NBS selection and engineering, permitting paths

Part II

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

Summer School on Nature-based Solutions for hydro-meteo hazards and climate change adaptation
29 August 2022

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Presentation

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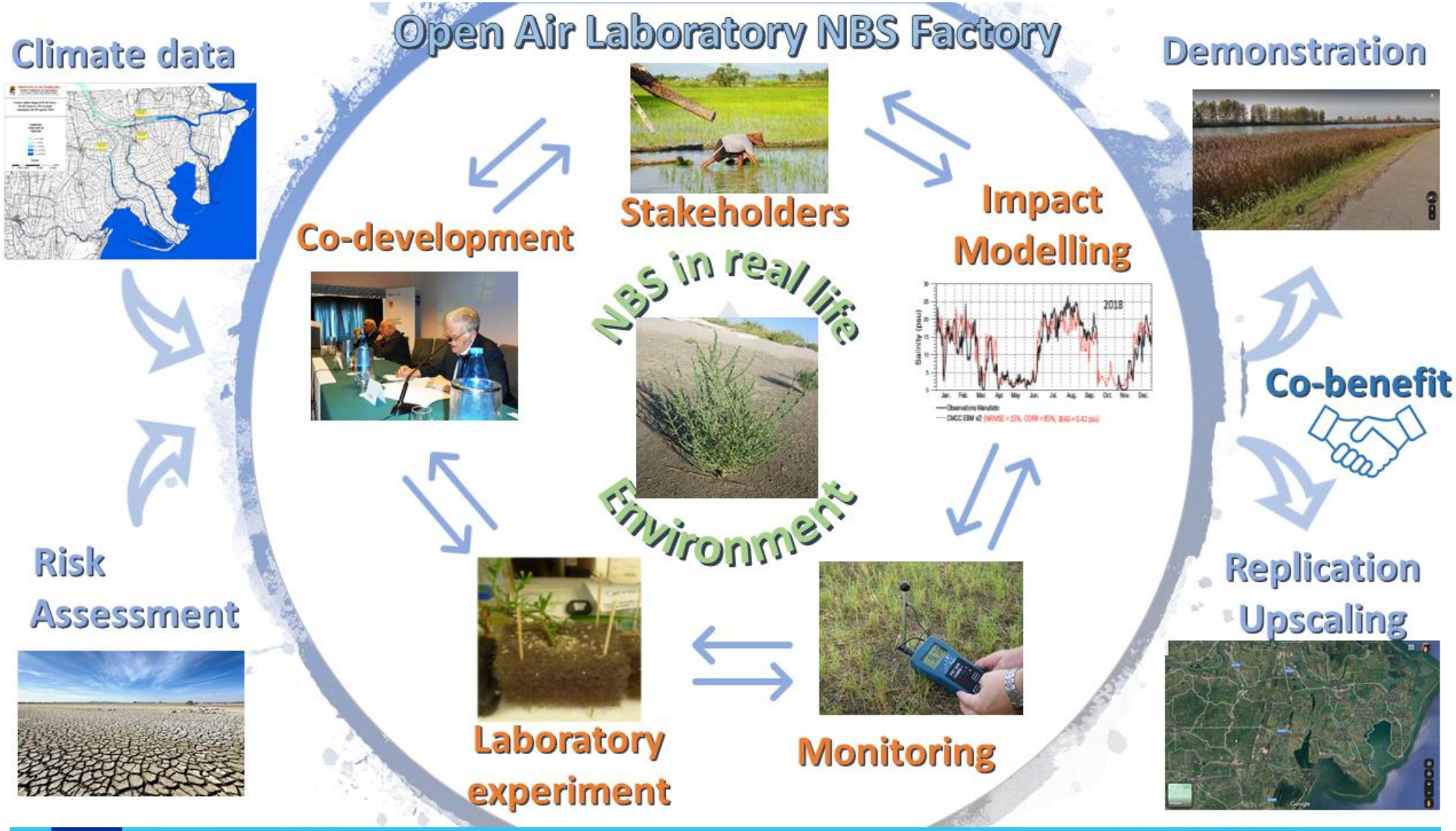
OAL = Open Air Laboratory



OAL- Italy examples

OAL-ITALY

MAIN OBJECTIVES OF NBS

- Reducing impact of river flooding
- Reducing impact of coastal erosion
- Reducing impact of drought

Laboratory flume tests

- **Simulate erosion**
- **Understand flow-vegetation interactions**

Salt wedge

Wave energy

OAL-Italy salt intrusion

Massimo Carlo Moscardi - Youtube: https://www.youtube.com/watch?v=JUa3FflUotA

http://www.ideafuturistica.cloud/index.php/it/chi-sono/moscardi-carlo-massimo

OAL-Italy salt intrusion

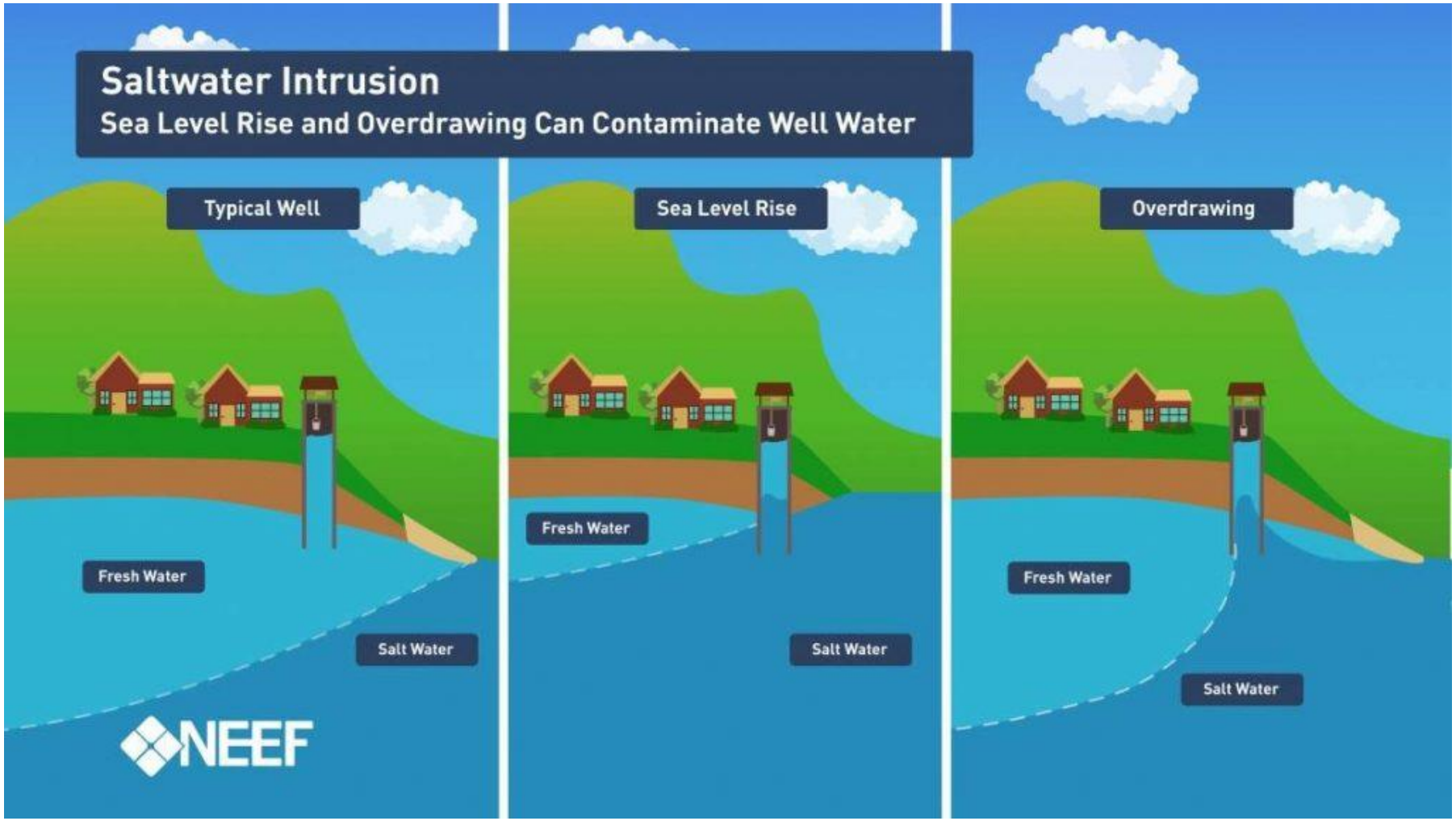
Factors that affect the saltwater intrusion

Rising of sea level – Change in precipitations

Subsidence - urbanization
Climate change

- ❑ Change in soil permeability
- ❑ Increased consumption of water
- ❑ Water pumping

OAL-Italy salt intrusion



Credit: The National Environmental Education and Training Foundation (NEEF)

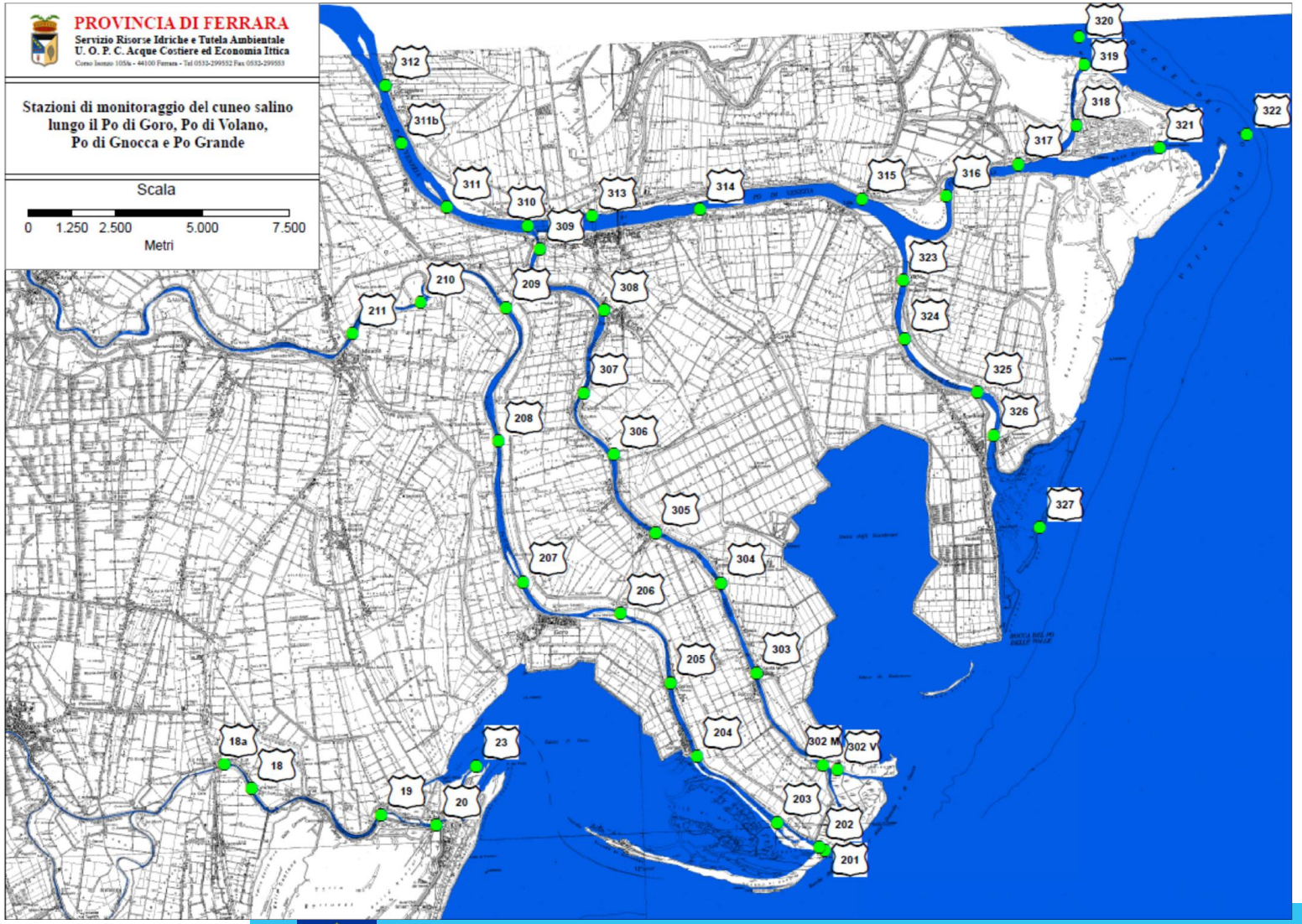
OAL-Italy salt intrusion

The Po river shows flow rates on average of about twelve thousand (12000) cubic meters per second, passing to 200 or less in periods of drought, and in future the flow rates are continuously decreasing.

The intrusion of salt water, if the influence of the tide is sensitive, is more intense the more the flow is reduced, and the usability of fresh water is carried more and more upstream.

