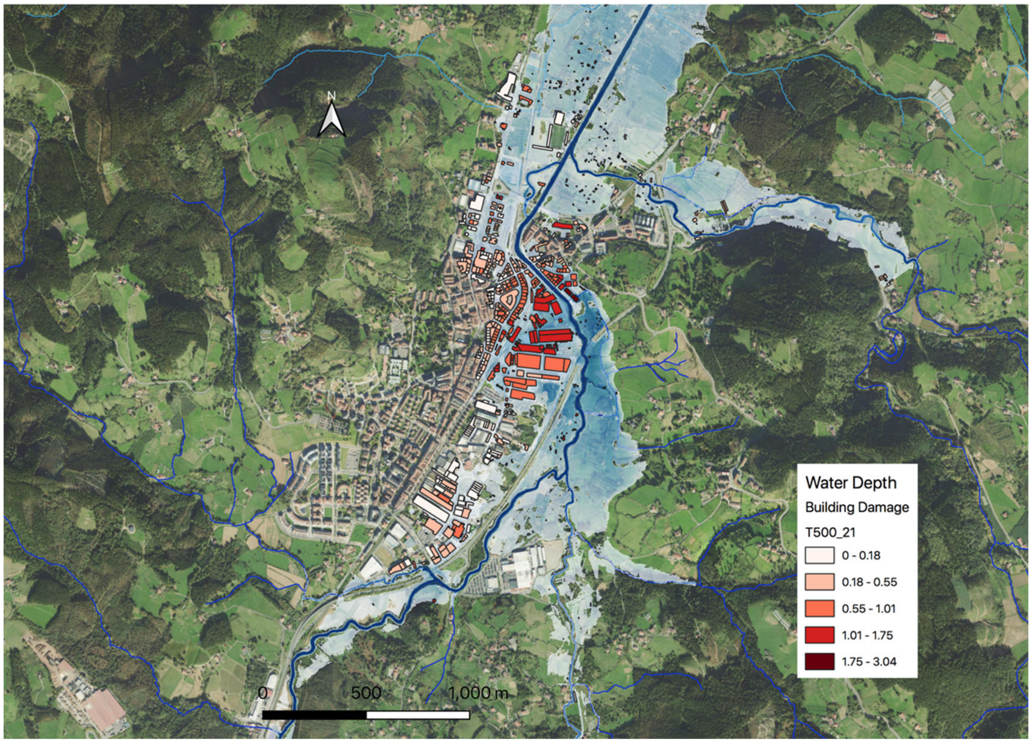


Figure 35 Flood Map T500, 2021 Scenario, Affected Buildings

The total damage of each flood scenario was calculated using the flood depth damage curves for the city of Gernika-Lumo (Martinez-Gomariz et al, 2020), developed by the Water Technology Centre "Cetaqua" and provided by Eduardo Martinez Gomariz for the porpoise of this research. Depth damage curves are important tools for the development of flood risk assessments, as one of the objectives of them is to calculate the total expected damage for a given flood event. The damage curve relates the total damage of a building, by square meter, with the depth of the flood that affects directly the infrastructure and elements inside. The damage curve might differ depending on the type of building that is affected, for example in the case of a dwelling building, it is expected to have less economic losses than in the case of an industrial building or a hospital.

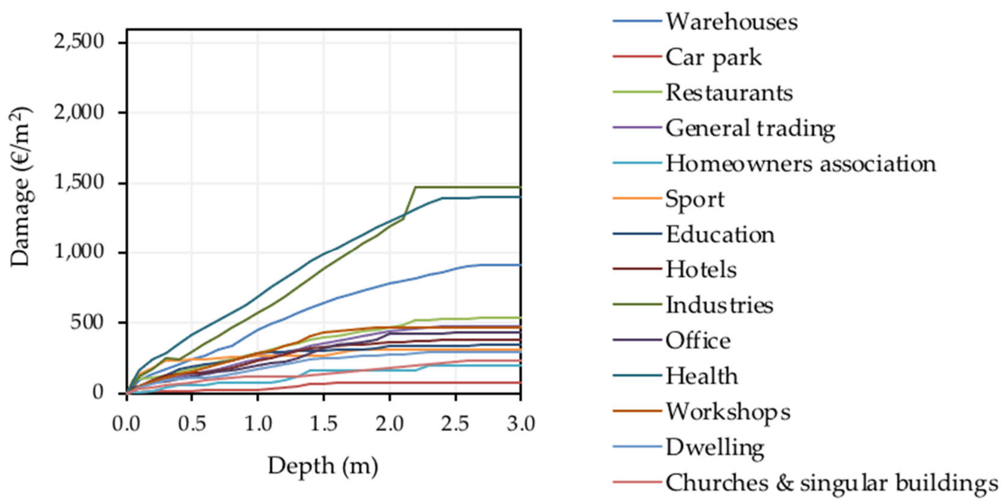


Figure 36 Flood Depth Damage Curve for Gernika-Lumo (Martinez-Gomariz et al, 2020)

The depth damage curve of Gernika-Lumo is one of many curves that were developed based on a regional adjustment of the damage curves in the city of Barcelona, Spain. This exercise was developed for several Spanish municipalities, and its objective was to close the gap in information that exists in the development of flood risk assessments in Spain (Martinez-Gomariz et al, 2020). The depth damage curve of Gernika-Lumo was used to calculate the total damage for each scenario, finding the total damage costs of the flood event. The next table presents all the damage costs for each scenario and the expected damage cost, that is the combination of the probability of the event and the total damage cost of the same event. For example, an event with 100 years return period has an occurrence probability of 1% in one year, this probability multiplied by the total damage cost is the expected damage cost of the event. Notice that the total damage cost is greater for all the scenarios for 500 years return period event, followed by the 100 and 50 years return period, as expected. For the expected damage cost the results shows that the 50 years return period event has the greatest expected costs, which means that this probability scenario is more likely to result in greater economic loses than the probability flood scenarios of 100 and 500 years. The damage cost values correspond to the year 2020, thus no discount rate was used in the calculations, assuming that the change of the value of the restoration costs for 2021 is negligible.

Table 10 Damage Costs and Expected Damage results.

T500	Probability	Total Damage Cost	Expected Damage Cost
	0.002		
Conserved	CON	€ 45,580,427	€ 91,161
2015	2015	€ 51,350,425	€ 102,701
2017	2017	€ 56,103,965	€ 112,208
2021	2021	€ 58,366,710	€ 116,733
Degraded	DEG	€ 66,878,950	€ 133,758

T100	Probability	Total Damage Cost	Expected Damage Cost
	0.01		
Conserved	CON	€ 13,399,022	€ 133,990
2015	2015	€ 13,536,820	€ 135,368
2017	2017	€ 14,510,059	€ 145,101
2021	2021	€ 15,735,871	€ 157,359
Degraded	DEG	€ 17,441,693	€ 174,417

T50	Probability	Total Damage Cost	Expected Damage Cost
	0.02		
Conserved	CON	€ 12,405,237	€ 248,105
2015	2015	€ 12,681,215	€ 253,624
2017	2017	€ 12,964,968	€ 259,299
2021	2021	€ 12,968,450	€ 259,369
Degraded	DEG	€ 13,211,829	€ 264,237

The next graph shows the comparison between the total damage costs and expected damage cost for every probabilistic and land use cover scenario, it also shows the total forest area (hectares) for each scenario. It is remarkable how the loss of forest area impacts the total damage cost of each scenario, showing how between 2015 and 2021 the complete water basin has lost 969 hectares of forest cover, and as a consequence the damage cost is likely to increase by € 7,016,285 due to the increase in the flood peak discharge for 500 years return event. If the actual scenario 2021 is compared with the conservation scenario the damage cost difference reaches €12,786,283. And for the degradation scenario, the damage from today scenario might increase by €8,512,241. Based on this, it can be said that the ecosystem service of water regulation that is provided by Green Infrastructure, in the present, by the catchments of the Oka and Golako rivers provides an approximately avoided cost of 8,5 million euros compared to the future trend of degradation of the catchment, and for 500 years return period event. For 100 year return period event the avoided cost is €1,705,821, and for the 50 years return period of €243,379, comparing same scenarios.

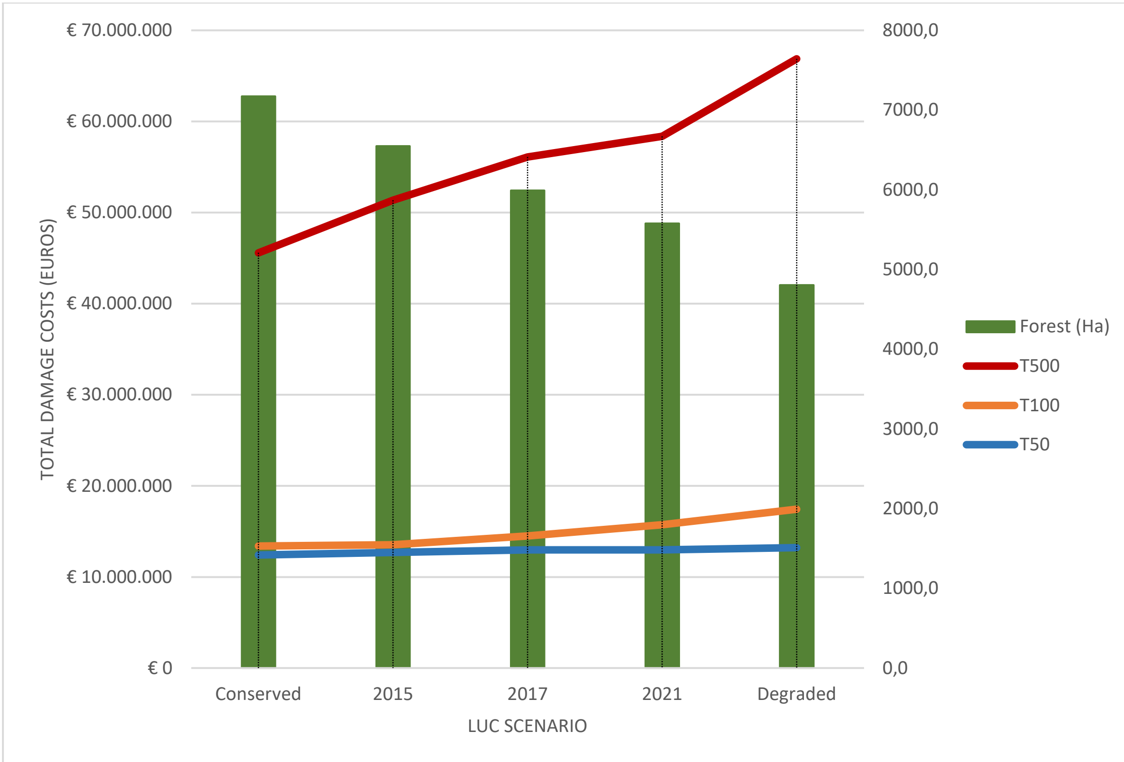


Figure 37 Total Damage Cost for all the Modelled Scenario.

