Summer Course

"NATURE-BASED SOLUTIONS (NBS) TO CONFRONT WATER EXTREMES IN EUROPE: DESIGN AND MODELLING TOOLS"

(Within the project TRITON; https://triton.wasser.tum.de/about-triton/consortium/)

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Structure

Elements of flood hydrology
Climate & Land use change impacts

- **Elements of flood hydrology**
  - Hydrographic network
  - Physiographic and geomorphological characteristics
  - Rainfall – Runoff models – Estimation of flood hydrographs
  - Real-time forecasting and warning
  - Hydrologic design and sizing of flood protection works
- **Climate change impacts on floods & flood risk**
- **Land use change impacts on floods & flood risk**

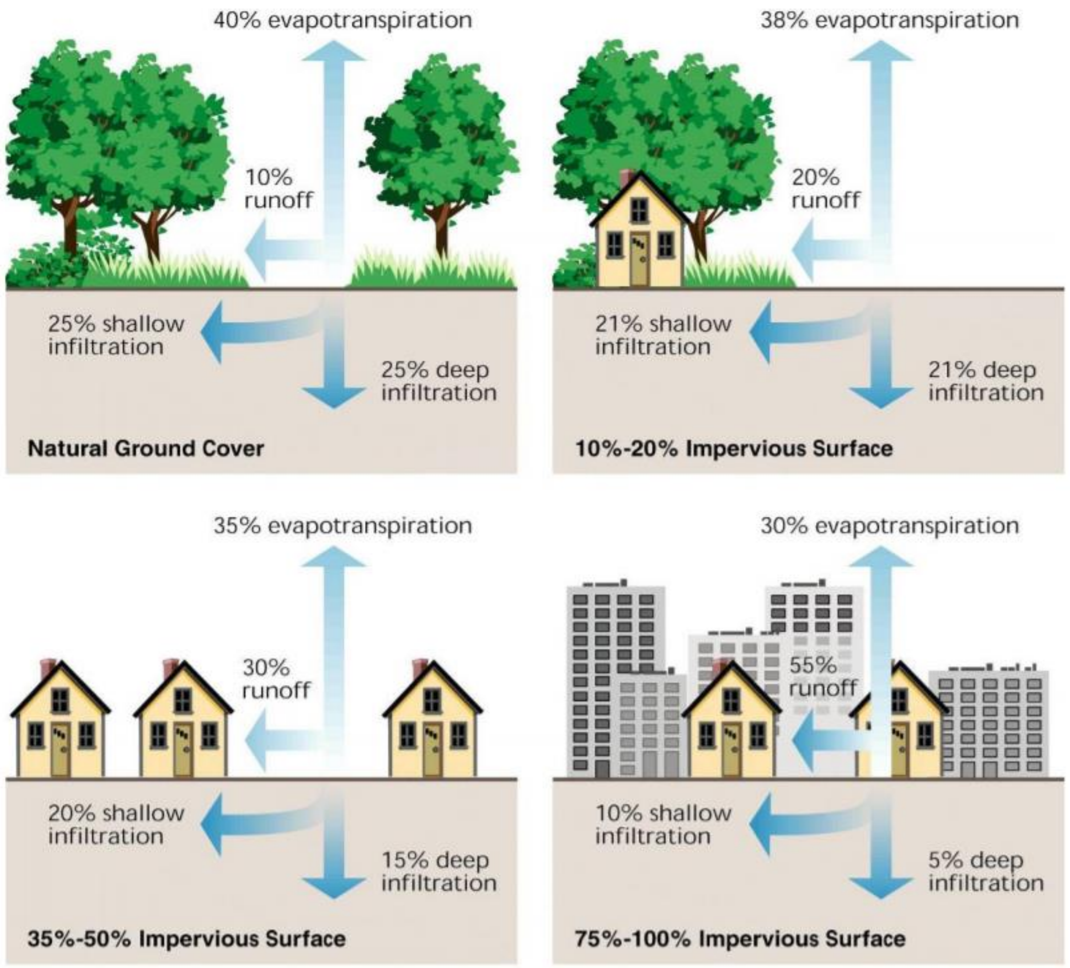
Causes of flood disasters (natural, anthropogenic)

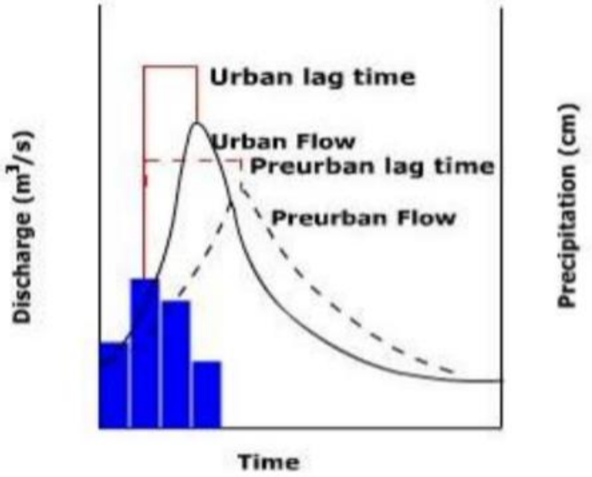
Anthropogenic factors leading to deterioration of flood risk

Storms are the natural cause of floods, however anthropogenic factors lead to the deterioration of flood risk. Particularly in urban regions, even small rainfall events can lead to catastrophic floods due to anthropogenic factors such as:

- Increasing urbanization and reduction in vegetation and forest areas $\Rightarrow$ increase of the runoff coefficient (may increase from 25%-30% to 90%-95%)
- Disappearance of the hydrographic network of cities (urbanization)
- Insufficient stream conveyance capacity to adequately relief small flooding events
- Insufficiency of storm water drainage networks
- Obsolete flood protection works studies based on generic and/or wrong concepts
- Lack of systematic monitoring of runoff volumes and discharges $\Rightarrow$ ineffective model calibration

Urban floods: Impact to the parameters of hydrological cycle





Πηγή: Urban Flood Risk Management (WMO, 2008)

Floods & Flood protection - Situation in Greece

Typology of floods in Greece

- Significant geographical variability of climatic variables related to floods due to extensive coastline and orography
- Significant effect of Pindos mountain range on rainfall and runoff processes
- Significant variation of average annual rainfall from 1800mm (Western Greece) to 400mm (Eastern Greece) and water scarcity issues at the eastern regions
- Variation of maximum rainfall: Maximum 24-h rainfall for T=50y 175mm in Western Greece, 100mm eastern of Pindos mountain range and 175mm at the eastern Aegean islands
- Aggravated by geomorphological and vegetation characteristics, more catastrophic floods occur at the “dry” Eastern regions of Greece compared to the “wetter” Western regions

- What are Nature-based Solutions?

European Commission definition:
*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 diverse, nature and natural features and processes into cities, landscapes and seascapes, **through locally adapted, resource-efficient and systemic interventions.***

Nature-based solutions must therefore **benefit biodiversity** and support the **delivery of a range of ecosystem services**.

Multiple benefits/services could be supplied simultaneously:

WATER SECURITY

1. Maintain or improve water quality
2. Maintain or improve river flows and aquifer recharge
3. Reduce impact of flooding

CLIMATE CHANGE MITIGATION

1. Reduce greenhouse gases emissions
2. Carbon sequestration

CLIMATE CHANGE ADAPTATION

1. Reduce soil erosion
2. Soil quality improvement
3. Reduce frequency and intensity of forest fires, flooding and droughts

HUMAN HEALTH AND WELL-BEING

1. Improve food security
2. Reduce exposure to polluting substances
3. Amenity value and recreational benefits

BIODIVERSITY CONSERVATION

1. Landscape diversity
2. Protect and expand natural habitats
3. Limit expansion of invasive species

JOBS AND SOCIAL COHESION

1. Create jobs particularly in rural areas
2. Promote urban-rural solidarity

Source: Trémolet S. et al. (2019). Investing in Nature for Europe Water Security. The Nature Conservancy, Ecologic Institute and ICLEI. London, United Kingdom.

Approach

- **Nature Based Solutions**: "Actions to protect, sustainably manage, and restore natural and modified ecosystems that address societal challenges effectively and adaptively, simultaneously providing human well-being and biodiversity benefits" (IUCN, 2016).

EXAMPLES:

- Upstream water retention measures 1.) natural ponds for emergency flood storage area 2.) regeneration of flood plains 3.) widening of rivers 4.) reforestation
- Urban green improvements: 1.) rain gardens, 2.) tree planting 3.) infiltration strips.

PURPOSE:

Increasing the natural retention capacity of the environment ("sponge like effect"), by doing so creating flood resilience.

NBS TO ADDRESS FLOODING

Floodplain reconnection or restoration

Land use restoration

Land use conservation

Wetlands

NBS to address flooding

Urban green infrastructure

NBS to address flooding

Combining agriculture landscape with forest to increase water retention capacity

- How to use NBS for flood mitigation?