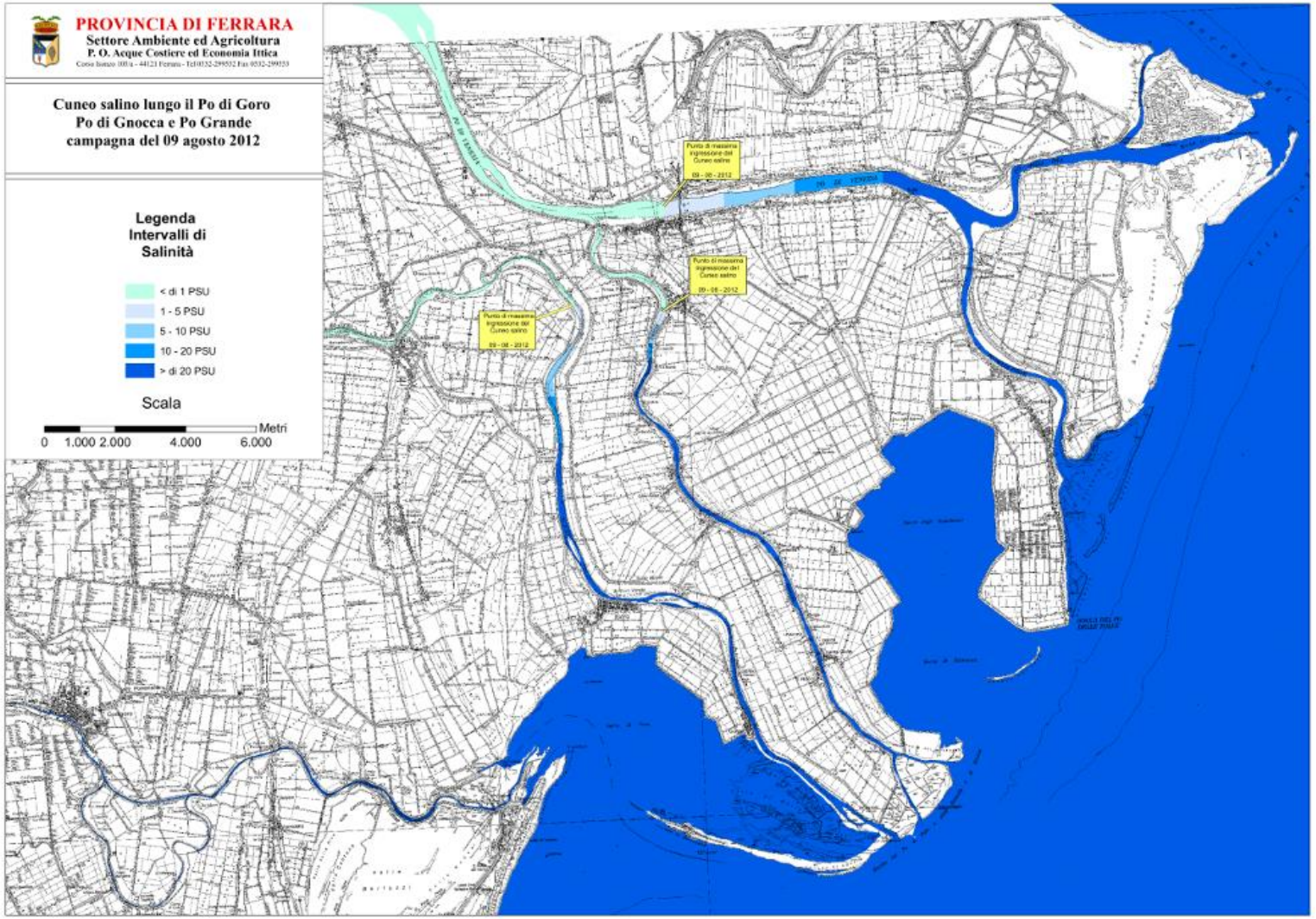
At the beginning of the 1950s, salt water penetrated inland for two or three kilometers from the mouth.
In the last 20 years, it was found that its presence reached about twenty kilometers from the mouth.

OAL-Italy salt intrusion



Planimetric view of the Po delta with the position of the sensors.

OAL-Italy salt intrusion



Planimetric view of the Po delta with highlighted sections of the river affected by the rising of the saline wedge, and the different degree of salinity for each stretch.

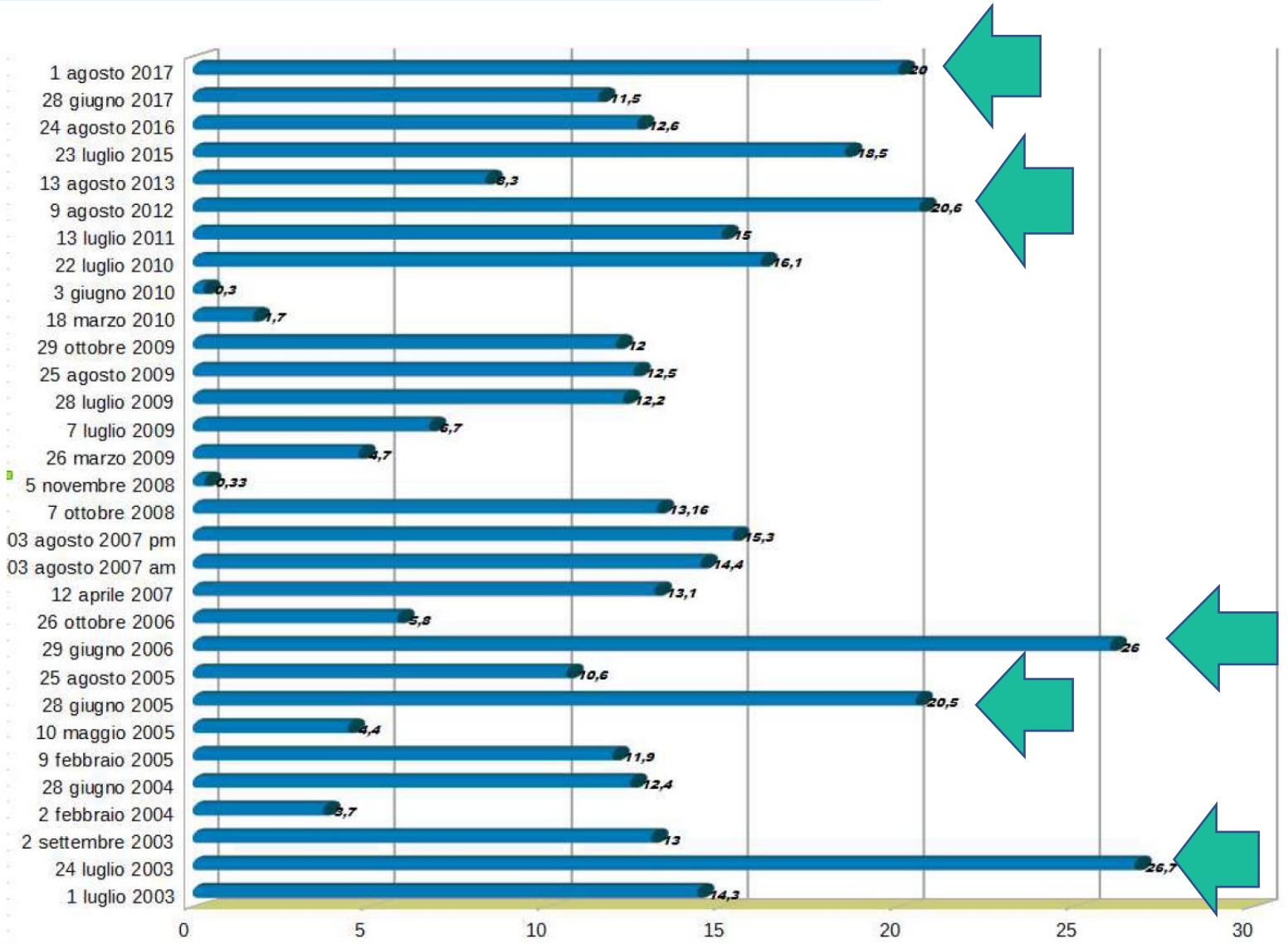
OAL-Italy salt intrusion

This graph shows the different distances, measured in km, of the rising of the saline wedge in the Po di Goro branch of the Po river.

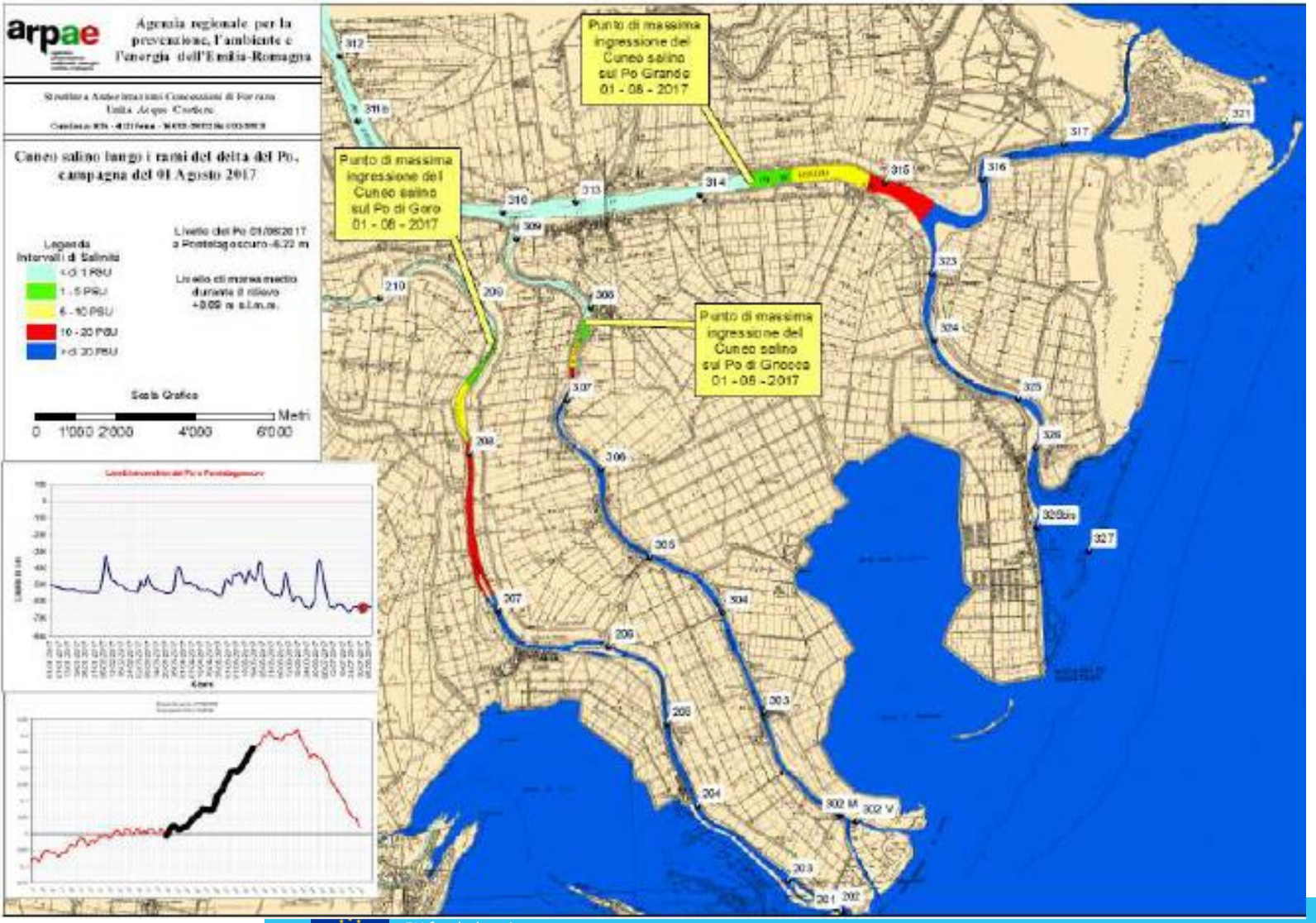
Last strong event was in August 2017.

In comparison with 2017, it can be noted that in other four occasions (2012, 2006, 2005 and 2003) higher intrusion events were recorded.

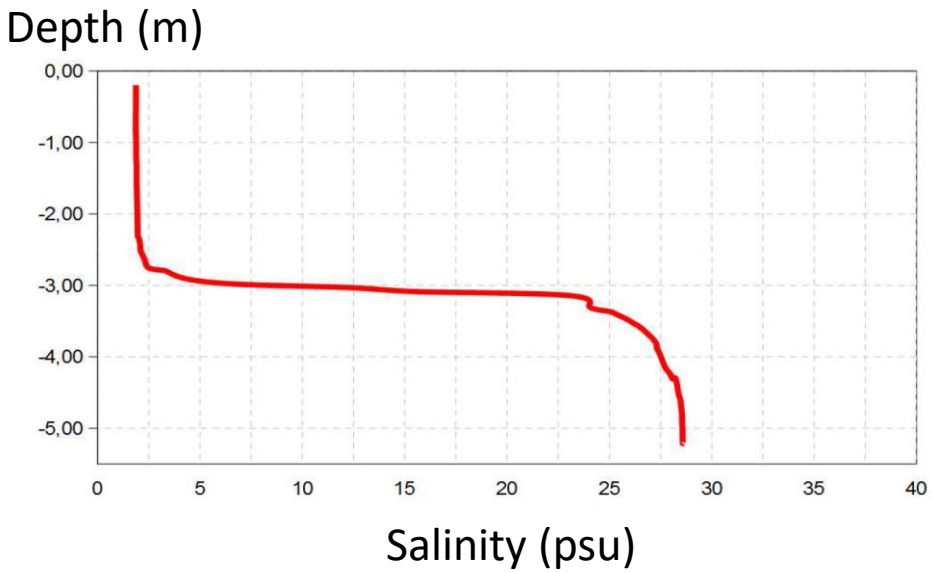
Credits: ARPAE



OAL-Italy salt intrusion



Planimetric view of the Po delta with highlighted sections of the river affected by the rising of the saline wedge, and the different degree of salinity for each stretch.



