KING'S College LONDON

Department of Geography

H2020 Restarting Economy in Support of Environment, through Technology (ReSET)

NAIAD 2020 Nature Insurance value: Assessment and Demonstration

NAIAD

Developing & deploying low-cost, distributed monitoring to evaluate NFM

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www.policysupport.org/reset

40m

Outline

1. The problem

2. Development of low-cost, DIY monitoring solutions

3. Deployments:
    a. leaky dams
    b. retention ponds
    c. regenerative agriculture

4. Challenges and practicalities

5. Findings

6. Setting up your own monitoring system

7. Conclusions

The problem

Each NFM is different:

- leaky dams, retention ponds and soil management regimes **vary in design and scale**
- **geographical context** is everything

Thus, our approach been to monitor **a wide range of interventions extensively rather than a single site intensively**

Monitoring is expensive in:

- specialist equipment and sensors (that are vulnerable)
- associated infrastructure (eg measurement weirs)
- time taken to visit, collect and analyse data

Hence, we developed network-connected, low-cost, DIY-build sensors and automatic web-based analysis techniques suitable for replication over large numbers of sites and NFM interventions

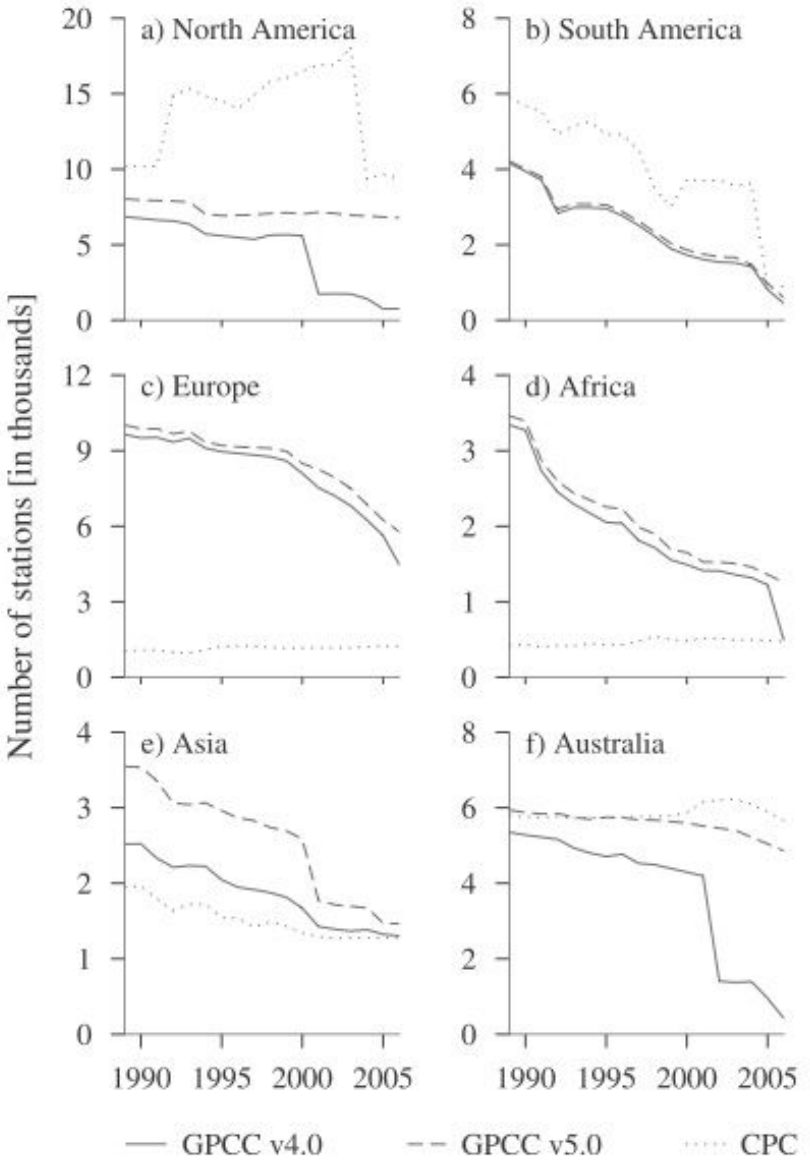
We monitored **sites on 13 rivers** (Blackwater, Brain, Brent/Lee, Colne, Medway, Mole, Ouse, Stour, Mar Dyke) and on farms in Herts, Bucks, Cambs & Norfolk

We built & deployed **101 FreeStation loggers** collecting **21,863,880 readings in 2020** (despite lockdowns). Many of the loggers are still collecting data. **Analysis ongoing**

Why FreeStation?

