OPERANDUM

Nature-based Solutions for hydro-meteorological risks

Training 6: NbS Modelling and Monitoring

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EU funded project
GA no. 776848

About OPERANDUM

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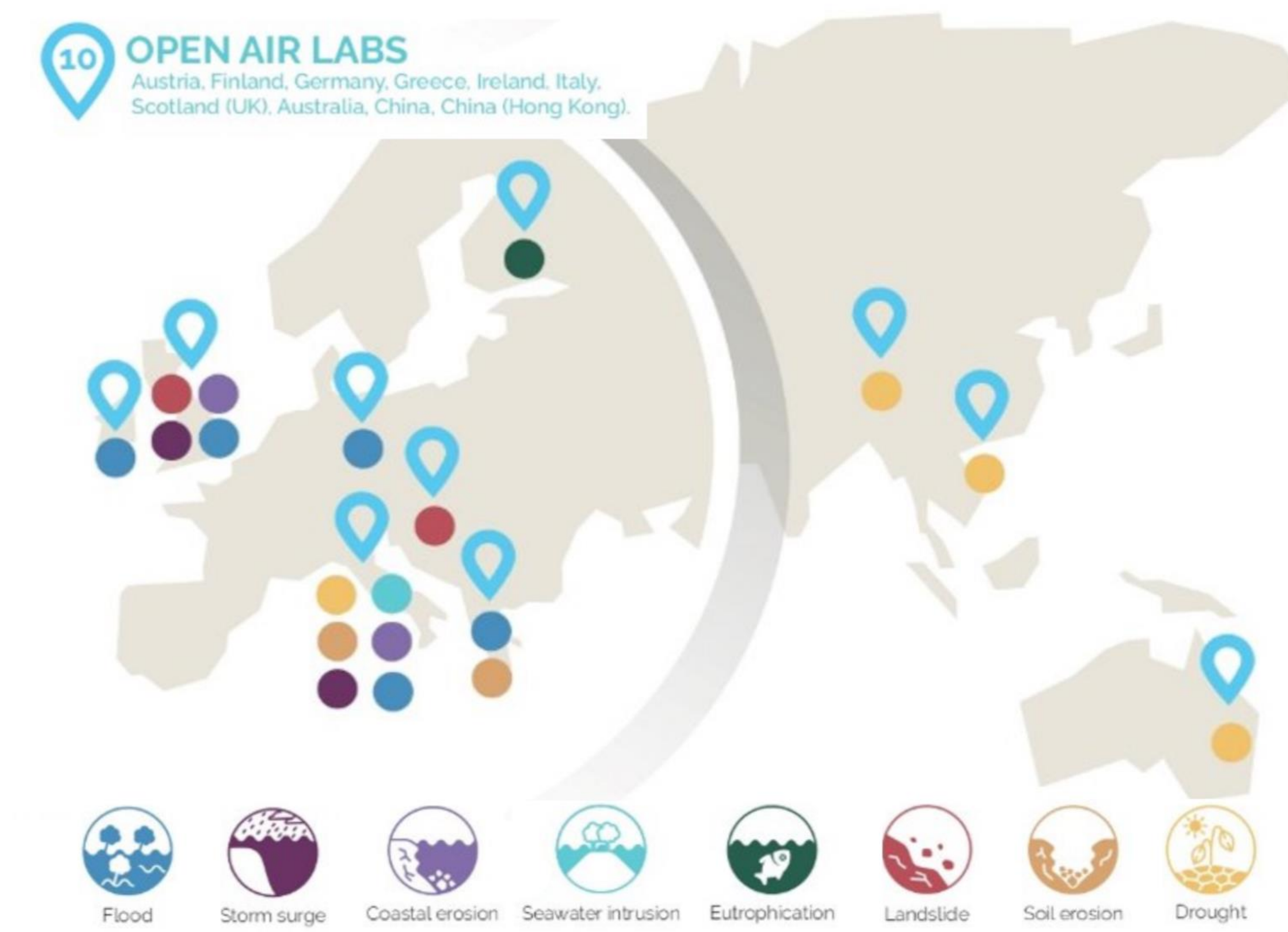
OPEn-air laboRAtories for Nature baseD solUtions to Manage hydro-meteo risks

- 4-year, European project, with 26 international partners
- Sustainable solutions based on Nature-based Solutions - to adapt to extreme weather events
- Demonstrate the tools and methods for the validation of these solutions in 10 open air labs



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NBS Modelling and Monitoring **at a glance**

Part I: Design of NbS interventions

Part II: Verification of compliance of NbS interventions

Part III: Impact of NbS interventions

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Learning objectives

After completing this training unit, you should be able to understand:

- The importance of modelling and monitoring of Nature-based Solutions, and how this can be used in designing NbS and evaluating their functioning and impact
- The difference between actionable and impact variables
- The different methods and tools used for modelling and monitoring NbS
- The practical relevance of remote sensing to monitor NBS
- OPERANDUM's approach to modelling and monitoring of Nature-based Solutions in OALs

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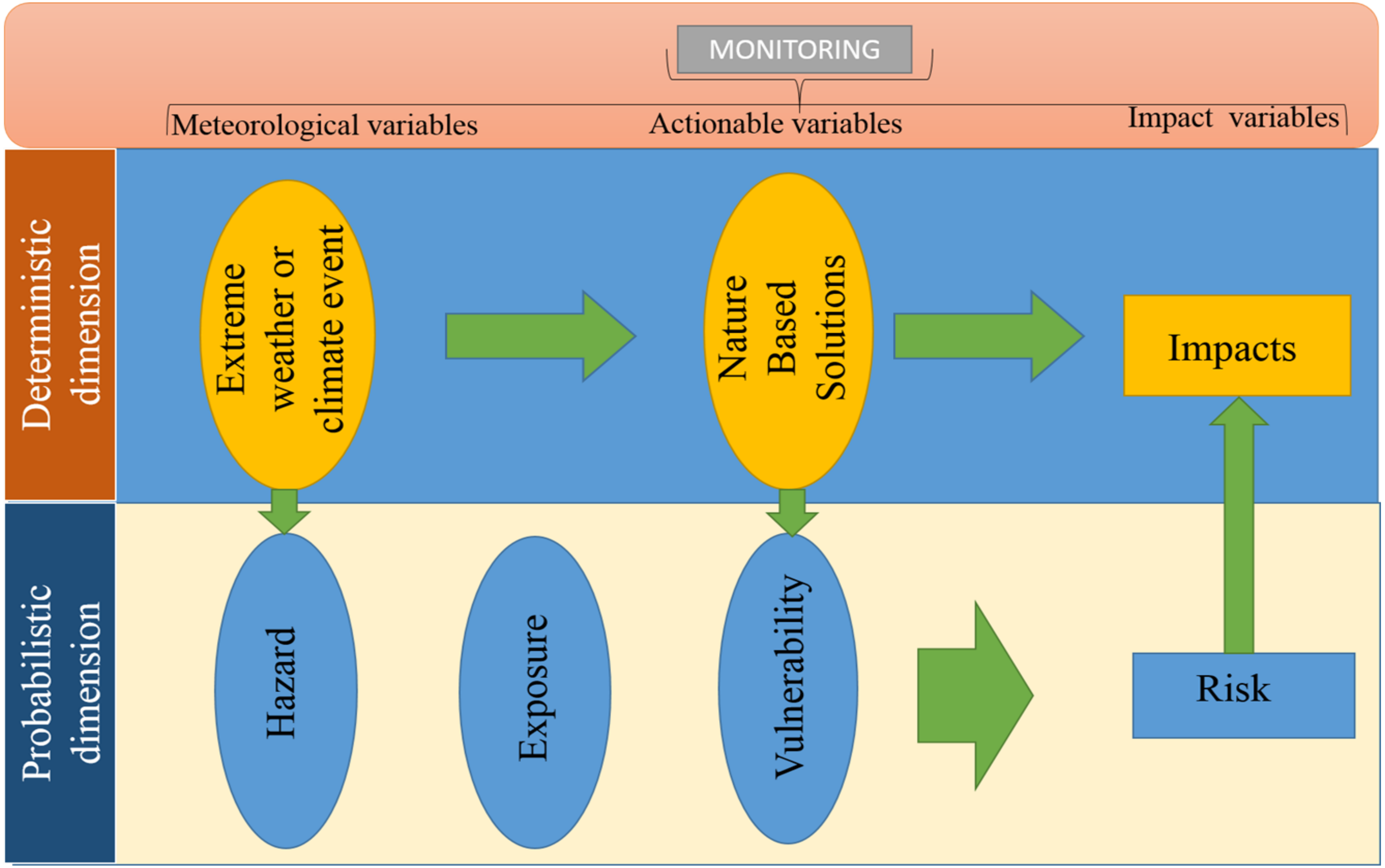
Observing vulnerability and risks: conceptual approach



Useful insights:
- **The reduction of the impact (Risk) after the intervention (NBS) via the Impact Variables**
- **NBS compliance with design via the Actionable Variables**

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Risk mitigation: actionable and impact variables

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OAL	Natural risk	Nature-Based solution	Actionable variable	Impact variable	Performance evaluation
OAL-Austria	Landslide	Sealing of drainage channels	Permeability of drainage channels	Infiltration; soil moisture; hydrological forcing of the landslide	Monitoring experiment
	Landslide	Optimized forest management	Tree species composition and stand structure; fractional vegetation cover; leaf area	Transpiration, evaporation, infiltration; hydrological forcing of the landslide	Modelling case study
	Landslide	Adaptation of land cover considering potential impacts of climate change	Land cover hydro-meteorological properties	Projected monthly water balance; hydrological forcing of the landslide	Modelling case study

Natural risks per OAL vs. NBS, identified actionable and impact variables and NBS performance assessment

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Modelling NBS functioning and impacts – II

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(Kumar et al., 2021)

Modelling methods for NBS

Types of models	Empirical Models	Conceptual Models	Physical Models
Working principles	Non-linear relationship between inputs and outputs, black box concept	Simplified equations that represent state variable storage in catchment	Physical laws and equations based on real state variable responses
Input data	All averaged data by catchment	Both averaged and specific data by sub-catchment	All specific data by cell /grid/mesh
Advantages	Small number of parameters needed, can be more accurate, fast run time	Easy to calibrate, simple model structure	Incorporates spatial and temporal variability, very fine scale
Limitations	Numerous assumptions, loss of spatial resolution, not ideal for large areas	Averaged data into subcatchment areas, loss of spatial resolution	Numerous input parameters & calibration needed, data intense, long computational time, site specific
Examples	Curve Number, Artificial Neural Network	HSPF TOPMEDEL, HBV	WRF, MIKE-SHE , HEC-RAS, ADCIRC, TELEMAC, FUNWAVE-TVD, LISFLOOD-FP

Models were utilised for the optimum allocation, design, performance and impacts of multiple NBS for five HMRs: flooding, droughts, heatwaves, landslides, storm surges and coastal erosion.

Modelling methods differ in accuracy and complexity, but help strategic planning, design and evaluation of NBS for HMR reduction and management

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Modelling NBS functioning and impacts – I

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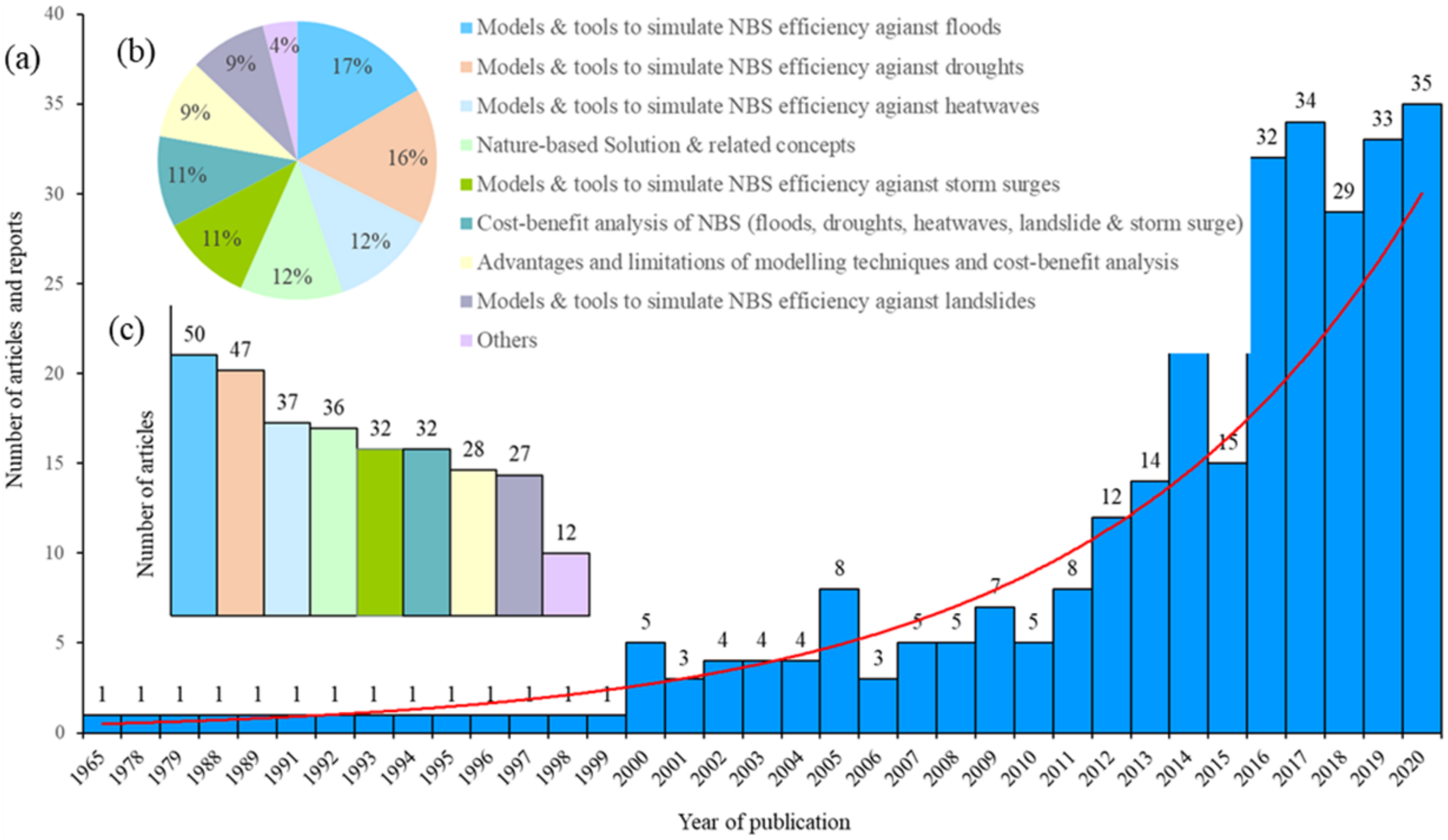
(**Kumar et al., 2021**)



A detailed literature review documented the use of modelling related to NBS.

64%: simulation of NBS performance and impact against HMRs.

of which: floods, 18%; droughts, 14%; heatwaves, 11%; landslides, 10%; and stormsurge, 10%.

Design of NBS interventions

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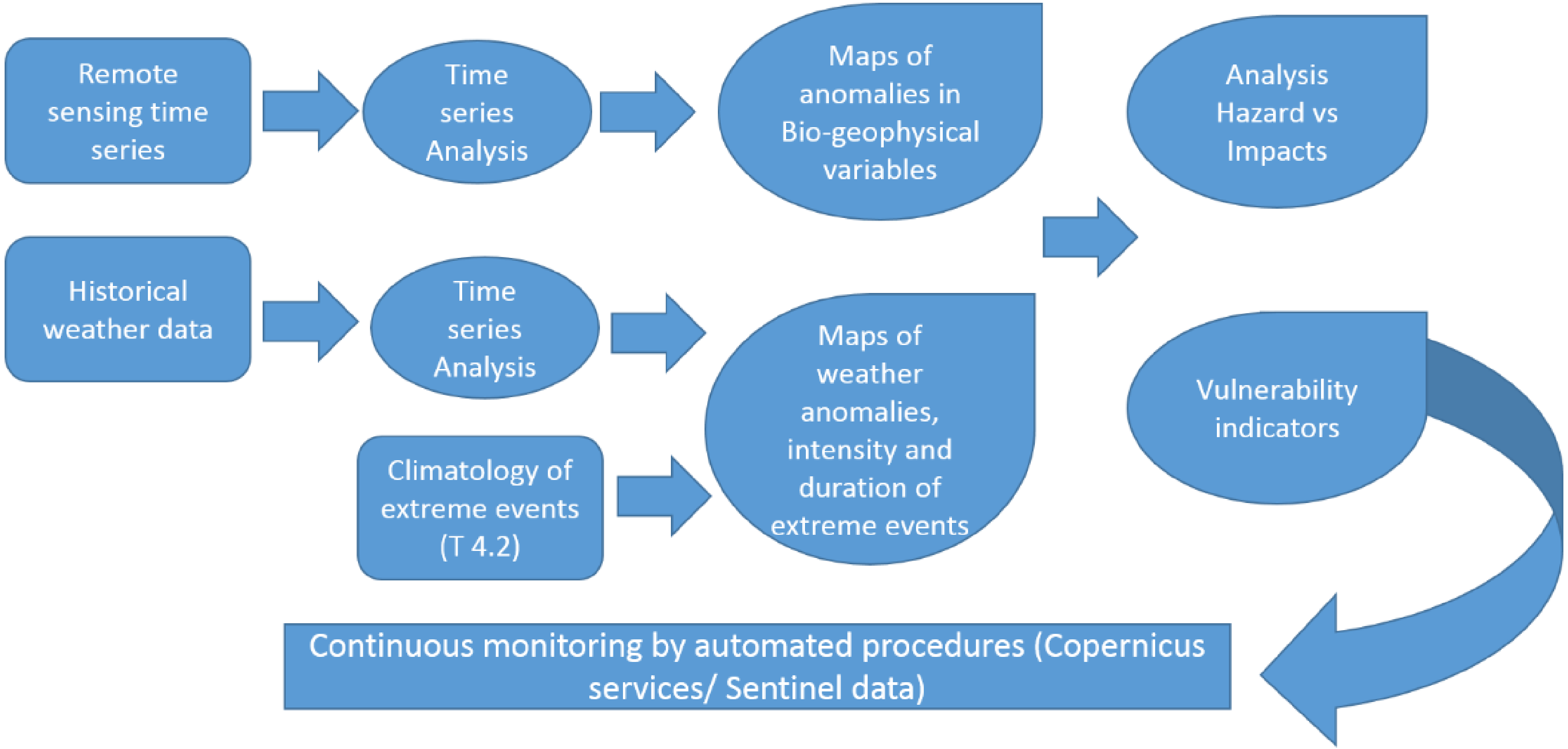
1) Identify the key hazard and its intensity

2) Define risks and relate to hazards

3) Factors determining risks, given the hazard intensity

4) Identify the variables to be modified to mitigate risks



Engineering approach to designing NBS

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1. **Problem definition**
2. Identification of the **input parameters**
3. **Solution behaviour modelling**
4. **Calculations and checks**
5. **Analysis and assessment** of calculations results

- What is the problem to be solved?
- How can the problem be solved?
- What is the best location to deploy the NB solution?
- When is the best time for the deployment of the solution?