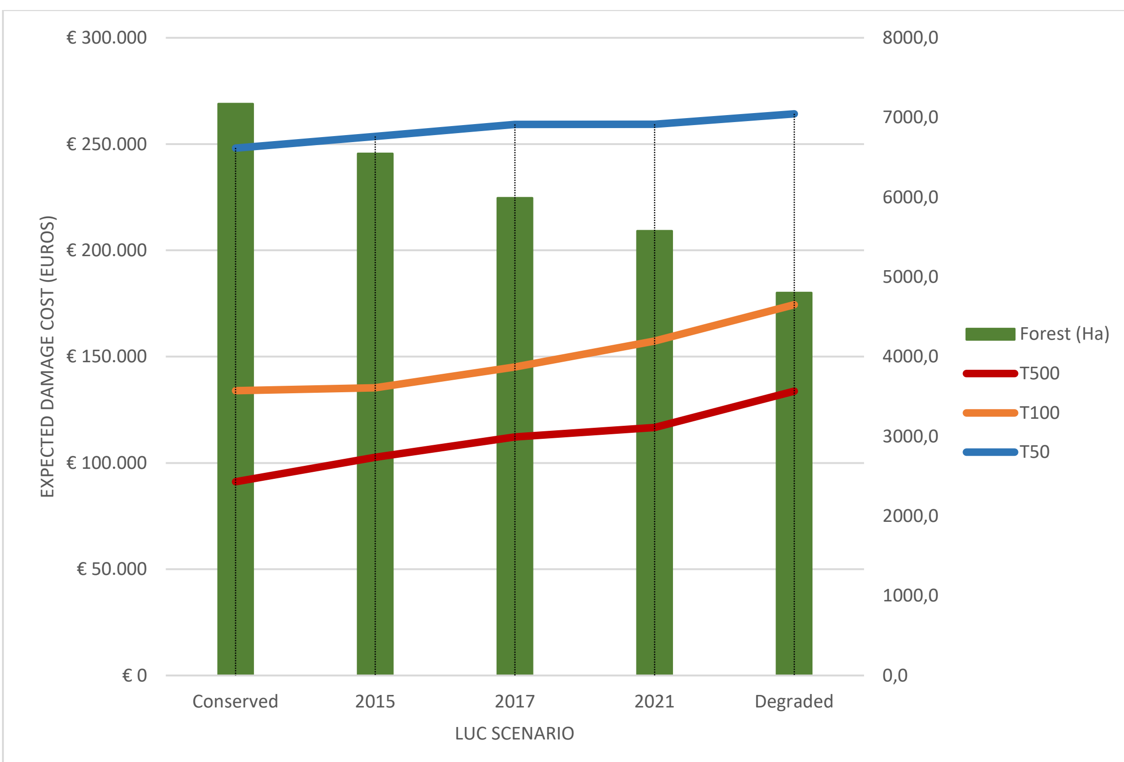


Figure 38 Expected Damage Cost for all the Modelled Scenario.

To understand the value of the forest per hectare, all the land cover scenarios were compared for the 500 years return period event, this analysis was developed by dividing the total damage cost difference between LUC scenarios and its change on the area of forest in the catchments. The final result is the avoided cost per hectare of forest, this is a better indicator of the contribution of each hectare in the reduction of damage costs for the worst probabilistic scenario (500 years). The mean avoided cost of damage is about €8,000 per hectare of forest, or in other words, each hectare of green infrastructure is contributing €8,000 to the reduction of 1loses in the urban area of Gernika-Lumo.

Table 11 Scenarios comparison, Total Damage Costs, Forest Loss and Cost per Hectare of Forest, for a 500 years return period event.

Total Damage Cost

	Restauration	2015	2017	2021	Degradation
Restauration		€ 5,769,998	€ 10,523,539	€ 12,786,283	€ 21,298,524
2015	-€ 5,769,998		€ 4,753,540	€ 7,016,285	€ 15,528,525
2017	-€ 10,523,539	-€ 4,753,540		€ 2,262,744	€ 10,774,985
2021	-€ 12,786,283	-€ 7,016,285	-€ 2,262,744		€ 8,512,241
Degradation	-€ 21,298,524	-€ 15,528,525	-€ 10,774,985	-€ 8,512,241	

Forest Loss (Hectares)

	Restauration	2015	2017	2021	Degradation
Restauration		626	1,181	1,595	2,370
2015	-626		556	969	1,744
2017	-1,181	-556		414	1,189
2021	-1,595	-969	-414		775
Degradation	-2,370	-1,744	-1,189	-775	

Avoided cost per hetare of forest

	Restauration	2015	2017	2021	Degradation
Restauration		€ 9,219	€ 8,907	€ 8,016	€ 8,986
2015	€ 9,219		€ 8,557	€ 7,240	€ 8,903
2017	€ 8,907	€ 8,557		€ 5,471	€ 9,065
2021	€ 8,016	€ 7,240	€ 5,471		€ 10,982
Degradation	€ 8,986	€ 8,903	€ 9,065	€ 10,982	

Between 2004 and 2013, the government of Spain spent 111 million euros to restore the areas of forest that were affected and damaged by fires in the country. In total the government invested 3,444 euros to restore one hectare of burned forest (Blanco et al, 2015). This means that the economic benefit of reforestation, only in terms of water regulation, is positively high, as the restoration of one hectare can bring a total benefit of €8,000 in avoided costs, with an investment of €3,444 per afforested hectare of forest. If we add other ecosystem services benefits that forest provide, as the carbon sequestration, erosion control, landslide control, climate regulation, groundwater recharge, soil formation, pollination among others, the benefit of Green Infrastructure would be greater, making the economic benefits of the forest much higher than its costs. It is possible to use this information to develop a complete cost-benefit analysis of an investment portfolio in nature for this same case study, in that sense it would be interesting to develop an afforestation project that aims to reduce the flood risk and provide other kind of services for the communities that are settled inside the Urdaibai area.

The total avoided cost results for each scenario shows the importance of green infrastructure in the reduction of flood hazard and total damage cost during a flood event. The biophysical properties of the natural forest contribute to the retention of water and reduction of total runoff inside a river catchment. This retention might decrease the economical loses that can cause an extreme flood event, the damage avoided cost of each scenario evidences the difference, in economic terms, of the contribution of the green infrastructure to the loses in the urban area of Gernika-Lumo. There is a direct connection between Green Infrastructure and the urban area in flood risk terms, the results of the research show that for strong rainfall events, the contribution of Green Infrastructure is significant, even more for less frequent events like 500 years return period event, and can be measured in economic terms, based on the urban area assets. A value to nature can be given based on the avoided damage contribution to urban areas. Extreme rainfall events are very likely to intensify as global temperatures rise due to global warming, precipitation is projected to increase over high altitudes based on the last Intergovernmental on Climate Change report (IPCC, 2021). Global warming catastrophic scenarios evidence how important is to invest in nature, not only for the carbon absorption and sequestration for the mitigation of climate change but also for water regulation and disaster risk reduction, as this research addresses. Cities need to prepare for more intense and frequent rainfall events that can cause floods in European cities and in other cities around the globe. These results show another method for valuating nature, in disaster reduction terms, looking forward to the creation of new tools and green markets, contributing to climate change mitigation, and the strengthening of ecosystem services and biodiversity.

Chapter 5: Conclusions and recommendations

There is a natural instinct that connect us, as with forests, this was normal for many different ancient cultures around the world that considered forests their home and sacred. Forests are a important part of communities' subsistence, and a source of plenty of resources, food, medicine and spirituality. In the Anthropocene era, we are starting to give again an important value to trees and forests, as we realize that we need them to tackle climate change and to avoid the course to a catastrophic planetary scenario. Forest is home of most of the biodiversity on the planet and provides plenty of valuable goods and services to humanity (Constanza et al, 1997). There are different kinds of studies that evidences the benefits and importance of trees and forest, including the water regulation and disaster risk reduction. Nevertheless, forest ecosystem services are not yet well valued and in other cases not valuated at all (Jenkins et al, 2018). This study aimed to evidence the importance of the ecosystems and its connection with urban areas, by assessing a flood risk analysis that relates the green infrastructure in the water basin, with total flood damages costs. In an era of climate crisis, Nature-based Solutions are not only an important tool for the mitigation of climate change, but also a strategy for integrated water resources management, as water basins are the main territories where ecosystems interact with cities through water. Thus, water basins would be developed and planned to maximise the quantity of services provision, without forgetting that we share the territory and resources with other species that are also part of the complexity of ecosystems.

The main research objective of this study was to assess the economic value of the ecosystem service of water regulation and the reduction of flood risk provided by the green infrastructure, that is, valuate the forest inside the catchments of the Oka and Golako rivers and its value in the reduction of the flood discharges. The study evidences the big potential that green infrastructure might have in the reduction of flood risk, by reducing the hazardous effect of floods. Five different land use cover scenarios were developed, three of them using satellite radar images of the present year, 2021, and previous years, 2017 and 2015, and other two developed scenarios that were based on the land use change trends. For every scenario there was a considerably increase and reduction on the amount of total flow discharge. From 2015 to 2020 the flood modelling results shows that there was an increment of 324.500 cubic meters of water for 500 years return period event that might reach the urban area of Gernika-Lumo. Between the extreme scenarios, the conservation and the degradation, the change of volume produced and not regulated by the catchment, for the same return period, might reach a total volume of 957.100 cubic meters, this is almost the 20% of the total volume produced by the same return period today, 2021.

In terms of economic losses all five scenarios result in different total flood damage costs, between 2015 and 2021 the difference of total flood damage costs might reach € 7,016,285 for the 500-year return period event. It can be said that this amount represents the value of the green infrastructure that has been lost in the last 6 years. Comparing the flood damage costs for the degradation and the conservation scenarios, the difference reaches € 21,298,524 for the 500-year return period event, a significant amount of damage costs. In order to check if green infrastructure is cost-effective, the area of green infrastructure in the whole water basin was related to the total difference in the damage cost, this was done by simply dividing the change of natural cover with the change on the total damage cost between scenarios. The result for the 500-years return period event shows for every scenario a total avoided damage cost of € 8,000 per hectare of forest. If the avoided cost per hectare is compared with the total cost of afforesting one hectare of forest in Spain, €3,444 (value for the year 2015), the investment on green infrastructure would be positive, with an approximate benefit of €4,556 per hectare. This benefit only considers the water regulation ecosystem service, but there are plenty of other ecosystem services like carbon absorption and sequestration, pollination, climate regulation and ground water recharge, that might be valuated and included into a complete ecosystem services assessment and that might increase the benefit of green infrastructure in the Oka and Golako rivers basins. There is an evident direct relationship between the economic losses and the cover of natural forest areas that helps in the regulation of flow discharge inside the Oka and the Golako river basins. It is also clear that the increase of the damage costs is higher for lower probability events. On the other hand, the expected damage cost is higher for 50 years return period events, because this event is more probable to happen, but the sensibility of the cost, with respect to the green infrastructure cover, is higher for 100 and 500 years return period event respectively.