- Ground based monitoring infrastructure is **declining globally** & we cannot remotely sense all the variables we need to measure

- **Technological barriers** to designing and building your own hardware are falling....
- **FreeStation:**
  - Environmental monitoring with **open source** DIY hardware since 2014
  - **3% the parts-cost** of equivalent proprietary loggers (33:1 stns)
  - **The world is variable: more samples is better than greater per-sample accuracy**
  - Web connected for **early warning,** nowcasting, model integration
  - There are many low cost sensing projects: this one is **designed for Geography students** (plug and play)



The FREESTATION FREESENSOR solution

- A variety of instruments, all **good-enough for the job**
- Designed with consumer, off the shelf (thus cheap) components
- All parts replaceable and all stations reconfigurable
- Easy to build, easy to ship, easy to install. **Robust.**
- Network enabled (WIFI, GSM), **IoT**
- Designs open-source for non-commercial uses
- Data collected (started 2014): 2019: 171,**27m**, 2020: 161,**34m**, 2021: 84,**5m** (so far, so estimate >**20m**)
- **//Smart:** online tools for easy visualisation, management and analysis

Low cost ≠ low accuracy, precision or quality

Low cost = non-specialist, consumer, mass produced and using your own labour

Accuracy

Similar results to commercial sensors and stations

- Davis **temperature** (720 hours) 6.97°C. SHT21: 6.66°C BME280: 6.96°C. **Within half degree**
- Davis **humidity** (720 hours): 78.1%. SHT21: 72.3% BME280 79.6%. **Within 2 or 6%**
- **Stage** sensors: sonar 1.20m, measurement 1.19 (n=112). **Within 1cm depth**
- *Full details in build documentation*

Reproducible between sensors under the same conditions:

- 4 BME280s under same conditions (1040 hours): 22.2, 22.5, 22.5, 22.1°C. **Within half degree**
- 4 SHT21s under same conditions (504 hours): 21.8, 21.7 21.7, 21.7, 21.4°C. **Within half degree**
- 3 FreeStation pyranometers under identical conditions (720 hours): 170 W/m^2, 168 W/m^2, 173 W/m^2. **Within 5 W/m^2**
- 6 replicates of channel profile: CSAs: 2.43, 2.44, 2.44, 2.44, 2.43, 2.42m^2. **CoV: 0.3%**
- *Full details in build documentation*

All components can be cheaply and easily replaced **to avoid need for expensive recalibration**