OAL-Italy salt intrusion

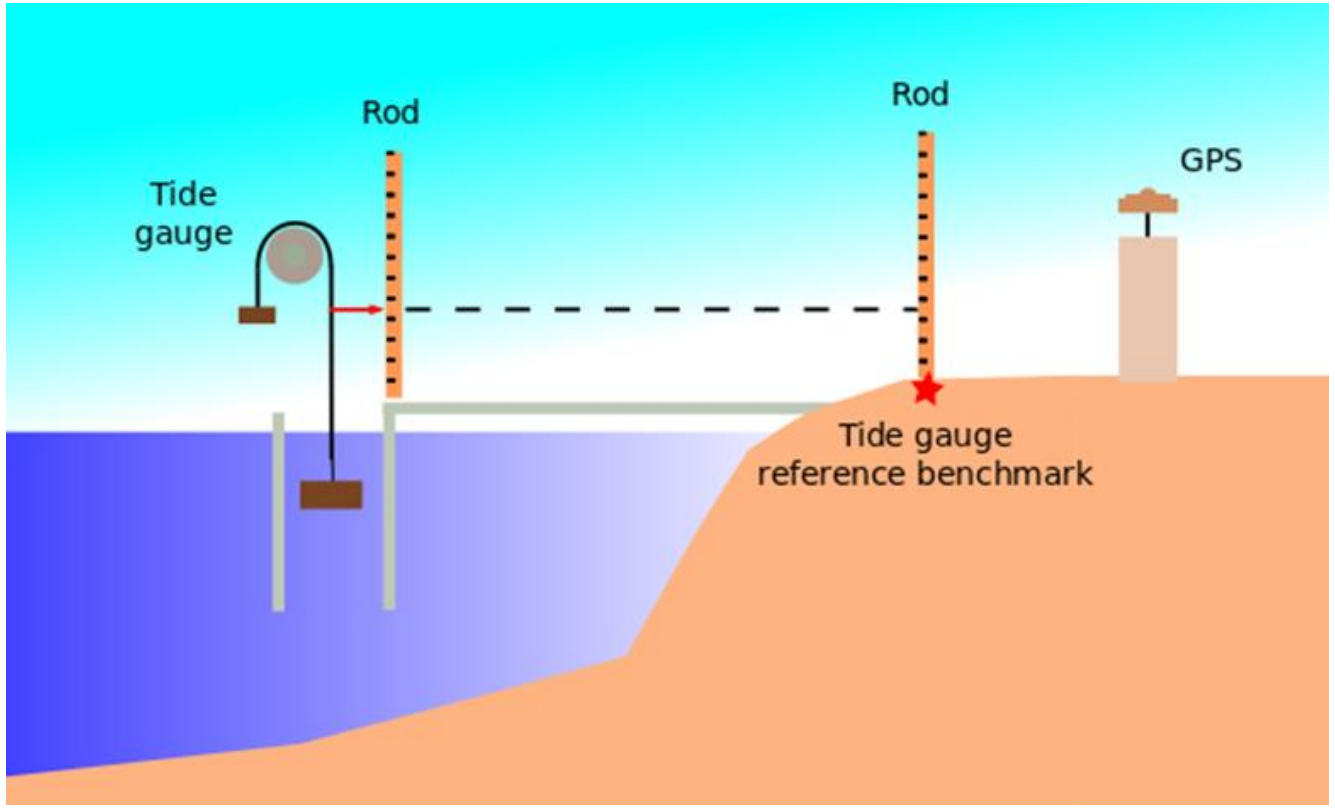
Set up a **new GNSS station** right next to the existing **tide gauge** at the Goro lighthouse. GNSS data allow monitoring vertical movements of the land which contaminate the **tide gauge** records.

OAL-Italy salt intrusion

Why monitoring land subsidence and sea-level rise at Po di Goro ?

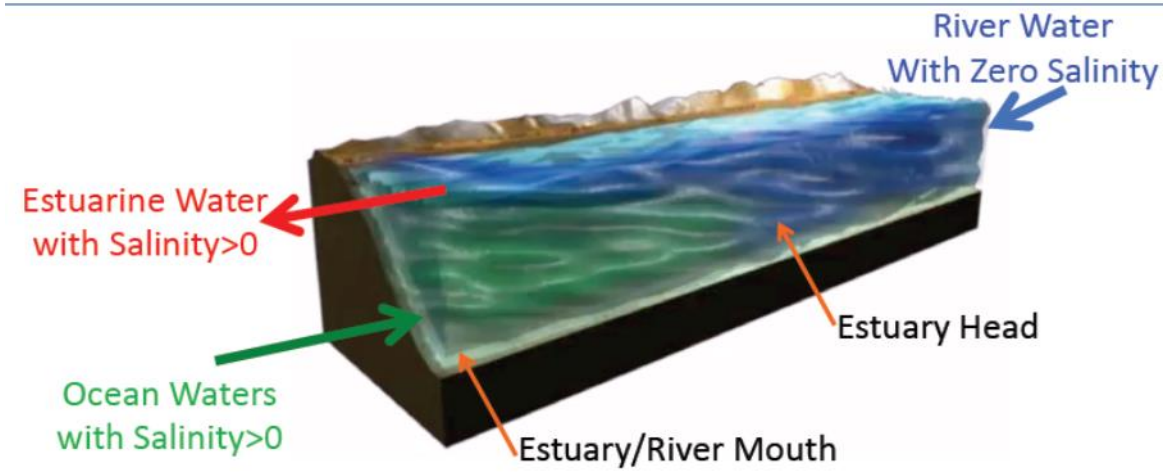
To give answers to population living on the coast

Crucial support for modeling salt intrusion and storm surges



OAL-Italy salt intrusion

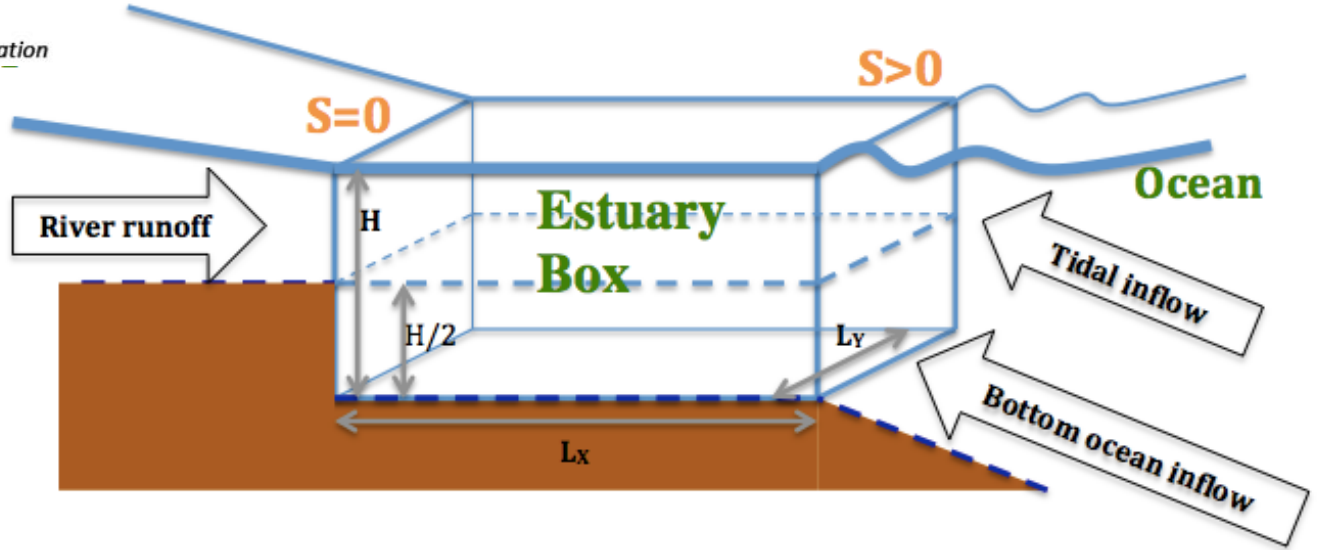
Set up a novel Estuary Box Model to provide scenarios of estuarine water exchange and salt wedge intrusion



Credits: NOAA Ocean Service Education

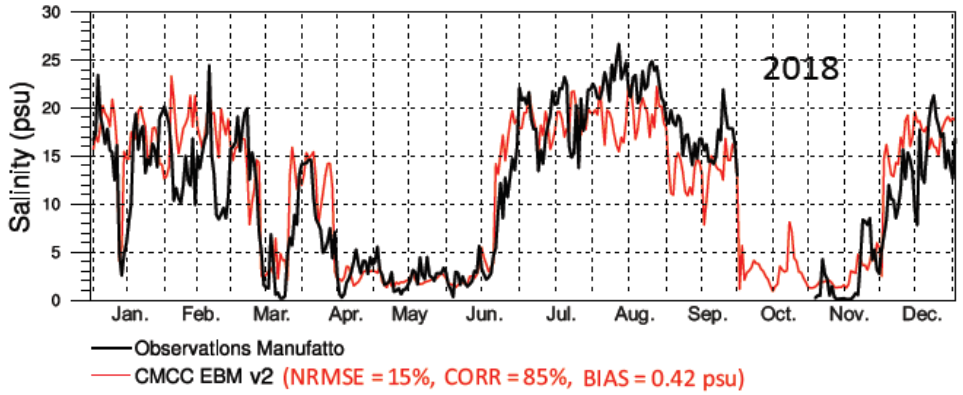
Method:

- ✓ 1D Box modeling of the estuarine water exchange with 2-layer flow at the estuary mouth
- ✓ Extension of the Box is based on the length of the salt wedge intrusion L_X
- ✓ Coupling with an hydrological model/obs at the estuary head and an ocean model/obs at the estuary mouth

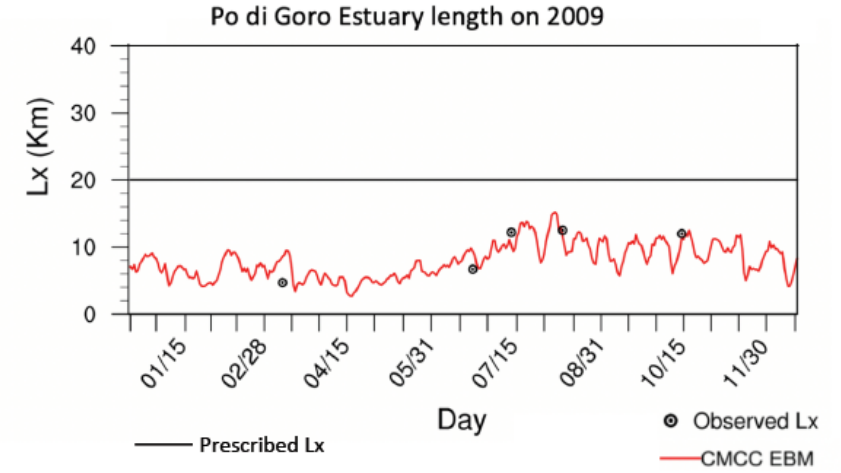


OAL-Italy salt intrusion

1. Reliable representation of salinity at river mouths



2. Reliable representation of length of salt wedge intrusion

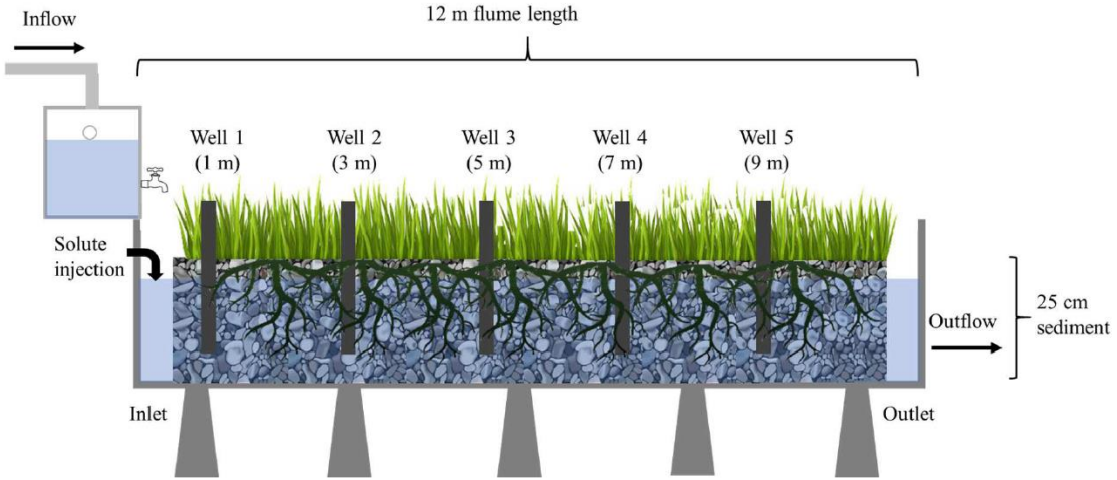


OAL-Italy salt intrusion

Urban River Lab (URL). Source: Naturalea

www.urbanriverlab.com

Artiplex portulacoides	Arthrocnemum macrostachym	Salicornia emerici
Channel 1	Channel 2	Channel 3
Channel 5	Channel 6	Channel 7
Channel 9	Channel 10	Channel 11



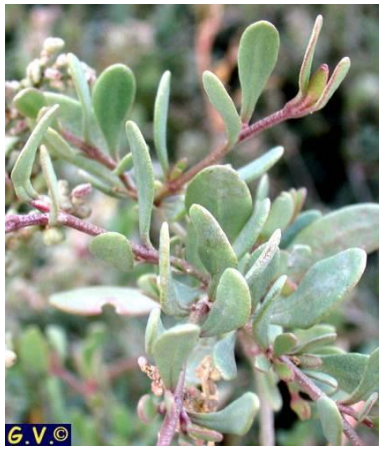
Section of the channel

OAL-Italy salt intrusion

	CHANNELS DISTRIBUTION
channel 1	Gravel / sand and *Atriplex portulacoides*
channel 2	Gravel / sand and *Arthrocnemum macrostachyum*
channel 3	Gravel / sand and *Salicornia emerici*
channel 4	Gravel / sand and *Atriplex portulacoides*, *Arthrocnemum macrostachyum*, *Salicornia emerici*
channel 5	Gravel / sand and *Atriplex portulacoides*
channel 6	Gravel / sand and *Arthrocnemum macrostachyum*
channel 7	Gravel / sand and *Salicornia emerici*
channel 8	Gravel / sand and Atriplex *portulacoides*, *Arthrocnemum macrostachyum*, *Salicornia emerici*
channel 9	Gravel / sand and *Atriplex portulacoides*
channel 10	Gravel / sand and *Arthrocnemum macrostachyum*
channel 11	Gravel / sand and *Salicornia emerici*
channel 12	Gravel / sand and Atriplex *portulacoides*, *Arthrocnemum macrostachyum*, *Salicornia emerici*

OAL-Italy salt intrusion

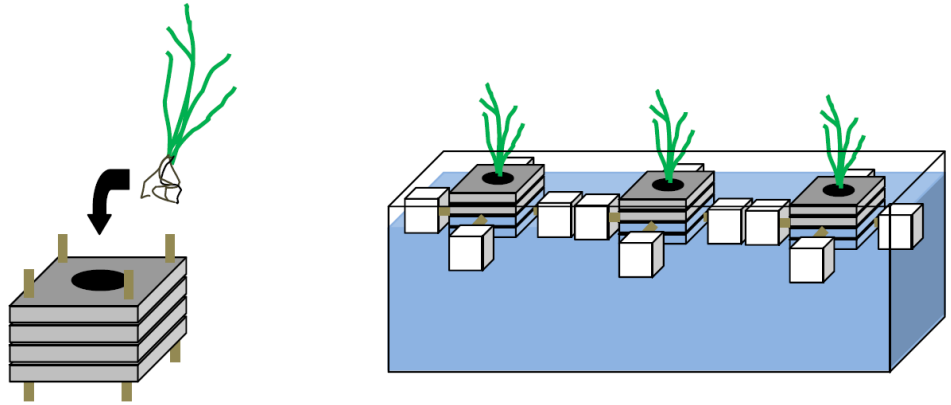
Atriplex portulacoides (porcellana di mare), is a halophyte plant of the family Chenopodiaceae (or Amaranthaceae)



It is perennial with 20-50 cm tall woody stems.
The leaves are opposite, fleshy, glaucous green in color, with a linear-lanceolate shape. The inflorescence is a terminal panicle with yellow glomeruli carried by triangular bracts. The fruit is entirely wrapped in two bracts completely welded together.
This is a widespread species in Europe.