The research proposes a conservation scenario, that would contribute a total avoided cost of € 12,786,283 in comparison with the actual scenario 2021. The conservation scenario consists of the reforestation and afforestation of 1,595 hectares of forest inside the Oka and Golako river basins, this is done mostly over the upstream areas of the catchment, where in the present there is a very intense timber industry activity and forest cover loss. Based on these areas, an investment portfolio in nature might be developed, where the strategic priority areas can be mapped and included into a financial analysis to assess the cost and benefits in a specific time frame, related with the time that a forest needs to reach maturity. In order to find the investment resources for a future project, it would be recommended to involve the industrial companies that are located inside the flood-prone area, who are the most affected by the possible floods. These companies could be the most interested stakeholders in the project, as they would be one of the primary benefited. The project can also be developed using the figure of Private-Public Partnerships due to the potential participation of both sectors in land planning and management.

The hydrologic modeling for ecosystem services valuation represents plenty of challenges that need attention. One of the most important is to reduce the uncertainty of the models regarding the kind of trees modeled as forest, this might change the quantity of canopy rain interception and the infiltration rate of the soil. There is an information gap and need for more research in this matter that is necessary to fill, in order to increase the reliability of this methodology. The understanding of the role of each species of forest in the retention of water and its role on the water cycle, could help to understand which kind of ecosystems provides more water regulation and be able to add this as input data in the hydrologic models. Having more detailed and precise hydrologic models will reduce the uncertainty of the difference of the total damage costs for each scenario, something that is very important for an effective decision making. This methodology might be very useful for urban resilience and land planning, disaster risk management, and the mitigation of climate change, it represents a new kind of integrated flood risk management that goes beyond civil engineering and turns into a land and urban management issue, involving different stakeholders that are also part of the entire river ecosystem. In the near future, it is hoped that this kind of study may be part of the integrated river basin management, as they provide a very interesting way of financing nature-based solutions in rural and urban areas and can give a guide in the strategic investment on green infrastructure in upstream river basins.

Urban planning also plays a very important role, and can be used to increase resilience in cities, as planning can be done based on flood risk reduction, this is also an opportunity to plan cities based on disaster risk reduction and adaptation to climate change (Rossano, 2021). This kind of study would be useful to create new financial mechanisms for nature-based solutions and Green Infrastructure, by creating new kinds of "water funds" for protecting nature inside water basins and calling the attention of investors that might be benefited from the water regulation as an ecosystem service. The strategic location of green infrastructure may also lead to a science-based policymaking for water basins, creating new areas and landscapes strategies that contribute to the regeneration of degraded ecosystems, and bringing more sustainable development options to people. These adaptation strategies are extremely necessary nowadays while facing the global warming consequences and can be used as a tool to mitigate global warming by increasing the carbon absorption and sequestration, and as an adaptation method, preparing water basins for stronger and more frequent rainfall events that the planet will face along this century.

Bibliography

- Abadie L. M, Sainz de Murieta E, Galarraga I. (2017**) Investing in adaptation: Flood risk and real option application to Bilbao**. Environmental Modelling & Software. Elsevier.
- Agencia Vasca del Agua, URA. (2018). **Revisión y Actualización de la Evaluación Preliminar del Riesgo de Inundación. 2do Ciclo.** Ministerio para la transición ecológica. Anexo 1 – Registro de eventos de inundación.
- Agencia Vasca del Agua, URA. (2018). **Revisión y Actualización de la Evaluación Preliminar del Riesgo de Inundación. 2do Ciclo.** Ministerio para la transición ecológica. Anexo 3 – Fichas de las ARPSIS.
- Almenar J, Elliot T, Rugani B, Philippe B, Navarrete T, Sonnemann G, Geneletti D. (2021). **Nexus between nature-based solutions, ecosystem services and urban challenges**. Land Use Policy 100 (2021) 104898. Elsevier.
- Aparicio, F. (1997). **Fundamentos de Hidrología de Superficie**. Balderas, México: Limusa. 303 p.
- Blanco A, Villagrán X, Grasso D. (2015, August 15). **El Coste de los Incendios: sólo se recupera un 19% de las hectáreas calcinadas**. *El Confidencial*. https://www.elconfidencial.com/espana/2015-08-15/coste-incendios-solo-recupera-19-hectareas-calcinadas_966540/
- Brunner G, CEIWR-HEC (2020) **HEC-RAS Hydraulic Reference Manual**, US Army Corps of Engineers, Hydrologic Engineering Center, Version 6.0 Beta.
- Brunner G, CEIWR-HEC. (2021). **HEC-RAS River Analysis System User's Manual. Version 6.0**. US Army Corps of Engineers. Hydrologic Engineering Center.
- Chaudhry M.H (2008). **Open-Channel Flow**. University of South Carolina. Springer.
- Chausson ,A., Turner, B., Seddon, D., Chabaneix, N., Girardin, C., Kapos, V., Key, I., Roe, D., Smith, A., Woroniecki, S., Seddon, N. (2020) **Mapping the effectiveness of nature-based solutions for climate change adaptation**. Global Change Biology.
- Chow V, Maidment D, Mays L. (1988). **Applied Hydrology**. Mc Graw Hill.
- Chow V. (1959). **Open-Channel Hydraulics**. University of Illinois, McGraw-Hill.
- Commission of the European Communities (2007) **Proposal for a Directive of the European Parliament and of the European Council on the assessment and management of floods.** Official Journal of European Union.
- Copernicus Sentinel data (2021). Retrieved from ASF DAAC (19 May 2021), processed by ESA.
- Costanza R, d'Arge R, de Groot R, Farber S, Grasso M, Hannon B, Limburg K, Naeem S, O'Neill R, Paruelo J, Raskin R, Sutton P, van den Belt M. (1997) **The value of the world's ecosystem services and natural capital**, Ecological Economics,Volume 25, Issue 1,1998,Pages 3-15,ISSN 0921-8009,https://doi.org/10.1016/S0921-8009(98)00020-2.
- Da Silva J, Wheeler E (2017) **Ecosystems as infrastructure**. Associação Brasileira de Ciência Ecológica e Conservação. Perspectives in Ecology and Conservation 15 (2017) 32-35.
- Directorate-General for Research and Innovation (European Commission), & Arnbjerg-Nielsen, K. (2021). **Evaluating the impact of nature-based solutions: A handbook for practitioners.** European Union. https://doi.org/10.2777/244577

- Egaña J, Gaztelumendi S (2018). **A Study of an intense and persistent precipitation event in Basque Country: the 11 January 2018 case.** EMS Annual Meeting 2018, European Conference for Applied Meteorology and Climatology, Budapest.
- European Commission, 2013. **Communication from the Commission to the European Parliament, the Council, The European Economic and Social Committee and the Committee of the Regions. Green Infrastructure (GI) – Enhancing Europe's Natural Capital.** European Commission, Brussels.
- European Environmental Agency (2021). **Nature based-Solutions in Europe: Policy, knowledge, and practice for climate change adaptation and disaster risk reduction**. EEA report No 01/202. doi: 10.2800/919315
- Eusko Jaurlaritza / Gobierno Vasco (2021). **GeoEuskadi**. Instituto Geográfico Nacional. Spain.
- Feldman A. (2000). **Hydrologic Modeling System HEC-HMS Technical Reference Manual**. US Army Corps of Engineers. Hydrologic Engineering Center.
- Gómez-Sanz V, Escorial Garcia I, Roldan Soriano M. (2019). **Lithology and hydrological properties of Madrid Autonomous Community soils**. Sociedad Española de Ciencias Forestales. https://doi.org/10.31167/csecfv0i45.19513
- Green-Gray Community of Practice (2020). **Practical Guide to Implementing Green-Gray Infrastructure.**
- Huizinga J, de Moel H, Szewczyk W. (2017). **Global Flood Depth-Damage Functions.** European Commission. European Union.
- IPCC (2012). **Managing the risk of extreme events and disasters to advance climate change adaptation**. Special report of the intergovernmental panel on climate change. United Nations Environment Programme (UNEP) and the World Meteorological Organization (WMO).
- IPCC (2021). **Summary for Policymakers. In: Climate Change 2021: The Physical Science Basis. Contribution of Working Group I to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change.** Cambridge University Press. In Press.
- Jenkins M, Schaap B. (2018). **Forest Ecosystem Services.** Background Analytical Study 1. Global Forest Goals. United Nations.
- Kamble B, Kilic A, Hubbard K (2013). **Estimating Crop Coefficients Using Remote Sensing-Based Vegetation Index**. Remote Sensing. https://doi:10.3390/rs5041588
- Kirpich Z.P. (1940). **Time of concentration of small agricultural watersheds**. Journal of Civil Engineering, 10(6), 362.
- Martinez-Gomariz E, Forero-Ortiz E, Guerrero-Hidalga M, Castán S, Gomez M (2020). **Flood Depth-Damage Curves for Spanish Urban Areas**. Sustainability. https://doi.org/10.3390/su12072666
- Messner F, Penning-Rowsell E, Green C, Meyer V, Tunstall S, van der Veen, A. (2007). **Evaluating Flood Damages: Guidance and recommendations on principles and methods**. FLOODsite.
- National Oceanic and Atmospheric Administration (NOAA) (2015). **A Guide to Assessing Green Infrastructure Costs and Benefits for Flood Reduction**. Economics of Green Infrastructure.
- NRCS-USDA (2007). **National Engineering Handbook**. United States Department ofAgriculture, https://www.nrcs.usda.gov/wps/portal/nrcs/detailfull/national/water/?cid=stelprdb1043063