Objective: To stop/minimise undesired fluvial floods resulting from excessive water level peaks. The water level peaks are initiated in the upstream river tributaries with high drainage, in combination with narrow floodplain space more downstream and sometimes blockages that build up water levels.

So we need different ecological benefits at different locations along the rivers: **retain** water, **infiltrate** water, **store** water, **use up** water, (safely) **flood** water, **drain** water, etc.


upstream
downstream
Agricultural water management
Large scale
Woodland creation
Floodplain restoration
Lakes
Water storage areas
Removal riverbed obstructions
Infiltration wetlands
Natural embankments
Green roofs/ facades
Urban wadi's
Rainwater gardens
Urban permeability
Small scale

Source: Built solid Ground project 2020

Small scale solutions with the purpose to enlarge drainage capacity and infiltrate water

Less drainage, more infiltration

Adjusted land use management: more infiltration, more belowground storage, buffer for drier periods.

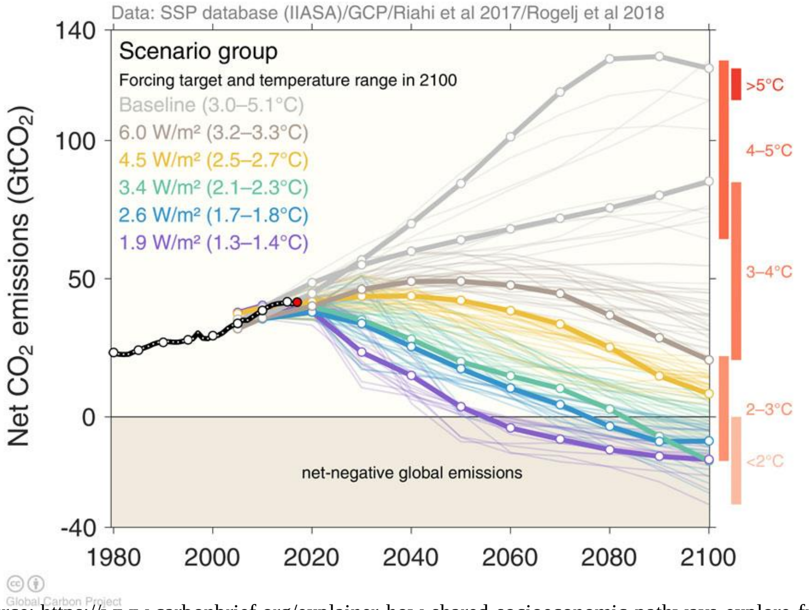
Less drainage, more infiltration. Swap hard surface for green spots

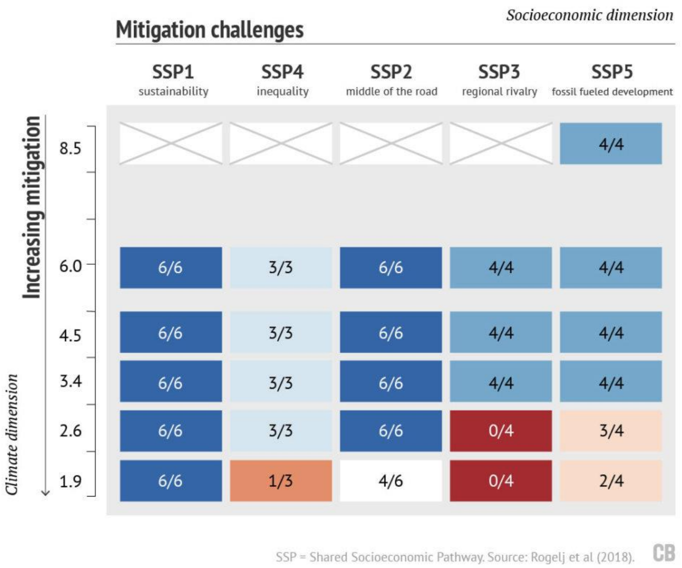
- What to expect for the future?

Flood mitigation programme – Repair the river system:

- Solutions **geographically spread** over region and rivers
- Solutions will be at **different scales** with **different costs and benefits**
- Solutions will be implemented **spread over time**
- Solutions will have **different stakeholders and business cases**
- All solutions contribute to the flood mitigation **locally and/or elsewhere**

- Special Report on Emissions Scenarios (SRES): Intergovernmental Panel on Climate Change (IPCC) 3rd and 4th Reports.
  - Population;
  - economic growth; and
  - greenhouse gas emissions.
- Representative Concentration Pathway (RCP): IPCC 5th report (RCPs - 2.6, 4.5, 6, and 8.5)
- Shared Socioeconomic Pathways (SSPs): IPCC 6th (latest) report (SSPs – SSP1-1.9, SSP1-2.6, SSP2-4.5, SSP3-7.0 and SSP5-8.5



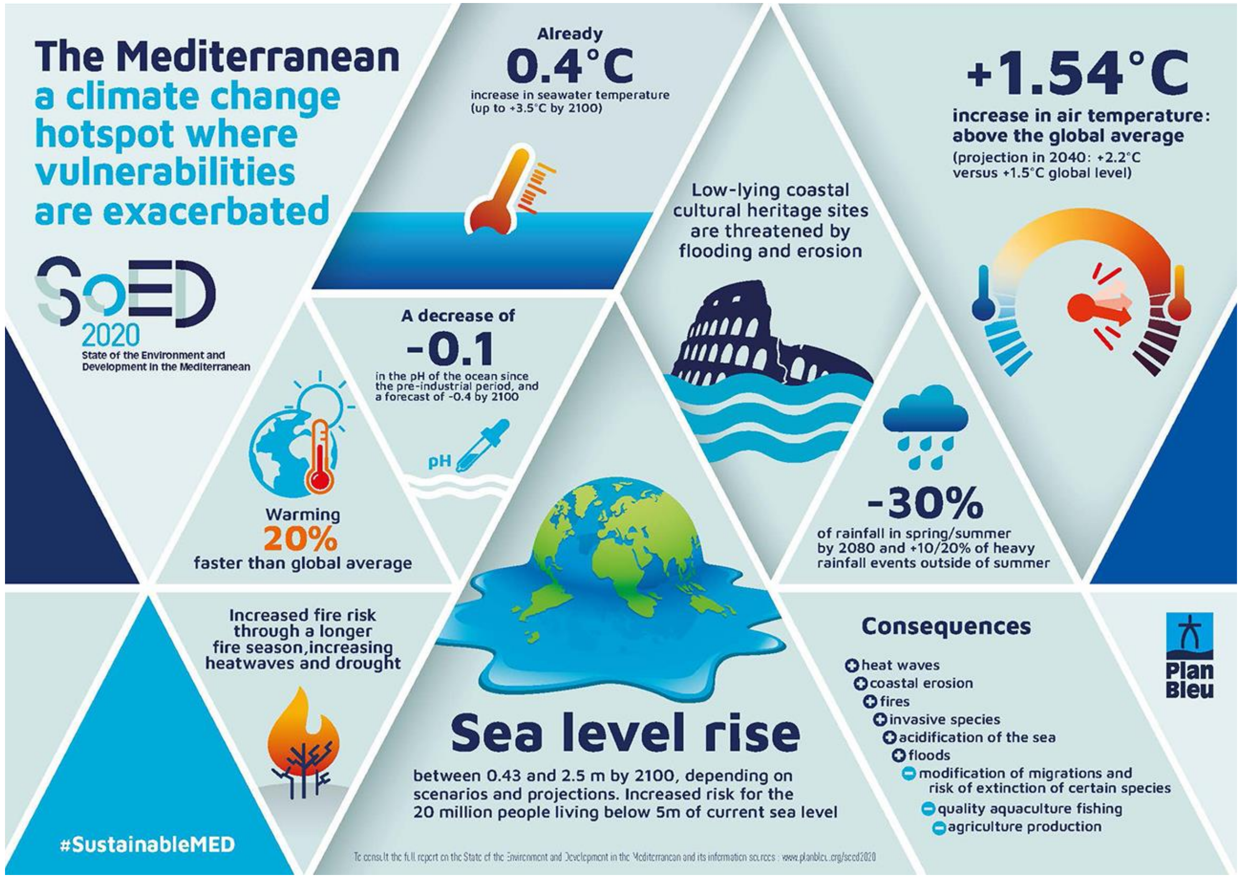


Source: https://www.carbonbrief.org/explainer-how-shared-socioeconomic-pathways-explore-future-climate-change/

TABLE 1 **Changes in global surface temperature, which are assessed based on multiple lines of evidence, for selected 20-year time periods and the five illustrative scenarios considered. (Temperature differences relative to the average global surface temperature of the period 1850–1900 are reported in °C.)**