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Example: Design of NBS Artificial dune OAL-IT

1. **Problem definition**
2. Identification of the **input parameters**
3. **Solution behaviour modelling**
4. **Calculations and checks**
5. **Analysis and assessment** of calculations results

1) **Reduction of the coastal erosion effects impacting on a protected area through a passive erosion protection system**, consisting of a vegetated embankment built using natural materials (dune)

2) **Topographical conditions of the site** (beach area, shoreline position, vegetated area position), **meteocean conditions** (offshore waves characteristics), **bathymetric conditions** of the nearshore area (necessary for nearshore analysis), **geotechnical and seismic parameters** (necessary for structure calculation), **vegetation conditions** (characteristics of existing flora), **anthropic variables** (other structures and loads)

3) **Models of the structure properly considering acting forces on the structure** (soil pressure, wave forces, anthropic loads, seismic actions), calculated considering literature formulas or specialistic models. The models consider the **relevant failure mechanisms**, such as slope stability, structural strength of materials composing the dune, bulkhead equilibrium

4) Details of **structural and geotechnical calculations for the verification of the embankment**, considering the required safety factors provided by local regulatory framework (**N.T.C. 2018**)

5) Description of the **verification results and validation through a monitoring system** installed during the dune construction and activated during the embankment lifetime.

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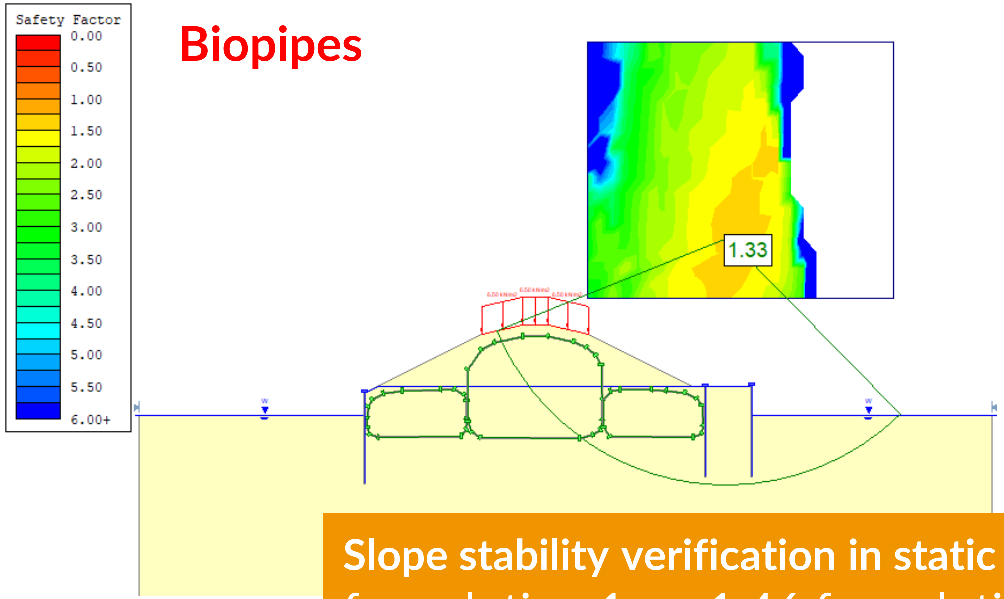
Example: Design of NBS Artificial dune OAL-IT

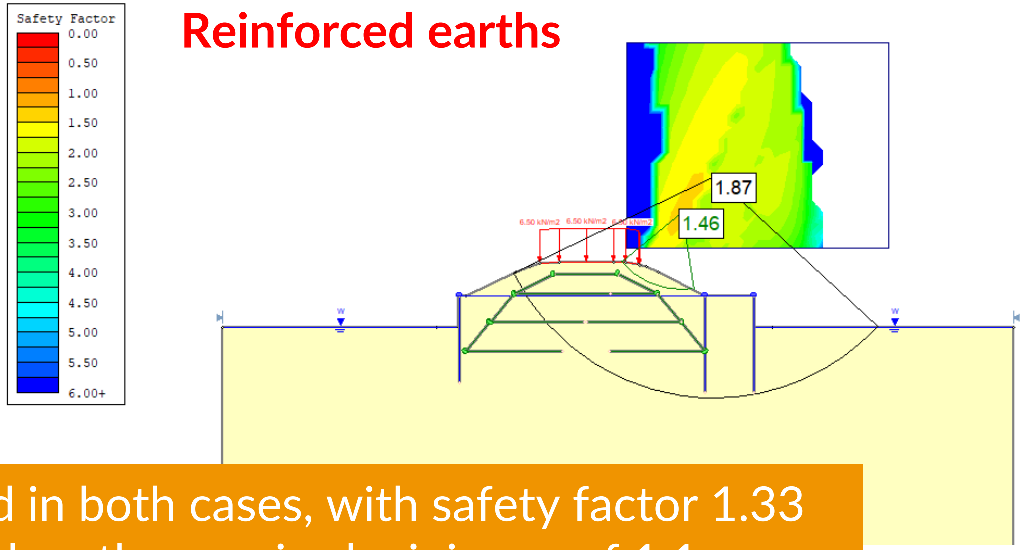
OAL	Natural risk	Nature-based solution	Actionable variable	Impact variable	Performance evaluation
Italy	Coastal erosion and marine flooding	Artificial dune	Increase of beach elevation; structural reinforcement of the NBS; vegetation cover	Erosion of emerged beach; flooded area	Monitoring experiment and modelling case study

Two concepts: biopipes and reinforced earths.
Different configuration and different materials.

Biopipes



Reinforced earths



Slope stability verification in static conditions: satisfied in both cases, with safety factor 1.33 for solution 1 vs. 1.46 for solution 2. Both higher than the required minimum of 1.1

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OAL-IT Panaro River deep-rooted herbaceous vegetation

Panaro River deep-rooted herbaceous vegetation OAL IT – II

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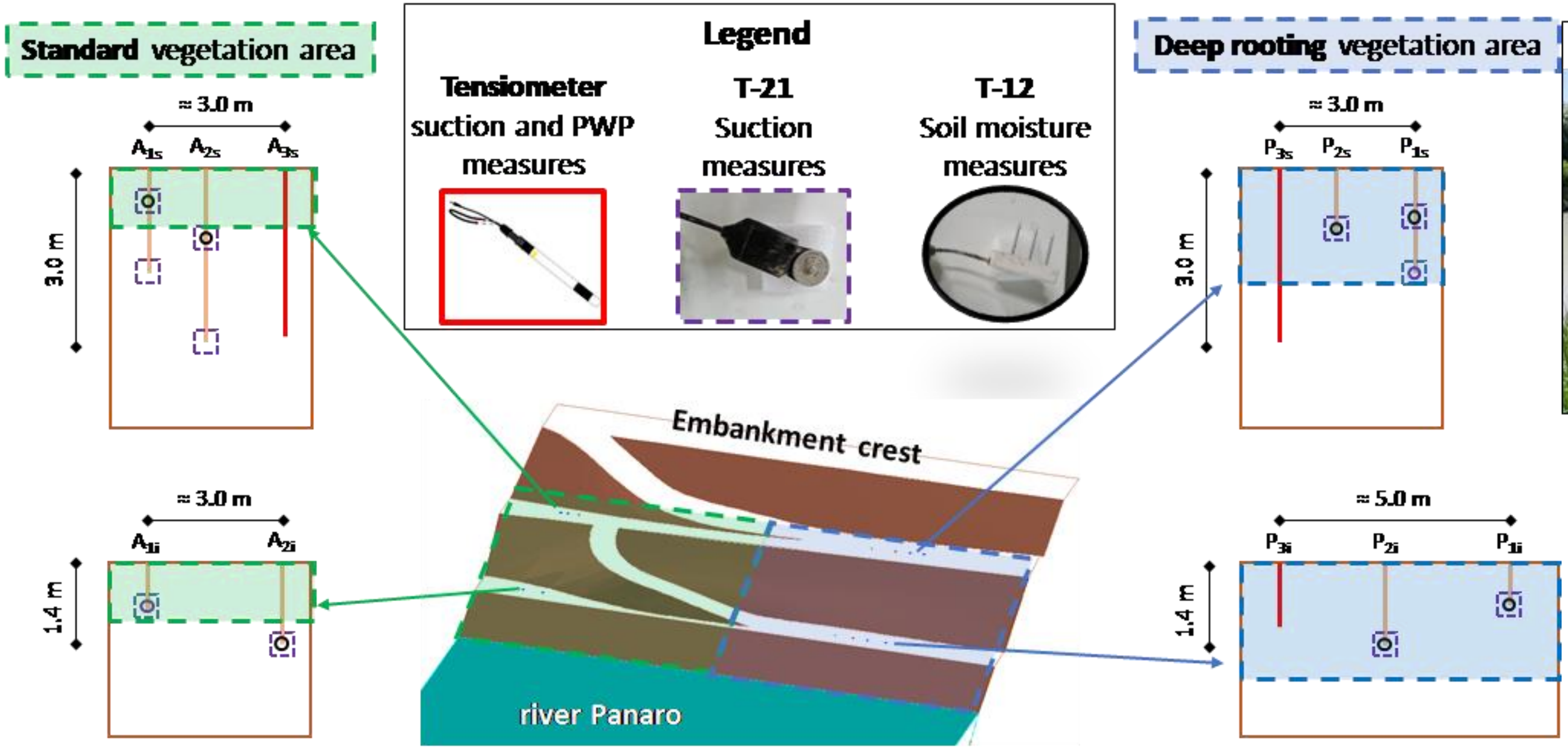
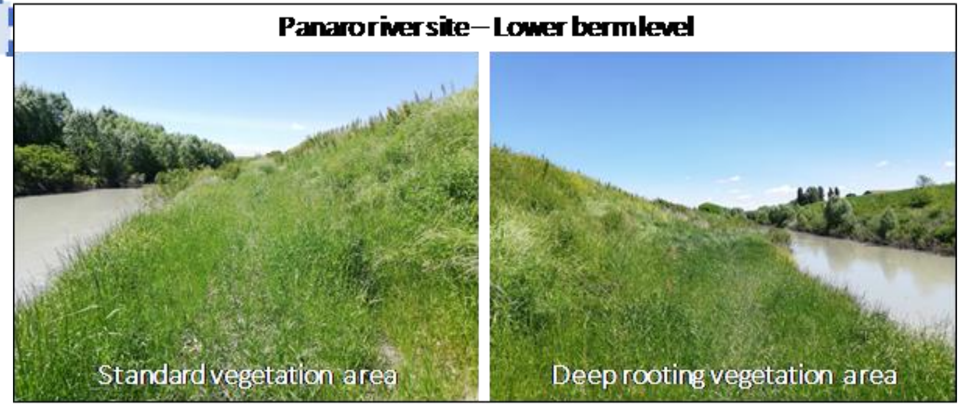
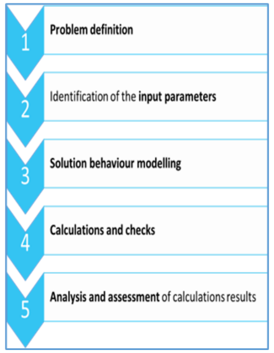
The intended function of the prototype is to improve water retention, hydraulic and strength properties of the vadose underground zone and to reduce erosivity of the soil cover using a nature-based solution (NBS).







To support the design of the NBS the site has been characterized in detail before the implementation: early subsurface characteristics have been assessed with the help of cone penetration tests with continuous measure of pore water pressure (CPTUs) in combination with laboratory experiments on disturbed and undisturbed soil samples collected at the site.

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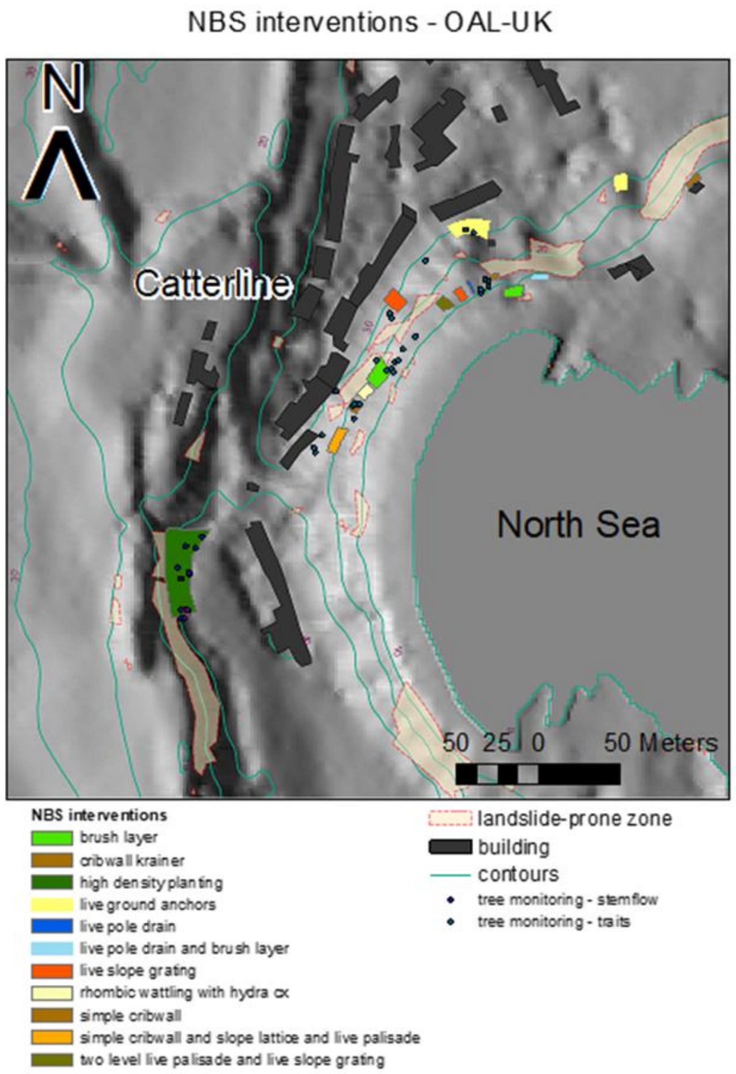
OAL – UK Mitigation of shallow landslides and erosion



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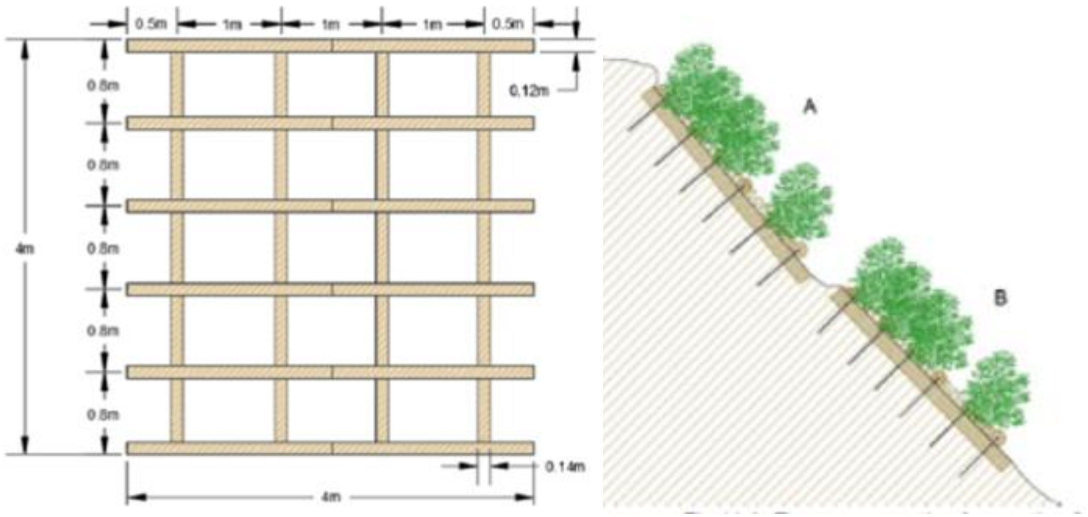
NBS Live ground anchors OAL - UK

OAL	Natural risk	Nature-based solution	Actionable variable	Impact variable	Performance evaluation
United Kingdom	Landslide	Live ground anchors	Soil strength; surface roughness; soil moisture; plant cover and architecture; rainfall partitioning	Slope stability; erosion	Monitoring experiment

The anchors prevent erosion due to the increase of surface roughness. Provide reinforcement to the soil by the action of the vegetation roots which will grow into the soil.



Angle of internal friction (º)

Slope angle (º)	5	10	15	20	25	30	35	40
5								
10	1.37							
15	0.68	1.37						
20	0.45	0.68	1.37					
25	0.33	0.45	0.68	1.37				
30	0.26	0.33	0.45	0.68	1.37			
35	0.21	0.26	0.33	0.45	0.68	1.37		
40	0.17	0.21	0.26	0.33	0.45	0.68	1.37	
45	0.14	0.17	0.21	0.26	0.33	0.45	0.68	1.37

centre to centre distance (m)

The local stability of the stabilised embankment was verified using the the Slope/W software. The fallow and stabilised slope scenarios have been analysed. The stability factor of safety was 0.676 (unstable) vs. 1.246 (stable) for the current and anchored conditions.