- Perdikaris J, Gharabaghi B, Rudra R. (2018). **Reference Time of Concentration Estimation for Ungauged Catchments.** Earth Science Research Vol 7. https://doi.org/10.5539/esr.v7n2p58
- Pistrika A, Tsakiris G (2007) **Flood Risk Assessment: A Methodological Framework**. Centre for the Assessment of natural Hazards & Proactive Planning, National technical University of Athens, Greece.
- PLANYC (2010), **NYC Green Infrastructure, A Sustainable Strategy for Clean Waterways**. New York City.
- Rossano F.L.M (2021). **Floodscapes: Contemporary Landscape Strategies in Times of Climate Change**. Nai010 Publishers.
- Ruangpan L, Vojinovic Z, Di Sabatino S, Leo S, Capobianco V, Oen A, McClain M, Lopez-Gunn E. (2019) **Nature-based Solutions for hydrometeorological risk reduction: A state-of-the-art review of the research area.** Natural Hazards and Earth System Sciences.
- Samuels, P., M. Morris, P. Sayers, J-D. Creutin, A. Kortenhaus, F. Klijn, E. Mosselman, A. van Os and J. Schanze. (2010) **Framework for integrated flood risk management.** Proceedings of the International Association of Hydraulic Research, IAHR, Venice.
- Schanze J, Bakonyi P, Borga M, Marchand M, Jiménez J, Kaiser G. (2009). **Methodologies for Integrated Flood risk Management – Research Advances at European Pilot Sites (Book Manuscrit)**. FLOODSite, European Community.
- Sudmeier-Rieux, K., Nehren, U., Sandholz, S., and Doswald, N. (2019) **Disaster and Ecosystems, Resilience in a Changing Climate** – Source Book. Geneva: UNEP and Cologne: TH Köln – University Applied Sciences.
- TEEB (2010) **The Economics of Ecosystem and Biodiversity: Mainstreaming the Economics of Nature: A synthesis of the approach, conclusions and recommendations of TEEB.**
- United Nations, Department of Economic and Social Affairs, Population Division (2015). **World Urbanization Prospects: The 2014 Revision**, (ST/ESA/SER.A/366).
- United States Department of Agriculture, Natural Resources Conservation Service (2004). **Hydrologic Soil-Cover Complexes**, Chapter 9. July 2004.
- United States Department of Agriculture, Natural Resources Conservation Service (2004). **Hydrologic Soil. Groups**, Chapter 7. May 2007.
- Van Thiel S (2014) **Research in Public Administration and Public Management: an introduction**. Routledge, New York.
- World Meteorological Organization (2009). **Integrated Flood Management, Concept Paper**. Associated Programme on Flood Management
- Yu D, Xie P, Dong X, Hu X, Liu J, Li Y, Peng T, Ma H, Wang K, Xu S (2018). **Improvement of the SWAT model for event-based flood simulation on a sub-daily timescale**. Hydrol.Earth Syst.Sci., 22, 5001-5019, 2018.
- Yu K, Wang S, Li S. (2011) **The negative approach to urban growth planning of Beijing, China.** Journal of Environmental Planning and Management, Vol. 54, No 9, 1209-1236.
- Zhang J, Yu Z, Tu T, Si J, Feng Q, Cao S. (2018) **Transforming flash floods into resources in arid China**. Land Use Policy. https://doi.org/10.1016/j.landusepol.2018.03.002
- Zhang, X. (2018)**. Urban resilience and urban sustainability: what we know and what do not know?** Cities- 141-148.

Annex 1: Data tables

Table 12 G063-Muxika (Oka) - Maximum precipitation (mm) in 24 hours (Own development based on data from: Open Data Euskadi)

YEAR	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DIC
2002	12.5	24.5	6.4	31.6	34.1	18.2	21.5	95	15.9	49.6	25.7	51.7
2003	42.4	28.9	29.6	11.1	46.4	21.2	15.6	14.9	31.7	25.9	36.9	35.2
2004	50.9	37.7	23.9	23	25.6	7.3	29	8.6	20.8	38.9	40.9	34.2
2005	37.3	23.1	26.5	45	31.6	2	3.7	32.5	29.3	18.6	69.5	33.2
2006	22.4	38.2	62.4	13.4	15.1	14.9	13.5	9.9	46.1	33.3	77.2	34.2
2007	44.8	31.5	29.2	28.1	8	18.7	7.2	73.2	17	19	15.7	23.4
MAX	**50.90**	**38.20**	**62.40**	**45.00**	**46.40**	**21.20**	**29.00**	**95.00**	**46.10**	**49.60**	**77.20**	**51.70**

Table 13 1082 - Bilbao (Aeropuerto) - Maximum precipitation (mm) in 24 hours (Own development based on data from: Open Data Euskadi)

YEAR	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DIC
1970	**21.4**	**33.2**	**18.1**	**18.4**	**17.5**	**16.8**	**9**	**63.7**	**43.4**	**35.7**	**32.2**	**22.4**
1971	**19.2**	**21.6**	**58.5**	**62**	**22.2**	**37.2**	**31**	**26.4**	**22.8**	**24.1**	**51.8**	**37.6**
1972	**37.1**	**34.5**	**12.5**	**32.4**	**32.3**	**16.9**	**29.3**	**30.3**	**18.4**	**8.2**	**19.1**	**25.2**
1973	**42.8**	**50.7**	**13.4**	**35.9**	**41**	**22**	**12.6**	**56.1**	**53**	**19.9**	**26**	**31.7**
1974	**12.8**	**29.5**	**32.8**	**20.4**	**17.1**	**10.1**	**56.3**	**33.9**	**16.1**	**58.8**	**47.8**	**22.1**
1975	**14.1**	**13.9**	**45.3**	**46.4**	**16.7**	**21.2**	**6.6**	**22.5**	**26.6**	**41.9**	**31.5**	**28.1**
1976	**25.6**	**23**	**27.9**	**51.1**	**6.2**	**1.5**	**42.9**	**25.5**	**20.3**	**27.8**	**19.3**	**39.7**
1977	**24.4**	**31.4**	**20**	**11.1**	**65.6**	**100.2**	**61.4**	**29.8**	**2.4**	**23.1**	**44.8**	**41.6**
1978	**36.8**	**13.6**	**36.4**	**30**	**62.4**	**40.5**	**6.8**	**24.4**	**38.3**	**29.1**	**41.5**	**18.6**
1979	**52.3**	**23**	**26.9**	**25.6**	**17.8**	**13.1**	**15**	**16.5**	**24.8**	**37.4**	**61.6**	**56.8**
1980	**19.4**	**8.2**	**26.5**	**23.4**	**40**	**26.9**	**16.1**	**15**	**4.9**	**43.4**	**33**	**43**
1981	**44.1**	**11.6**	**53**	**27.9**	**19.6**	**13.2**	**14**	**3**	**19.4**	**43.7**	**8.4**	**22.8**
1982	**55.9**	**23.5**	**18.6**	**4.6**	**11**	**24**	**23.6**	**12.6**	**14.8**	**29.4**	**26.6**	**38.5**
1983	**8**	**20**	**17.6**	**29.7**	**10.2**	**13.4**	**51.4**	**252.6**	**10**	**15.5**	**14.9**	**20.1**
1984	**28.1**	**28.8**	**6.9**	**12.7**	**27.5**	**15.2**	**3**	**67.3**	**39.4**	**39.3**	**54.6**	**66.2**
1985	**32.4**	**17**	**27.7**	**11.4**	**47.3**	**17.5**	**28.2**	**16.1**	**0.3**	**30**	**48.8**	**14.9**
1986	**53.7**	**18.3**	**14.6**	**25.2**	**9.2**	**35.9**	**5.6**	**16.7**	**25.3**	**16.4**	**22.8**	**17**
1987	**25.1**	**16.1**	**19.9**	**15.1**	**9.6**	**52.4**	**13.6**	**14.2**	**37.8**	**34.9**	**30.6**	**15.1**
1988	**26.7**	**20.7**	**18.8**	**48.9**	**16.4**	**35.6**	**48.7**	**30.2**	**23.8**	**2.6**	**3.8**	**26.9**
1989	**30.4**	**34.3**	**15.5**	**92.4**	**29.4**	**8.9**	**4.7**	**17.9**	**17.9**	**12.7**	**46.4**	**6.7**
1990	**34.8**	**14.5**	**12.4**	**41.4**	**11.9**	**13**	**21.6**	**16**	**14.9**	**33.9**	**38.7**	**34**
1991	**16.7**	**9.8**	**83.8**	**20.4**	**39.6**	**7.2**	**13.7**	**9.1**	**64**	**34.9**	**33.6**	**8.8**
1992	**10**	**13.9**	**35.4**	**10**	**23.4**	**68.6**	**15.6**	**36.5**	**44.9**	**84.6**	**29.7**	**26.9**
1993	**6.1**	**21**	**22.9**	**66.9**	**11.4**	**19.8**	**20.3**	**56**	**16.7**	**17.2**	**24.6**	**56**
1994	**16.5**	**18.8**	**14.3**	**55.6**	**23**	**14.8**	**43.3**	**19**	**44.7**	**43.9**	**37.1**	**36.8**

1995	**45.2**	**26.4**	**34.1**	**36.1**	**30.4**	**11**	**12.8**	**7.2**	**14.7**	**12.8**	**53.5**	**14.4**
1996	**14.9**	**34.2**	**13.6**	**9.2**	**23**	**23.1**	**37.1**	**41.4**	**26.3**	**24.5**	**37.4**	**62**
1997	**52.4**	**9.1**	**8.2**	**14.6**	**12.7**	**23.5**	**67.7**	**25.1**	**21.6**	**9.4**	**33.1**	**22**
1998	**41.3**	**21.9**	**9.1**	**25.3**	**27.9**	**9.4**	**8.7**	**26.1**	**26.3**	**65.7**	**50.8**	**9.6**
1999	**25.5**	**29.2**	**25.7**	**15.5**	**19.7**	**10.7**	**8.7**	**10.4**	**18.6**	**6.4**	**25.3**	**32.1**
2002	**16.9**	**21.3**	**6.8**	**12.2**	**17.9**	**11.6**	**12.3**	**30.9**	**20.8**	**25.4**	**29.5**	**62.6**
2003	**26.4**	**18.6**	**18.8**	**14.5**	**30.7**	**15.1**	**11.3**	**9.9**	**41.1**	**22.3**	**26.3**	**26.1**
2004	**33.9**	**29.8**	**26.7**	**26.6**	**10.3**	**9.9**	**32.3**	**6.5**	**7.2**	**34.2**	**43.4**	**31.4**
2005	**23.1**	**19.2**	**22.3**	**32.2**	**45.6**	**10.5**	**6.3**	**36.8**	**30.4**	**24.7**	**52.6**	**35.3**
2006	**19.7**	**30.2**	**31.4**	**16.6**	**28**	**22.8**	**18.8**	**13.8**	**23.4**	**28.2**	**85.2**	**32.5**
2007	**36.2**	**44.1**	**30.3**	**12.8**	**24.4**	**13.3**	**7.8**	**41.9**	**14.9**	**13.2**	**18.5**	**15.1**
2008	**16.1**	**14.7**	**31.4**	**17.8**	**92.5**	**32.8**	**6**	**17.7**	**21.1**	**47.5**	**55.4**	**34.1**
2009	**51.1**	**18.1**	**27.8**	**18.8**	**15.7**	**12.2**	**5.7**	**10.5**	**90.1**	**14.9**	**37.1**	**18.9**
2010	**48.2**	**9.4**	**14**	**12.4**	**21.4**	**108.1**	**13.9**	**7.5**	**15.9**	**24.7**	**24.8**	**25.4**
2011	**6.3**	**27**	**26.3**	**10.1**	**8.2**	**13.5**	**25**	**13.7**	**12.4**	**16.3**	**81.1**	**36.3**
2012	**13.9**	**16.7**	**8.9**	**48.5**	**22.3**	**23.2**	**10**	**3**	**23.5**	**24.9**	**33.6**	**27.6**
2013	**43.9**	**57.7**	**19.5**	**24.3**	**19.3**	**28.2**	**13.9**	**19.8**	**11.9**	**17.9**	**49.9**	**15.4**
2014	**19.7**	**37.7**	**35**	**11.2**	**20.2**	**8.3**	**11.5**	**6.4**	**8.1**	**6.3**	**64.4**	**25.2**
2015	**82.1**	**32.8**	**26.6**	**19.1**	**17.5**	**9.1**	**11.3**	**21.8**	**15**	**30.5**	**35.3**	**4.7**
MAX	**82.10**	**57.70**	**83.80**	**92.40**	**92.50**	**108.10**	**67.70**	**252.60**	**90.10**	**84.60**	**85.20**	**66.20**