FreeStation Loggers and Stations

Gen 2 Soil moisture

Generation 1 - based on Arduino pro-mini microcontroller

Generation 2 - based on Particle Photon and Electron microcontroller

Local - not connected

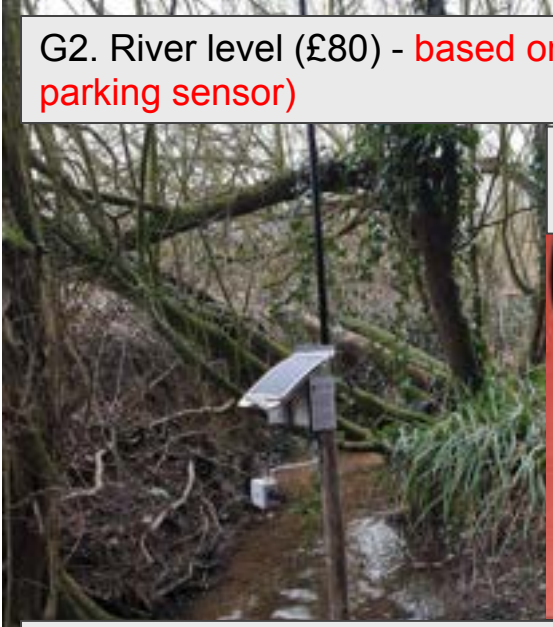
Live - connected, IoT

Gen 2 AWS

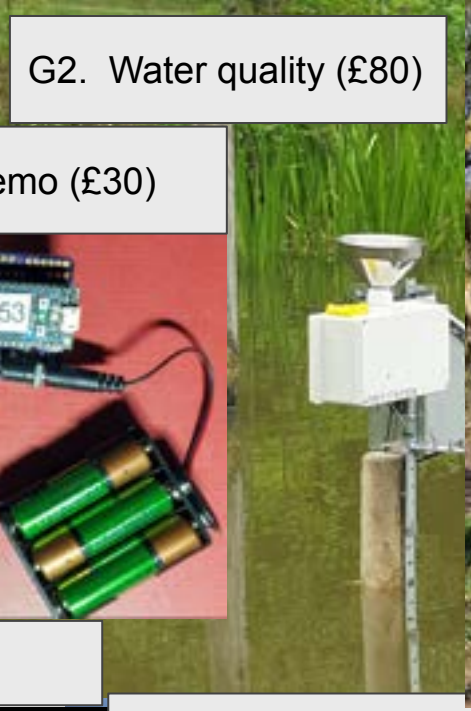
Gen 2 Stage

Gen 1 AWS

G2. River level (£80) - based on sonar (car parking sensor)

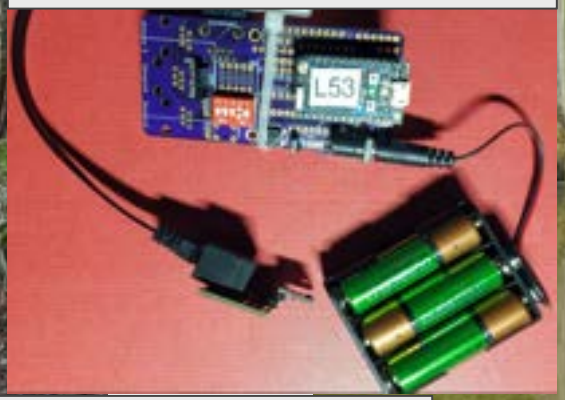


G2. Water quality (£80)



G2. Pole photography (£60)

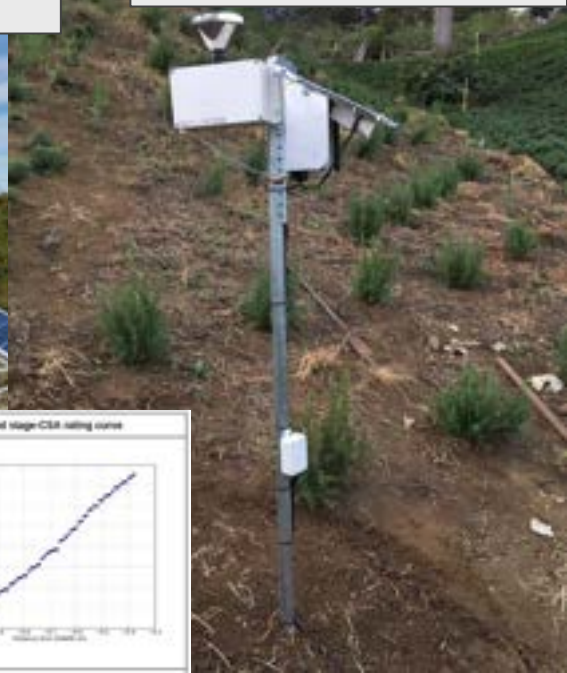
G2. Classroom demo (£30)

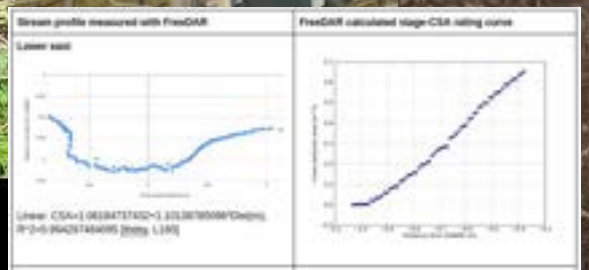


G2. Scanning LIDAR (£160)
Used to provide channel cross-sections

G2. Weather station (£130)