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OAL – DE Elbe Cooperative Floodplain Management

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Example: Cooperative Floodplain Management (CFM) OAL - DE

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1 Problem definition
2 Identification of the **input parameters**
3 Solution behaviour modelling
4 Calculations and checks
5 **Analysis and assessment** of calculations results

1) The Elbe floodplain contributes to the natural flood protection of the lower Middle Elbe. Some areas should be kept free of higher vegetation to guarantee unhindered runoff, while in other ones floodplain forest development can be tolerated or even afforested.
2) High accuracy terrain and surface models, vegetation stage in terms of roughness, vegetation flexibility, entanglement, water depths, flow velocity, cross-sectional area. Observance of and compliance with the legal guidelines for nature conservation, flood protection and the interests of agriculture.
3) The hydraulic modelling of the NLWKN is based on 2-D-HN model of the software Hydro_AS-2D, with 1.1 million account points and approx. 2.2 million elements based on the Digital Terrain Model of Lower Saxony from 2015. Roughness is specified with a gridded data set at a resolution of 1m x 1m
4) Modelled potential, local vegetation removal can lead to local, decisive lowering of the water level in the cm range. For practical implementation, it must be checked to what extent the NATURA 2000 regulations are compatible with regard to the removal of protected species and the associated compensation measures.
5) The estimated effect of vegetation removal has hydraulic significance. Significant water level reductions in the decimetre range could be achieved with a modelled, sectional trees and shrubs removal over a longer flow length

Example: Cooperative Floodplain Management (CFM) OAL - DE

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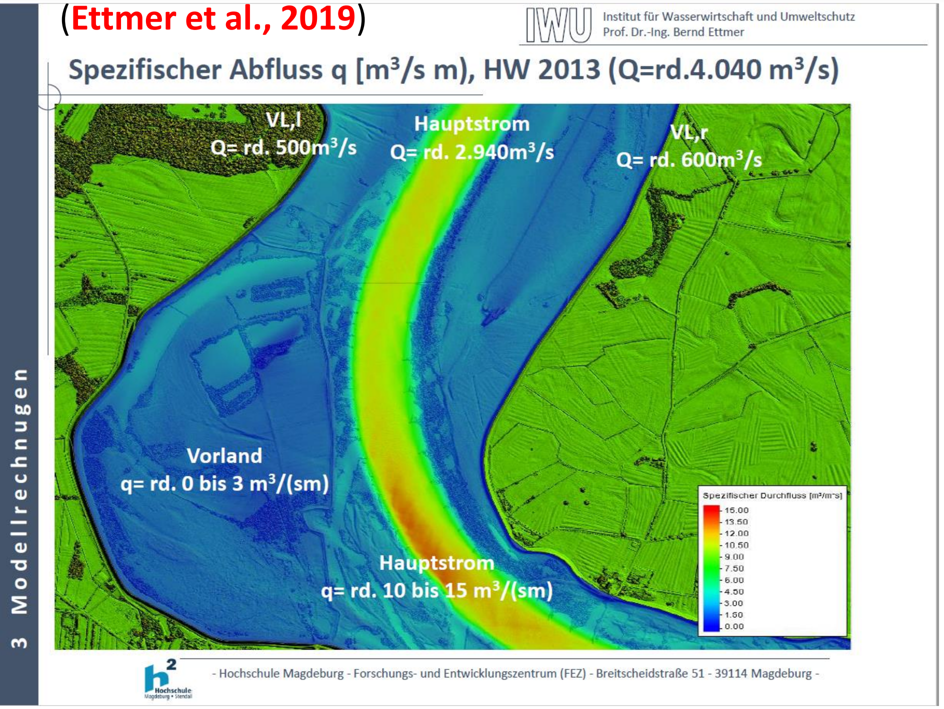
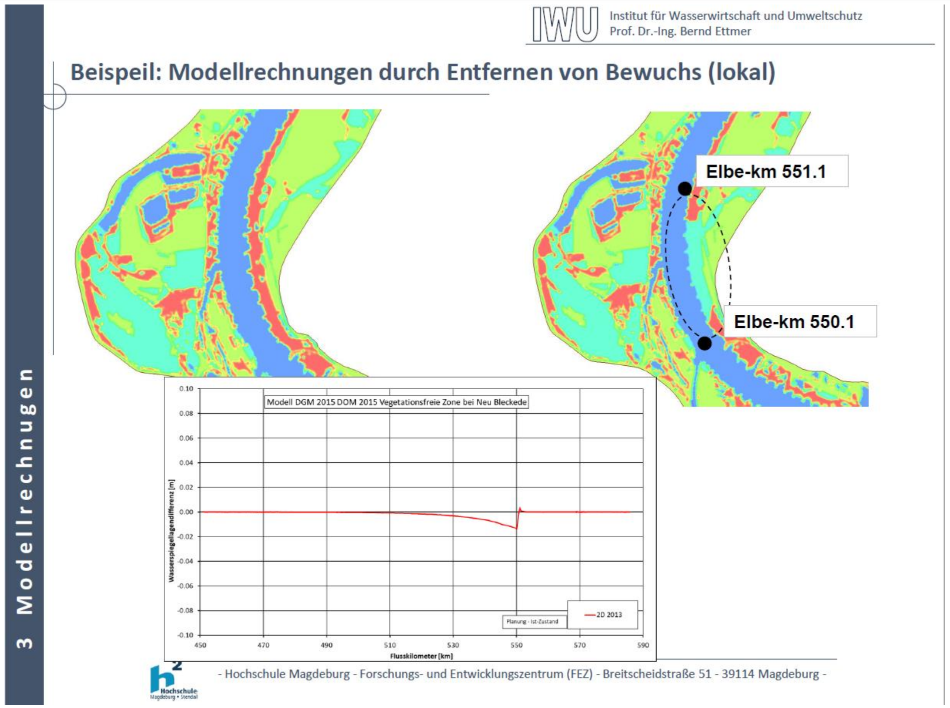


2013 flood event: Specific discharge q in m³/(s m) for the highest value (HW) of discharge Q=~4040 m³/s"



Vegetation roughness: actual (left)vs. removal of trees and shrubs on the right side of the Elbe (right); estimated change in river water level (bottom)

Simulations:

- **Significant water level reductions in the decimetre range could be achieved with trees and shrubs removal over a longer flow length;**
- **As part of the CFM work, the modelling results help identifying further clearing measures and afforestation measures.**

Design of NBS interventions

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- Design clarifies how exactly we intend to manipulate one or more bio-geophysical properties of a landscape
- The design approach makes a NBS intervention verifiable and replicable
- NBS interventions aim at manipulating complex soil – vegetation systems: process understanding and experimental data may not be sufficient for robust design
- Engineering of NBS is not the main driver in NBS implementation, but a technical service to the stakeholders

Next up: *Verification of compliance of NBS interventions*

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Part II Verification of compliance of NBS interventions

Challenges = knowledge gaps in the assessment of NBS performance:

- Effectiveness of single and multiple NBS against hydro-meteorological risks
- Assessment of multiple benefits of NBS
- Application of innovative concepts, technology and models

Phases	Actionable variables	Impact variables
Design of NBS	Core objective of design	
Verification of compliance	Actual vs design properties	
Impact of NBS intervention		Do the modified landscape properties have any beneficial effects on HM processes and risks?

Review the design of NBS Identify the key – hazards, their likely intensity and associated risks

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Evaluation of NBS performance

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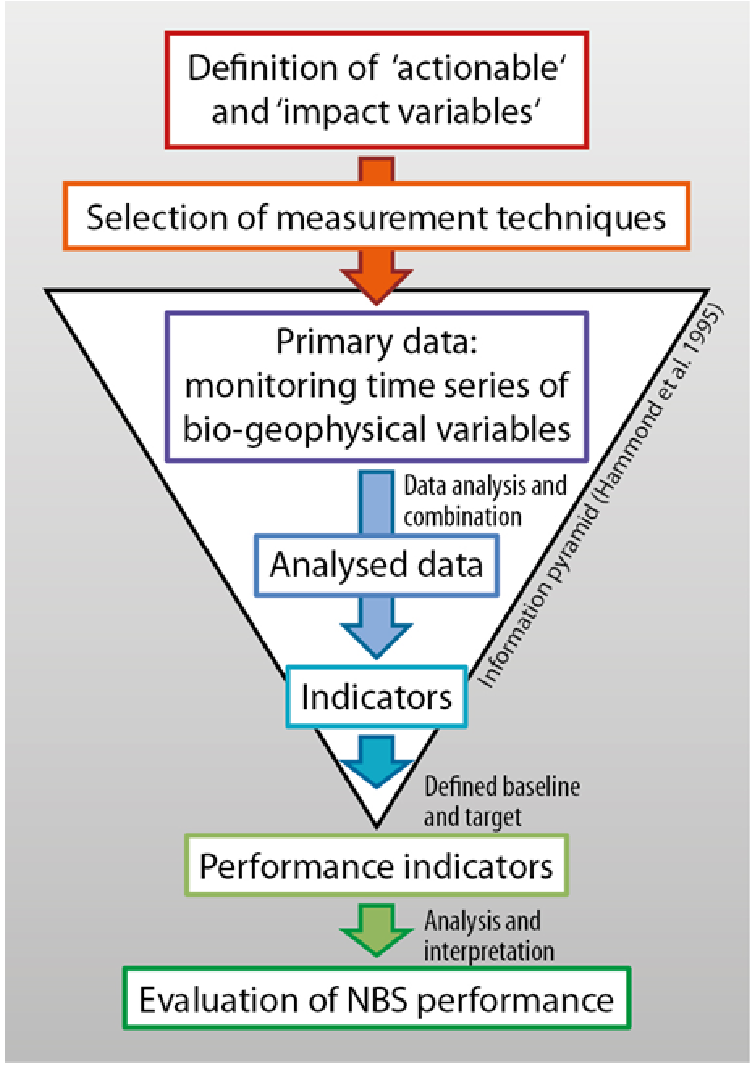
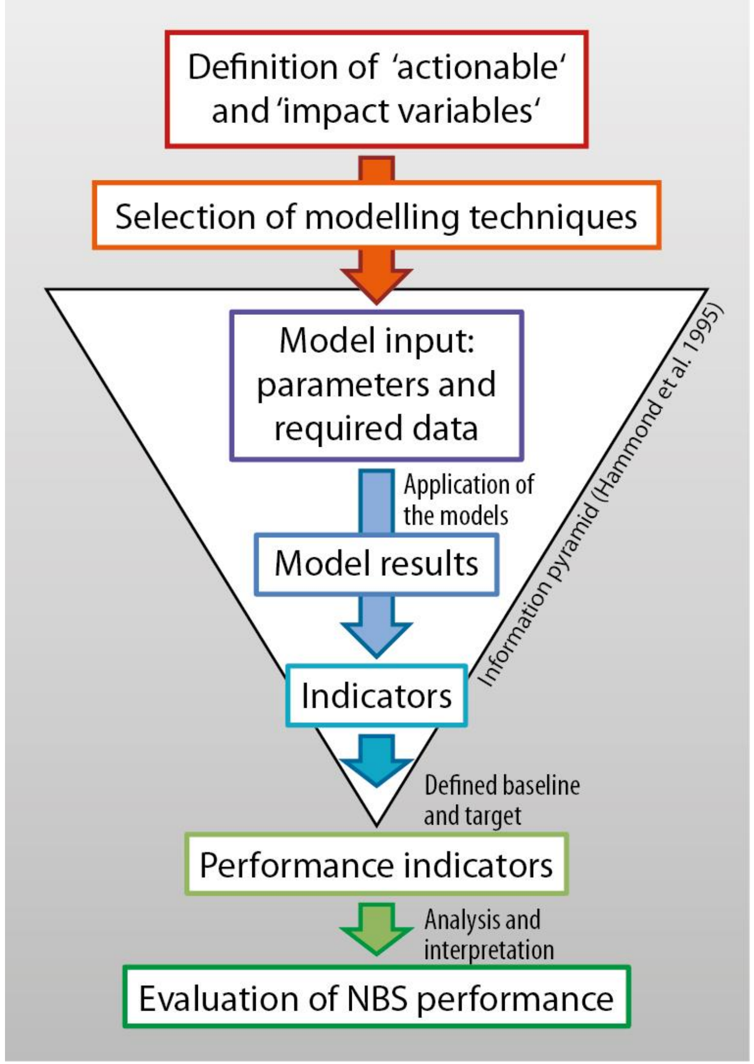
Evaluating NBS performance with numerical experiments



Evaluating NBS performance with monitoring experiments



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Risk mitigation: actionable and impact variables

OAL	Natural risk	Nature-based solution	Actionable variable	Impact variable	Performance evaluation
OAL-Finland	Lake eutrophication	Riparian buffer zones	Sedimentation rate; number and size of riparian buffer zones	Amounts of sediments and nutrients retained	Modelling case study and monitoring
	Lake eutrophication	Constructed wetlands	Sedimentation rate; number and size of constructed wetlands	Amounts of sediments and nutrients retained	Monitoring experiment
	Lake eutrophication	Sedimentation ponds and pits	Sedimentation rate; number and size of constructed wetlands	Amounts of sediments and nutrients retained	Monitoring experiment
	Lake eutrophication	Overland flow area (OFA)	Sedimentation rate; number and size of constructed wetlands	Amounts of sediments and nutrients retained	Monitoring experiment
	Lake eutrophication	Submerged dams	Number and size of dams	Water flow in streams; transport of suspended solids/sediments and nutrients retained	Monitoring experiment
	Lake eutrophication	Peak flow control structures	Flow velocity; number and size of control structures	Peak flow rate in streams; erosion/sediments and nutrients retained	Monitoring experiment
	Lake eutrophication	Continuous cover forestry	Forest area in the catchment	Evapotranspiration; nutrient uptake; soil water content; erosion; surface runoff /nutrients retained	Modelling case study and monitoring

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Monitoring NBS operation and impacts – observables

OAL	Risk	Impact	Observable Impact variable
Ireland	Flood (Urban)	Direct physical impact	Flooded area
UK	Slope instability	Geo-morphological changes	Change in surface elevation (DTM) and/or vegetation cover;
UK	Coastal erosion	Erosion	coastline change
Austria	Landslides	Geo-morphological changes	Landslides movements , mass movements, surface object deformation
		Land cover changes	Land cover, vegetation indicators
		soil moisture changes	soil moisture indicators
Finland	Nutrient load due to heavy precipitation	Deterioration of water quality	Chlorophyll content, suspended sediments; water color; water turbidity;
Hong Kong	Heat Island	Urban temperature increase	SUHI indicator

Monitoring NBS operation and impacts – Remote Sensing

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Impact variable	Risk	Method	Data
Flood extent	Flood Storm Surge	Thresholding [3] on Normalized difference Water Index [4] or SAR backscatter signal (VV or VH) .	Multispectral /SAR
Normalized Drought Anomaly Index (NDAI)	Agricultural drought/Hydrological drought	Combination of NDVI and LST normalized anomaly [5]	Multispectral/Thermal
Surface Urban Heat Island Intensity (SUHII)	Heat Island	Retrieval of Land Surface Temperature from thermal Infrared Remote Sensing. Temperature - Emissivity Separation [6]. SUHII is calculated as LST_{urban} - LST_{rural}	Thermal
Landslides movements	Landslides	Permanent Scatterers High resolution interferometric synthetic aperture radar (PS-InSar)[7]	InSAR
Chlorophyll content	Deterioration of water quality	Hyperspectral s/multispectral EO data detecting algal pigment spectral signatures [8].	Hyperspectral/Multispe ctral

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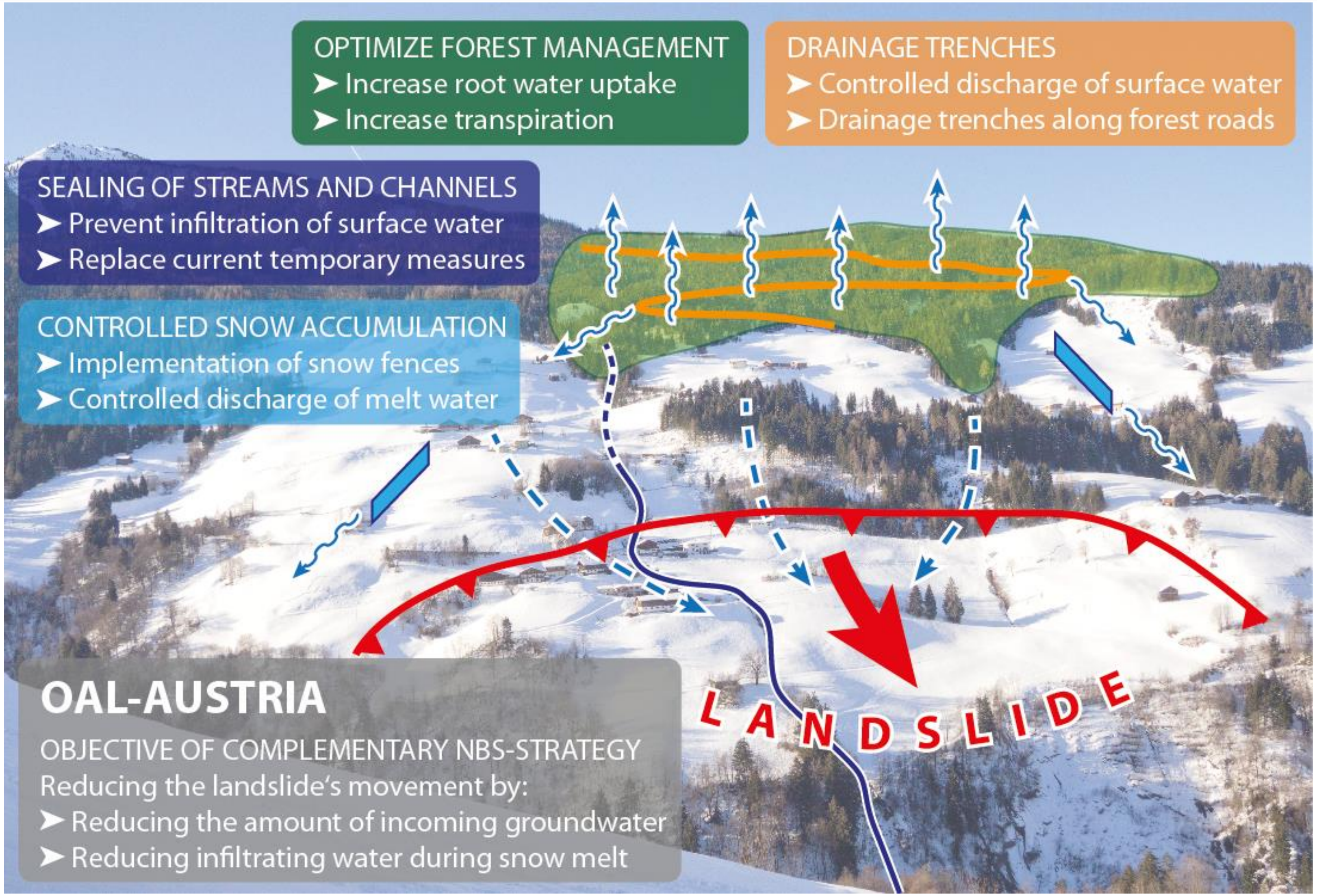
OAL – AT Sealing drainage channels