Table 14 Hyetograms values for T50, T100 and T500

Instant (min)	T50	T100	T500
5	0.89	1.04	1.47
10	0.93	1.08	1.54
15	0.97	1.13	1.61
20	1.02	1.19	1.69
25	1.07	1.25	1.78
30	1.14	1.32	1.88
35	1.21	1.41	2.01
40	1.3	1.51	2.16
45	1.41	1.64	2.33
50	1.55	1.8	2.56
55	1.72	2	2.85
60	1.96	2.28	3.25
65	2.32	2.7	3.84
70	2.91	3.39	4.82
75	4.21	4.9	6.97
80	19.35	22.52	32.04
85	5.85	6.81	9.69
90	3.41	3.97	5.64
95	2.57	2.99	4.26

Instant (min)	T50	T100	T500
100	2.12	2.47	3.51
105	1.83	2.13	3.03
110	1.63	1.89	2.69
115	1.47	1.72	2.44
120	1.35	1.57	2.24
125	1.25	1.46	2.08
130	1.17	1.37	1.94
135	1.1	1.29	1.83
140	1.05	1.22	1.73
145	0.99	1.16	1.65
150	0.95	1.1	1.57
155	0.91	1.06	1.5

Table 15 Curve Number Tables

LUC	**2021**		**Oka**		**Golako**	
CN	AREA	**CN*AREA**	AREA	**CN*AREA**	AREA	**CN*AREA**
30	2698278.0	80948340	1638491.3	49154737.5	1081343.9	32440316
55	21137610.0	1162568550	16440872.0	904247960.0	4580668.5	251936768
68	615743.9	41870587.75	343590.7	23364168.9	297355.0	20220138
70	31183034.0	2182812380	16758721.0	1173110470.0	14393383.0	1.008E+09
74	802666.3	59397302.5	502515.4	37186140.1	271650.4	20102130
77	943407.7	72642391.94	558474.8	43002560.6	422956.8	32567672
79	8849120.0	699080480	6714009.0	530406711.0	2243306.8	177221233
83	5913341.0	490807303	4719616.0	391728128.0	1173646.6	97412670
85	978593.1	83180410.31	942356.3	80100286.6	42646.2	3624926.6
86	14093939.0	1212078754	9110190.0	783476340.0	4730806.5	406849359
88	6685220.0	588299360	4410720.0	388143360.0	2364819.0	208104072
89	1961584.4	174581009.4	963620.9	85762257.9	1003061.9	89272507
90	1510771.8	135969457.5	792385.1	71314661.3	627424.8	56468233
92	277084.8	25491799.88	238387.0	21931608.3	29209.7	2687294.5
98	2051746.9	201071193.8	1647444.8	161449585.5	403094.2	39503227

CN comp	**72.32**		**72.12**		**72.65**

LUC	**2017**		**Oka**		**Golako**	
CN	AREA	**CN*AREA**	AREA	**CN*AREA**	AREA	**CN*AREA**
30	2959969.25	88799077.5	1842183.5	55265505	1185330.5	35559915
55	22525234	1238887870	17119100	941550500	5477991.5	301289533
68	409029.9063	27814033.63	239506.2344	16286423.94	148385.3906	10090207

70	33536054	2347523780	17827546	1247928220	15687373	1.098E+09
74	796069	58909106	475654.9063	35198463.06	317217.5938	23474102
77	758684.5	58418706.5	386119.875	29731230.38	350516.6563	26989783
79	9165789	724097331	7439243	587700197	1639249.625	129500720
83	3221660.25	267397800.8	2468928.75	204921086.3	716222.375	59446457
85	719101	61123585	678227.9375	57649374.69	34467.47266	2929735.2
86	12657937	1088582582	9285903	798587658	3348018.25	287929570
88	4875372.5	429032780	2567417.25	225932718	2200660.5	193658124
89	2487165.75	221357751.8	1169551.5	104090083.5	1290485.5	114853210
90	646531.1875	58187806.88	471178.1563	42406034.06	270482.0313	24343383
92	208913.125	19220007.5	156686.3281	14415142.19	32130.69531	2956024
98	4701645	460761210	3661983.25	358874358.5	968010.1875	94864998

CN comp	**71.74**		**71.75**		**71.47**

LUC	**2015**		**Oka**		**Golako**	
CN	AREA	**CN*AREA**	AREA	**CN*AREA**	AREA	**CN*AREA**
30	2876404	86292120	1771674.625	53150238.75	1178320.25	35349608
55	24768300	1362256500	18604262	1023234410	6166172.5	339139488
68	365048.2188	24823278.88	175712.5156	11948451.06	165911.2188	11281963
70	36709336	2569653520	20015558	1401089060	16608064	1.163E+09
74	914819.625	67696652.25	626745.3125	46379153.13	262303.3125	19410445
77	1007181.188	77552951.44	508111.375	39124575.88	470860.7188	36256275
79	6493899.5	513018060.5	5432538.5	429170541.5	1050381.625	82980148
83	4211249	349533667	3441503.25	285644769.8	710964.625	59010064
85	789471.75	67105098.75	738664.0625	62786445.31	33299.08203	2830422
86	9071228	780125608	6689387	575287282	2270179.5	195235437
88	5605469	493281272	3197520.25	281381782	2430833	213913304
89	2056145	182996905	905423.125	80582658.13	1145021.125	101906880
90	1033570.188	93021316.88	745379.25	67084132.5	351685.0625	31651656
92	263890.2813	24277905.88	208168.9688	19151545.13	33883.27734	3117261.5
98	3503143.25	343308038.5	2722984.5	266852481	788078.3125	77231675

CN comp	**70.58**		**70.58**		**70.45**

LUC	**AFFORESTED**		**Oka**		**Golako**	
CN	AREA	**CN*AREA**	AREA	**CN*AREA**	AREA	**CN*AREA**
30	3951756.75	118552702.5	2417446	72523380	1574404	47232120
55	27145512	1493003160	20181198	1109965890	6951914	382355270

68	136343.3125	9271345.25	95130.98438	6468906.938	39725.22266	2701315.1
70	39730880	2781161600	21016112	1471127840	18631714	1.304E+09
74	131945.1406	9763940.406	70508.84375	5217654.438	60756.22266	4495960.5
77	998384.875	76875635.38	505873	38952221	462097.8125	35581532
79	5576881	440573599	4844965	382752235	705122.6875	55704692
83	2821426.75	234178420.3	2517053.75	208915461.3	307286.2813	25504761
85	774078.125	65796640.63	725233.8125	61644874.06	22783.58398	1936604.6
86	8046454	691995044	6183514	531782204	1775366.875	152681551
88	3839603.5	337885108	2750964.25	242084854	1083096.5	95312492
89	2053945.875	182801182.9	905423.125	80582658.13	1143852.75	101802895
90	991787.5625	89260880.63	736425.6875	66278311.88	318970.1563	28707314
92	263890.2813	24277905.88	208168.9688	19151545.13	33883.27734	3117261.5
98	3206266.75	314214141.5	2625615	257310270	554984.75	54388506
CN comp	**68.92**		**69.24**		**68.19**	

LUC	**DEGRADATED**		**Oka**		**Golako**	
CN	AREA	**CN*AREA**	AREA	**CN*AREA**	AREA	**CN*AREA**
30	2377211.5	71316345	1450467.625	43514028.75	948731.75	28461953
55	18263406	1004487330	14166682	779167510	3910597.5	215082863
68	622341.1875	42319200.75	342471.5313	23288064.13	298523.375	20299590
70	26685904	1868013280	14256217	997935190	12411795	868825650
74	1117135.5	82668027	692777.375	51265525.75	403094.1563	29828968
77	941208.625	72473064.13	557355.625	42916383.13	421204.1875	32432722
79	9660583	763186057	7538850.5	595569189.5	2253238	178005802
83	7976083.5	662014930.5	6168964.5	512024053.5	1833786.375	152204269
85	978593.0625	83180410.31	942356.3125	80100286.56	42646.19531	3624926.6
86	15558530	1338033580	9409014	809175204	5899779.5	507381037
88	9735352	856710976	6625593	583052184	3177433.5	279614148
89	1963783.375	174776720.4	963620.875	85762257.88	1004814.438	89428485
90	1501975.5	135177795	785670	70710300	627424.8125	56468233
92	277084.7813	25491799.88	238387.0469	21931608.31	29209.72266	2687294.5
98	2042950.5	200209149	1642968	161010864	403094.1563	39503227
CN comp	**74.02**		**73.84**		**74.37**	

Table 16 Peak discharges for the all the modelling scenarios.