G2. Rainfall and soil moisture (£80)





Key NFM Deployments

//Smart:River
//Smart:Soil

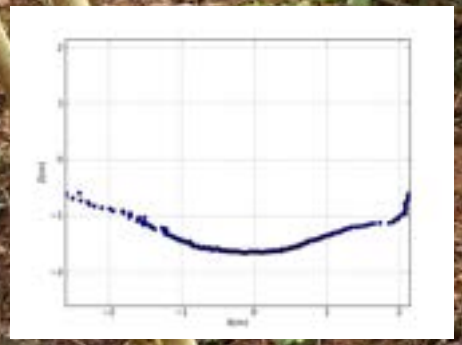
- **Blackwater:** Spains Hall (10 **leaky dams** and **Beaver** re-introduction). *Spains Hall Estate,* EA, Essex and Suffolk Rivers Trust, Essex Wildlife Trust, Anglian Eastern Region RFCC
- **Colne:** Bishops Wood (**leaky dams**). *Hertfordshire County Council /DEFRA*
- **Mole:** Dorking (**retention pond** and proposed leaky dams). *Unum/Environment Agency*
- **Stour:** Paddle Brook, Nethercote Brook (**leaky dams**). *SAFAG/DEFRA*
- **Mar Dyke:** Thorndon Country Park (**leaky dams**). *Essex County Council/Environment Agency/DEFRA*
- **Leck:** upstream of Leckhamstead (**leaky dams**). *Buckinghamshire County Council/Environment Agency/Freshwater Habitats Trust.*
- **Lannock Manor Farm**, Herts. (**regenerative agriculture**). *John Cherry/Groundswell*
- + six other rivers and four other farms

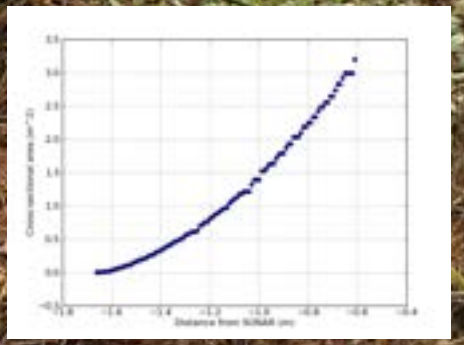
Two types of natural flood management enhance flood storage by land

At a **point** NFM (surface stores)

Areal (diffuse) NFM (good soil management)

//SmartRiver: deployments: either side of dam
Local (no signal and under canopy. Low power)

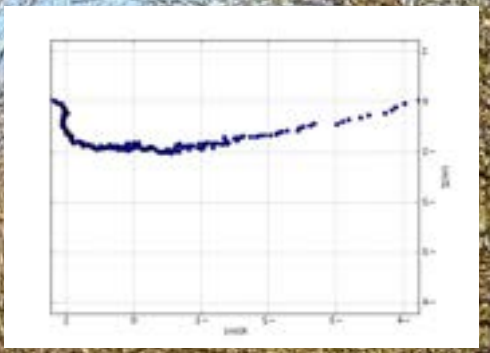


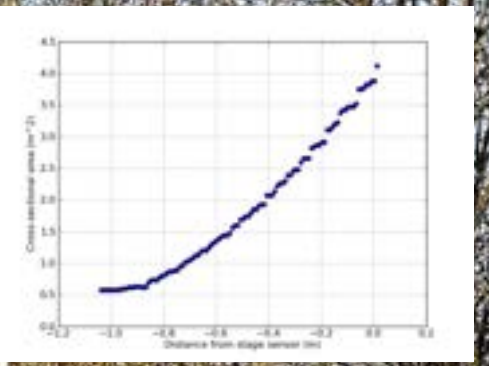


//Smart:River

Bishops Wood (Herts CC/EA/DEFRA)