	Near term, 2021–2040		Mid-term, 2041–2060		Long term, 2081–2100	
Scenario	**Best estimate (°C)**	***Very likely* range (°C)**	**Best estimate (°C)**	***Very likely* range (°C)**	**Best estimate (°C)**	***Very likely* range (°C)**
SSP1-1.9	1.5	1.2 to 1.7	1.6	1.2 to 2.0	1.4	1.0 to 1.8
SSP1-2.6	1.5	1.2 to 1.8	1.7	1.3 to 2.2	1.8	1.3 to 2.4
SSP2-4.5	1.5	1.2 to 1.8	2.0	1.6 to 2.5	2.7	2.1 to 3.5
SSP3-7.0	1.5	1.2 to 1.8	2.1	1.7 to 2.6	3.6	2.8 to 4.6
SSP5-8.5	1.6	1.3 to 1.9	2.4	1.9 to 3.0	4.4	3.3 to 5.7

Source: IPCC, 2021: Climate Change 2021: The Physical Science Basis. Contribution of Working Group I to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change [Masson-Delmotte, V., P. Zhai, A. Pirani, S.L. Connors, C. Péan, S. Berger, N. Caud, Y. Chen, L. Goldfarb, M.I. Gomis, M. Huang, K. Leitzell, E. Lonnoy, J.B.R. Matthews, T.K. Maycock, T. Waterfield, O. Yelekçi, R. Yu, and B. Zhou (eds.)]. Cambridge University Press. In Press.

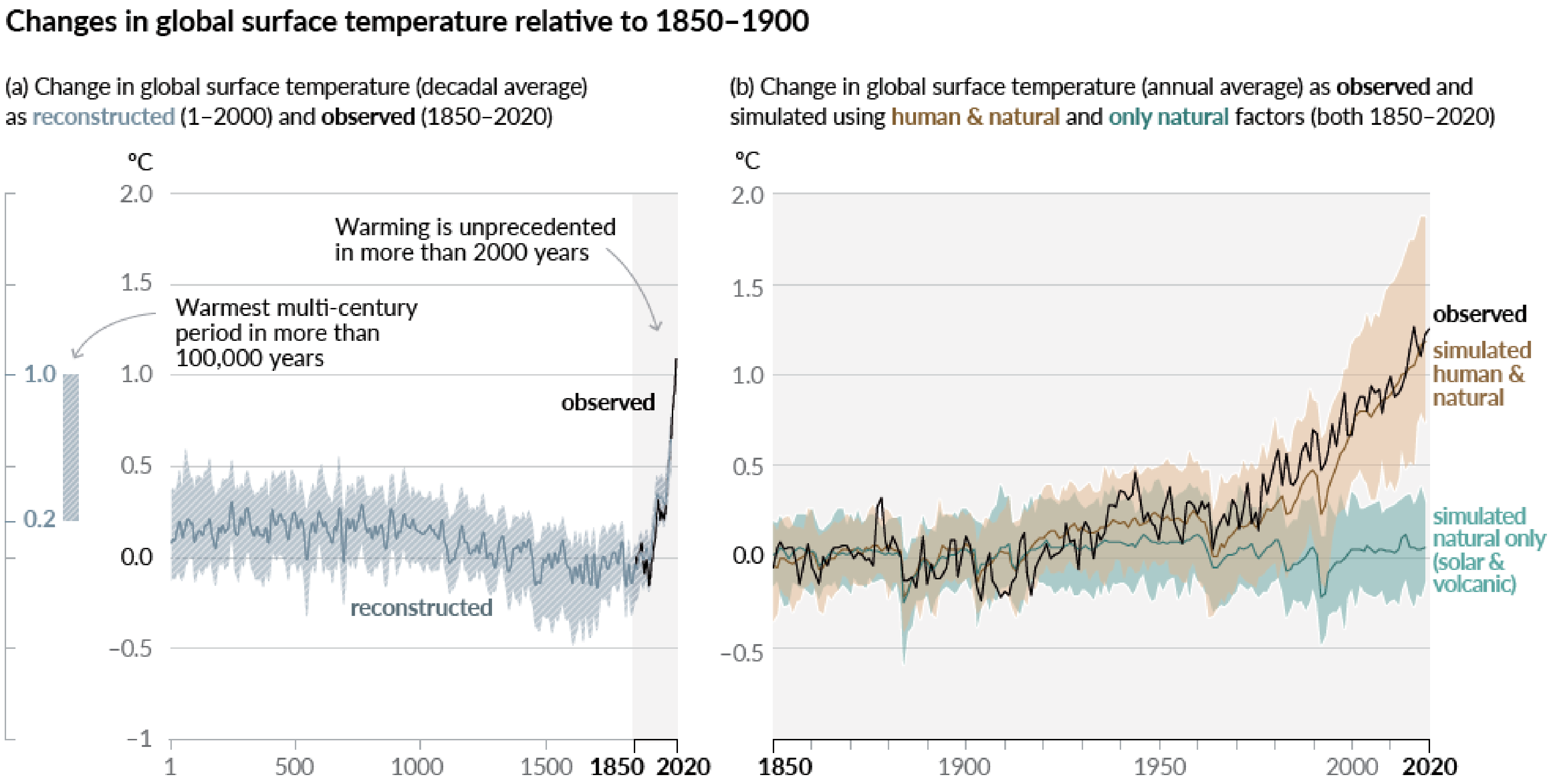


- The Mediterranean region is warming 20% faster than the global average.
- 2°C global warming will reduce precipitation by about 10 % to 15%.
- An increase of 2°C to 4°C would reduce precipitation by up to 30% in Southern Europe.
- Coastal zones face heightened disaster risks, including flooding and erosion, and the salinization of river deltas and aquifers that sustain food security and livelihoods.
- The Mediterranean is home to more than 510 million people.
- By 2050, water demand is projected to double or even triple.
- Impacts will exert additional pressure on already strained ecosystems and on vulnerable economies and societies.
- Water temperature is expected to rise by between 1.8°C and 3.5°C by 2100 with hotspots in Spain and in in the Eastern Mediterranean.

Source: https://www.unep.org/unepmap/resources/factsheets/climate-change

Main climate change impacts in the Mediterranean region

i. Increased weather and climate extreme;
ii. Increase of extreme temperatures;
iii. Reduction of rainfall and river flows;
iv. Increased risk of drought
v. Increased soil degradation and desertification,
vi. Increased risk for forests, ecosystems and biodiversity
vii. Increased competition between different water users
viii. Increased water demand for agriculture
ix. Reduced yield of crops
x. Increased mortality from extreme temperatures
xi. Reduction of energy production potential
xii. Increased energy demand for cooling



Source: IPCC, 2021: Climate Change 2021: The Physical Science Basis. Contribution of Working Group I to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change [Masson-Delmotte, V., P. Zhai, A. Pirani, S.L. Connors, C. Péan, S. Berger, N. Caud, Y. Chen, L. Goldfarb, M.I. Gomis, M. Huang, K. Leitzell, E. Lonnoy, J.B.R. Matthews, T.K. Maycock, T. Waterfield, O. Yelekçi, R. Yu, and B. Zhou (eds.)]. Cambridge University Press. In Press.

Flood protection studies and works

A comprehensive flood protection study includes:

- Identification of streams and surveying of the greater study area - Import into GIS system
- Mapping of the existing storm water drainage networks (if any)
- Development of IDF curves
- Hydrological study for main streams (drainage basins, peak discharges and flood volumes under different return periods)
- Assessment of risk zones (delineation of inundation areas under equal risk)
- Hydraulic study – Conveyance capacity assessment of existing stream cross sections –Identification of critical locations
- Assessment of the hydraulic sufficiency of existing works and identification of required modifications
- Proposals for constructive and non-constructive flood protection measures
- Program for the prioritization of flood protection works and measures

Non–structural flood protection measures

Non-structural flood protection measures pertain mainly to forecasting of severe storms and floods, providing early warning and planning of emergency response systems.