Salicornia glauca (Arthrocnemum glaucum), is of the family Chenopodiaceae (Amaranthaceae), commonly found on saline soils near coastal ponds and marshes

OAL-Italy salt intrusion



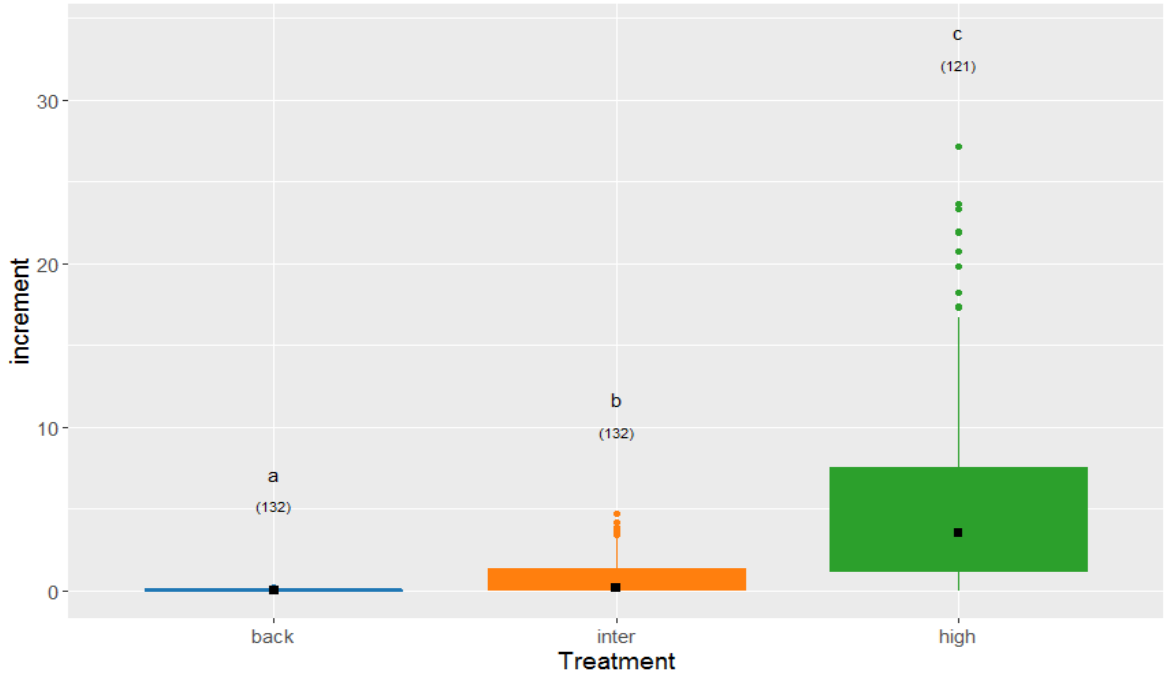
(a) (b)

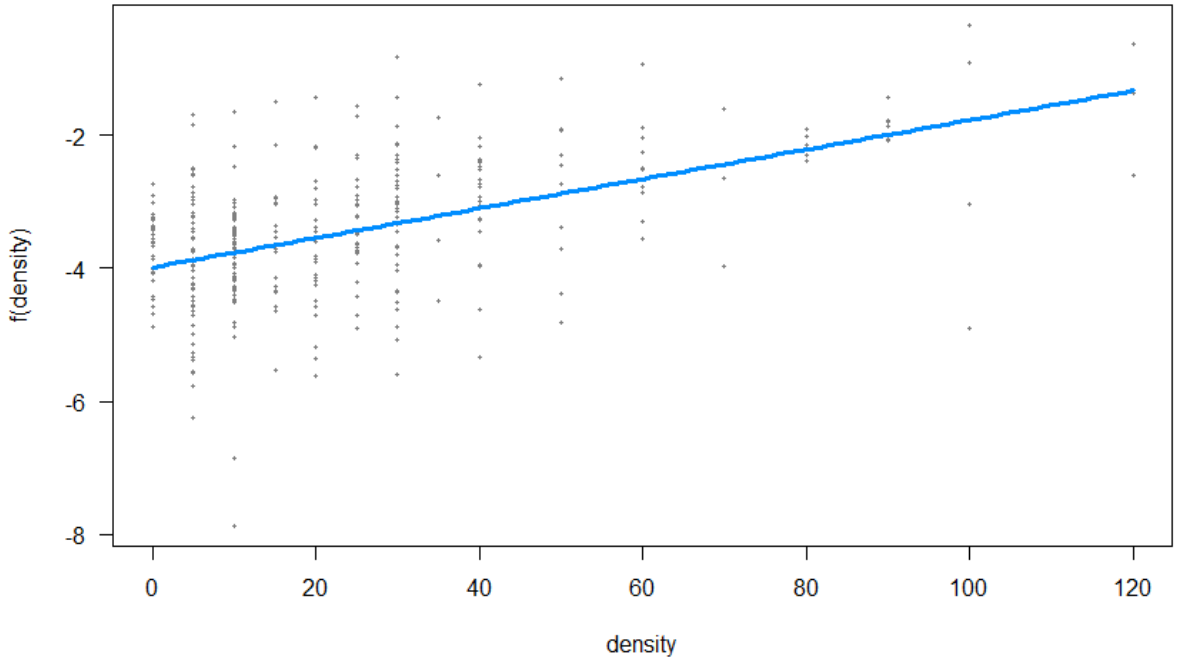
Figure 1. Plants were planted within gravel into the biohaven® matrix (a) and placed in plastic tubs which were filled with mariculture effluent. Plants were arranged in threes with polystyrene floats around the edge (b).

(a) (b)

Figure 2. Example of planted *Aster tripolium* (a) and three plants (*Spartina anglica*) in a tub (b).

OAL-Italy salt intrusion





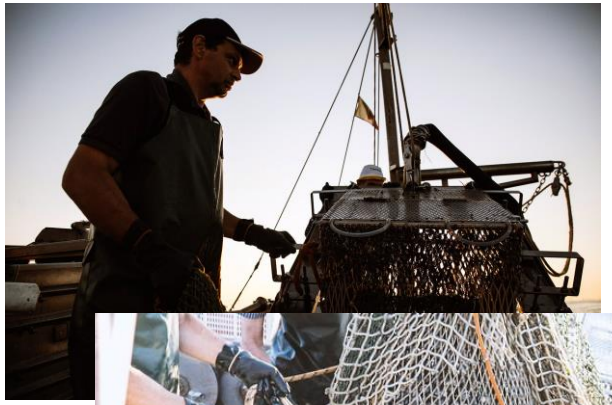
OAL-Italy salt intrusion

In summary, these data seem to indicate that the increase in conductivity between the surface and bottom of the wells depends on the experimental treatment and the plant density and is greater as the conductivity increases in the well channels and density. Therefore, the results seem to indicate that Atriplex portulacoides has retained some of the salt that has been added to the channels.

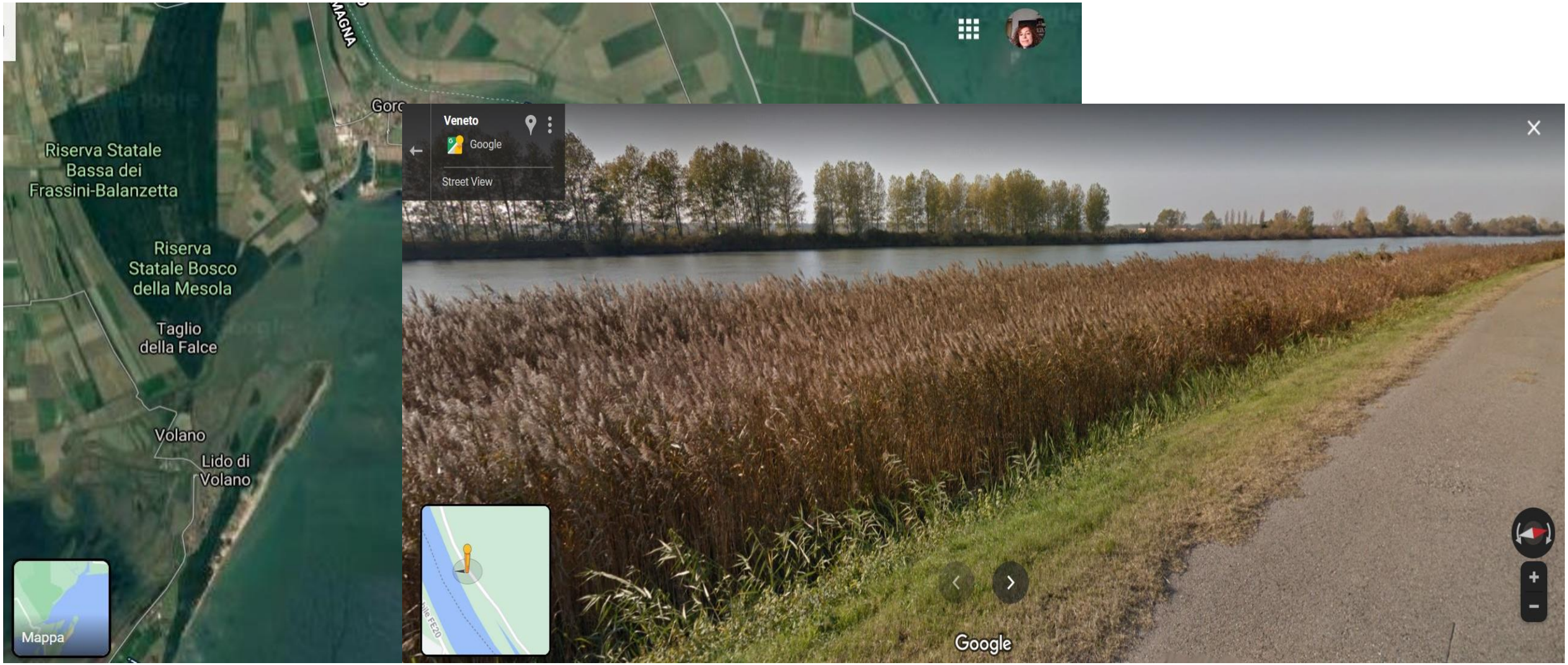
Salicornia emerici Duval-Jouve
Credit: Photo by Giuliano Salvai

OAL-Italy salt intrusion

OAL-Italy salt intrusion



OAL-Italy salt intrusion



OAL-Italy salt intrusion

Find proper NBS from the models the sites and from laboratory

Find feasible sites with SHs

Agreement with SHs and Local Authorities

Implementation of the NBS

Monitoring of the NBS performances

Demonstration of the NBS efficacy

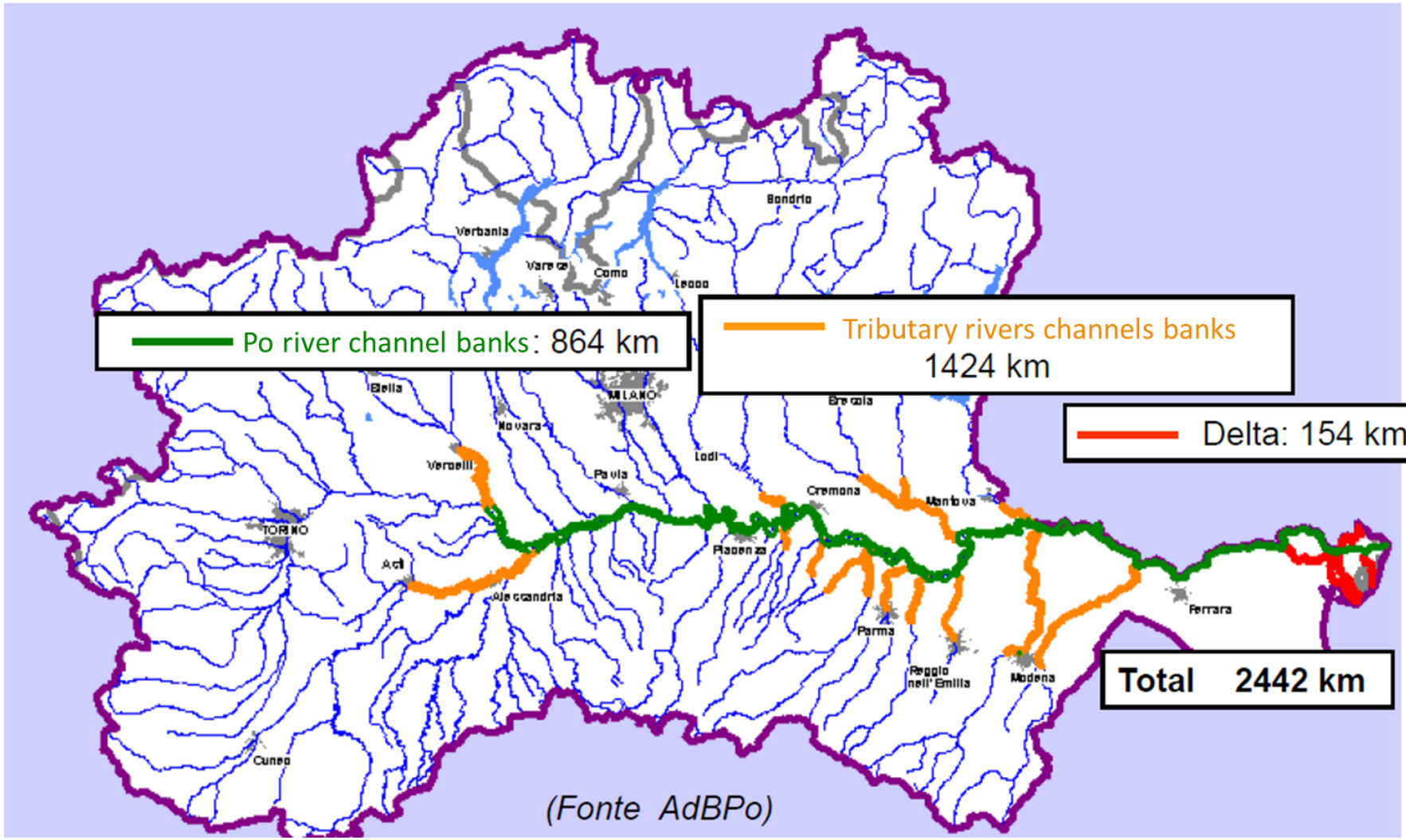
Replication

Upscaling

OAL-Italy river flooding

The Po River is the longest (652 km) river in Italy.