//SmartRiver: deployments: either side of dam Live

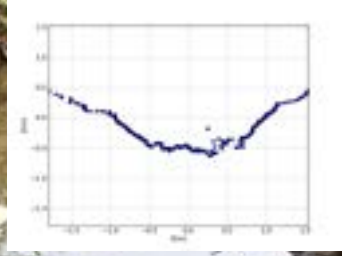


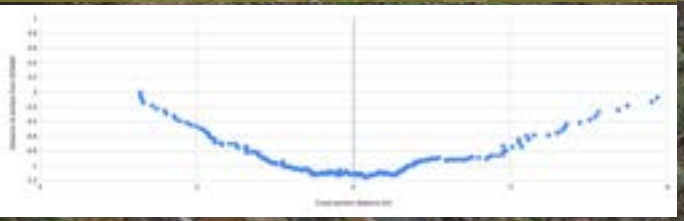


Spains Hall

//Smart:River

Retention pond





Velocity measurement

Upstream and downstream of array of dams

Beaver pond

//Smart:River

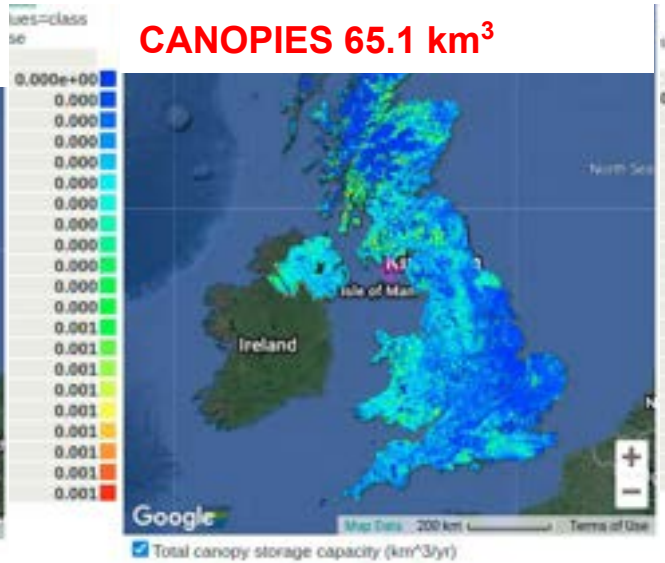
Problems

- **Trash** build-up - always point sonar downstream
- **Vegetation** growth (regular clearing or use pressure-based sensor instead of sonar)
- **Shade** - avoid heavy shade to get sufficient solar power
- **Signal** - 2G and 3G signal not great in wooded ditches. If no signal use FreeStation*Local*
- **Force of water** - elevate on gantry or attach to dam
- Even on gantry expect very high flows
- Vandalism - rare

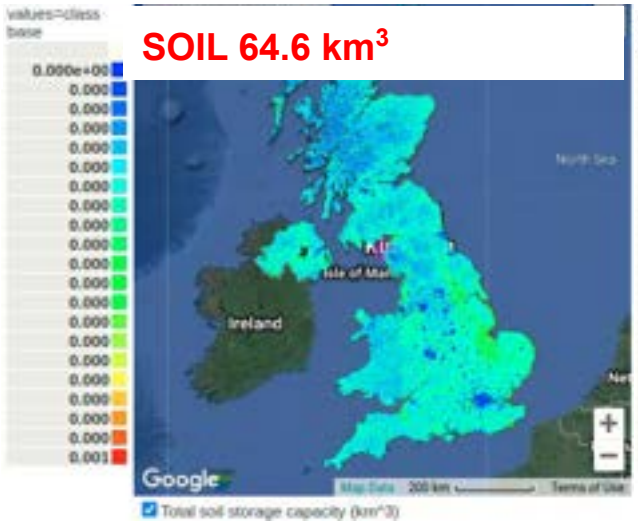
Protect against theft and vandalism!