Scenario	2021	T50	T100	T500	T50	T100	T500
River Basin	Area (KM2)	Peak Discharge (m3/s)	Peak Discharge (m3/s)	Peak Discharge (m3/s)	Volume (1000 M3)	Volume (1000 M3)	Volume (1000 M3)
Oka_Basin	65.85	96.9	130.4	248.7	1395.2	1885	3570.6
Golako_Basin	33.71	51.1	69.4	137.5	661.4	897.3	1786
Junction	99.56	145.6	197.2	382.3	2056.6	2782.3	5356.7

Scenario	2015	T50	T100	T500	T50	T100	T500
River Basin	Area (KM2)	Peak Discharge (m3/s)	Peak Discharge (m3/s)	Peak Discharge (m3/s)	Volume (1000 M3)	Volume (1000 M3)	Volume (1000 M3)
Oka_Basin	65.85	87.4	119.1	235.5	1253.8	1713.5	3381.7
Golako_Basin	33.71	44.1	60.9	127	569	784	1650.5
Junction	99.56	129.5	177.7	358.9	1822.8	2497.5	5032.2

Scenario	2017	T50	T100	T500	T50	T100	T500
River Basin	Area (KM2)	Peak Discharge (m3/s)	Peak Discharge (m3/s)	Peak Discharge (m3/s)	Volume (1000 M3)	Volume (1000 M3)	Volume (1000 M3)
Oka_Basin	65.85	93.1	126	245.5	1334.7	1811.2	3524.8
Golako_Basin	33.71	46.7	64.1	131.8	602.4	824.7	1712.7
Junction	99.56	137.7	187.6	373.6	1937.1	2635.9	5237.5

Scenario	Degraded	T50	T100	T500	T50	T100	T500
River Basin	Area (KM2)	Peak Discharge (m3/s)	Peak Discharge (m3/s)	Peak Discharge (m3/s)	Volume (1000 M3)	Volume (1000 M3)	Volume (1000 M3)
Oka_Basin	65.85	105.3	141.1	263.9	1522.7	2038.5	3787.4
Golako_Basin	33.71	52.5	71.2	141.3	673.7	918.2	1830.8
Junction	99.56	156.3	209.9	401.3	2196.4	2956.7	5618.2

Scenario	Conserved	T50	T100	T500	T50	T100	T500
River Basin	Area (KM2)	Peak Discharge (m3/s)	Peak Discharge (m3/s)	Peak Discharge (m3/s)	Volume (1000 M3)	Volume (1000 M3)	Volume (1000 M3)
Oka_Basin	65.85	82.3	113.6	224.2	1195.1	1644.4	3221.3
Golako_Basin	33.71	35.6	50.8	111	458.2	656.6	1439.8
Junction	99.56	117.1	162.8	332.4	1653.3	2300.9	4661.1

Table 17 Discharge distribution for the hydraulic model, for the all the scenarios.

2017	T50	T100	T500
Reach	**Q (m/s)**	**Q (m/s)**	**Q (m/s)**
aflud	11.6	15.8	30.7

Corta	5.0	5.0	5.0
GOLAKO-1	46.7	64.1	131.8
KANPANTXU-1	11.6	15.8	30.7
KANPANTXU-1.1	23.3	31.5	61.4
OKA_5	69.8	94.5	184.1
OKA-4.2	69.8	94.5	184.1
OKA-3	93.1	126.0	245.5
OKA-4.1	93.1	126.0	245.5
OKA-2	137.7	187.6	373.6
OKA-2	137.7	187.6	373.6
Oka Peak	93.1	126.0	245.5
Golako Peak	46.7	64.1	131.8
Total Peak	137.7	187.6	373.6

2015	T50	T100	T500
Reach	**Q (m/s)**	**Q (m/s)**	**Q (m/s)**
aflud	10.9	14.9	29.4
Corta	5.0	5.0	5.0
GOLAKO-1	44.1	60.9	127.0
KANPANTXU-1	10.9	14.9	29.4
KANPANTXU-1.1	21.9	29.8	58.9
OKA_5	65.6	89.3	176.6
OKA-4.2	65.6	89.3	176.6
OKA-3	87.4	119.1	235.5
OKA-4.1	87.4	119.1	235.5
OKA-2	129.5	177.7	358.9
OKA-2	129.5	177.7	358.9
Oka Peak	87.4	119.1	235.5
Golako Peak	44.1	60.9	127.0
Total Peak	129.5	177.7	358.9

2021	T50	T100	T500
Reach	**Q (m/s)**	**Q (m/s)**	**Q (m/s)**
aflud	12.1	16.3	31.1
Corta	5.0	5.0	5.0

GOLAKO-1	51.1	69.4	137.5
KANPANTXU-1	12.1	16.3	31.1
KANPANTXU-1.1	24.2	32.6	62.2
OKA_5	72.7	97.8	186.5
OKA-4.2	72.7	97.8	186.5
OKA-3	96.9	130.4	248.7
OKA-4.1	96.9	130.4	248.7
OKA-2	145.6	197.2	382.3
OKA-2	145.6	197.2	382.3
Oka Peak	96.9	130.4	248.7
Golako Peak	51.1	69.4	137.5
Total Peak	145.6	197.2	382.3

DEGRADATION	T50	T100	T500
Reach	**Q (m/s)**	**Q (m/s)**	**Q (m/s)**
aflud	13.2	17.6	33.0
Corta	5.0	5.0	5.0
GOLAKO-1	52.5	71.2	141.3
KANPANTXU-1	13.2	17.6	33.0
KANPANTXU-1.1	26.3	35.3	66.0
OKA_5	79.0	105.8	197.9
OKA-4.2	79.0	105.8	197.9
OKA-3	105.3	141.1	263.9
OKA-4.1	105.3	141.1	263.9
OKA-2	156.3	209.9	401.3
OKA-2	156.3	209.9	401.3
Oka Peak	105.3	141.1	263.9
Golako Peak	52.5	71.2	141.3
Total Peak	156.3	209.9	401.3

CONSERVATION	T50	T100	T500
Reach	**Q (m/s)**	**Q (m/s)**	**Q (m/s)**
aflud	10.9	14.9	29.4
Corta	5.0	5.0	5.0
GOLAKO-1	44.1	60.9	127.0

KANPANTXU-1	10.9	14.9	29.4
KANPANTXU-1.1	21.9	29.8	58.9
OKA_5	65.6	89.3	176.6
OKA-4.2	65.6	89.3	176.6
OKA-3	87.4	119.1	235.5
OKA-4.1	87.4	119.1	235.5
OKA-2	129.5	177.7	358.9
OKA-2	129.5	177.7	358.9
Oka Peak	82.3	113.6	224.2
Golako Peak	35.6	50.8	111.0
Total Peak	117.1	162.8	332.4

Table 18 Flood Damage curves values (Euros/m2) for each building type and Flood depth.

Depth inside the property [m]	Deposito (Warehouses)	Edificacion en ruinas (Ruins)	Edificacion generica (Dwelling)	Edificacion ligera (Workshops)	Edificio religioso (Churches)	Edificio singular (Singular Buildings)	Invernadero (Industries)	Nave (Industries)
0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
0.05	45.80	2.64	16.11	22.12	11.93	11.93	56.62	56.62
0.10	91.60	5.28	38.52	53.53	32.88	32.88	123.61	123.61
0.20	135.54	13.20	68.46	85.61	44.84	44.84	174.87	174.87
0.30	172.04	19.80	98.40	110.01	56.80	56.80	250.86	250.86
0.40	208.54	19.80	103.54	134.95	68.76	68.76	244.67	244.67
0.50	238.27	19.80	108.68	158.53	80.72	80.72	298.72	298.72
0.60	268.60	23.76	113.82	182.11	91.20	91.20	352.77	352.77
0.70	311.27	23.76	122.78	209.80	101.67	101.67	411.15	411.15
0.80	338.52	26.40	139.83	233.38	112.14	112.14	465.20	465.20
0.90	402.81	26.40	156.87	259.70	118.13	118.13	522.15	522.15
1.00	449.82	26.40	173.92	283.27	119.61	119.61	576.19	576.19
1.10	491.88	31.68	190.96	306.85	121.10	121.10	630.24	630.24
1.20	533.93	39.60	208.00	335.91	122.59	122.59	690.08	690.08
1.30	575.98	52.80	225.05	367.72	124.07	124.07	752.80	752.80
1.40	611.83	66.00	242.09	405.01	125.56	125.56	821.31	821.31
1.50	641.56	71.28	249.37	432.34	134.48	134.48	889.82	889.82
1.60	674.37	76.56	254.51	443.44	143.40	143.40	949.65	949.65
1.70	706.58	79.20	259.65	454.54	152.33	152.33	1009.49	1009.49
1.80	730.74	79.20	264.79	462.89	161.25	161.25	1066.43	1066.43
1.90	757.99	79.20	269.94	467.80	170.17	170.17	1120.48	1120.48
2.00	784.03	79.20	275.08	467.80	179.09	179.09	1189.95	1189.95
2.10	802.63	79.20	280.22	467.80	188.01	188.01	1244.35	1244.35

Depth inside the property [m]	Deposito (Warehouses)	Edificacion en ruinas (Ruins)	Edificacion generica (Dwelling)	Edificacion ligera (Workshops)	Edificio religioso (Churches)	Edificio singular (Singular Buildings)	Invernadero (Industries)	Nave (Industries)
2.20	821.23	79.20	285.36	467.80	196.94	196.94	1474.81	1474.81
2.30	839.83	79.20	290.51	467.80	205.86	205.86	1474.81	1474.81
2.40	864.60	79.20	292.21	467.80	214.78	214.78	1474.81	1474.81
2.50	883.20	79.20	292.21	467.80	223.70	223.70	1474.81	1474.81
2.60	901.80	79.20	292.21	467.80	232.62	232.62	1474.81	1474.81
2.70	914.82	79.20	297.17	467.80	234.11	234.11	1474.81	1474.81
2.80	914.82	79.20	297.17	467.80	234.11	234.11	1474.81	1474.81
2.90	914.82	79.20	297.17	467.80	234.11	234.11	1474.81	1474.81
3.00	914.82	79.20	297.17	467.80	234.11	234.11	1474.81	1474.81