Implementation steps include:

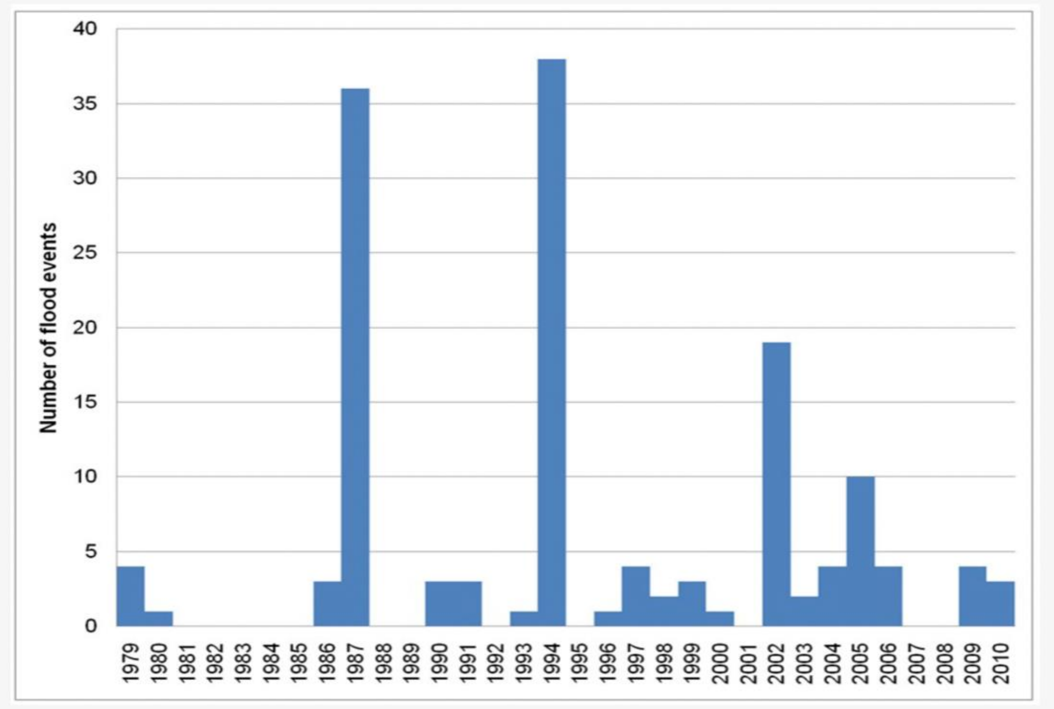
- Installation of automated telemetry network of rainfall-runoff monitoring stations at critical locations
- Development of data collection and processing software
- Calibration of rainfall-runoff models
- Identification of critical locations
- Real-time storm & flood forecasting and monitoring systems (radar, satellite and ground-based stations)
- Early-warning systems for floods and composition of emergency plans
- Operational organization of regional authorities and stakeholders for prevention and reaction against flood disasters.

Climate change impacts such as increased river flooding threaten the economic stability of Greece.

- River flooding imposes a major financial stress and death toll on EU economies → 4,300 lives and EUR 170 billion between 1980 and 2017 (EEA, 2021)
- Buildings, transport, bridges, energy, farmland, communication and livelihoods → EUR 12 billion per year overall climate change impacts (EIB, 2021)
- Economic losses forecasted to rise by 1000% under a 3C warming scenario → EUR 50 billion only for river flooding (EIB, 2021)
- Greece → lack of data but conservative estimate suggests EUR 3 billion over the past 10 years in infrastructure damages, an average of 300 million EU per year (WWF, 2020)

Photo © 2011 David Y. Lee

Within Greece, the Thessaly region is particularly vulnerable to the impacts of climate change, such as flooding events.



The annual distribution of flooding events in Thessaly between 1979 and 2010 (Bethrellos et al. 2018)

- Flood occurrences have been steadily increasing between 1990 and 2010 in the Thessaly region.
- Major flooding events took place in 1994 and most recently, 2018 and 2020.

Nature-based Solutions against river flooding provide a **major opportunity to lower the economic and human cost of climate change** in **Greece**.

- Evidence from across the EU suggests that nature-based solutions to flood prevention are the most cost- effective options to reduce flood risks (Dige et al., 2017)

- In Greece, restoring and recreating natural retention areas (i.e. floodplains) across rivers and water streams has a Benefit Cost Ratio (BCR) of 2.5 EUR compared to 1.1 EUR for “grey” infrastructure solutions, such as creating and strengthening dyke systems (WWF, 2020)

Photo: © André Künzelmann/UFZ

→ these figures do not account for additional co-benefits provided nature-based solutions.

Nature-based Solutions have a wide range of additional benefits – other than adaptation to climate change.

- Environmental benefits → food supply, fresh water supply, temperature and air quality regulation, carbon sequestration & storage, wastewater treatment, pollination, erosion protection, maintenance of fertility, biological control etc.
- Economic benefits → avoided damage on infrastructure & farmland, avoided cost of services disruption, creation of stable green jobs, improved economic attractiveness of the area → all very important for project preparation since they are the easiest to monetize!
- Social benefits → recreation, through open and quality green & blue spaces.
- Health & wellbeing benefits → better air quality, which also lowers public sector health costs, importance of green & blue spaces for wellbeing and productivity).
- Institutional benefits → a replicable and scalable model that can be quickly applied to other regions.

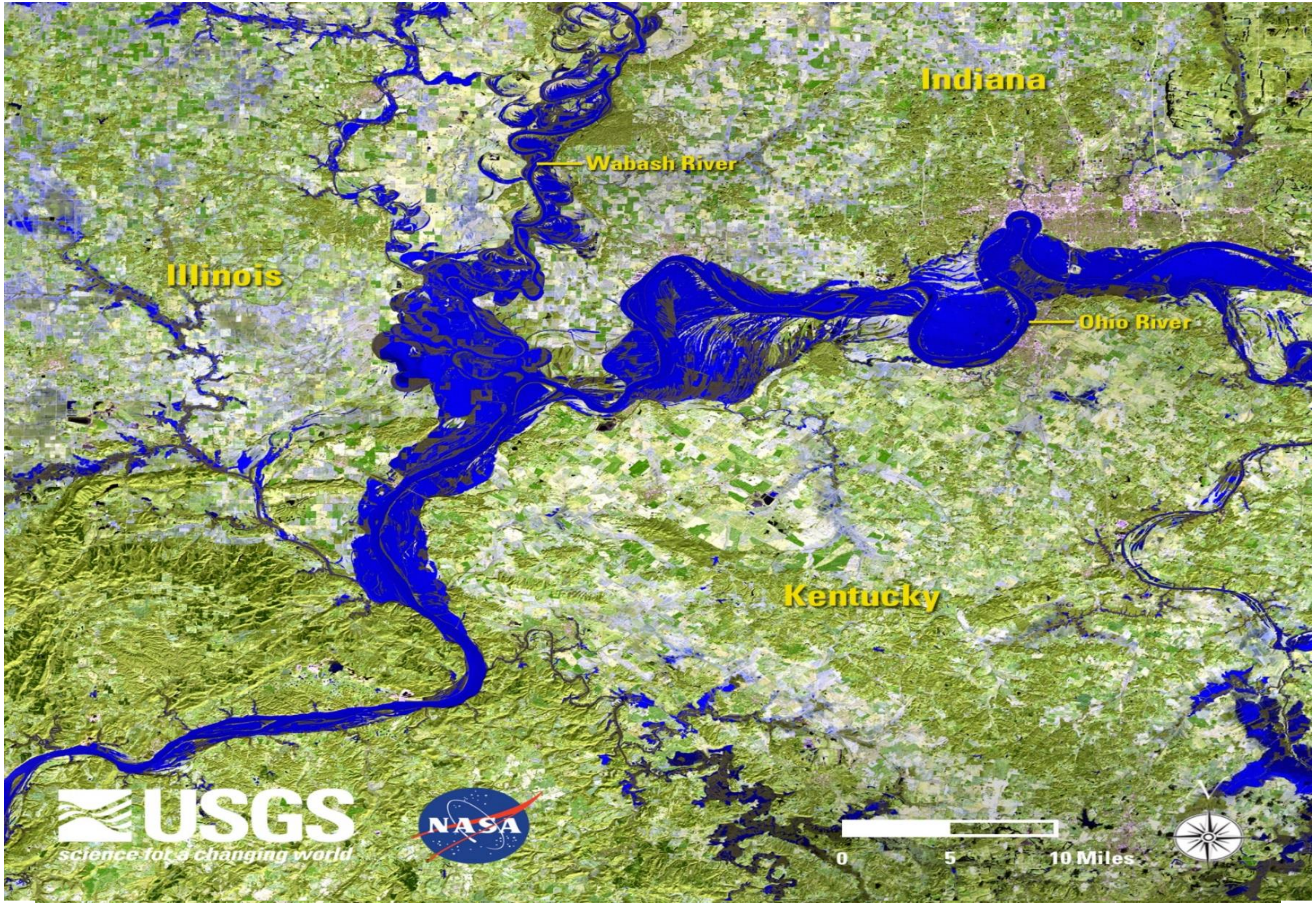
Adding several co-benefits, Nature-based solutions need to be seen as an unprecedented opportunity with a significant net benefit to society.

- **Investing EUR 1.5 trillion** globally **in five areas from 2020 to 2030** could generate **EUR 6 trillion in total benefits**.