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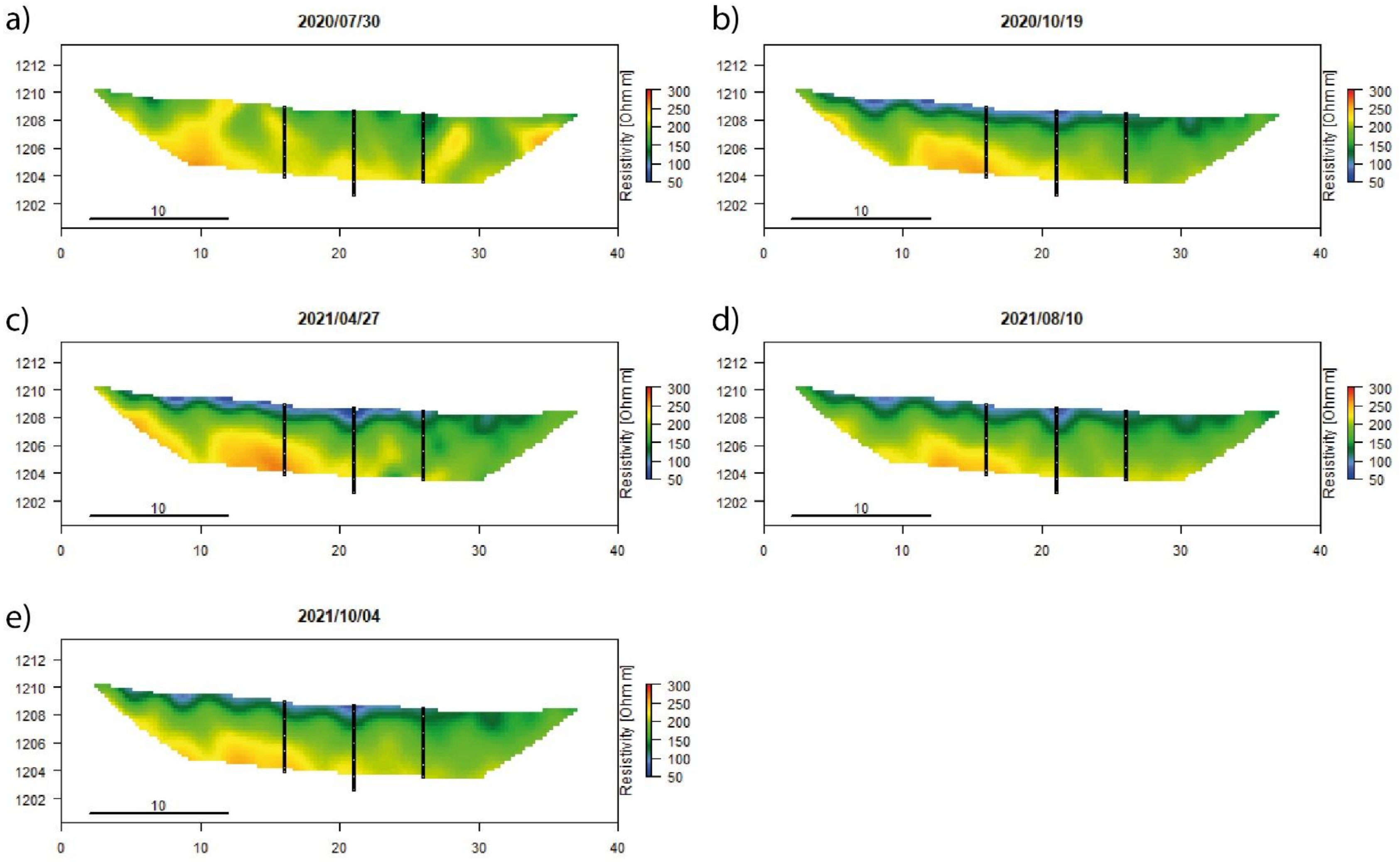
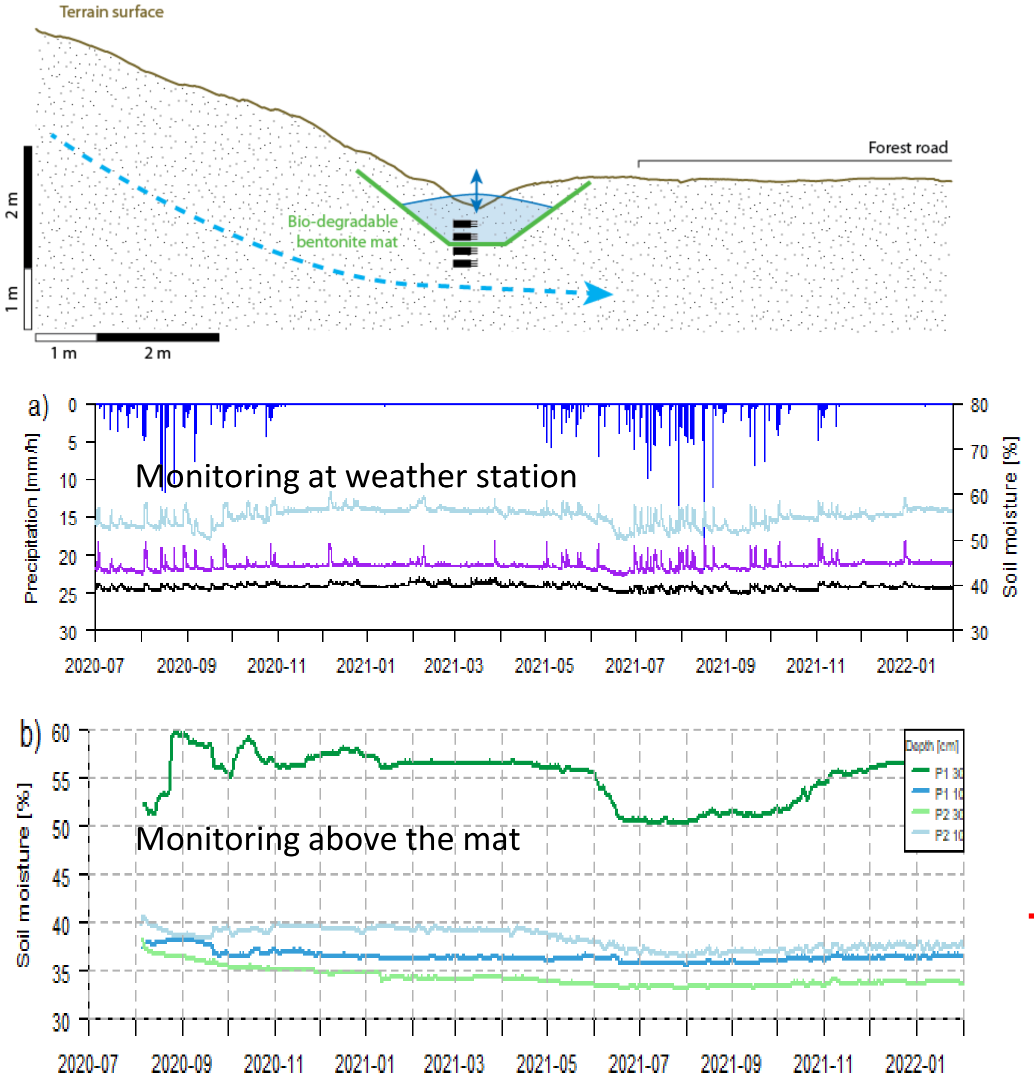
OAL-AT: Sealing drainage channels

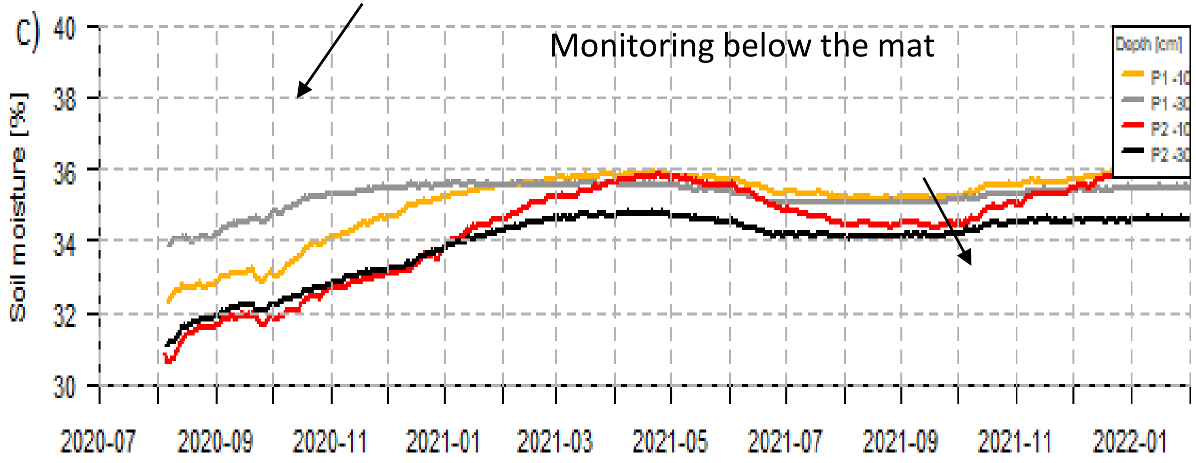


Resulting ERT transects of the monitoring profile (see Figure 3b), starting with the baseline measurement before the co-deployment of the bentonite mat (a). Subsequently, seasonal measurement campaigns were conducted except for the winter season where snow cover prevents ERT measurements (b-e). The recorded depths of the DCPTs are shown as vertical black lines.

OAL-AT: Sealing drainage channels



Interflow below mat, peaks around snow melt



→Bentonite prevents infiltration of surface water since the start of the monitoring

→BUT: also prevents water from exfiltrating

→Conclusions: bentonite mat works well, but design has to be adapted to local conditions (have to be assessed carefully before implementation)

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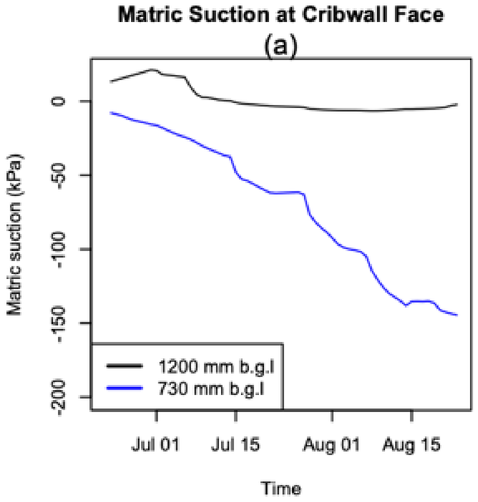
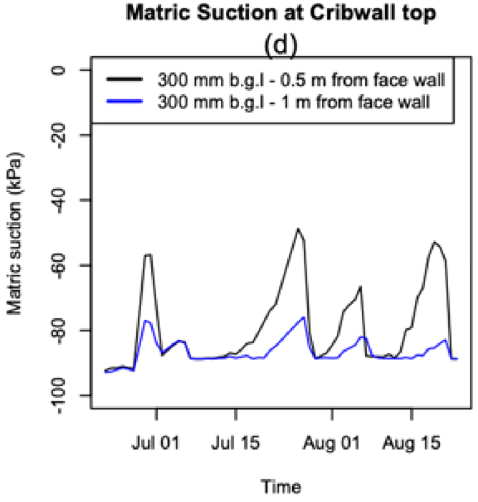
OAL – UK : Cribwall

Evolution of the plant cover over time at the face and top of cribwall





The observations on matric suction and soil moisture retrieved in the cribwall indicate soil unsaturated conditions and positive hydro-mechanical stress conditions in the ground throughout the monitoring period and hence an adequate eco-engineering performance of the NBS.

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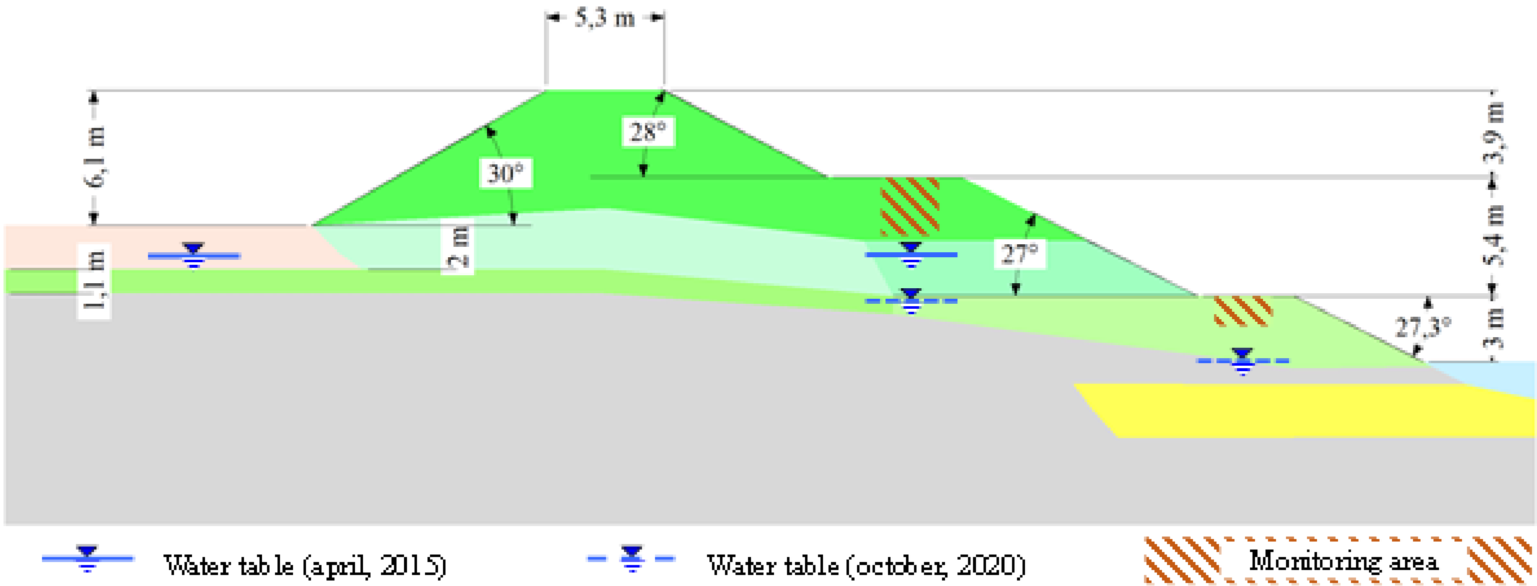
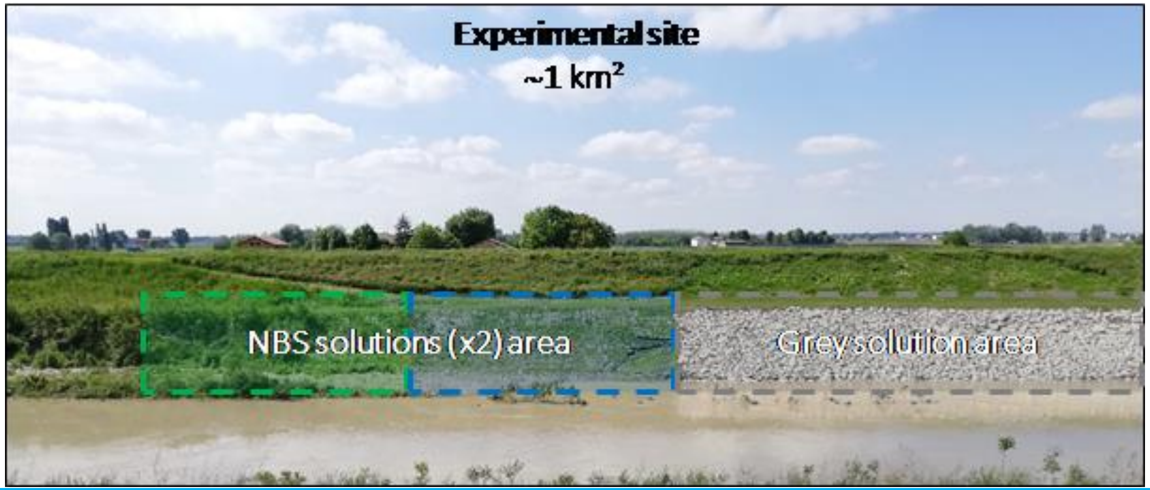
OAL – IT: deep rooting vegetation



Establishment of a dense vegetation cover using deep rooting perennial, herbaceous species on an earth embankment of the Panaro river, Italy reduce the **risk** of riverbank failure by progressive erosion.