Annex 2: Flood Maps

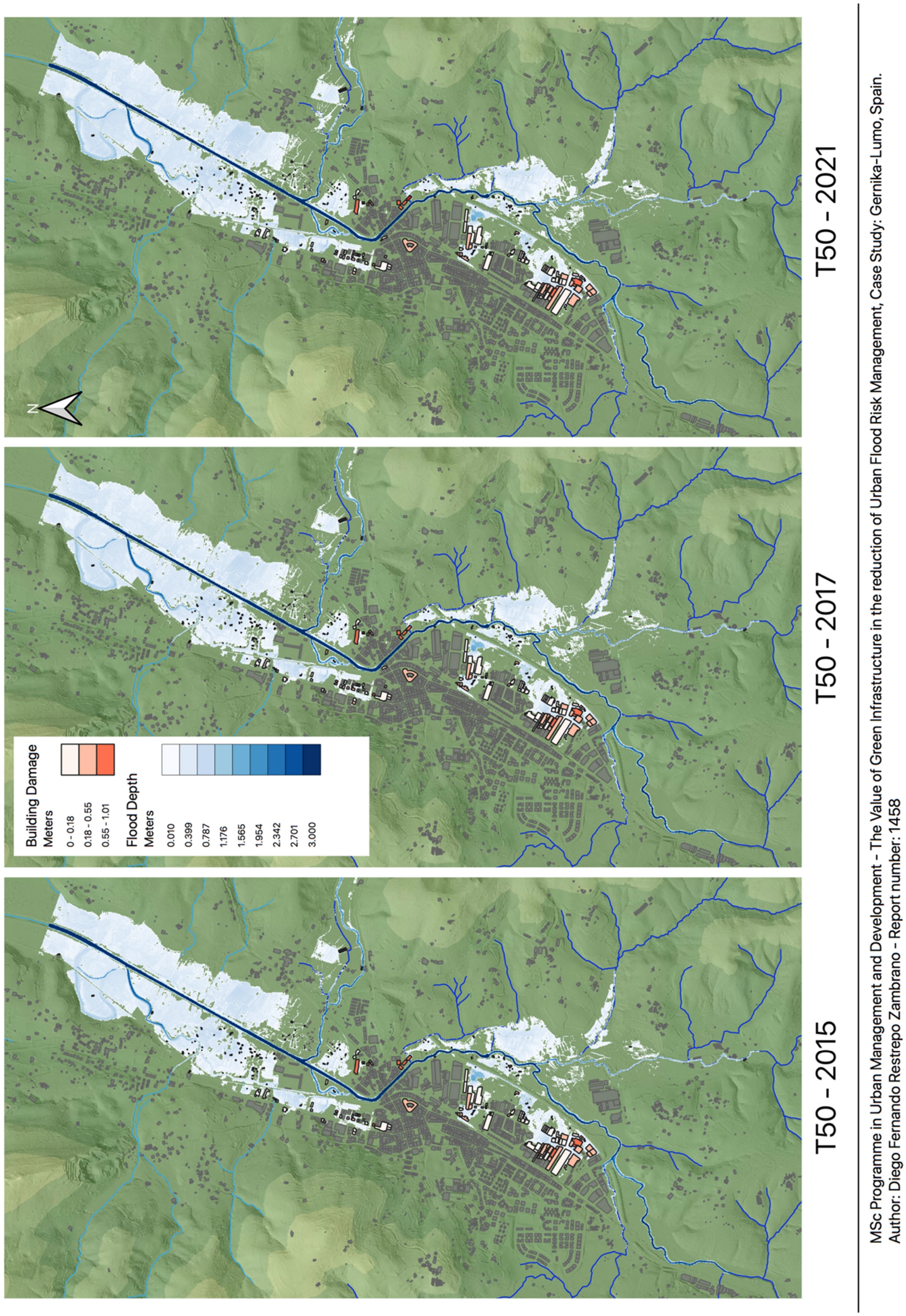
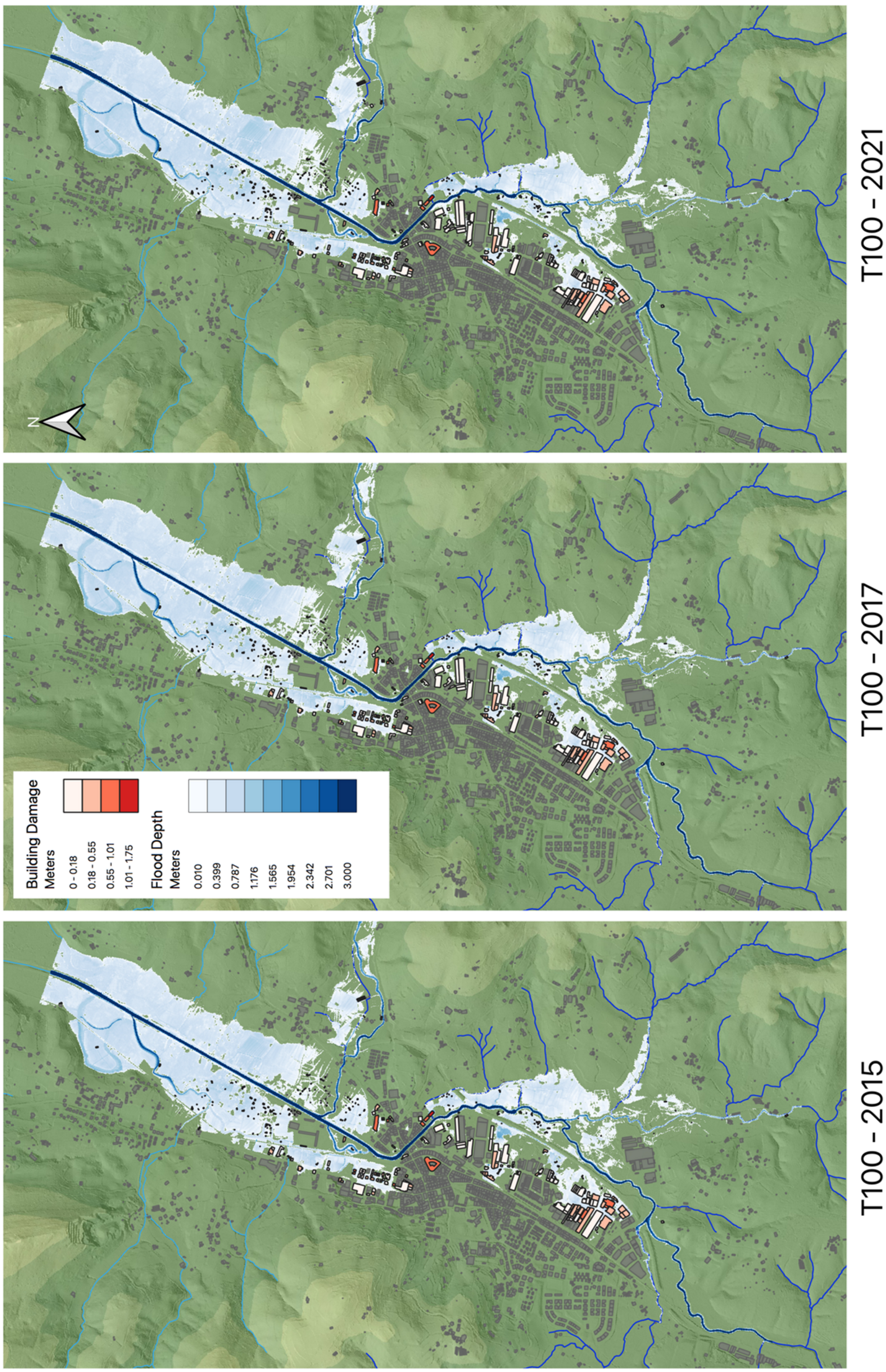


Figure 39 Flood maps for 50 years return period, scenario 2015, 2017,2021.



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Author: Diego Fernando Restrepo Zambrano - Report number: 1458

Figure 40 Flood maps for 100 years return period, scenario 2015, 2017,2021

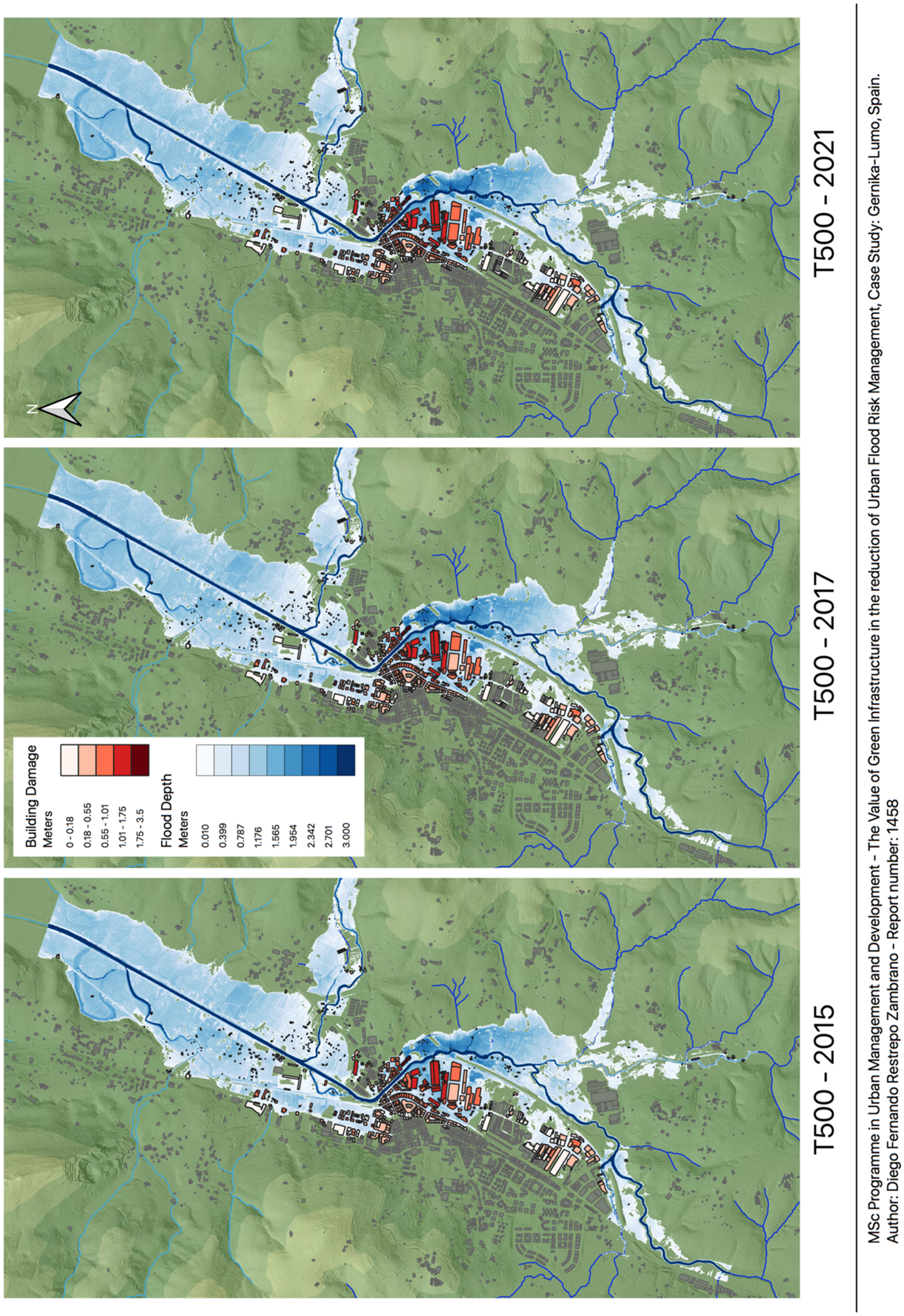

Figure 41 Flood maps for 500 years return period, scenario 2015, 2017,2021.