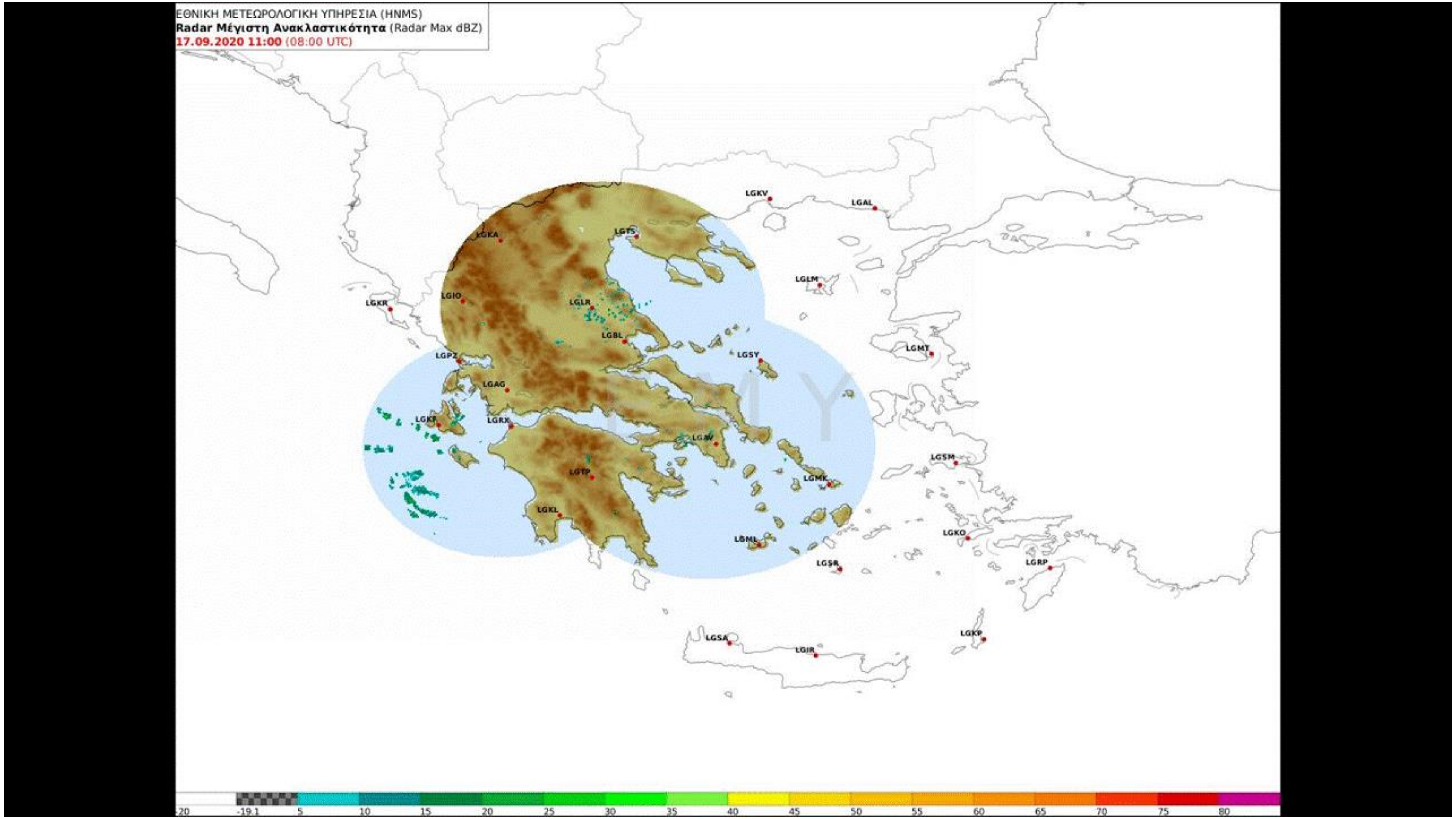
- Through a triple dividend of **avoided losses**, **economic benefits**, and **social and environmental benefits**.

- These five areas of investment are **early warning systems**, **climate- resilient infrastructure**, **improved dryland agriculture crop production**, global mangrove protection, and **making water resource management more resilient** (EIB, 2021)

Photo © 2020 AP photo/Vaggelis Kousioras –


Indiana
Wabash River
Illinois
Ohio River
Kentucky
USGS
science for a changing world
NASA
0
5
10 Miles

Flood event September 2020



INTRODUCTION

RETENTION PONDS

- RETENTION PONDS ARE **NATURE BASED SOLUTIONS (NBS)** AGAINST FLOOD PROTECTION, DESIGNED TO ATTENUATE THE SURFACE RUNOFF DURING RAINFALL EVENTS BY PROVIDING ADDITIONAL STORAGE CAPACITY.

- RETENTION PONDS FEATURE OTHER BENEFITS SUCH AS

  ✓ ARE HIGHLY EFFECTIVE AT WATER QUALITY TREATMENT AND INTERCEPTING SEDIMENT LOADING.

  ✓ WELL-DESIGNED AND MAINTAINED PONDS CAN OFFER AESTHETIC, AMENITY AND ECOLOGICAL BENEFITS TO THE URBAN LANDSCAPE.

  ✓ CAN BE APPLIED IN URBAN AND RURAL, E.G. AGRICULTURAL AND FORESTED AREAS.

INTRODUCTION

RETENTION PONDS EXAMPLES

USE AS WATER TREATMENT AND WATER STORAGE

USED AS FLOOD PROTECTION DESIGNATED AGRICULTURAL AREAS

MAIN OBJECTIVE

HOW MUCH WATER VOLUME SHOULD THE RETENTION POND BE DESIGNED FOR?