Lower level of the berm in the standard vegetation area (left) and deep-rooting vegetation area (right), 24 june 2021

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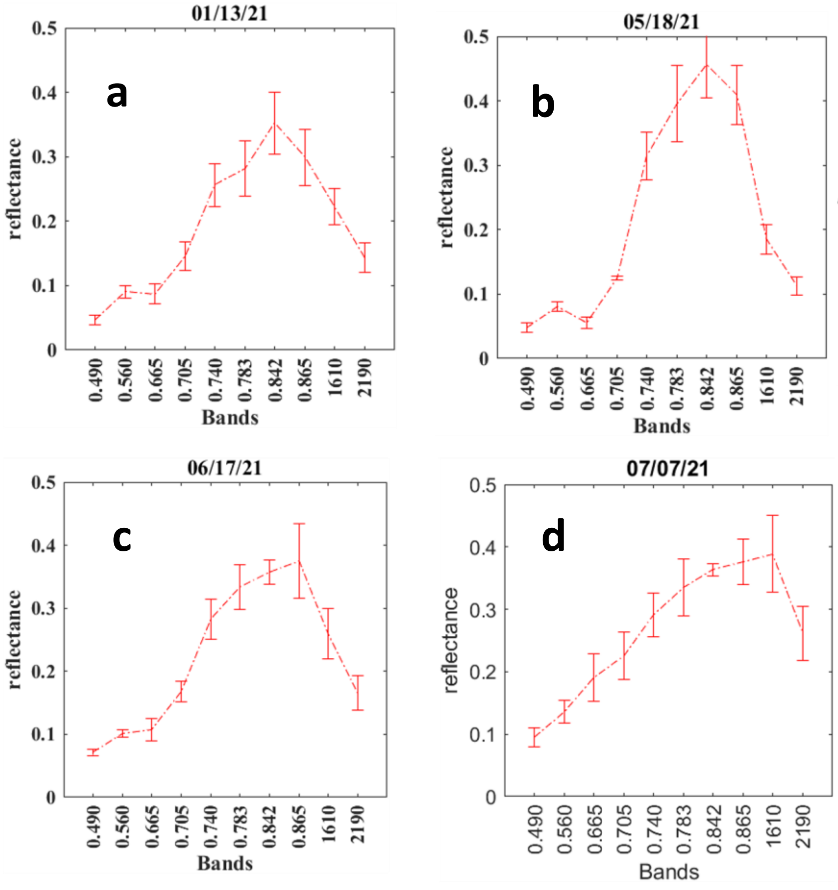
OAL – IT: deep rooting vegetation

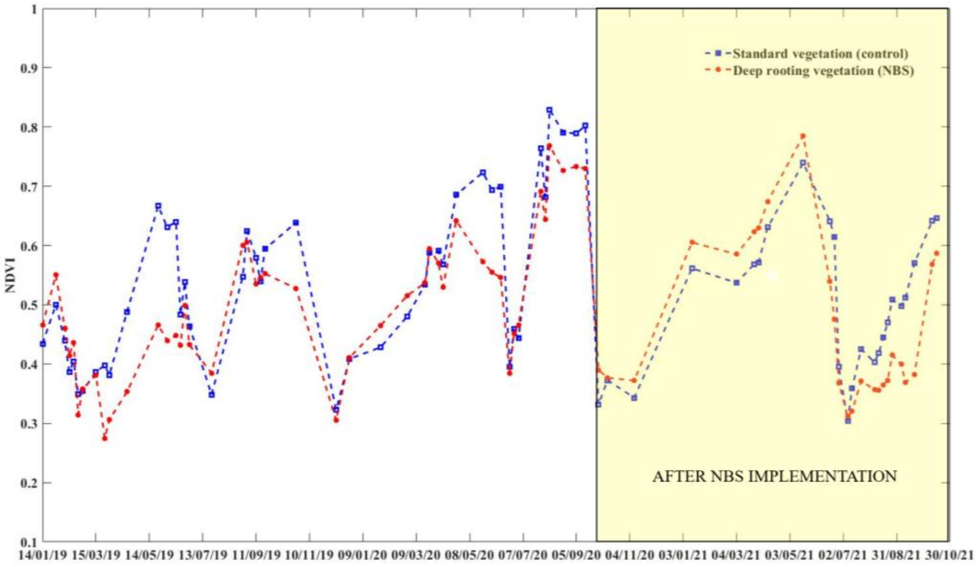
Monitoring of the vegetation cover on the river embankments with Very High Resolution spaceborne imagery



Spectral profiles (left) of the deep rooting vegetation at key stages during 2021:

a) initial development,
b) full development,
c) crop stress (withering),
d) dry vegetation,
e) start of vegetation recovery,
f) full recovery.

Time series of mean NDVI the Standard vegetation (blue) and NBS (red) areas



$$NDVI = \frac{\rho_{783} - \rho_{665}}{\rho_{783} + \rho_{665}}$$

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OAL – DE monitoring: managed grazing

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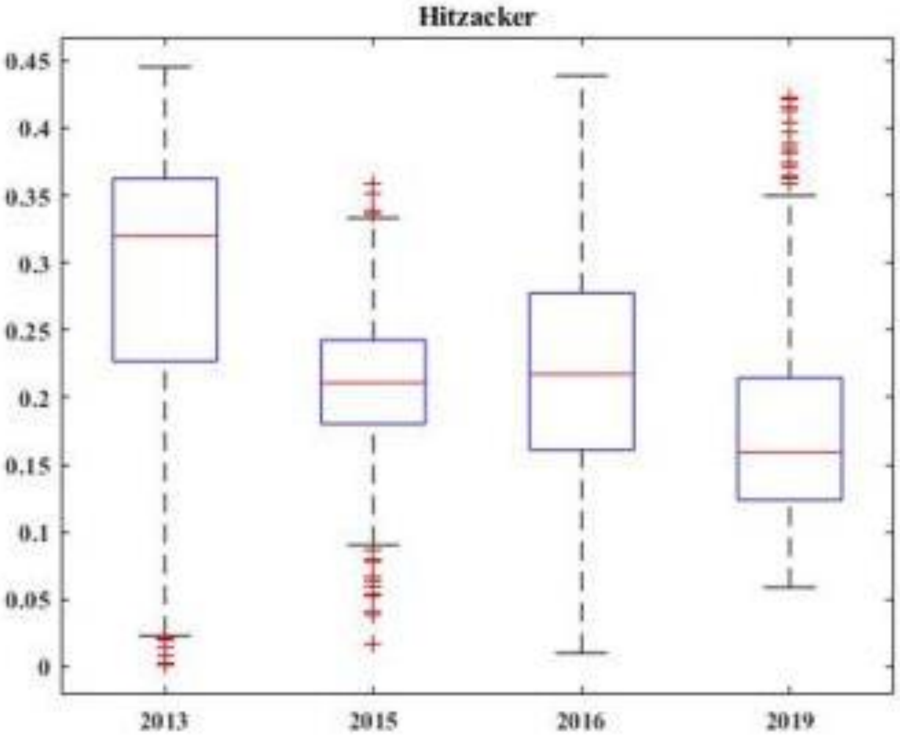
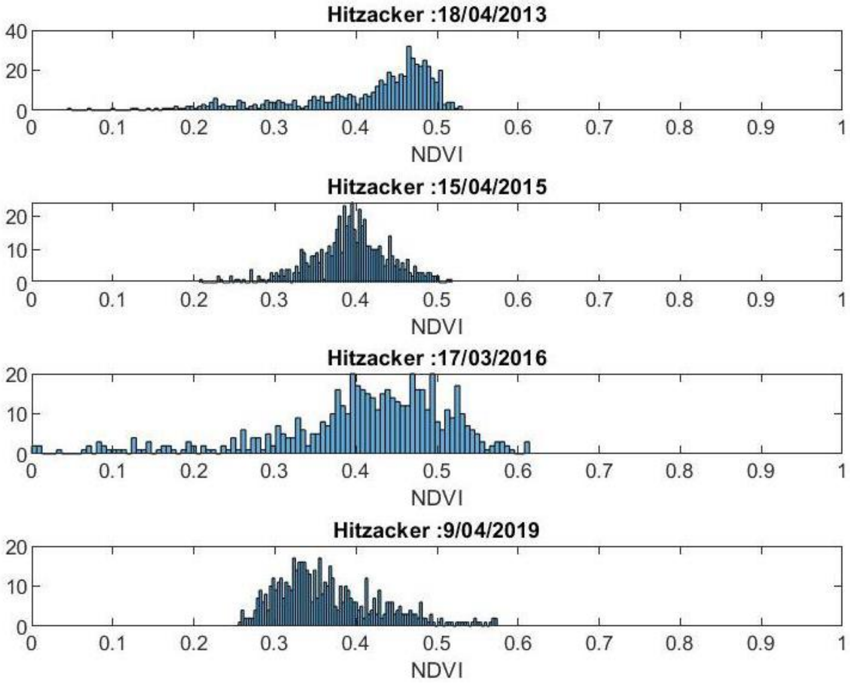
Question: Does the vegetation grow back after being cut? Or, alternatively, are the animals doing what we hoped for?



Context: 7 sites where woody vegetation (mixed forest) has been cut back to try and reduce flood risk (autumn 2014-Feb 2015)



Preliminary experiment: RAPIDEYE data used to estimate fractional vegetation cover over 4 of the 7 sites, pre- and post-cutting, using a simple algorithm

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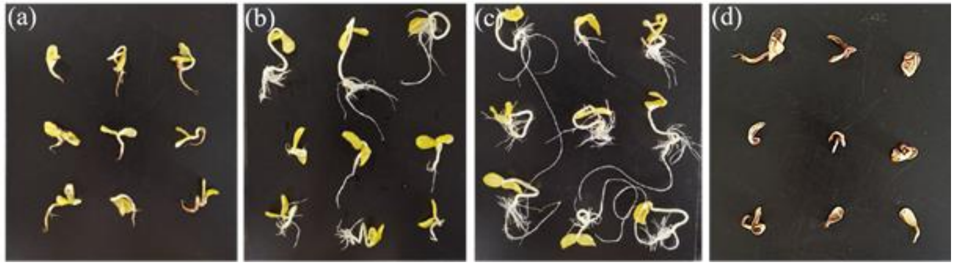
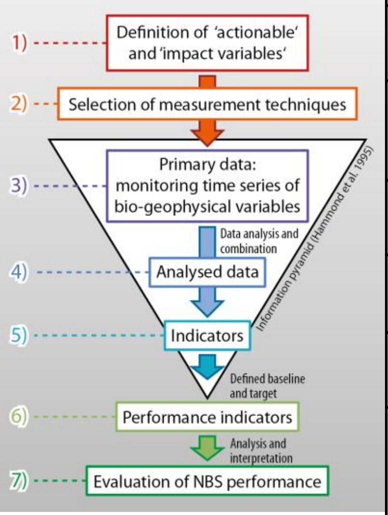
OAL – PRC Manipulation of the plant root environment

Plant growth-promoting rhizobacteria (PGPR) were applied to different crops to reduce crop vulnerability to drought





1)	Actionable variables: the variety of plant growth-promoting rhizobacteria Impact variables: drought resilience of plant and water use efficiency
2)	Lysimeter, Li6100
3)	Time series of soil moisture, evapotranspiration, root depth
4)	Yield production, evapotranspiration
5)	Water yield, water using efficiency
6)	Water yield
7)	Evaluate the effectiveness of Bacteria on improve the drought resilience of drought and water yield

Measuring and monitoring the effectiveness of plant growth-promoting rhizobacteria by a detailed field experiment

Verification of compliance of NBS interventions

- By design NBS modify one or more bio-geophysical properties and verifying whether and to what extent this has been achieved is very relevant
- Well defined experiments are a good answer to the need of verifying whether a NBS is functioning as designed
- Modeling of a NBS structure is useful to articulate hypotheses to be tested against measurements
- Likewise modeling is the only option to evaluate NBS functioning under different hydro-climatic conditions
- The motivation of distinguishing actionable and impact variables is to identify more precisely what a NBS has been designed to achieve and which beneficial consequences a NBS interventions may have

Next up: *Impact of NBS interventions*

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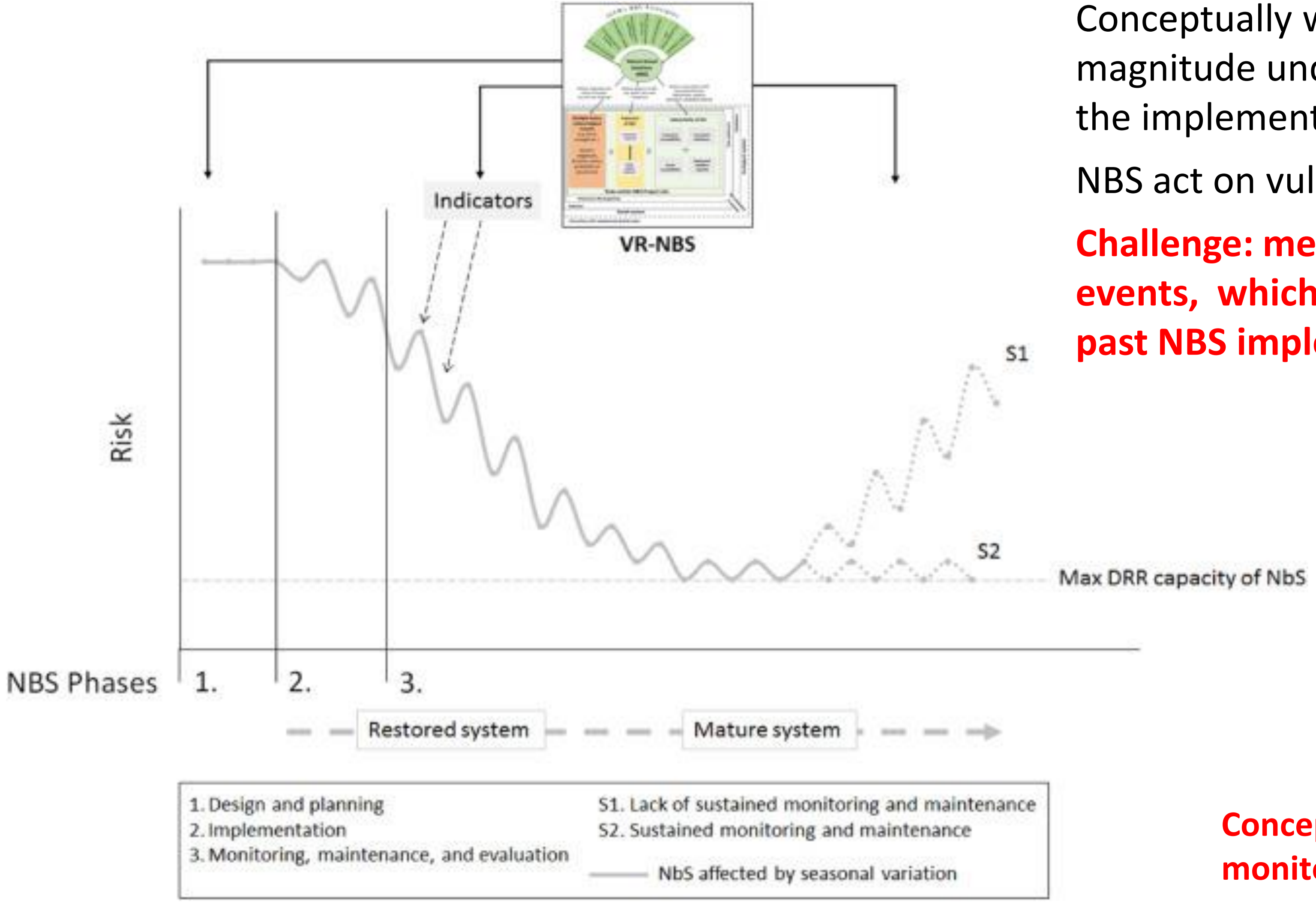
Monitoring of risk reduction



Conceptually we need to compare a specific HM risk magnitude under current conditions with the magnitude past the implementation of a NBS.

NBS act on vulnerability.