River basin: 71,000 km^2 (3200 municipalities in 7 administrative regions).



OAL-Italy river flooding

The area has been historically subject to periodic flooding events (1928, 1934, 1952, 1960, 1966, 1969, 1972, 1973, 1982, 2014, 2020).

The people living in the «Comparto Secchia-Panaro» are extremely conscious of flood risk.

OAL-Italy river flooding

LEGGE ELETTORALE» La proposta Renzi scuote il Pd. Cuperlo si dimette

GAZZETTA DI MODENA

QUOTIDIANO D'INFORMAZIONE — MERCOLEDÌ 22 GENNAIO 2014

In un lago di fango e rabbia

Alluvione Secchia: falla chiusa. Centinaia ancora intrappolati in casa. Class action per i danni

I sindaci al governo: fate in fretta

Vertice dei Comuni alluvionati. 54 milioni i soli danni alle campagne. SERVIZI ALLE PAG. 2, 3, 4, 5

«Alluvione, tutti a Roma»

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OAL-Italy river flooding

Additional funding following the 2020 flood (due to bank failure on the Panaro river - Fossalta)

TERREMOTO » San Felice: la villa del duca d'Este sarà restaurata per polo culturale

GAZZETTA DI MODENA

QUOTIDIANO D'INFORMAZIONE — LUNEDÌ 20 GENNAIO 2014

MESSA IN DUOMO
Vescovo e Kyenge, sintonia sul tema dell'integrazione

VIGNOLA
«Falso infermiere, è colpa dell'agenzia interinale»

SASSUOLO
Caselli: «Chi vive qui da anni avrà più aiuti contro la crisi»

Paesi sott'acqua, migliaia di sfollati

Bassa, il Secchia rompe l'argine e scorre su strade e case. Danni per milioni

2014

DA BASTIGLIA A SAN PROSPERO

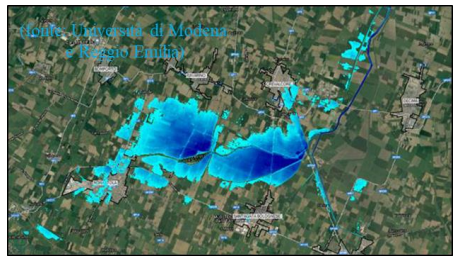
Notte di paura Famiglie in fuga dall'alluvione

MENU | CERCA — la Repubblica — ABBONATI | QUOTIDIANO R | ACCEDI

Maltempo, esondazione del Panaro: sessanta famiglie evacuate nel Modenese

▲ (ansa)

Sigillata la falla nell'argine. Chiuso un ponte, aperte le strutture d'accoglienza. La Regione chiede lo stato d'emergenza. Allerta meteo per 36 ore

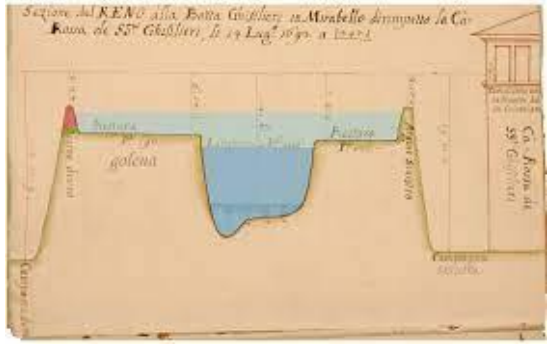


OAL-Italy river flooding

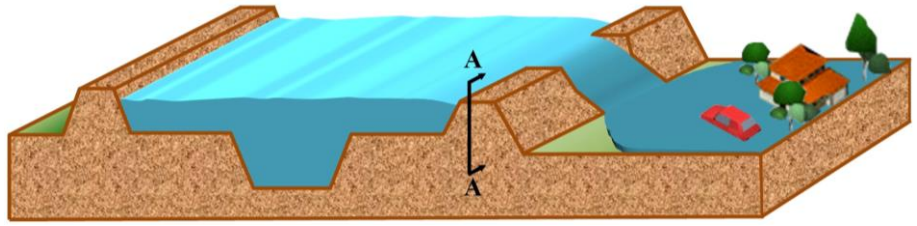
Following the Panaro River flood in 1982, a **detention basin** was designed and built upstream (not fully operational, yet due to a complex construction and authorisation process), in order to decrease the flood peaks.

The river network, also due the centuries-old artificial banks that increase the deposition on the bottom, is now often of the **"perched" type ("fiumi pensili")**

⇒ **the river bed is higher than the ground elevation of the surrounding plains**

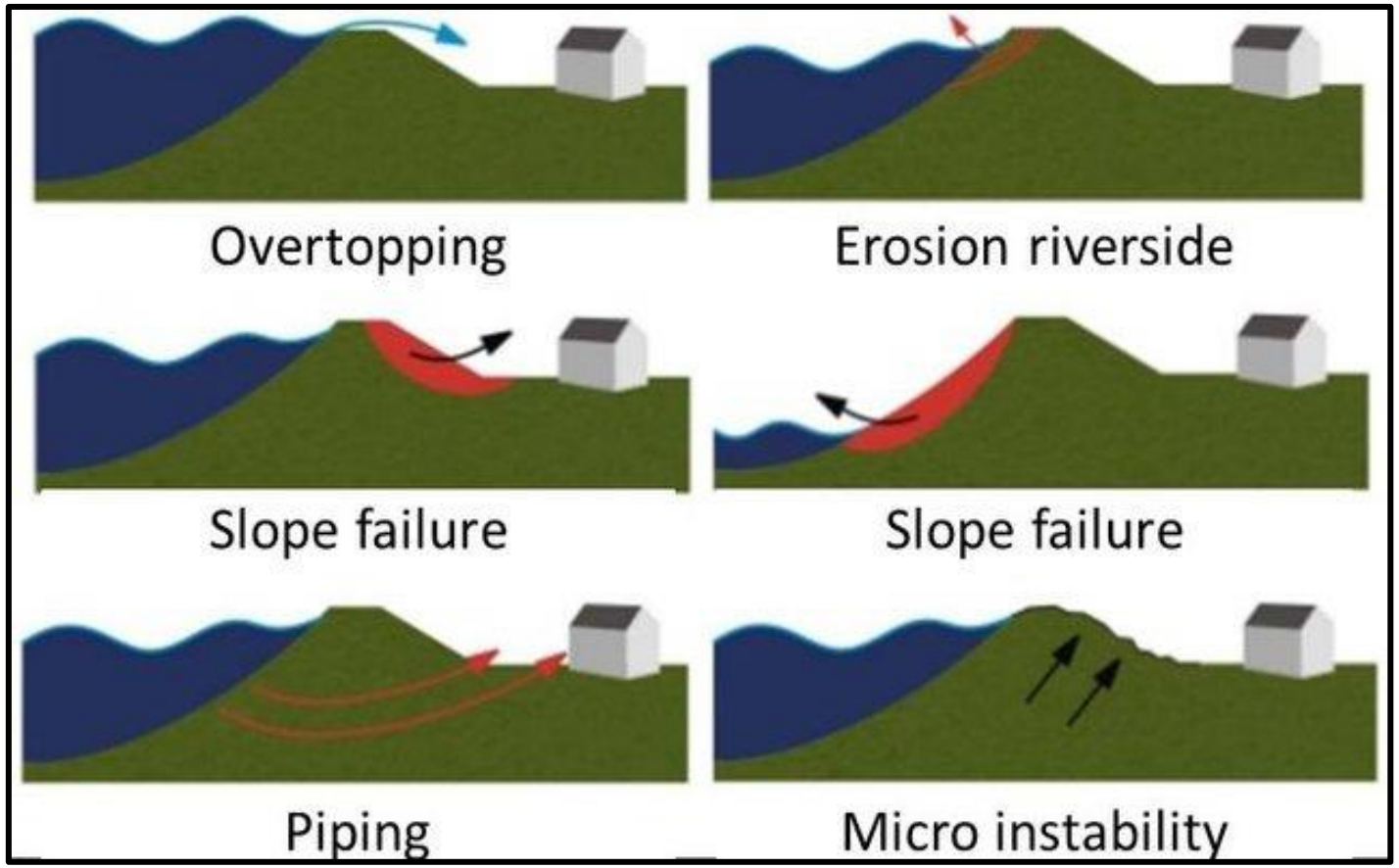


The earth embankment system is what prevents even a minor flood from inundating land and properties.



OAL-Italy river flooding

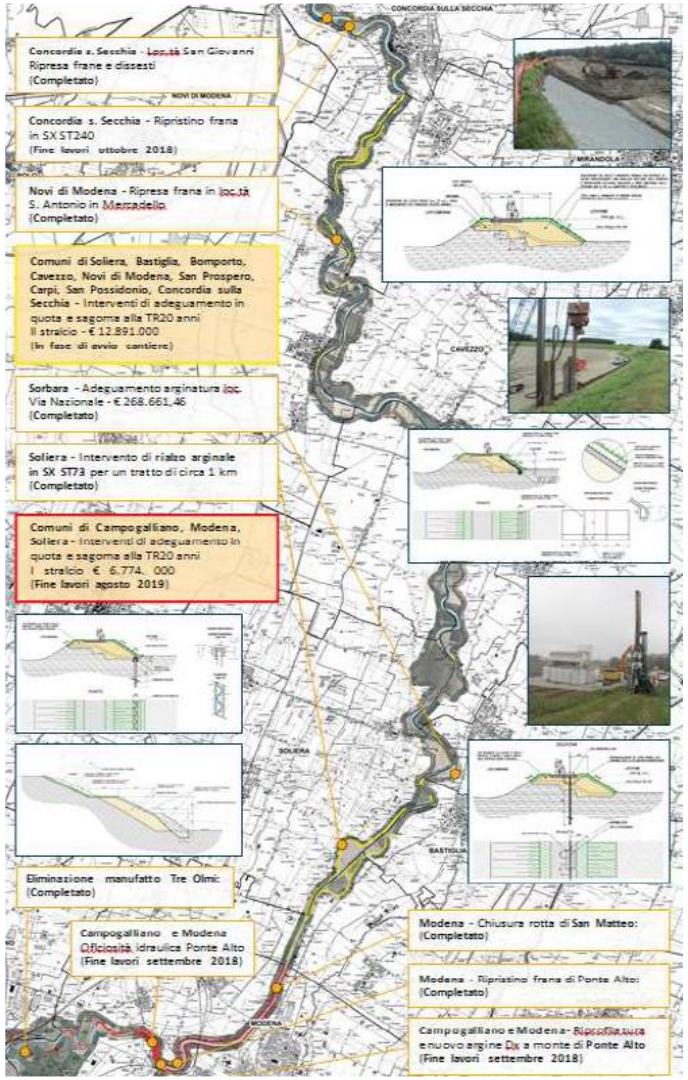
Flood events in this area are due to embankments failures (not only overtopping).

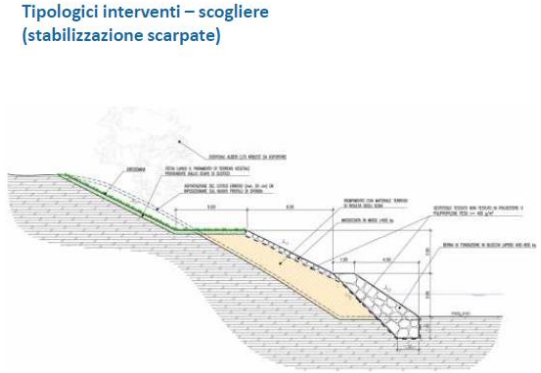


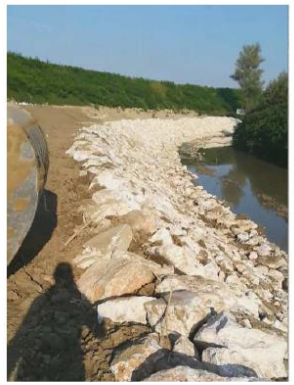
Is it possible to test a NBS able to reduce riverside surface erosion and slope failure when due to toe erosion?