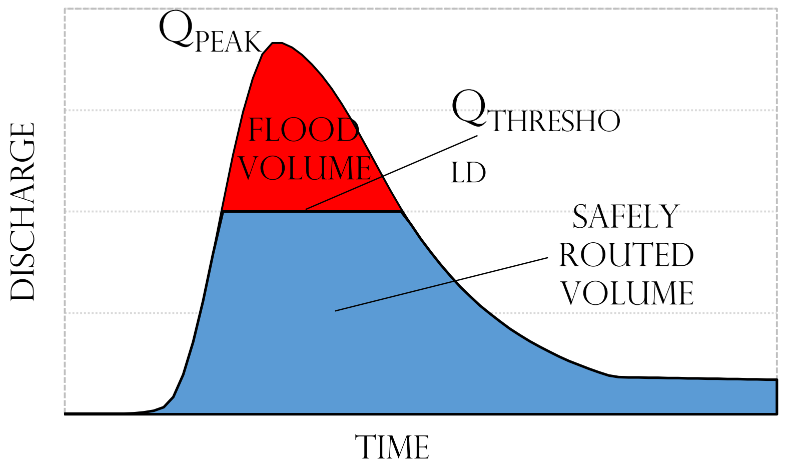
METHODOLOGY

DESIGN VOLUME STEPS

1. DETERMINE DESIGN FLOOD HYDROGRAPH

2. CALCULATE FLOOD THRESHOLD DISCHARGE

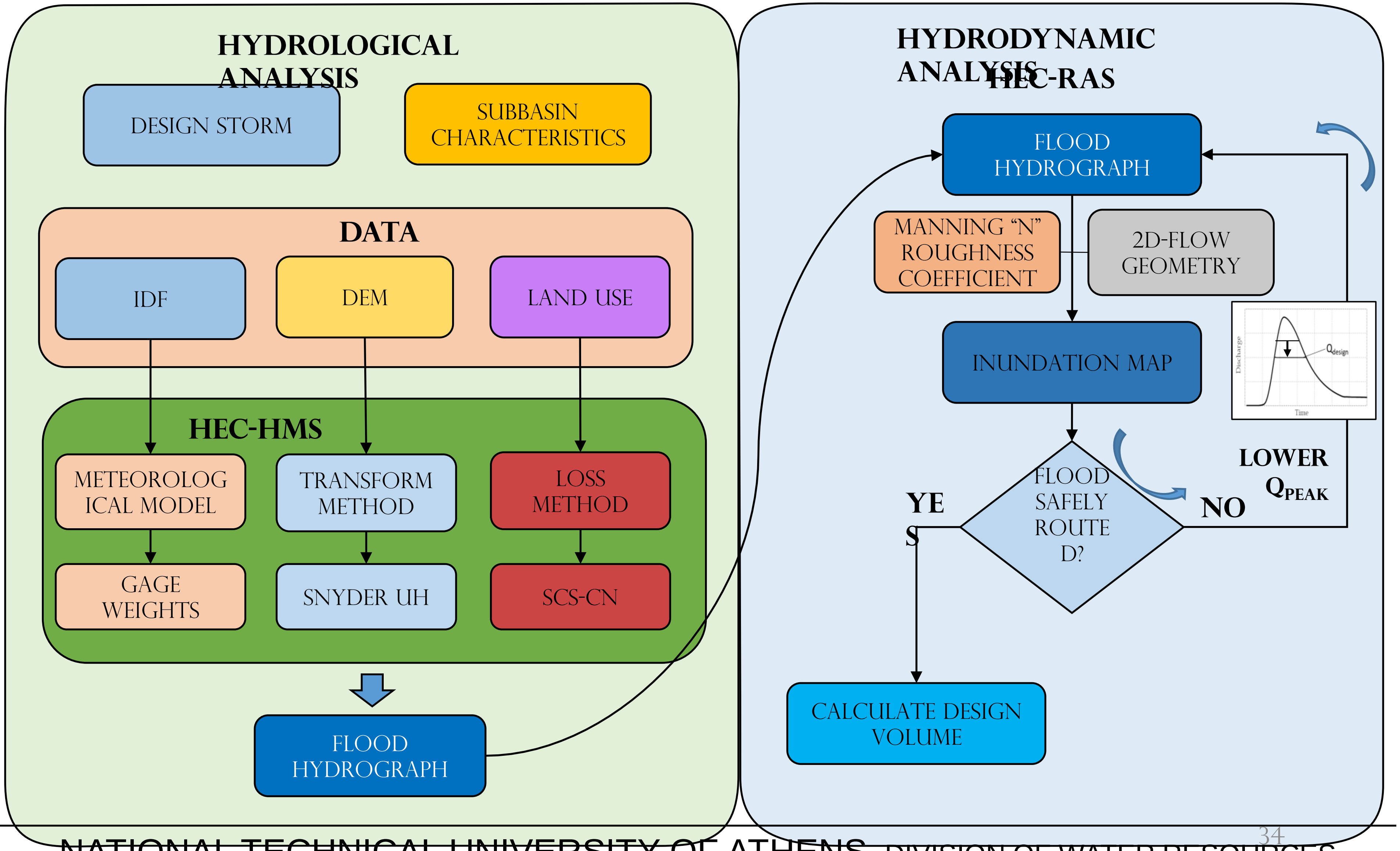
3. CALCULATE VOLUME NEEDED TO BE UPHELD



VOLUME THAT NEEDS TO BE UPHELD = TOTAL GENERATED VOLUME − VOLUME THAT CAN BE SAFELY ROUTED

METHODOLOGY

COMBINED HYDROLOGICAL AND HYDRODYNAMIC ANALYSIS



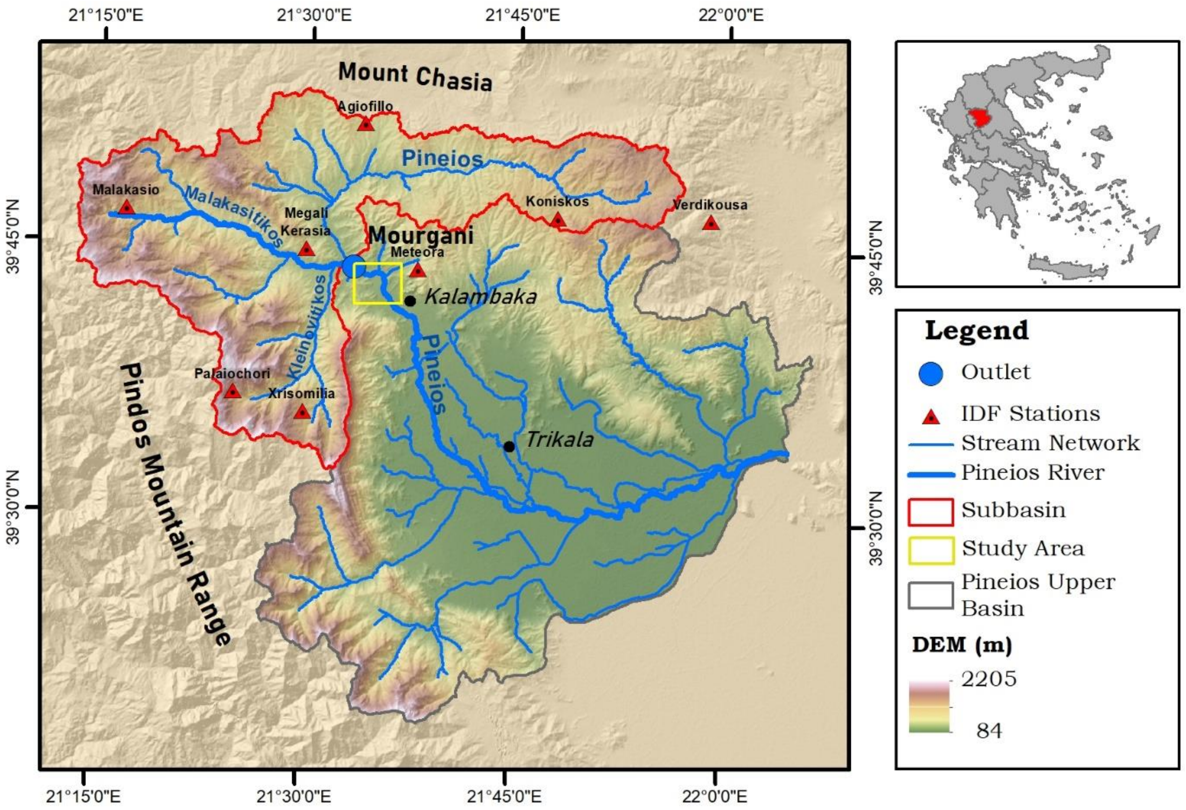
CASE STUDY

STUDY AREA: UPPER PINEIOS SUBBASIN

UPSTREAM KALAMBAKA SETTLEMENT

DOWNSTREAM MOURGANI SETTLEMENT

AGRICULTURAL AREA PRONE TO FLOODING AND SEDIMENT TRANSPORT



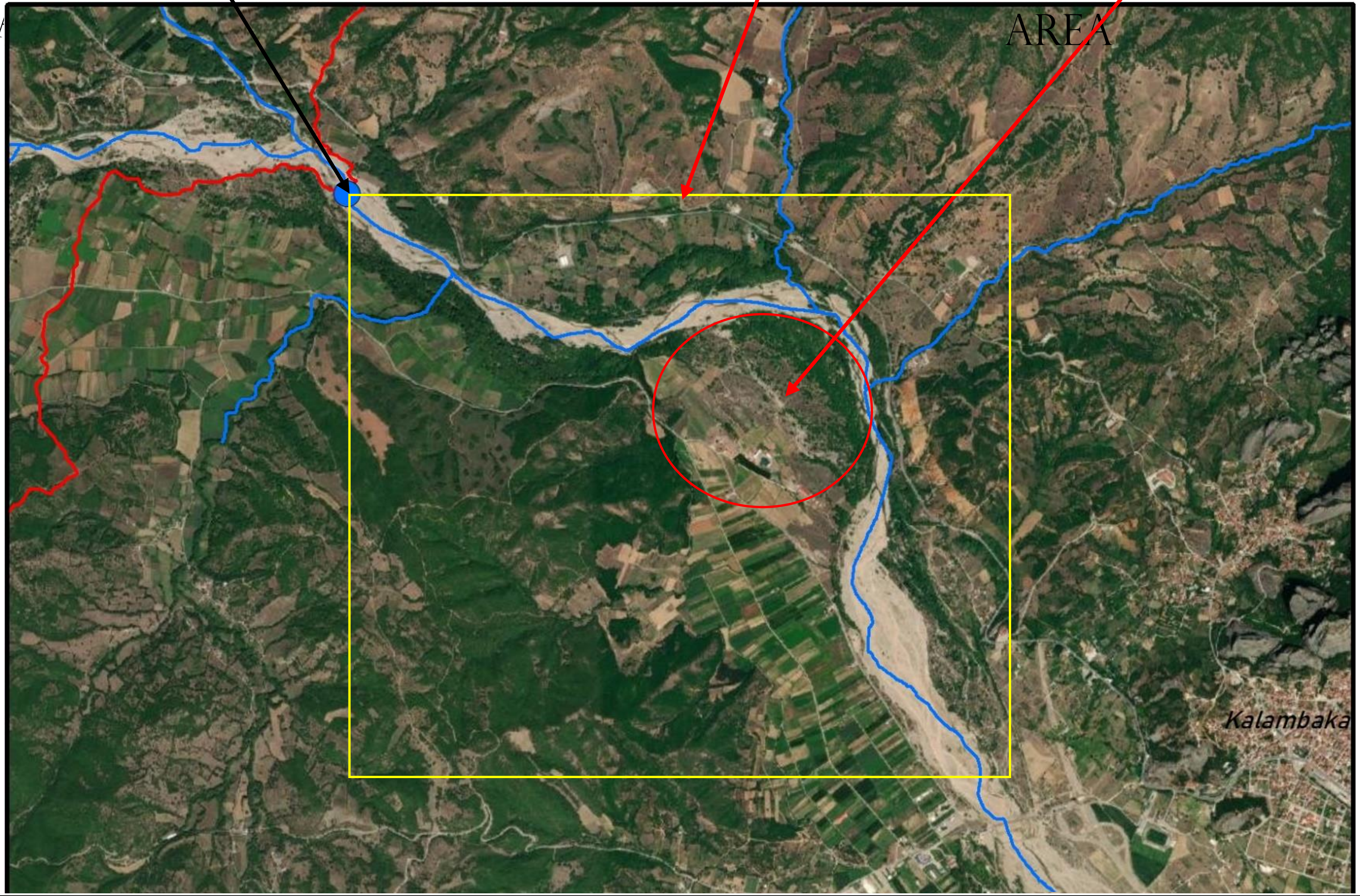
CASE STUDY

STUDY AREA

FLOOD HYDROGRAPH ESTIMA

FLOOD ANALYSIS AREA

INUNDATION FLOODING AREA



RESULTS

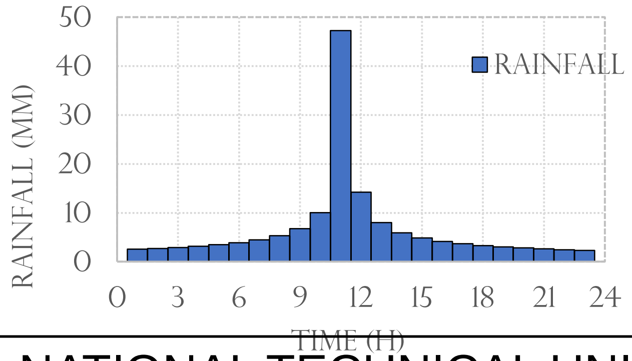
HYDROLOGICAL ANALYSIS

BASIN CHARACTERISTIC	STUDY AREA
AREA	950 KM^2
H_{MEAN}	865 M
MEAN SLOPE	38.97 %
MEAN CN	80.05
LONGEST FLOWPATH	65.80 KM
CENTROIDAL LONG. FLOWPATH	5.20 KM

DESIGN STORM:

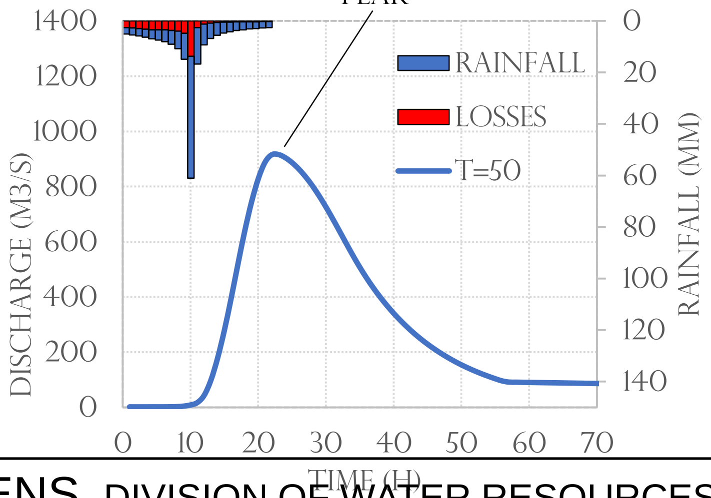
50 YEARS RAINFALL RETURN PERIOD

24 HOUR DESIGN STORM



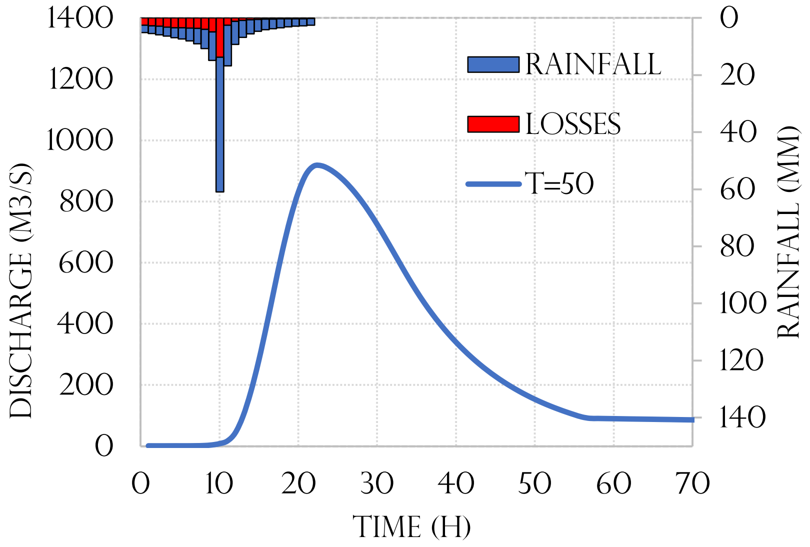
HEC-HMS

Q_{PEAK}=961 M^3/S



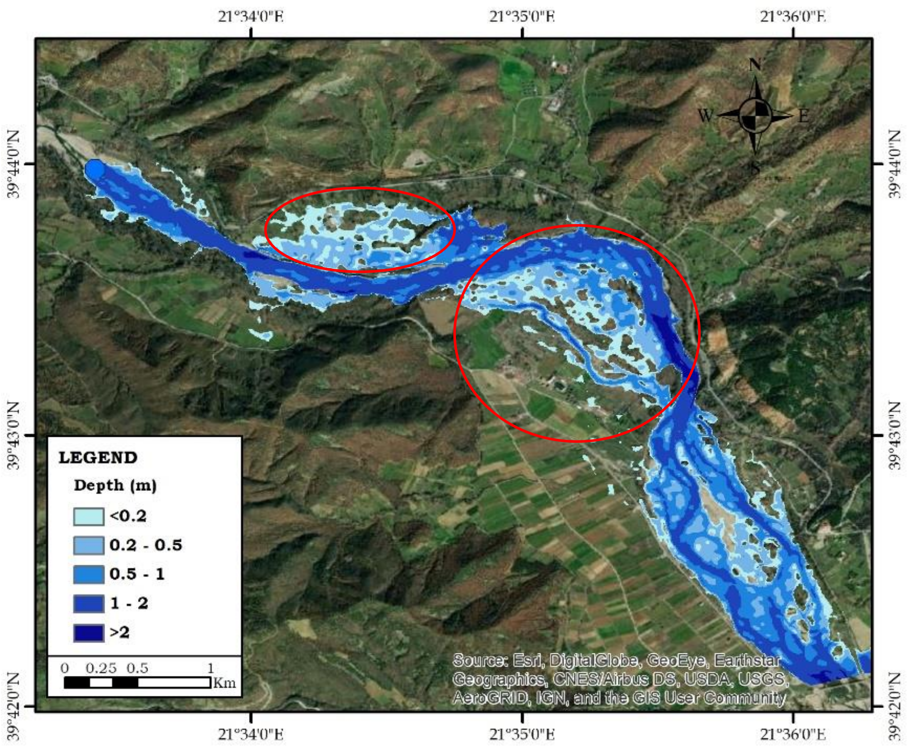
RESULTS

BASE SCENARIO



Q_{PEAK}= 961 M^3/S

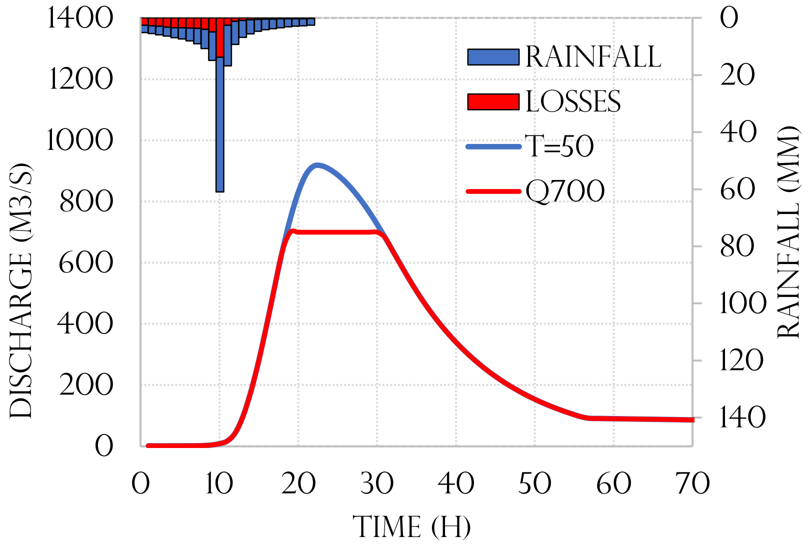
V = 78.17 10^6 M^3



– EXCESSIVE FLOODING OVER THE REGION

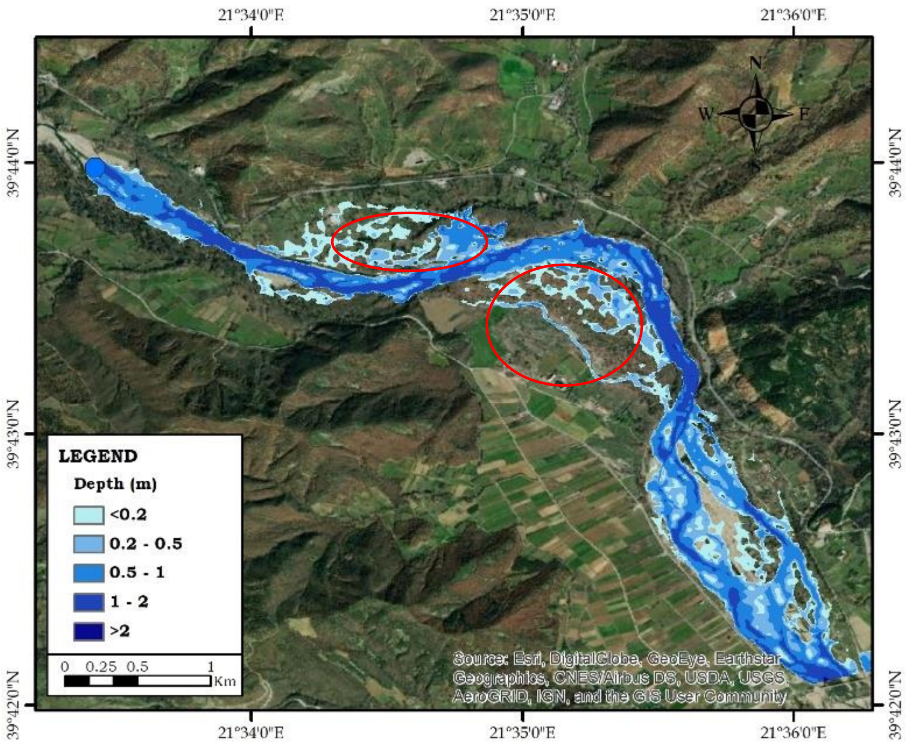
RESULTS

SCENARIO 1 - THRESHOLD AT 700 M^3/S



Q_{PEAK}= 700 M^3/S

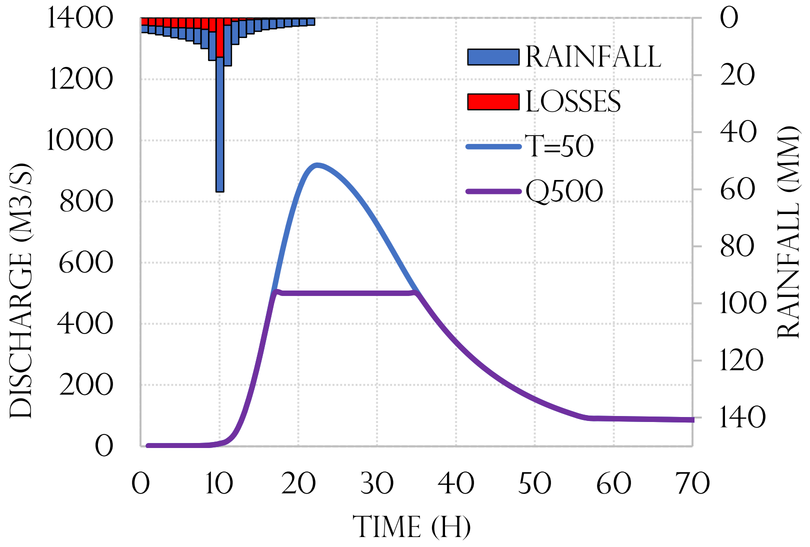
V = 72.14 10^6 M^3

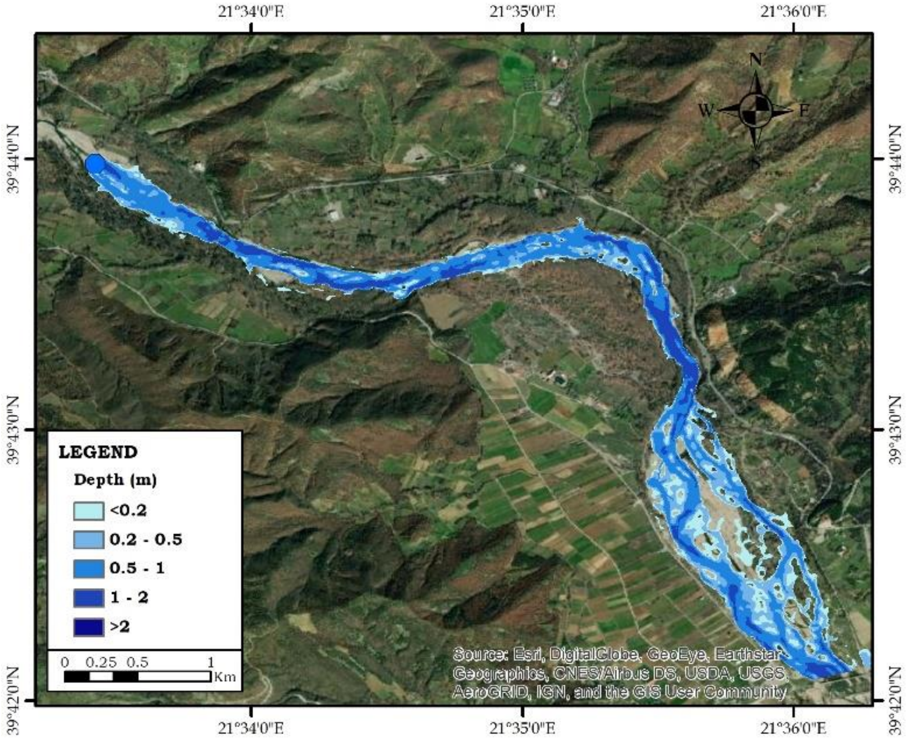


– REDUCTION IN FLOOD EXTEND, BUT STILL FLOOD OCCURS

RESULTS

SCENARIO 2 – THRESHOLD AT 500M³/S





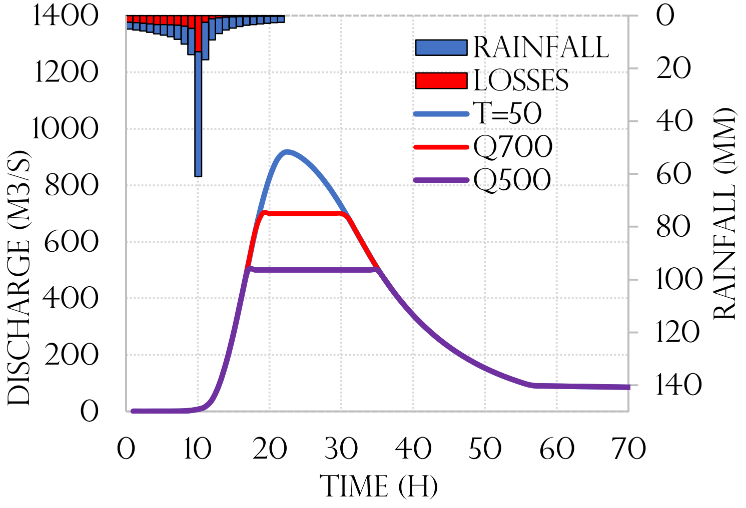
Q_{PEAK}= 500 M³/S

V = 61.24 10⁶ M³

✓ WATER IS SAFELY ROUTED THROUGH THE AREA

RESULTS

RETENTION POND VOLUME CALCULATION



	MAX Q (M^3/S)	V (10^6 M^3)	ΔV (10^6 M^3)
DEFAULT	916	78.17	-
SCENARIO 1	700	72.14	6.03