- **Label** the device to indicate what it is and that it is of no value
- Bits that could be useful should be screwed on and that will deter most
- Work with local people
- Put out of sight
- Don't put next to paths
- Disguise where possible

Soil can store a lot of water, if carefully managed



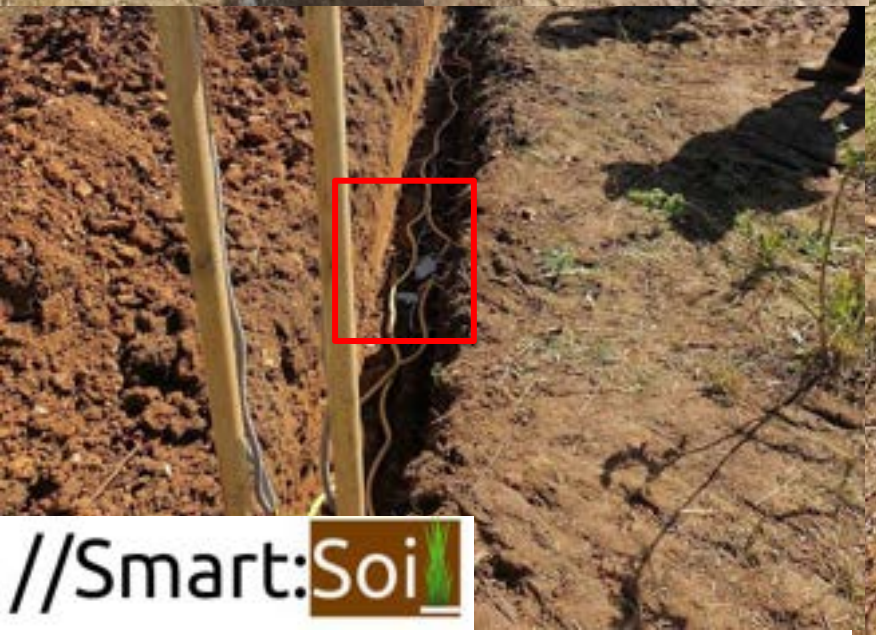
- Most of the storage is in the **soil and canopies.** No longer a good idea to use available floodplain storage, since we have many assets there