Challenge: metrics of risks are based on the probability of events, which cannot be observed in a short period of time past NBS implementation

Conceptual framework for assessing risk level over time by monitoring related indicators (Shah et al. 2020)

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Monitoring of impacts and modelling of HM risk reduction

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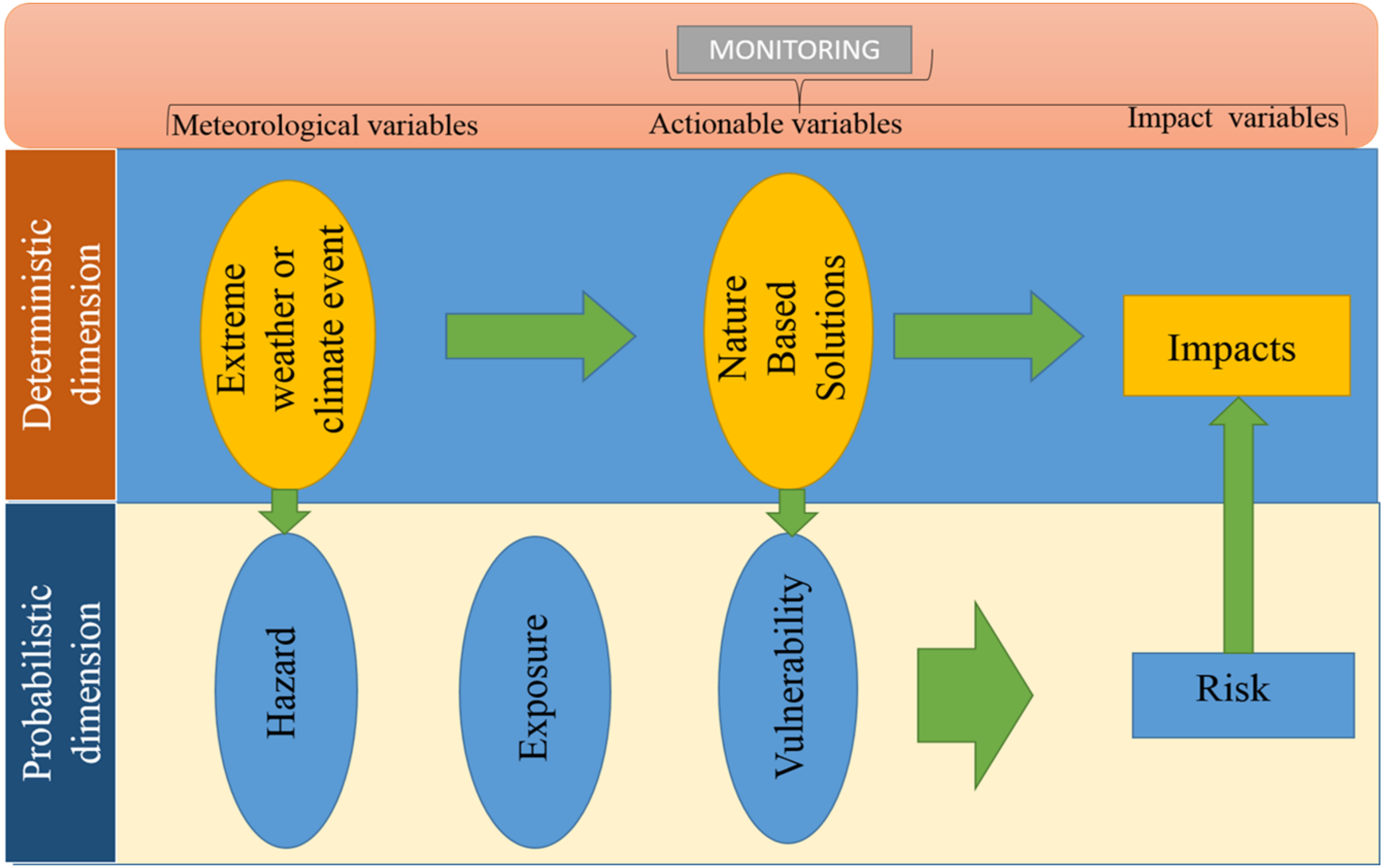
- Observations may document the impact of NbS in a limited number of specific events
  - ➢ Document reduction in vulnerability

- Ensemble numerical experiments is the tool to estimate the probability of impact magnitude taking into the reduced vulnerability
  - ➢ Risks pre- and past the implementation of NbS



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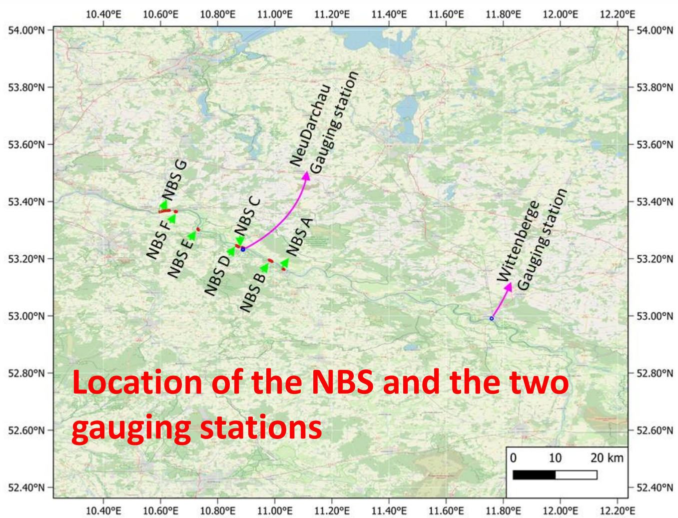
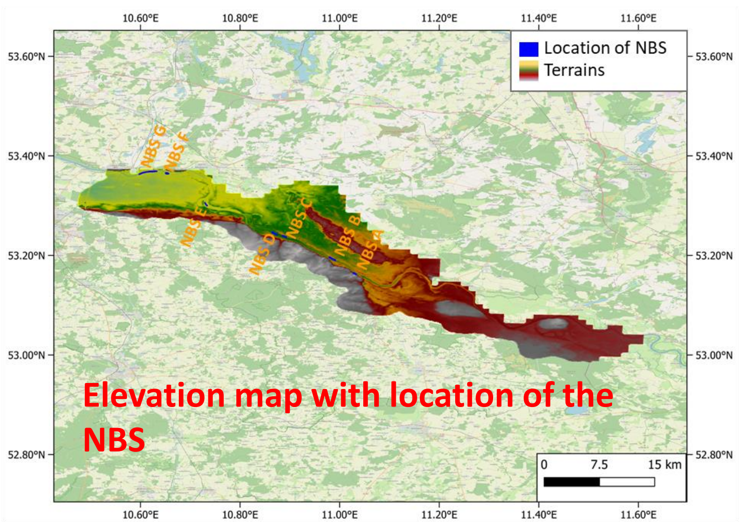
OAL-DE modelling: impacts of the roughness of riparian vegetation on floods by HEC-RAS I Approach

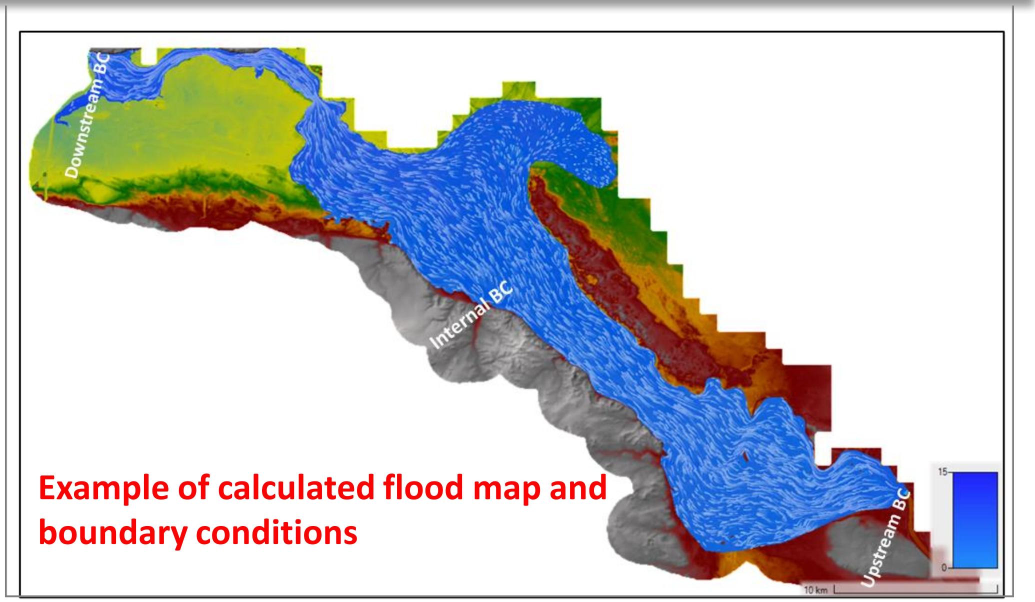
OPERANDUM



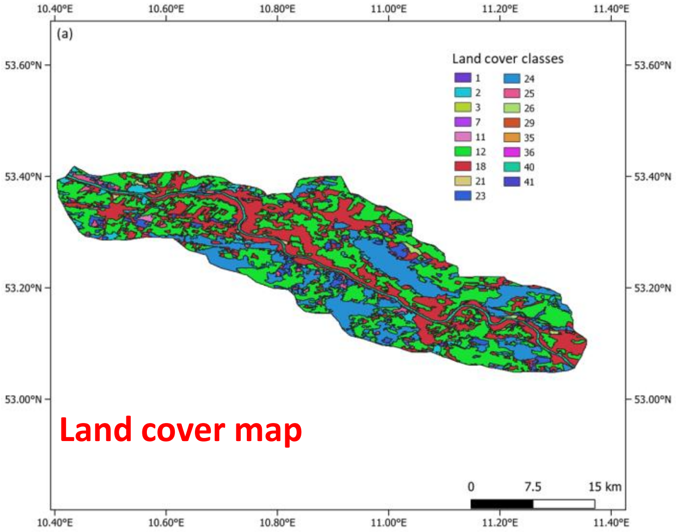
Location of the NBS and the two gauging stations



Elevation map with location of the NBS



Example of calculated flood map and boundary conditions



Land cover map

HEC-RAS uses Manning's formula to compute frictional losses along the ground surface.

A land cover map is used to assign a Manning's coefficient to every different area within the model domain.

Example: OAL-DE modelling impacts of the roughness of riparian vegetation on floods by HEC-RAS – II Results

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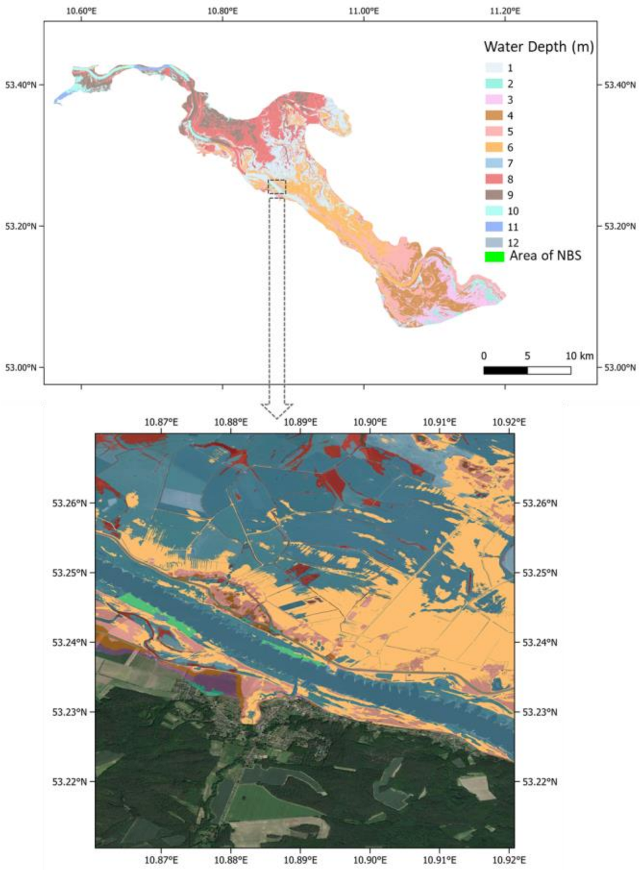
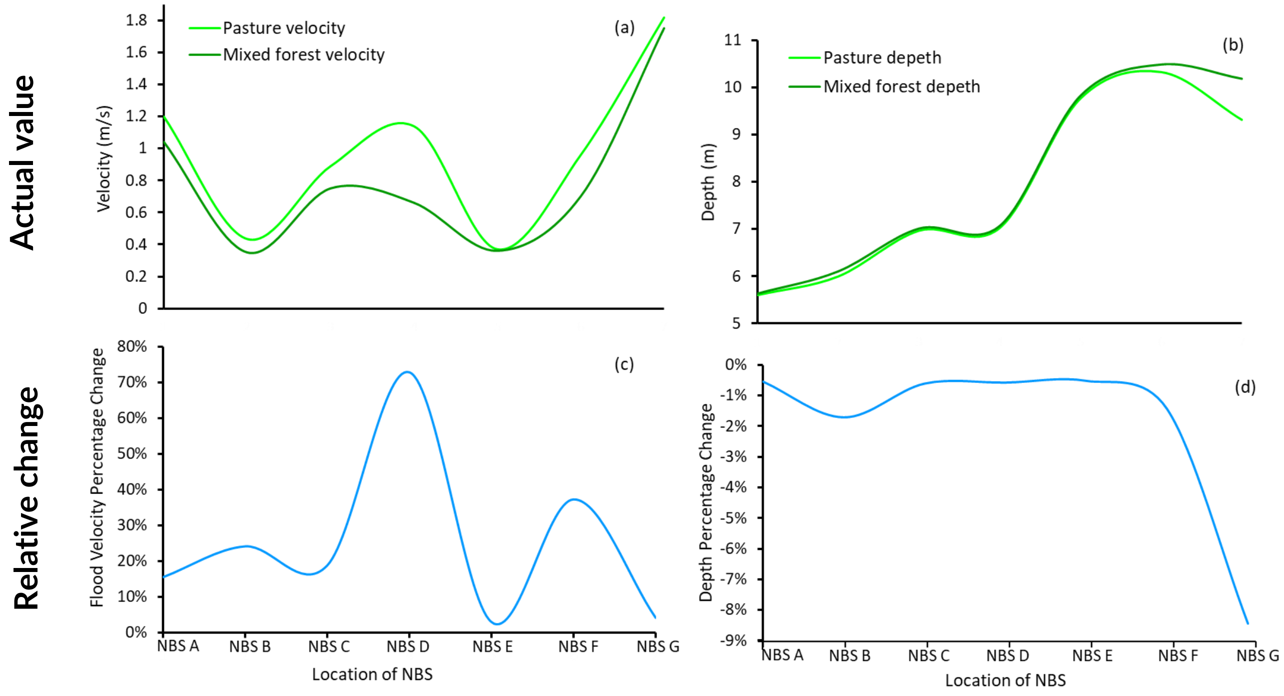
Calculated water depth for the event on June 11th – 13th 2013. Pre – NBS with riparian forest.



Calculated water velocity and depth for the event on June 11th – 13th 2013.

Mixed (riparian) forest pre-NBS vs. pasture post-NBS.



NBS works as designed, but effect is significant on the velocity, directly related to roughness (actionable v.) and rather small but relevant on depth

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OAL – FI Protection of lake water quality

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OAL – FI: Impact continuous cover forestry (CCF) on lake water quality

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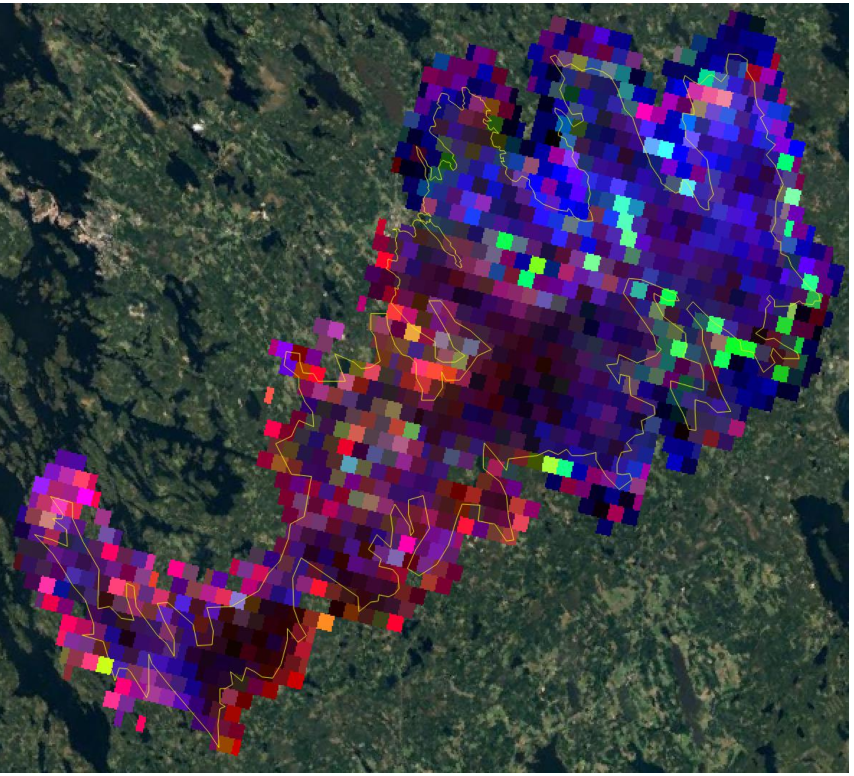
Water quality has been monitored by remote sensing 2000 – 2012
Need to construct a linkage between small/ local NBS interventions and landscape impacts!

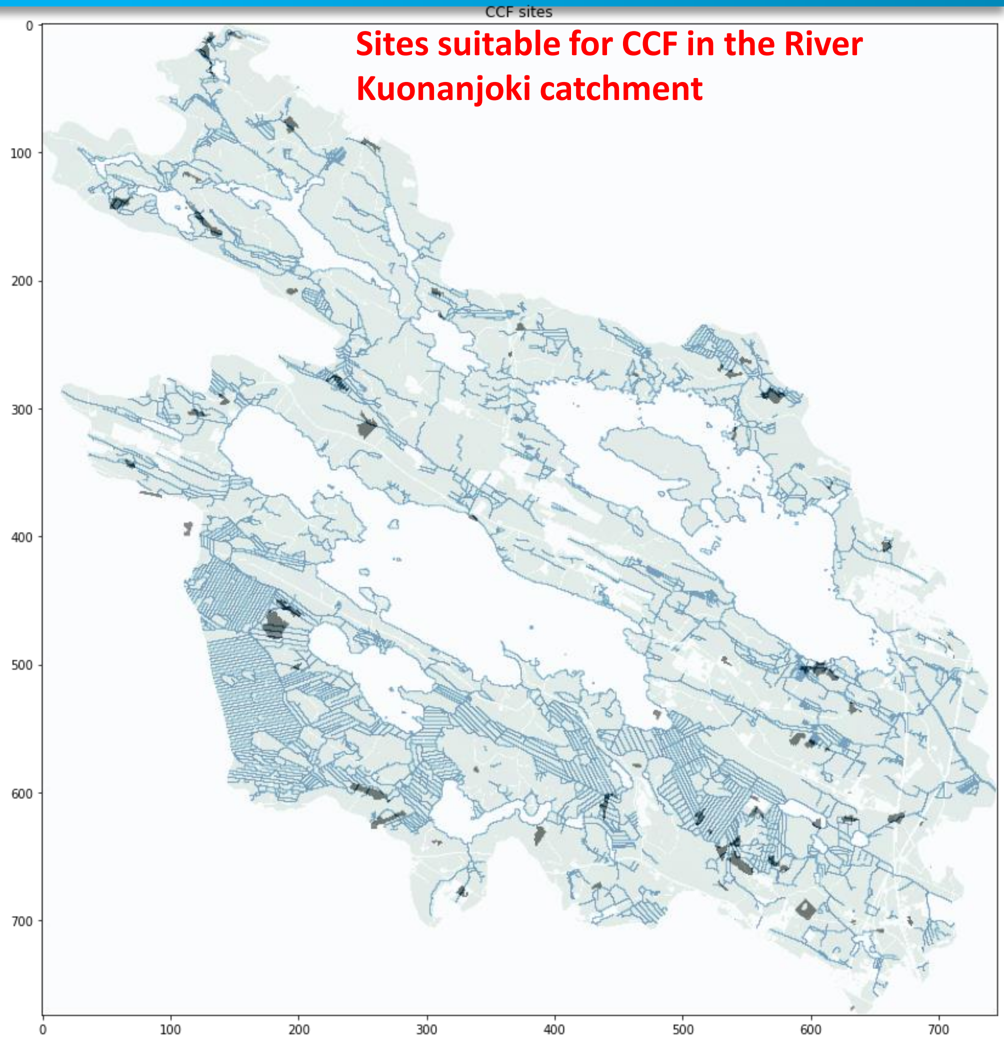


Chlorophyll change from 2010 to 2012. Bands are estimated chlorophyll in May:
R: 2012 G: 2011 B: 2010

CCF increases transpiration and interception, thus reducing runoff and sediment discharge into the lake

Mitigation of water quality risk can only be evaluated by numerical experiments.