SCENARIO 2	500	61.24	16.93

POND DESIGN VOLUME

55% DISCHARGE PEAK REDUCTION

NEED 21% FLOOD VOLUME TO BE UPHELD

FACTORS THAT SHOULD BE CONSIDERED:

WHETHER A SINGLE POND IS FEASIBLE OR BETTER CREATE MULTIPLE PONDS.

WHETHER OTHER STRUCTURAL MEASURES CAN BE COMBINED (E.G. SMALL DAMS OR LEVEES).

CONCLUSIONS

- THE METHODOLOGY APPLIED, COMBINES HYDROLOGICAL AND HYDRODYNAMIC ANALYSIS FOR DESIGNING RETENTION PONDS.

- FOR THE PARTICULAR SECTION, AT LEAST A 50% DECREASE OF THE DISCHARGE PEAK WAS REQUIRED IN ORDER TO SAFELY ROUTE THE HYDROGRAPH, LEADING TO A 21% OF THE FLOOD VOLUME NEEDED TO BE UPHELD.

- IN CASES OF LARGE VOLUMES, IT IS SUGGESTED THAT THEY CAN BE DIVIDED IN MULTIPLE RETENTION PONDS, IF SPACE IS AVAILABLE, OR CAN WORK IN CONJUNCTION WITH OTHER STRUCTURAL MEASURES.

- RETENTION PONDS BEING A NBS ARE A SUITABLE AND ENVIRONMENTALLY FRIENDLY STRUCTURAL MEASURE FOR FLOOD PROTECTION WHICH FEATURE OTHER BENEFITS AS WELL

QUESTIONS???