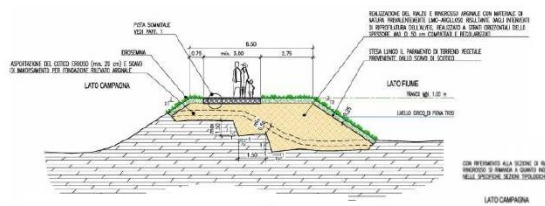
OAL-Italy river flooding

Engineering hydraulic works (detention basins and embankments) have been done in the Modena «river node» following the 2014 flood (source AIPo, 2020)





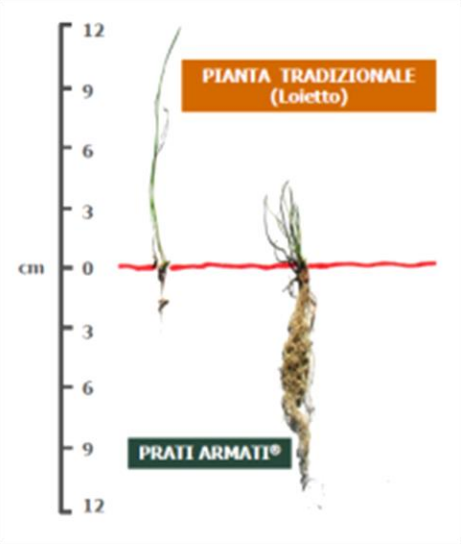




Hard-engineering works on the banks

OPERANDUM

OAL-Italy river flooding



NBS to be tested (for the first time in riverbanks):

Herbaceous perennial deep-rooting plants as **coverage of the earth embankments.**

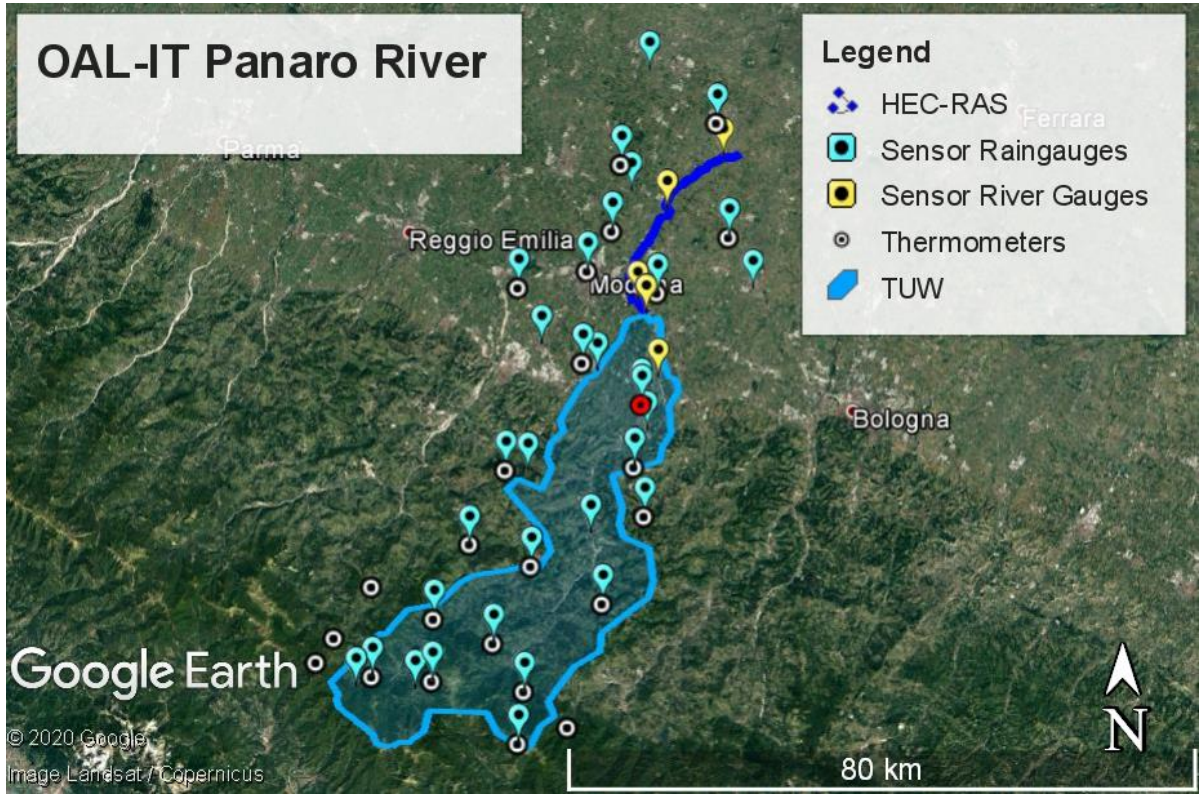
PRATI ARMATI® technology, developed by an engineering company based in Milan, who has identified mixtures of seeds with special physiological characteristics coupled to a deep and durable rooting structure.

AIM: MITIGATING SURFACE EROSION OF RIVERBANKS

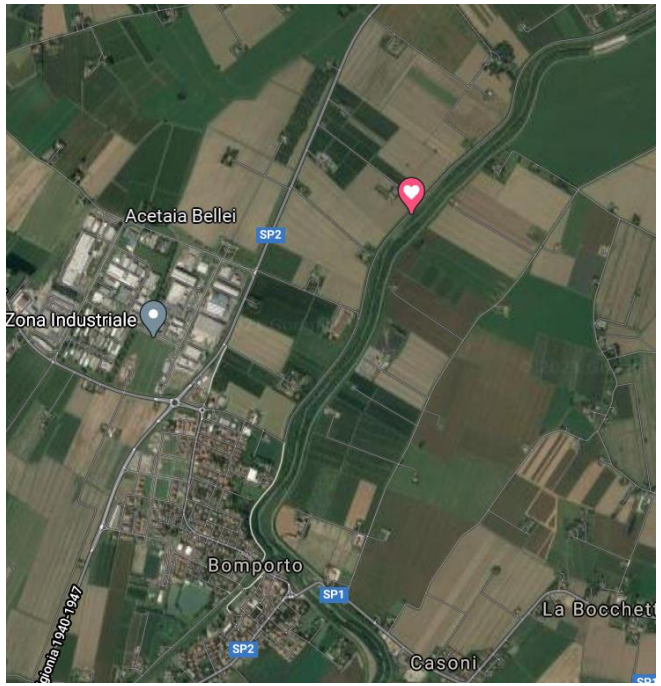
- the aerial parts of vegetation reduce the mechanical impact of river flow and rainfall
- the belowground parts, facilitating drainage in the topmost layers and promoting plant water uptake, thus contributing to the regulation of the drying/wetting cycle, **reinforce mechanically the soil forming the top of the embankment**

⇒ **decrease the risk of shallow instability mechanisms**

OAL-Italy river flooding



Panaro River – tributary of Po river
Catchment drainage area at the OAL river section: ~1100 km²

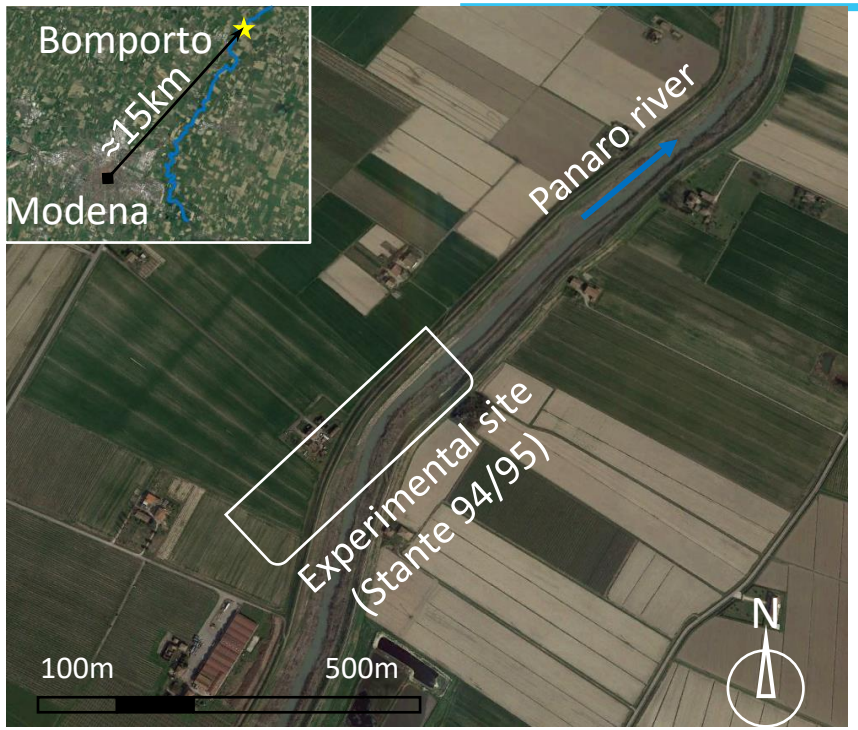


Open-Air Lab location: reach of the Panaro river just downstream the town of Bomporto (province of Modena), on the left river side.

Association of civil protection volunteers

The volunteers are specifically trained **not only for the rescuing operations**, but also for **addressing the issues related to the riverbanks**:
monitoring (cracks, animal burrow holes, sand boils, etc.)
and **carrying out emergency interventions** during the floods

OAL-Italy river flooding



In this section (“Stante 94/95”) remediation works (piles and riprap) on the Panaro riverbank have been recently (Spring 2019) concluded by the Po river authority (AIPO) to improve bank stability. On the adjacent bank, cracks have already appeared.

OAL-Italy river flooding

Hydrological and hydraulic modelling

Rainfall-runoff and flow propagation models

⇒ Analysis of forcing/governing phenomena in historical flood events

⇒ Evaluation of hydrological and hydraulic forcing under climate change scenarios

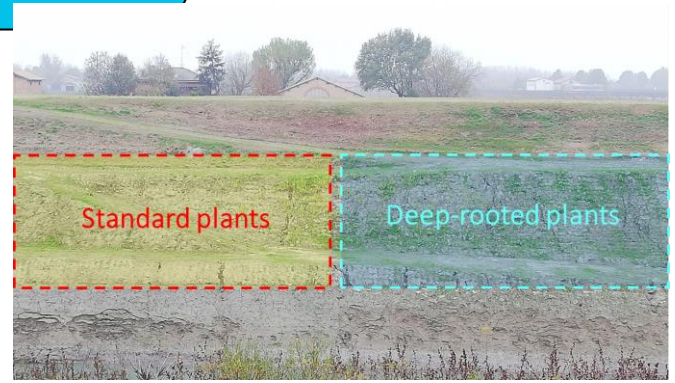
⇒ Detailed numerical local modelling

Lab experiment

Lab model testing different plants under different hydraulic conditions

Open Air Lab

Plant seeding along a river stretch



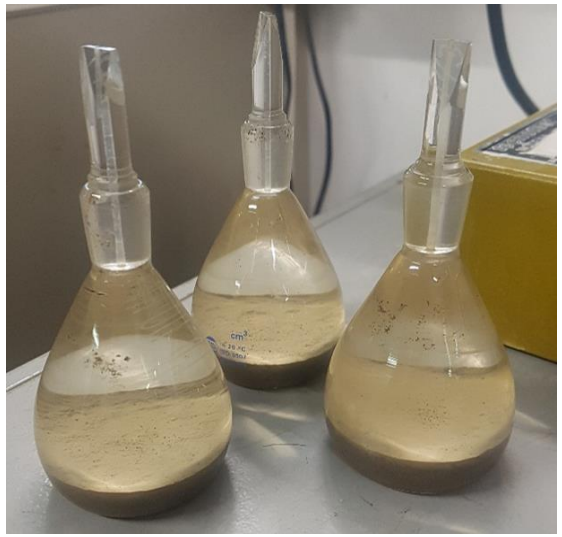
- water level and velocity
- (solid transport)

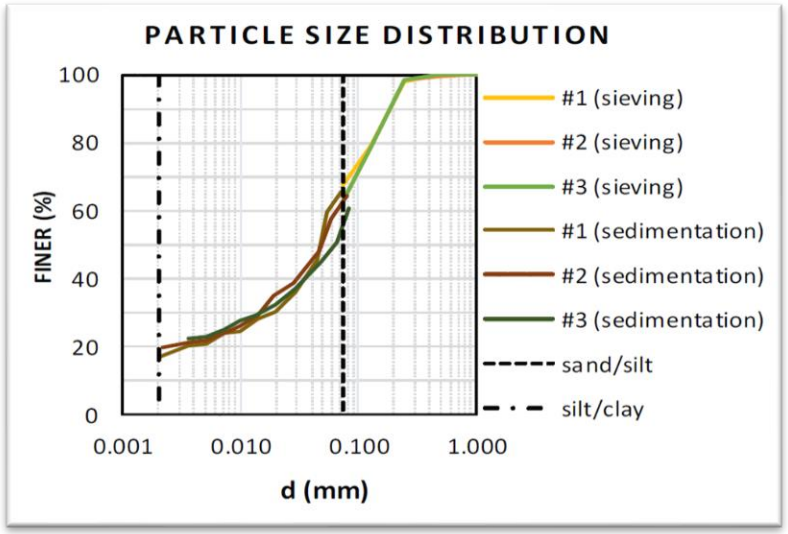
- soil water content/suction
- water infiltration dynamics
- *roots characteristics*
- *presence of animal burrowing?*

OAL-Italy river flooding

Soil samples have been taken from the site to perform laboratory classification tests:

Specific gravity (useful for the of unit weigth), **granulometric curve**, **Atterberg limit** (for plasticity data), **organic matter** and **calcareous content** have been determined from specimens collected **0.2** to **0.6 m** depth, representative for the vadose zone, where atmosphere-vegetation-soils interactions occur.