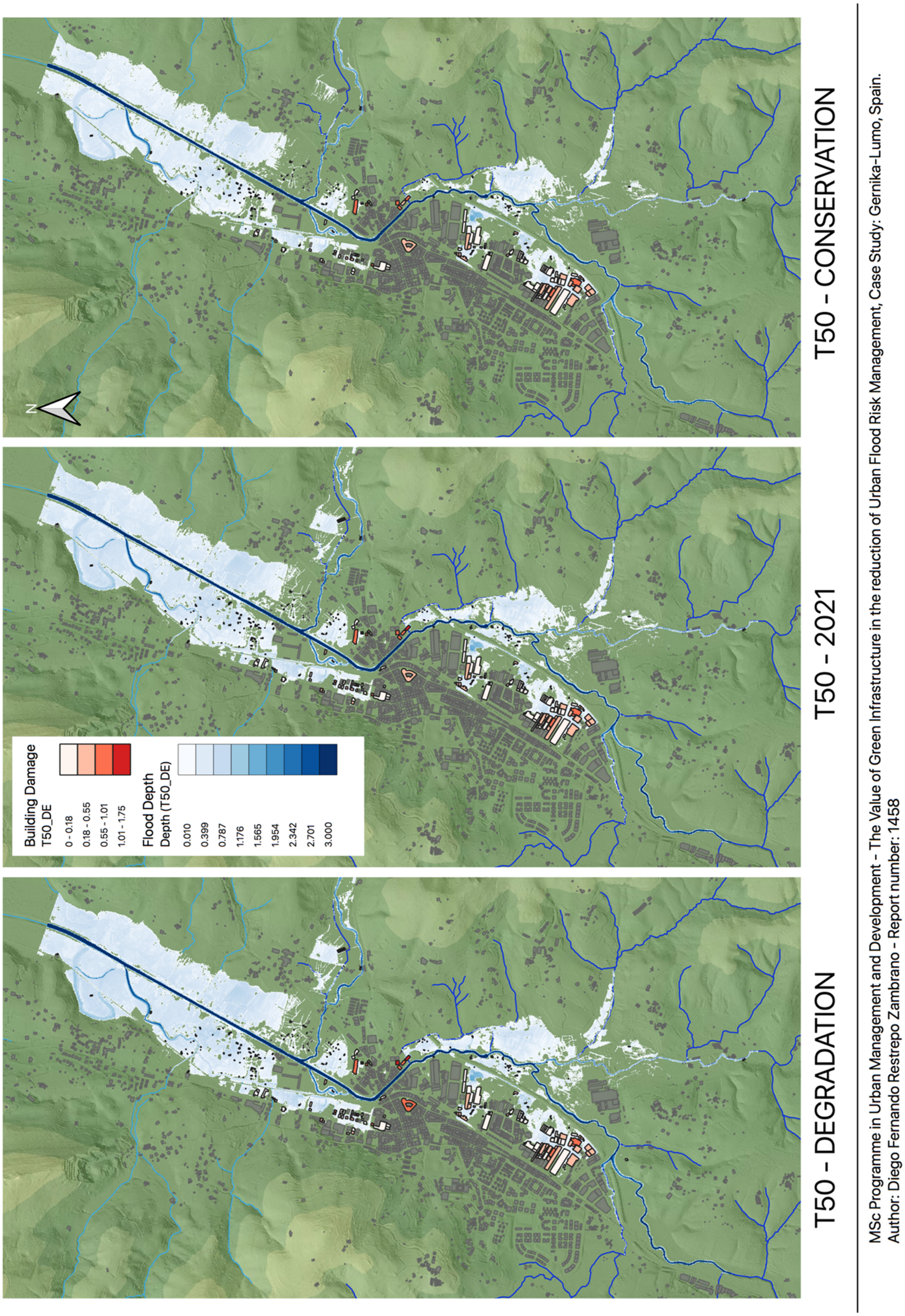

Figure 42 Flood maps for 50 years return period, scenario degradation, 2021 and conservation.

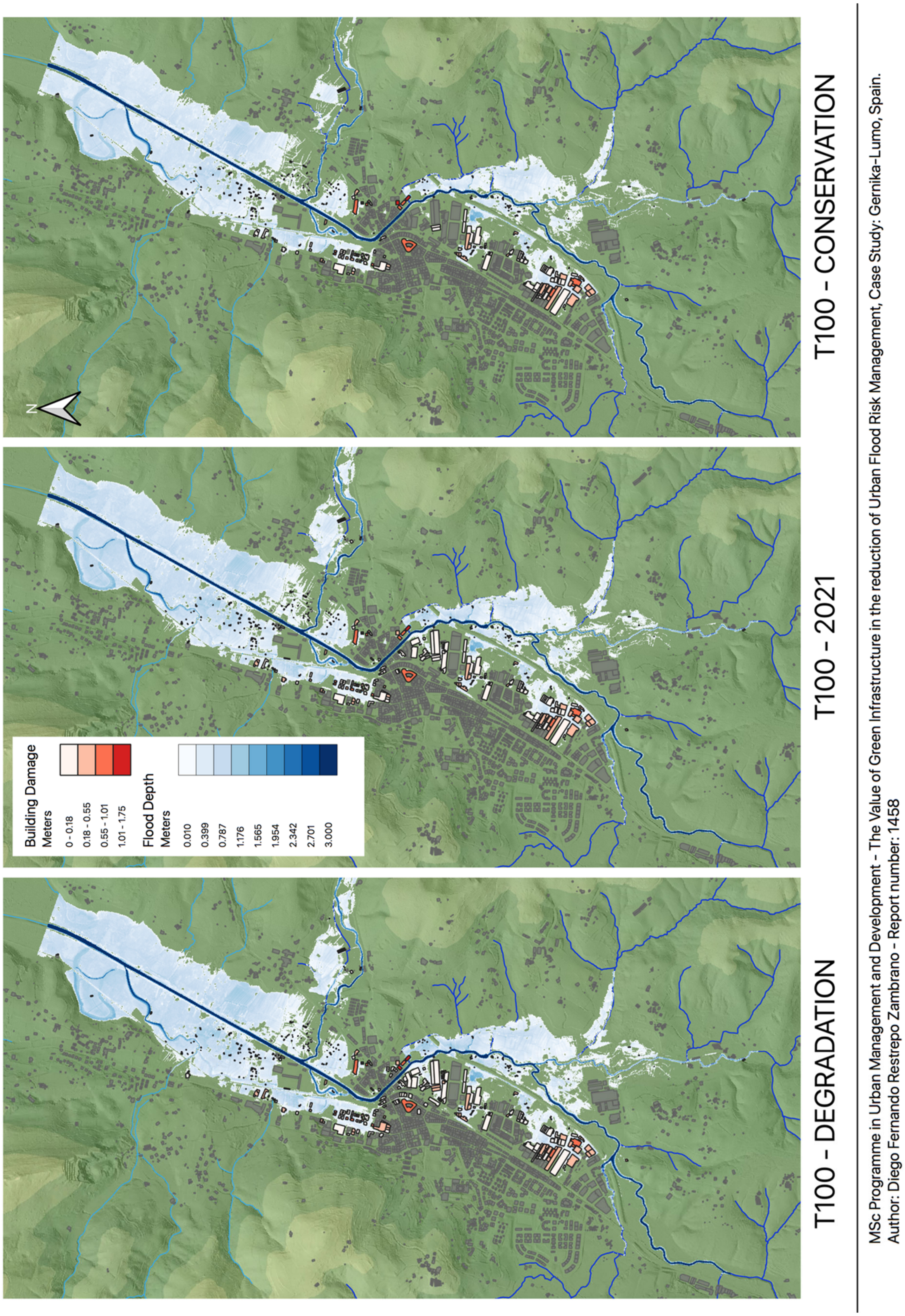

Figure 43 Flood maps for 100 years return period, scenario degradation, 2021 and conservation.

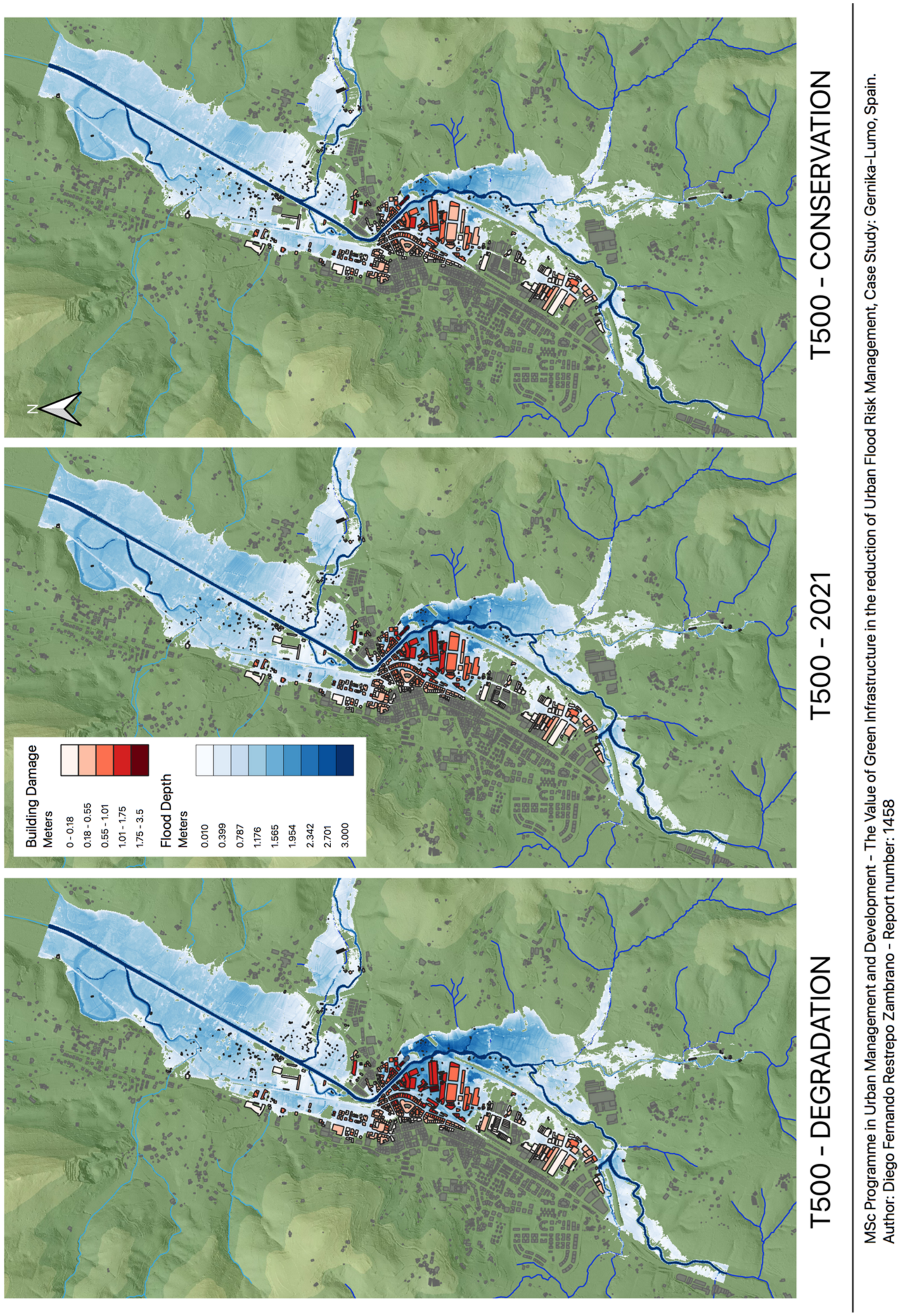

Figure 44 Flood maps for 500 years return period, scenario degradation, 2021 and conservation.

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