The model NutSpaFHy was run with varying forest management scenarios in current and future climate conditions.



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Example: OAL – FI impact continuous cover forestry (CCF) on lake water quality

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NutSpaFHy results for P export load

	2006-2016 TP kg/year Savonlahti	2040-2050 TP kg/year Savonlahti, MPI	2040-2050 TP kg/year Savonlahti, Had	2070-2080 TP kg/year Savonlahti, MPI	2070-2080 TP kg/year Savonlahti, Had
No (additional) clear-cuts	505.9	604.9	568.7	804.2	719.2
CCF sites (67ha)	508.6 / 0.0404 kg/ha/year	606.4	570.8	805.9	720.8
clear-cuts on the CCF sites	510.1 / 0.0626 kg/ha/year	607.4	571.9	807.0	722.1
Business-as-usual (174 ha)	519.8	613.5	579.7	814.4	728.0

**The difference in nutrient export between CCF and clear-cut are clear:
Per hectare the P export load in CCF scenario is 0.040 kg/ha/year and for clear-cut scenario the P export load is 0.063 kg/ha/year.
For N, the load per ha in CCF scenario is 2.52 kg/ha/year and 97% larger (4.97 kg/ha/year) if same areas were clear-cut.**

NutSpaFHy results for N export load

	2006-2016 TN kg/year Savonlahti	2040-2050 TN kg/year Savonlahti, MPI	2040-2050 TN kg/year Savonlahti, Had	2070-2080 TN kg/year Savonlahti, MPI	2070-2080 TN kg/year Savonlahti, Had
No (additional) clear-cuts	13924.7	15883.9	14962.2	20269.8	18527.3
CCF sites (67ha),	14094.5 / 2.52 kg/ha/year	16033.2	15121.0	20413.1	18666.8
clear-cuts on the CCF sites	14259.7 / 4.97 kg/ha/year	16215.3	15312.1	20642.1	18894.1
Business-as-usual (174 ha)	14322.8	16201.7	15322.1	20620.0	18846.3

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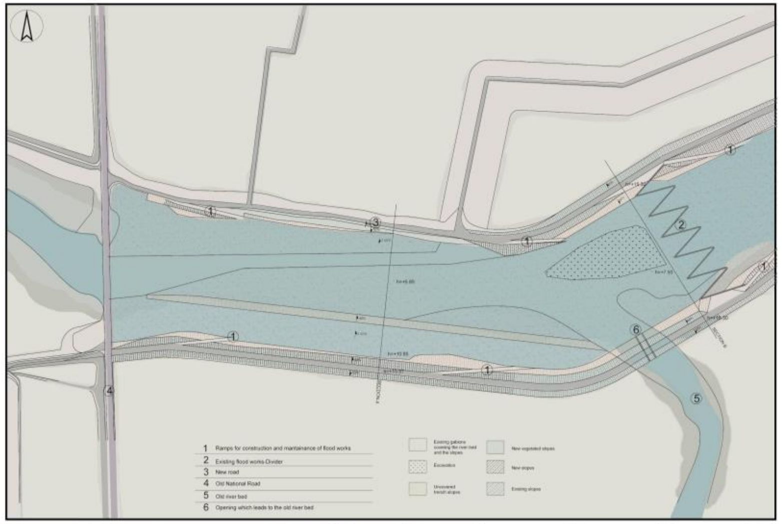
OAL – GR: Flood water retention basins – I

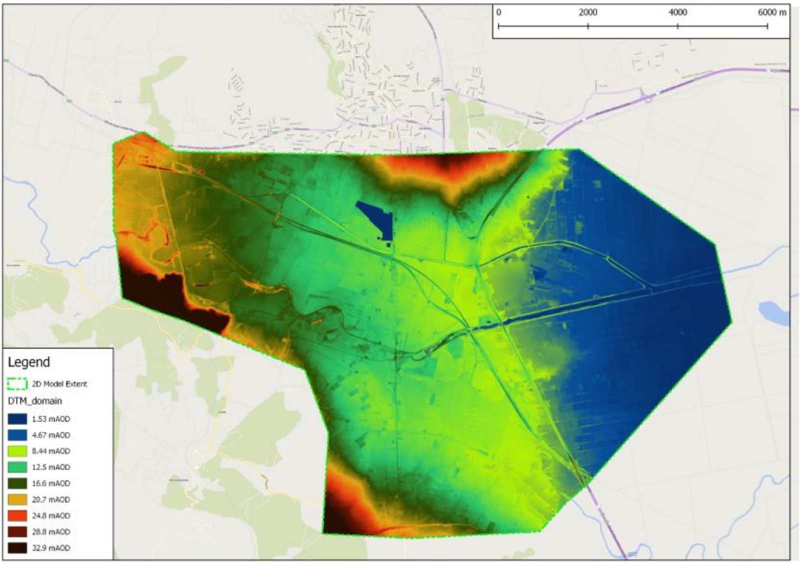


Engineering representation of the NBS deployed in Komma (left).
Situation before and after deployment (top)

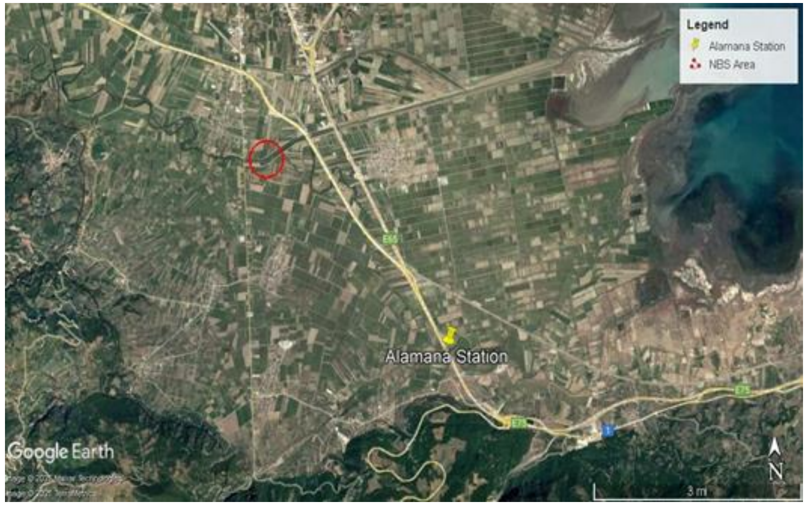
The basin serves multiple objectives:

a) enhance water storage to mitigate floods and to supply irrigation water;

b) increase infiltration and reduce runoff



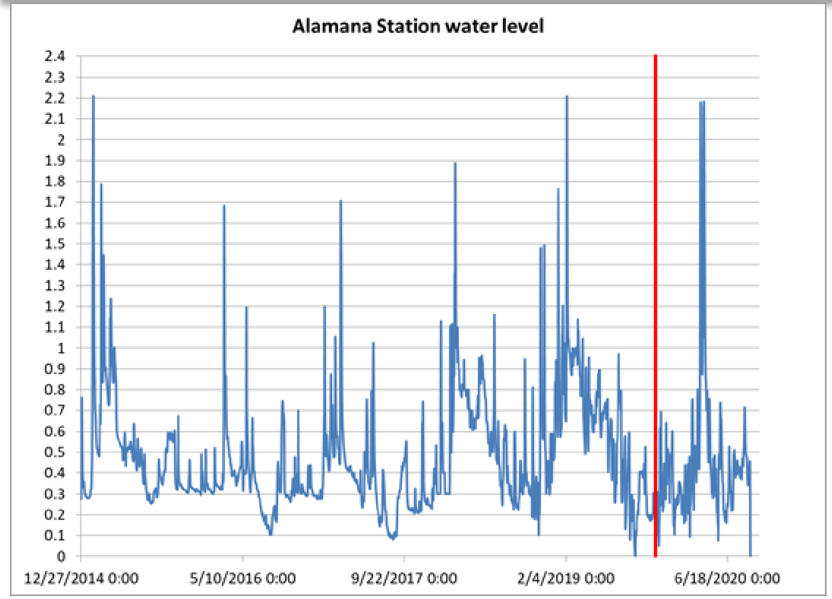
Impact of water reservoirs on river flow and flood mitigation evaluated by a combination of monitoring (right) and modelling (left)



River Spercheios catchment ground elevations used for DTM construction (left)

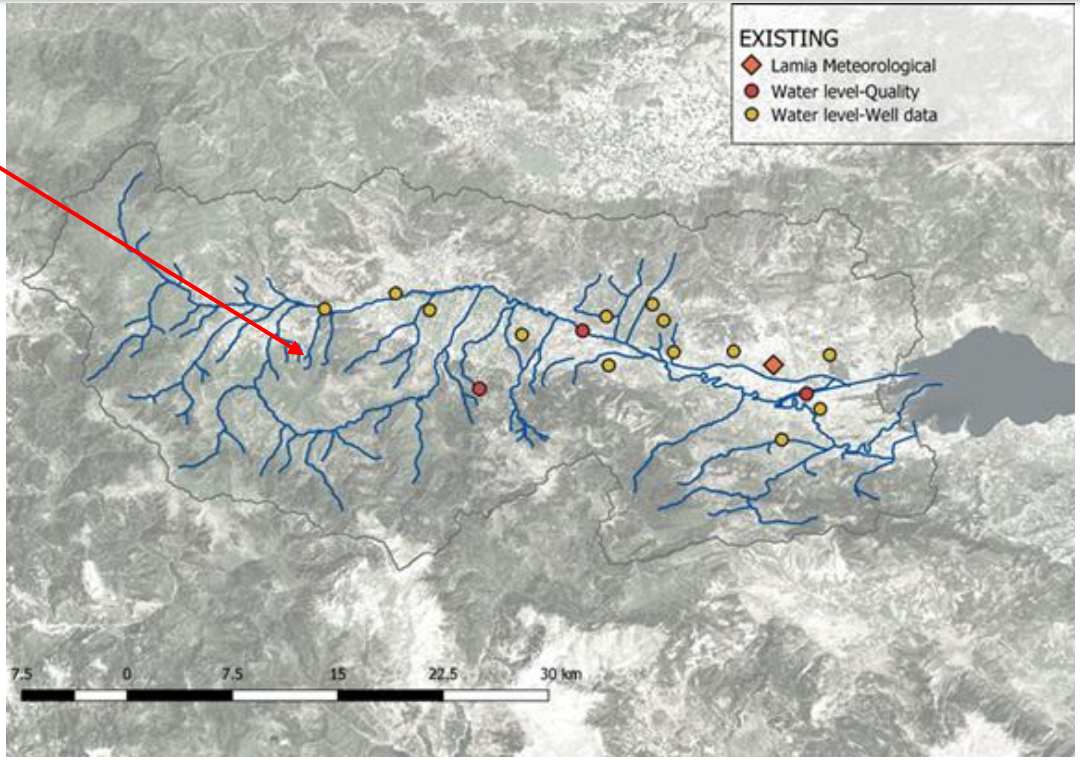
OAL – GR: Flood water retention basins – II

OPERANDUM



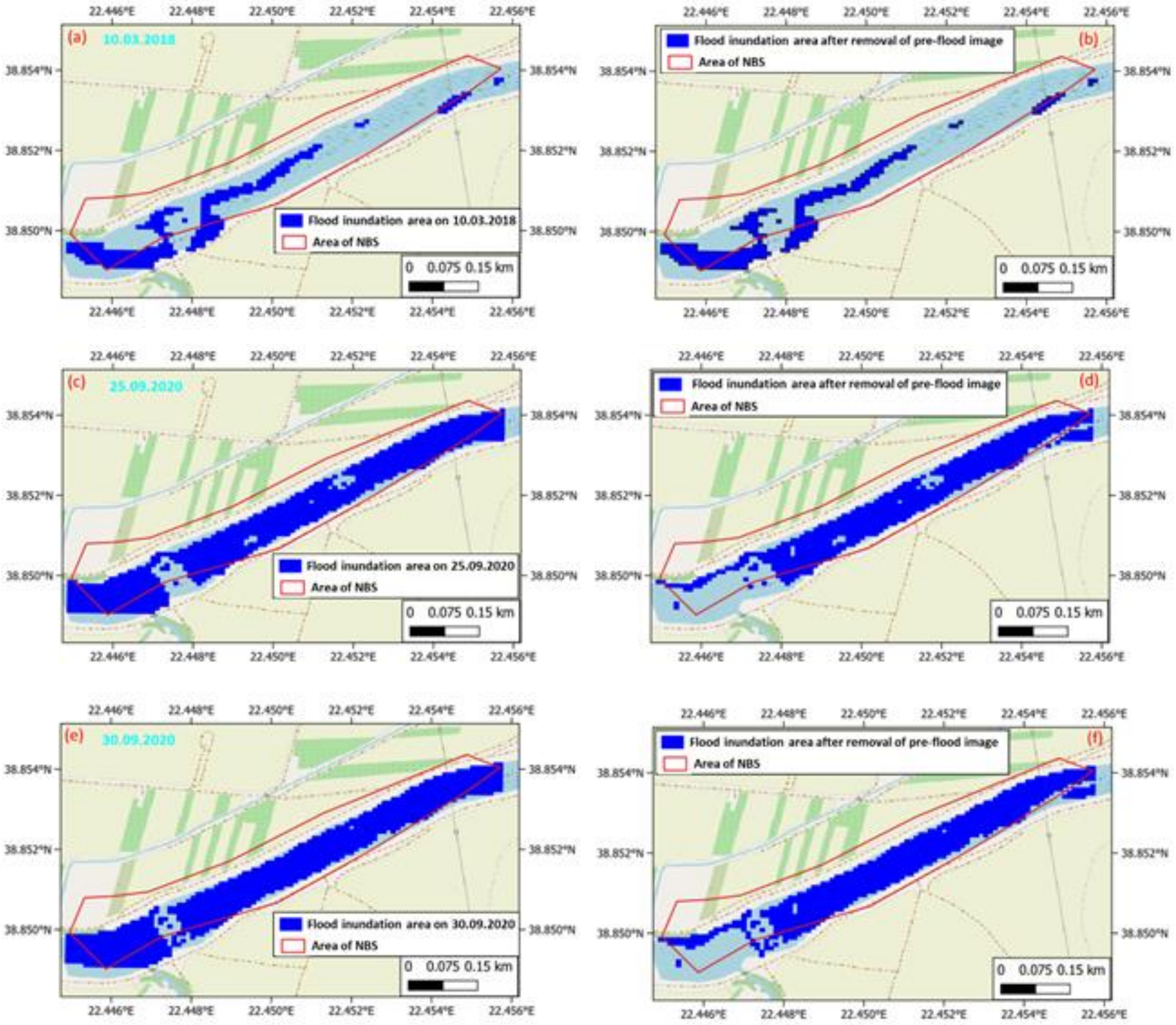
Time series of surface water level at the Alamana automated station. Red line: NBS operational.

Locations of NBS reservoirs (red) and water level measurements (yellow)



Flood in response to intense precipitation 3rd to 5th April 2020. Observed water level jumped to above 2 m. No direct evidence of mitigating effect of reservoir, but the numerical experiment suggest such mitigation.

OAL – GR: Flood water retention basins – III



Remote sensing experiment using S2 MSI, Planet Scope image data and the Copernicus HRL imperviousness for the year 2018 (before NBS) and 2020 (past NBS). Google Earth HR images and Open Street Map data were used to interpret the results visually.