OAL-Italy river flooding

Seeding and growing of the vegetation in the lab

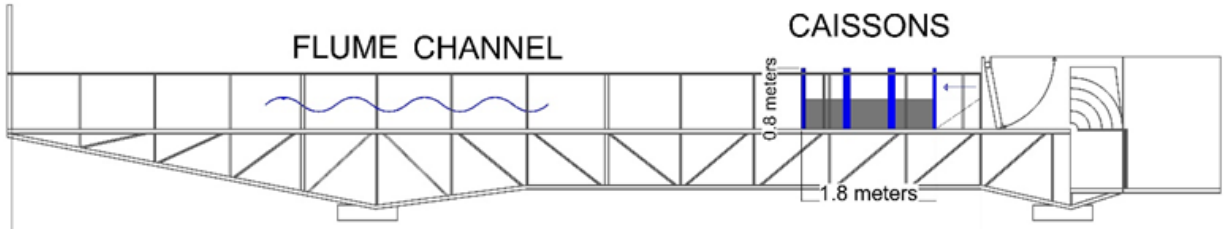


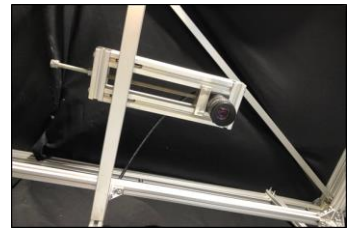

Laboratory flume tests was performed in different soil surface conditions, i.e.:

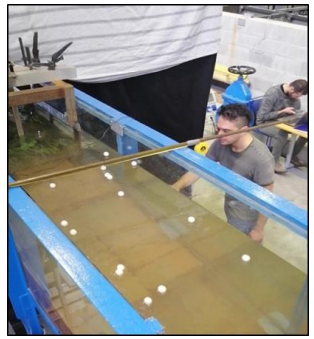
1) Smooth, compacted and **non-vegetated soil;**
2) Soil vegetated with **standard herbaceous plants** typically used by the river authority (when any vegetation is planted, since generally there is no artificial seeding along the banks)
3) Soil vegetated with **deep-rooted herbaceous plants**

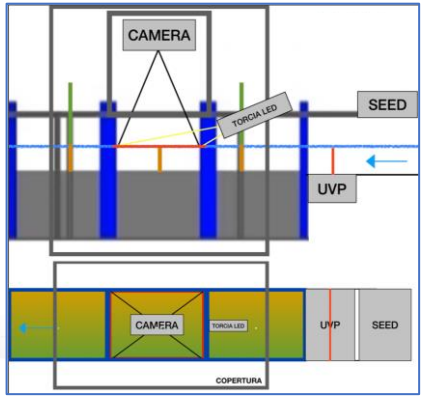
Experiment set up and monitoring system

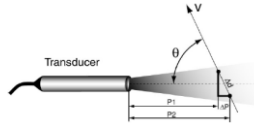
A set of experiments in a recirculating, tilting hydraulic flume have been designed and implemented, in order to gain, in a controlled environment, information on the influence of the vegetation on both hydraulic and erosive processes











Monitoring system

Camera for Particle Image Velocimetry, Acoustic Doppler Velocimeter UVP, custom-made system for weighting of bed load sediment transport, turbidimeter for suspended sediment transport.

*The main **monitoring challenge** resulted to be the **estimation of the volumes of soil eroded during the experiments**, due to the very limited quantities that are eroded and to the particularly fine-grained texture of the soil.*

OAL-Italy river flooding

Experiment runs

The flume was set with **two channel slopes** (0.4% and 8.5%) - for subcritical (slow) and supercritical (fast) flow - and the experiments were repeated for three different discharges values**, for each soil cover**.

0.4%, Fr ≈ 0.3

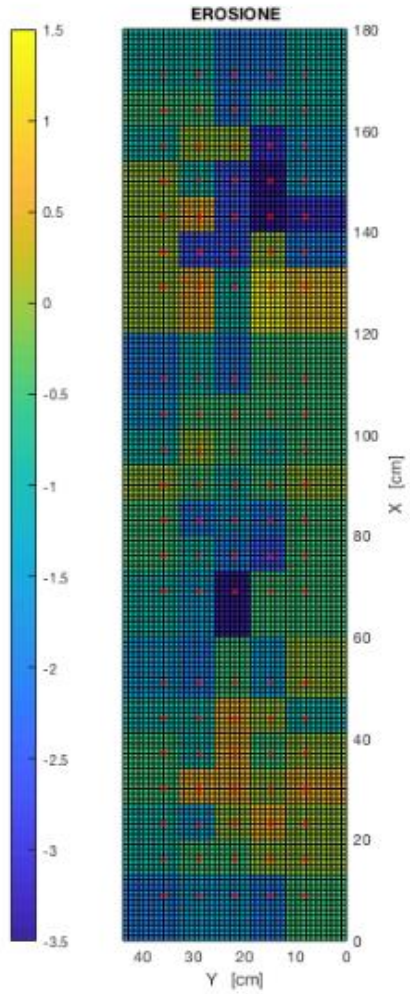
8.5%, Fr ≈ 2

OAL-Italy river flooding

Influence of plants density on erosion

Partial and local states of failure were obtained during the erosion test at the higher bed slope for the bare soil and, to a lesser extent, for the deep-rooted plants, while erosion processes were negligible for the “standard grass”.

The presence of vegetation resulted in a substantial decrease in the surface erosion rate <u>in comparison with bare soil</u>



At the time of experiments (i.e. around three months from the plants seeding),

- **the standard vegetation** was characterized by **high plants density** on the soil surface, with **limited exposure of bare soil to flow erosion**;
- **the deep-rooting plants were much less dense:** the soil was more exposed to erosion processes

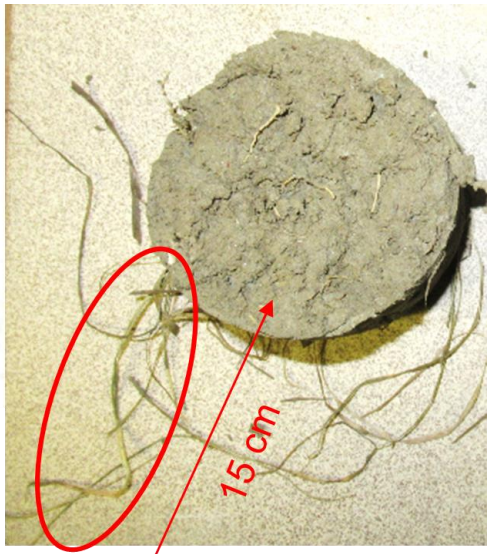
OAL-Italy river flooding

Even if root depth seems to have had less influence than plants density on the erosion in our "protected" lab tests, **the conditions of the two types of vegetation are expected to be very different in the real-world case** study, where the plants grow in a natural environment and for a much longer period**. The perennial PratiArmati vegetation** is in fact characterized by its **root depth and tensile strength, in addition to its adaptability to difficult climatic conditions.**

Soil coring for analysis of the roots
(after the flume experiments not to disturb the soil)

At the time of the experiment (3 months after seeding) the deep-rooted species had a **root system** up to **15 cm long**, while this length was limited to **a few centimeters** for the standard plants.

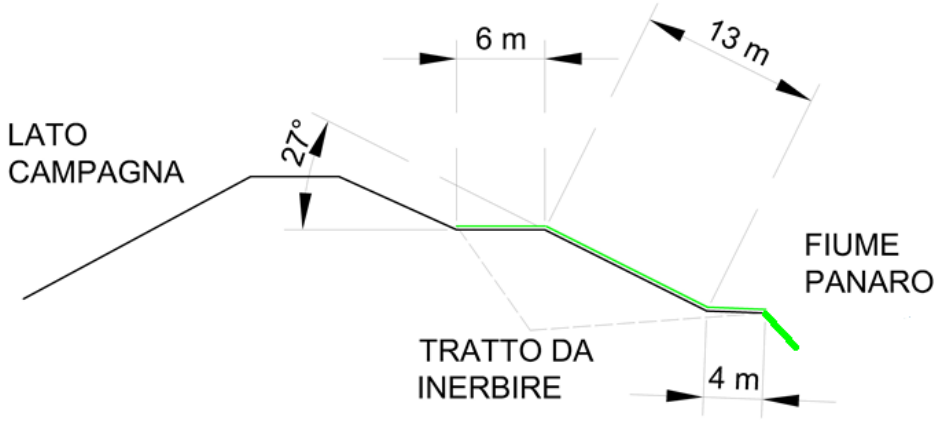
Standard plants



Deep-rooted plants

OAL-Italy river flooding

Riverbank soil preparation,
September 2020



- Removal of existing natural vegetation through mowing + topsoil stripping
- Shaping of bank profile
- Plowing/harrowing

Riverbank soil preparation,

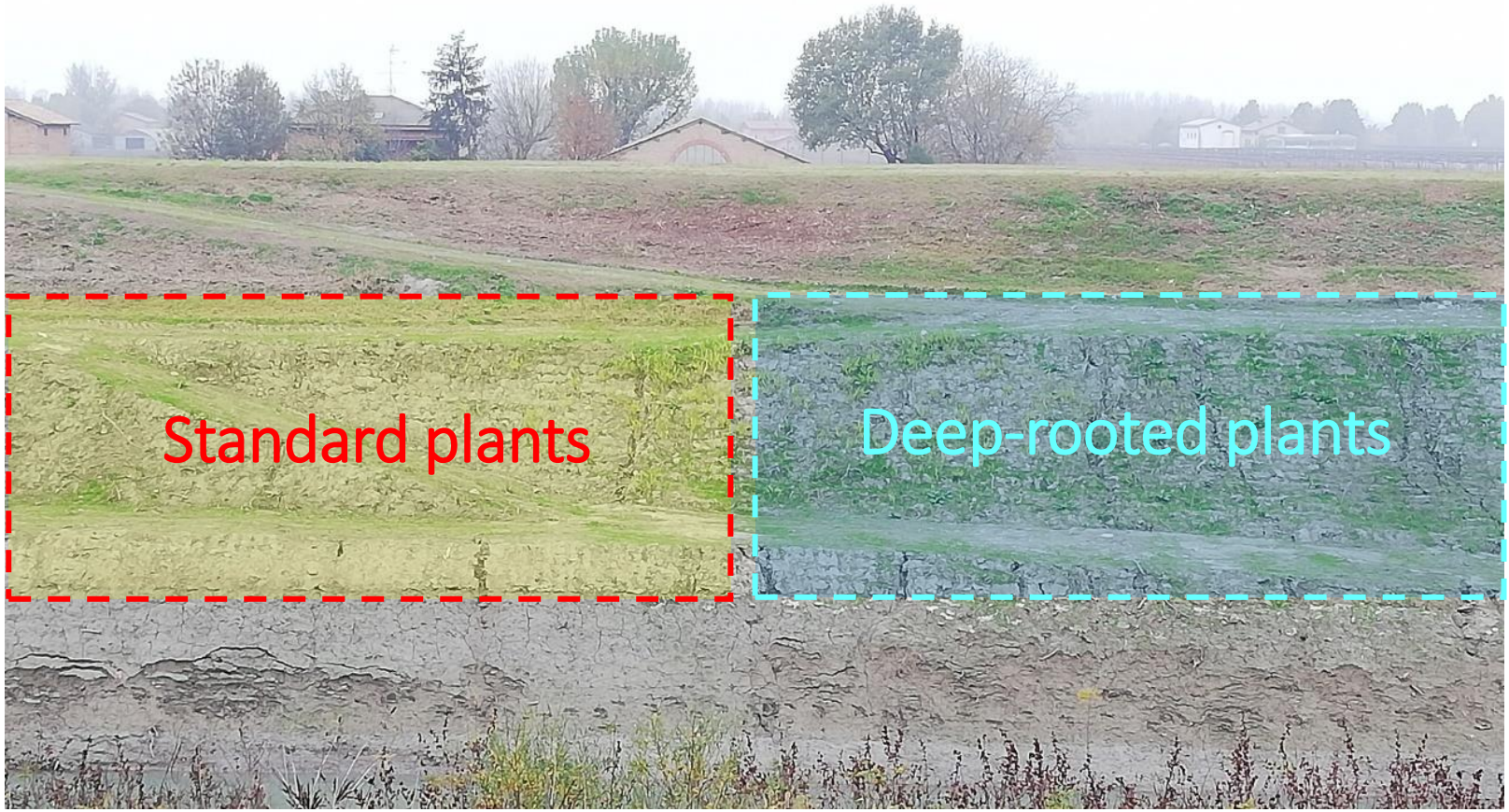
September 2020

BEFORE MOWING

AFTER MOWING

AFTER TOPSOIL STRIPPING AND SOIL HARROWING

NBS vegetated area



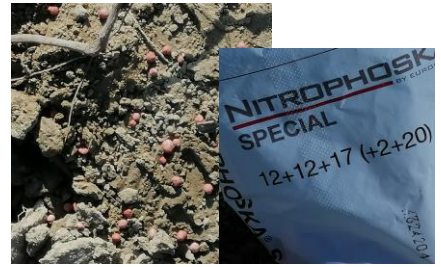
~ 500 m² standard plants

~500 m² deep-rooted plants

OAL-Italy river flooding

NBS implementation: Seeding – Oct. 6th, 2020

Deployed by PratiArmati srl in presence of DICAM researchers and AIPo experts



- Spreading of **fertiliser** (nitrogen, phosphorus, potassium compound), 50 g/m^2
- Sowing of **PratiArmati seed mixture** (12 deep-rooted species, varying percentages by weight), 30 g/m^2
- Sowing of **'standard' grass seed mixture** (compliant with the rules of the AIPo River Authority, 8 species, same percentage by weight), 30 g/m^2

Vegetation growth: monitored through surveys and pictures by us and by the Civil Protection Volunteers

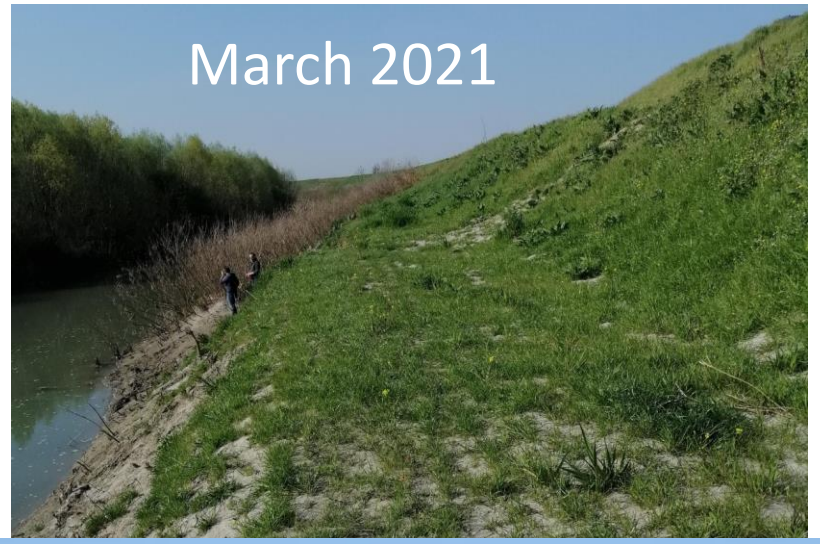
Vegetation growth: monitored through surveys and pictures by us and by the Civil Protection Volunteers

Standard vegetation

09/11/2020:
Civil Protection Volunteers survey

Deep-rooted vegetation

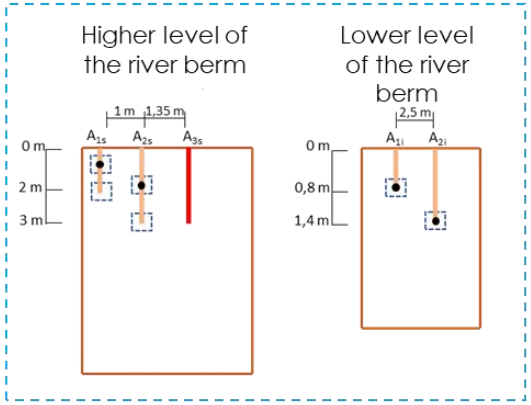
Vegetation growth



Monitorning

Calibration (in the lab) and installation at different depth (through borehole drilling) of:

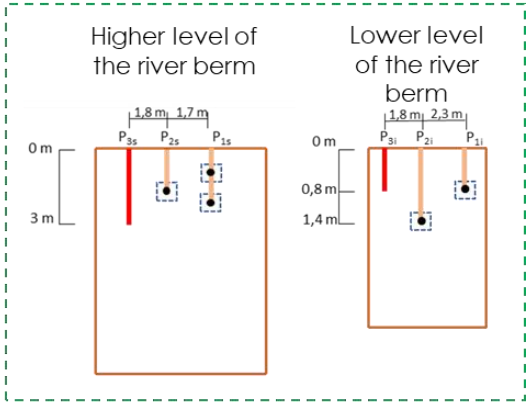
- **Suction (direct and indirect) and pore water pressure sensors**
- **Soil water content sensors**



Tensiometer suction and pore water pressure (direct) measures

T-21 Suction (indirect) measures

T-12 Soil water content (indirect) measures



08-09/10/2020: sensor installation
26/11/2020: trench excavation for extension cables

Standard vegetation area

Deep rooting vegetation area (PratiArmati -PA)

AIM: to quantify the effects of the growth of different vegetation species for analyzing the plant-soil-atmosphere interaction

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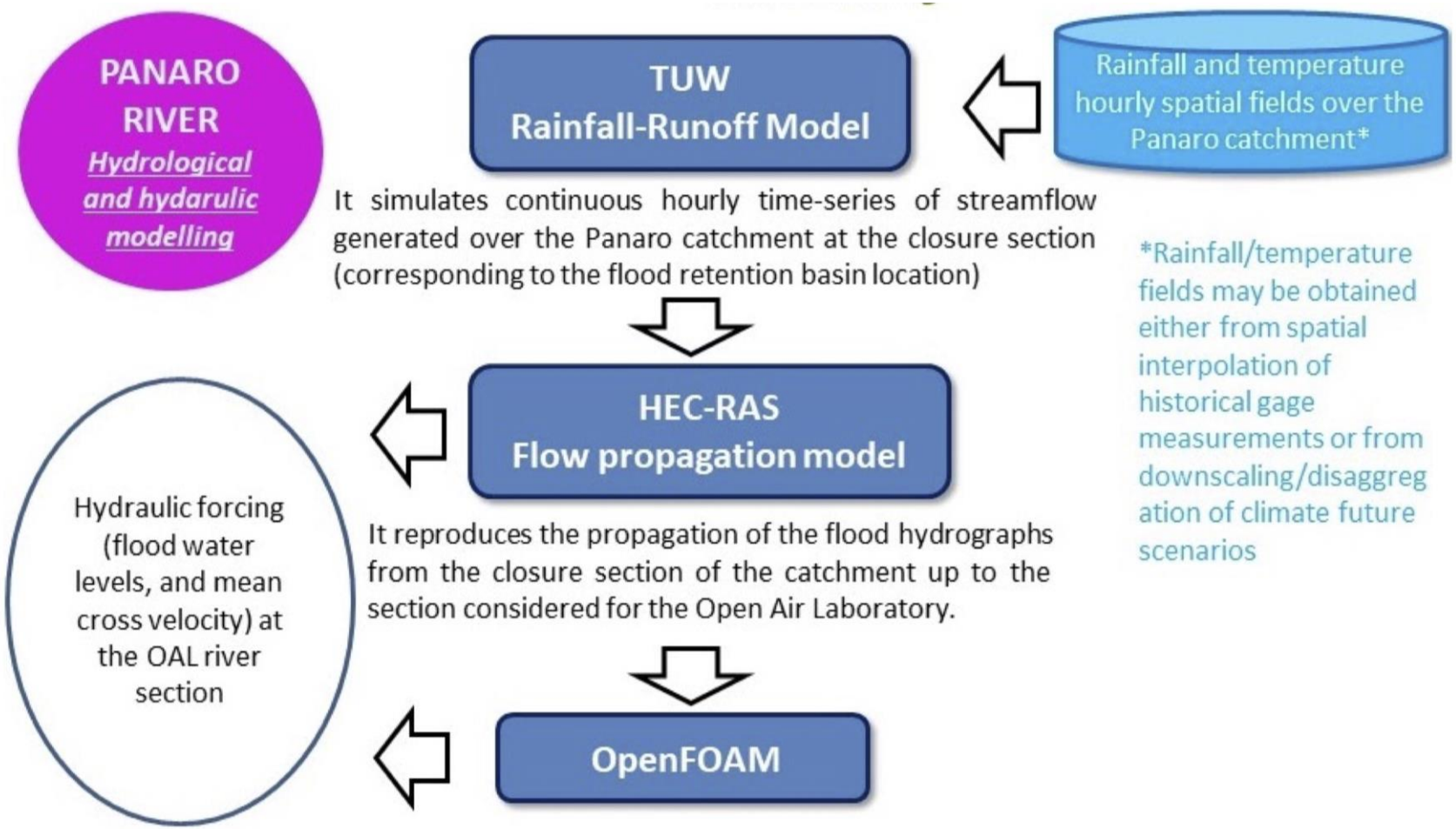
Modelling



*Rainfall/temperature fields may be obtained either from spatial interpolation of historical gage measurements or from downscaling/disaggregation of climate future scenarios

Hourly, bias-corrected climate scenarios (CMCC)

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Stakeholders

Dept Civil and Env. Eng. UNIBO (experts in water and in geotechnical engineering)
+ Po River Authority (AIPo)

+ Prati Armati srl: NBS implementation + help in co-design and in monitoring
+ Local Civil Protection Volunteers (Volontari Protezione Civile Bomporto): monitoring
+ Dept. Industrial Eng. UNIBO: OpenFoam 3D flow modelling
+ CMCC: local climate scenarios including bias-correction methods

- Municipality (Comune di Bomporto)
- Civil Protection Volunteers training and coordination (Consulta Provinciale del Volontariato per la Protezione Civile di Modena)
- Wild-life experts (Ambito Territoriale di Caccia MO1 Bassa Pianura)
- Land reclamation consortium (Consorzio di Bonifica Burana)
- Province (Provincia di Modena)

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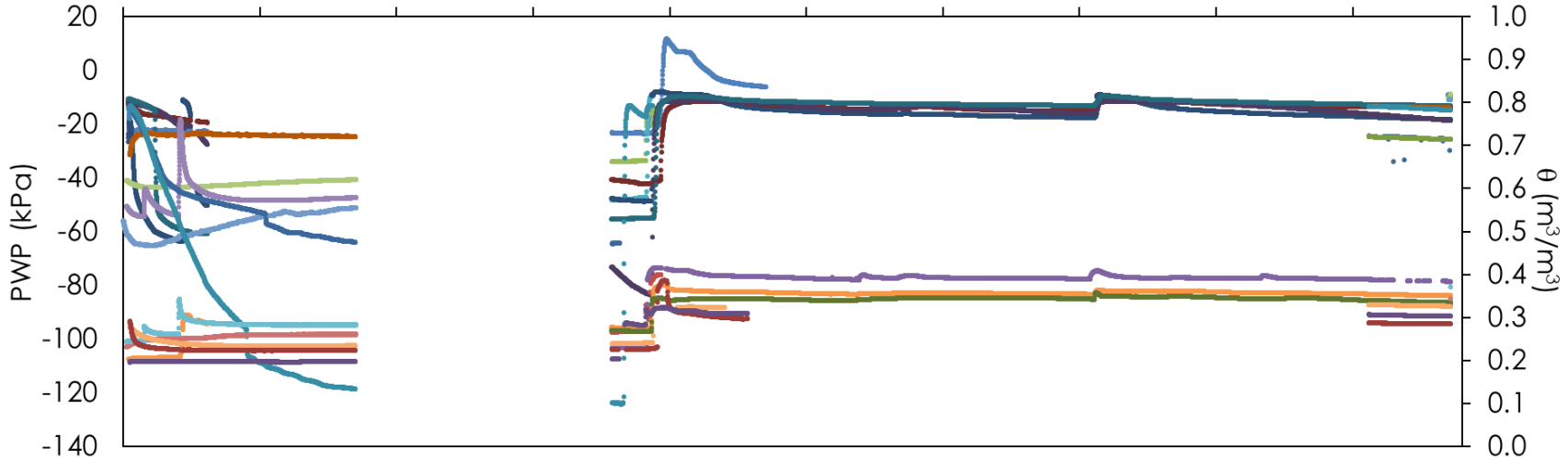
Monitoring

16/12/2020:
Following the Dec 6th flood event

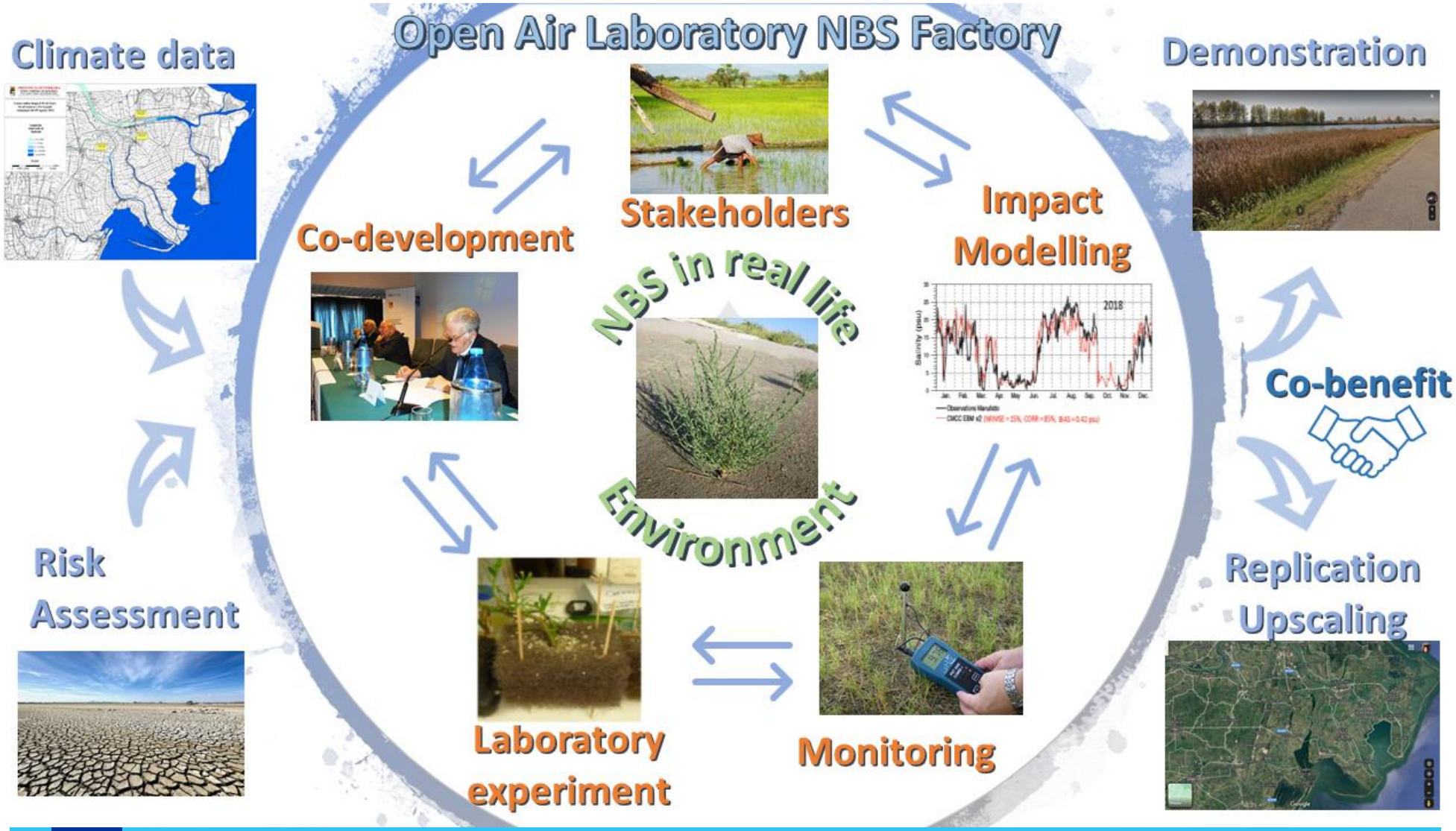
OAL-Italy river flooding

Soil sensors data transmission: interruption due to the Dec flood



1. **Monitoring test: 9 Oct - 3 Nov 2020**
2. **No transmission from 3 to 26 Nov 2020**
3. **Continuous monitoring after Nov 26th 2020**
4. **Flood event (Dec 6th)**
5. **Set of sensors discontinued due to the Dec 6th flood event (short circuit interruption)**
6. **Interventions for restoring the damaged sensors at the end of Feb 2021**

OAL-Italy river flooding



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Thank you!!

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