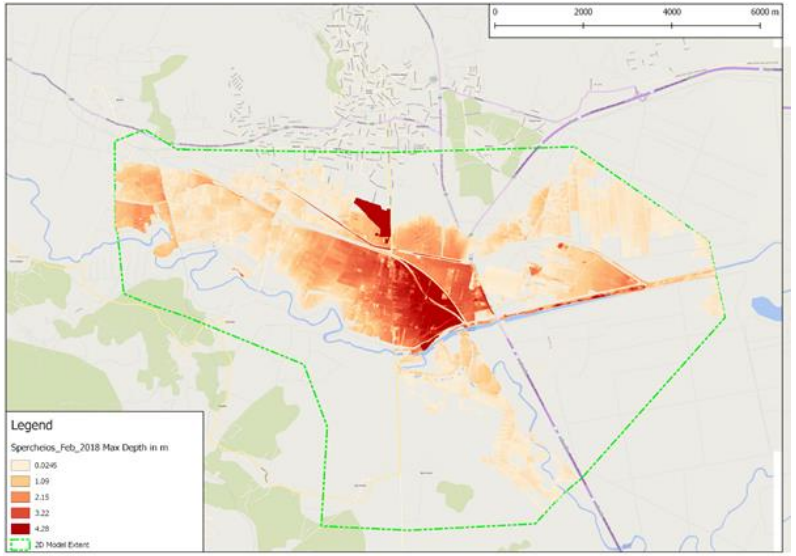
Flood inundation maps generated from NDWI (left column) and ΔNDWI (right column) for (a) and (b) before NBS in place and (c) – (f) after NBS in place at Komma

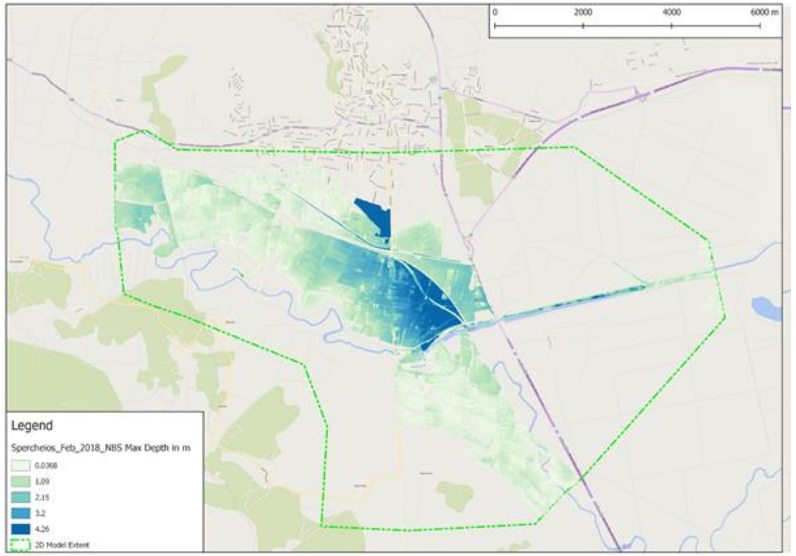
OAL – GR: Flood water retention basins – IV

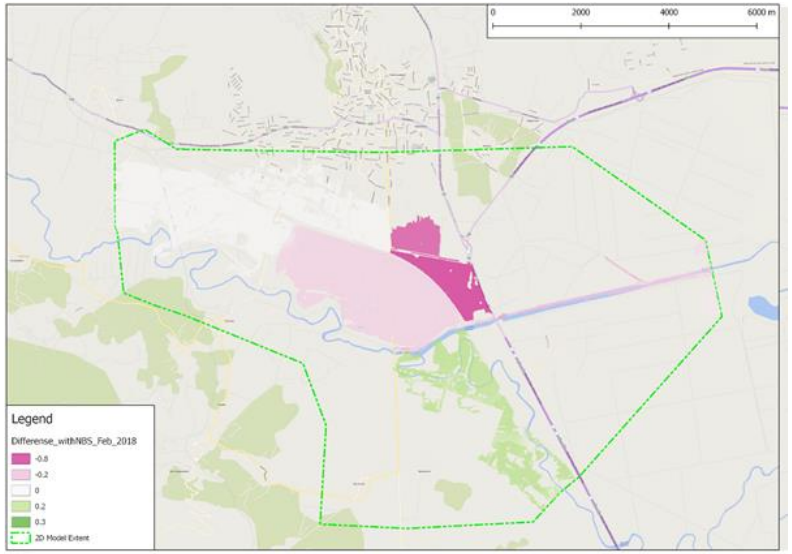
OPERANDUM

The extreme flood event in February 2018, one of the most devastating of the last few years in the area, was modelled with and without water reservoirs.

	Baseline Results (No NBS)	Results with NBS	Location
Maximum Depth (m)	12.26	12.26	Upstream of Athinon Road (left bank)
Mean Depth (m)	1.13	1.09	N/A
Maximum Velocity (m/s)	2.55	2.55	Upstream end of the model
Mean Velocity (m/s)	0.24	0.21	N/A
Flooded Area (km^2)	25.45	20.19	N/A







Water depth without NBS reservoirs

With NBS reservoirs

Difference

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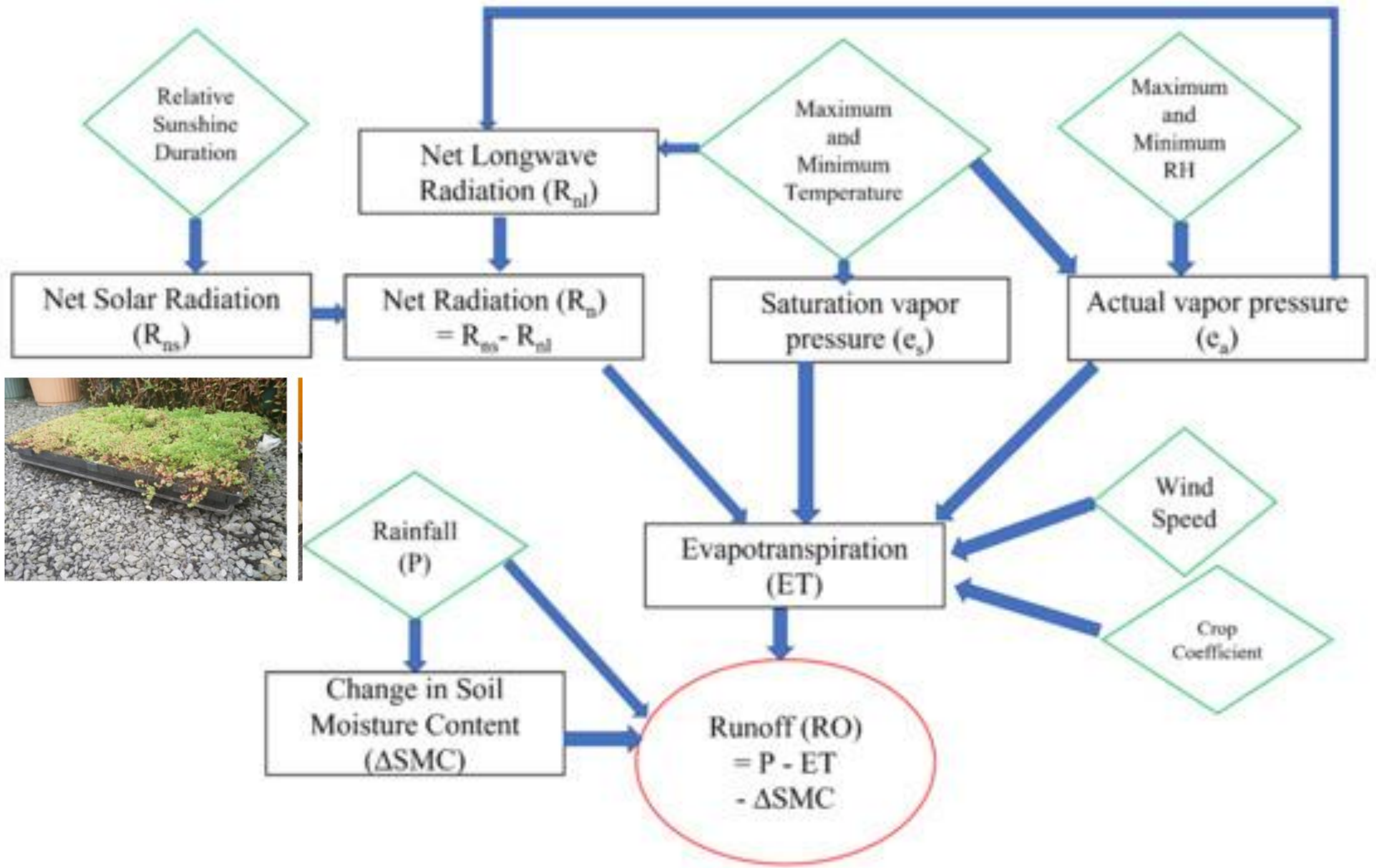
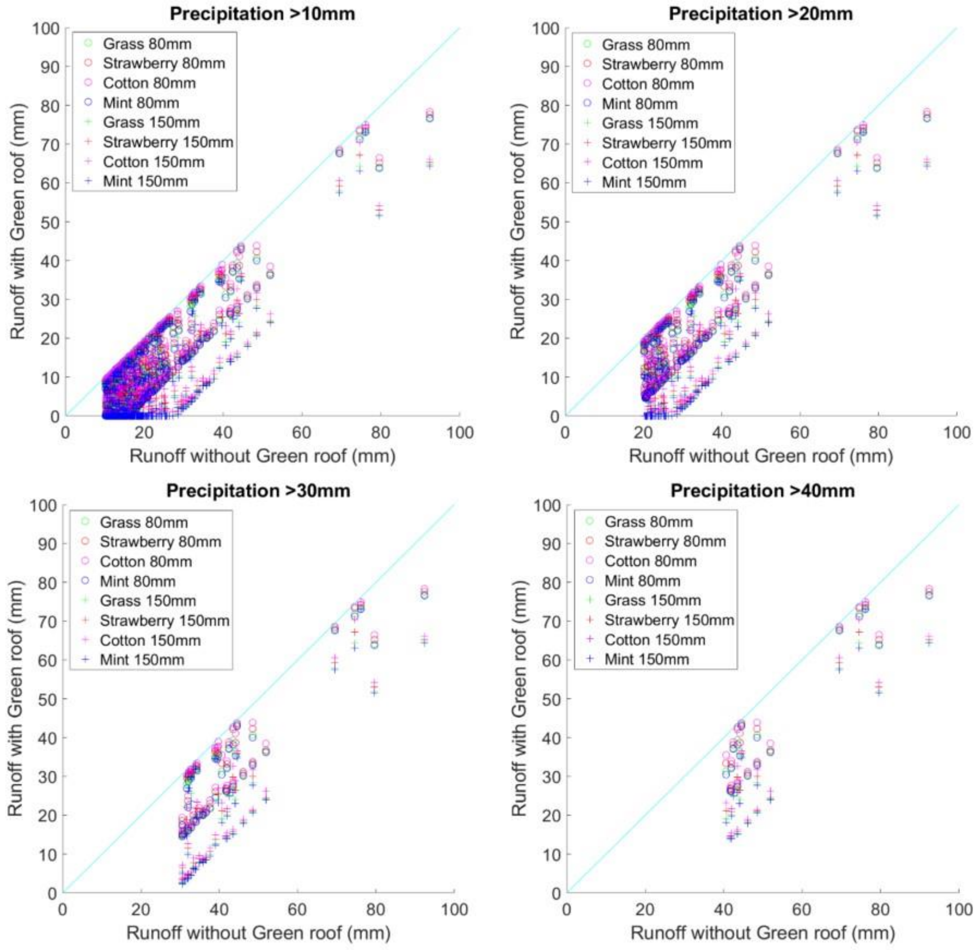
OAL – IR: Green roofs

Green roofs intended to mitigate the risk of urban flooding. Model developed to carry out numerical experiment to evaluate the impact of alternate configurations on urban runoff.





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Impact of NBS interventions

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- The question of whether a given NBS intervention or a system thereof can deliver the intended risk mitigation can only be answered by numerical experiments
- Likewise, numerical experiments are necessary to assess whether multiple NBS implementations or a system thereof are required to achieve such goal, provided the functioning of a single implementation has been verified.
- The inherent probabilistic nature of HM risks can only be captured by ensemble numerical experiments
- Monitoring past NBS implementation is necessary to build confidence in risk mitigation by NBS

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Design of upscaling and replication using the NBS experiments? - I

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OAL	Monitoring	Modelling (local, prototype)	Upscaling and replication
AT	NBS1: sealing of drainage channels; experiments to evaluate performance of mat and design NBS2: optimized forest management; ALS to characterize forest structure; S2/MSI for evolution of forest conditions; NBS3: -	NBS1: - NBS2: hyrdrological function of forest cover; NBS3:-	Catchment scale monitoring of ground deformation by InSAR NBS2: catchment – scale hydrological role of managed forest cover NBS3: adaptation of land cover to mitigate risk of landslides by manipulating the catchment water cycle;
FI	NBS1: land cover forms modified to capture dissolved organic matter and pollutants; water quality monitoring NBS2: continuous forestry	NBS1:- NBS2:-	NBS1: NBS2: potential of continuous forestry to mitigate the impact of hydrometeorological changes under future climate.
GR	NBS: dynamic flood water storage capacity; moniting of flooded area by S"/MSI images	NBS:Impact of current configuration on flood extent and river water level	NBS: Impact on on flood extent and river water level of alternate configurations under climate scenarios
DE	NBS: riverine vegetation cover controlled by managed grazing; monitoring to assess functioning of managed grazing Impact: propagation of flood water during severe hydro-met events;	Parameterization of hydraulic roughness vs. vegetation cover Propagation of flood water vs. hydraulic roughness	NBS configurations (number and extent of managed grazing patches); Impact under climate and hydrologic scenario (stage-height boundary conditions)
PRC	NBS-1: improved crop resistance to stress NBS-2: yield and water use with reduced irrigation	NBS1: Parameterized response to stress; NBS2: ET and soil moisture vs. irrigation (calibration)	Regional water use and crop yield in response to reduced irrigation and climate scenario

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Upscaling and replication using the NBS experiments

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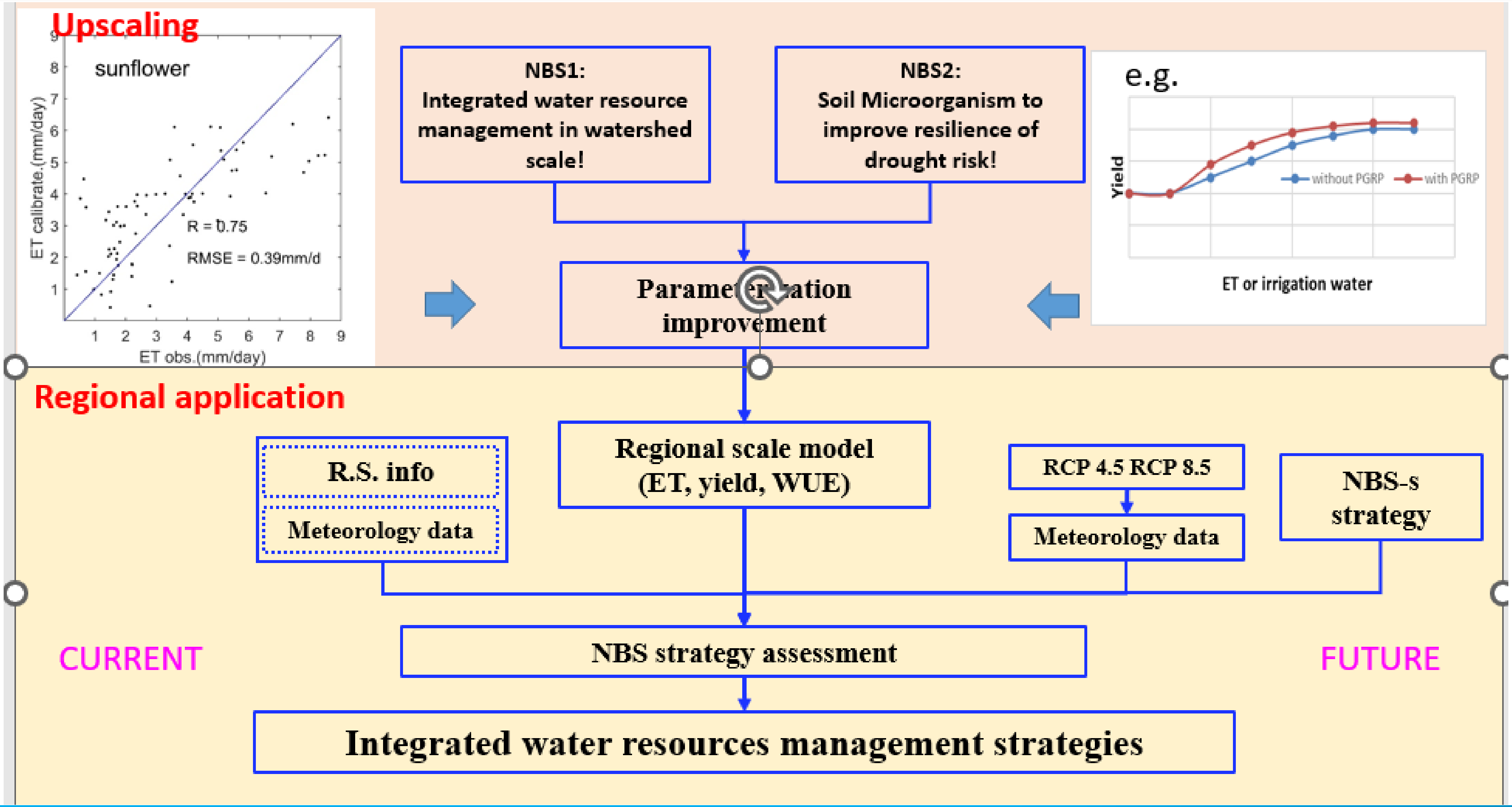

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Conclusions

- Quantitative, evidence based, design and evaluation of NBS interventions is a support to stakeholders, not the main driver of decisions
- The approach presented is a practical way to address such questions as “how large needs a system of NBS interventions to be to deliver the expected mitigation of HM risks?”
- Monitoring and modelling need to be combined at the design – stage already to evaluate alternate configurations and to size-up the interventions
- Given the limited size of a single NBS intervention, detailed process models implemented at high spatial resolution are required to support design and to assess the functioning of deployed NBS
- To evaluate the contribution of deployed NBS to HM risk mitigation model implementations at lower spatial resolution and larger domain are needed.
- Very diverse remote sensing techniques have been applied to observe NBS functioning and to characterize HM events over large areas

Take home messages

OPERANDUM

- Design clarifies how exctly we intend to manipulate one or more bio-geophysical properties of a landscape
- The design approach makes a NBS intervention verifiable and replicable
- Engineering of NBS is not the main driver in NBS implementation, but a technical service to the stakeholders
- Well defined experiments are a good answer to the need of verifying whether a NBS is functioning as designed
- Likewise, modeling is the only option to evaluate NBS functioning under different hydro-climatic conditions
- The motivation of distinguishing actionable and impact variables is to identify more precisely what a NBS has been designed to achieve (actionable) and which beneficial consequences a NBS interventions may have (impact)
- Likewise, numerical experiments are necessary to assess whether multiple NBS implementations or a system thereof are required to achieve such goal, provided the functioning of a single implementation has been verified.
- Monitoring past NBS implementation is necessary to build confidence in risk mitigation by NBS

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Further reading

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Next steps

Unit 7: Promoting NbS Uptake and Public Acceptance

Unit 8: Replication and Business Uptake

Unit 9: GeoIKP – NbS Platform

Unit 10: Good Practices from OALs

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Thank you!

Training 6: NBS Modelling and Monitoring

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