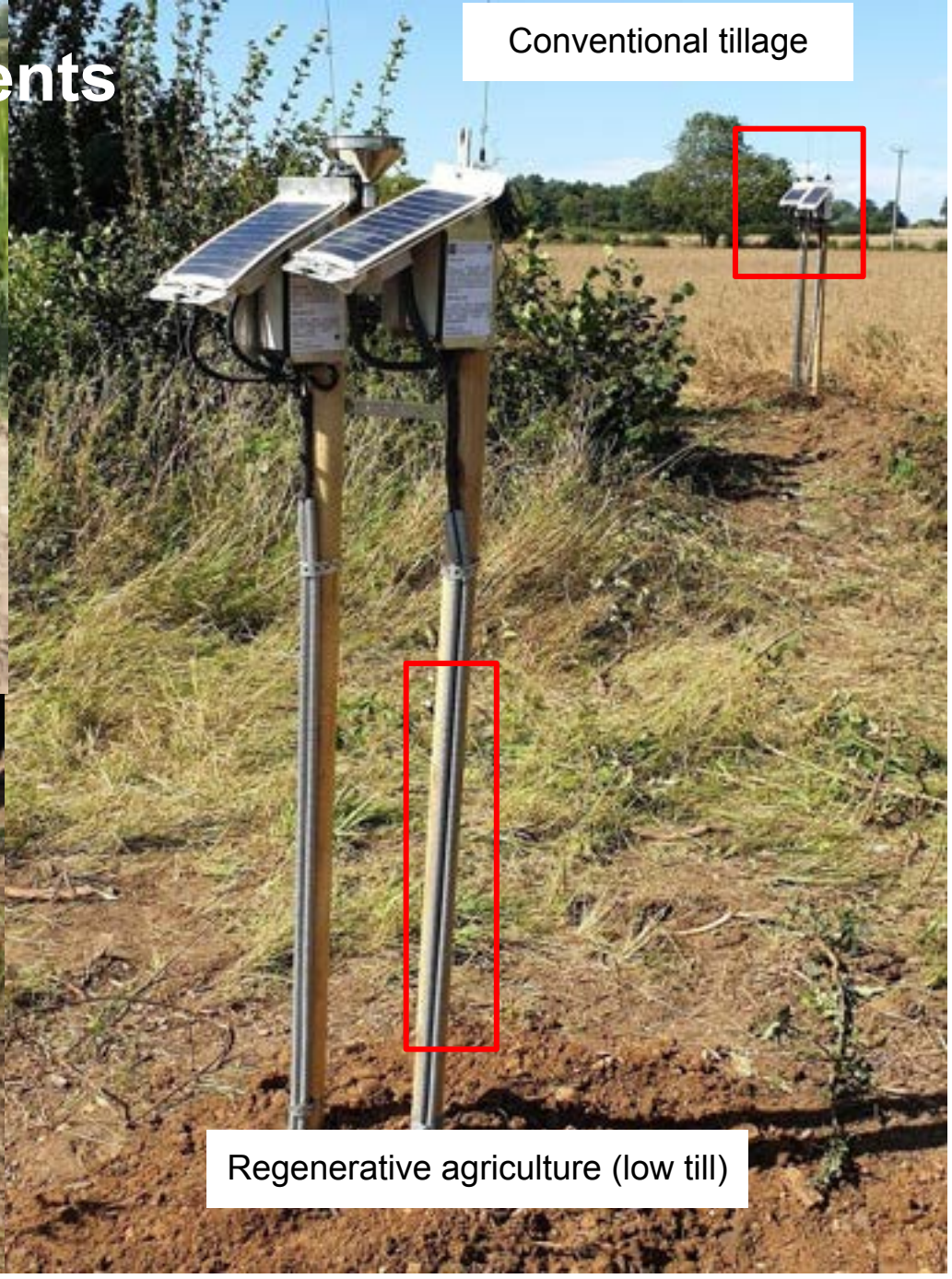


Conservation (regenerative) agriculture

- **Ploughing** is an established technology for weed control
- However, its long term use **has serious impacts** on soil organic matter, structure, infiltration rates and soil water storage volumes
- **Regenerative agriculture (RA)** is the process by which farmers **reduce/stop their use of the plough** and either plant weed-resistant crops or control weeds through other techniques, regenerating soil health in the process
- RA **significantly increases soil storage for water** and thus the ability of land to help manage **flood and drought** risk
- Since RA can be implemented **over large areas** it can have **significant impact at low cost. It is also cheaper for the farmer (less equipment, fuel)**, **but in the first two years** there are **costs and risks to farmers in transitioning**

//SmartSoil: deployments



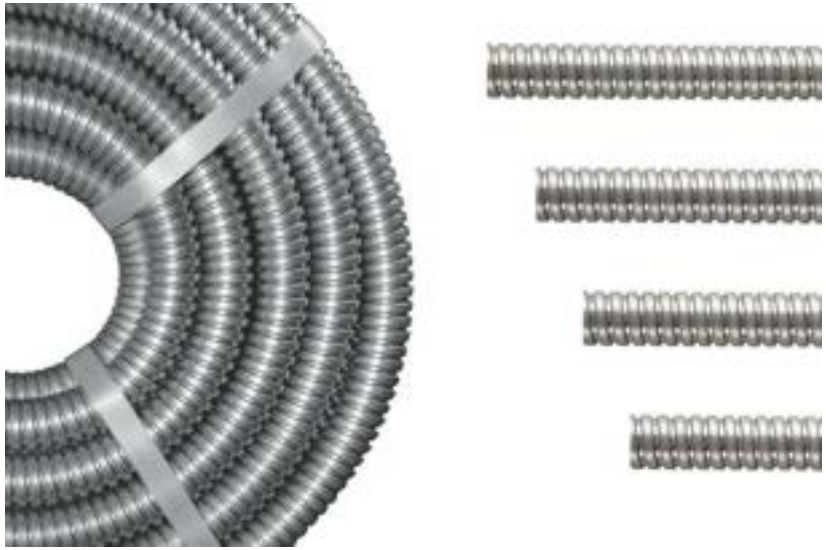


Conventional tillage

Regenerative agriculture (low till)

//Smart:Soil

Protect against wildlife!
Cover cables with metal



Hi Idrissa,

Not good news we may have lost the depth sensor to a crocodile L

apologies if I'm repeating myself, but I thought I'd sent an email over the weekend (but can find no trace of it) telling you that a hare (it looks like) has chewed through the cable that heads underground on the machine on our field. This may explain the wilding fluctuating results...not sure how long it's been like this

Best wishes John

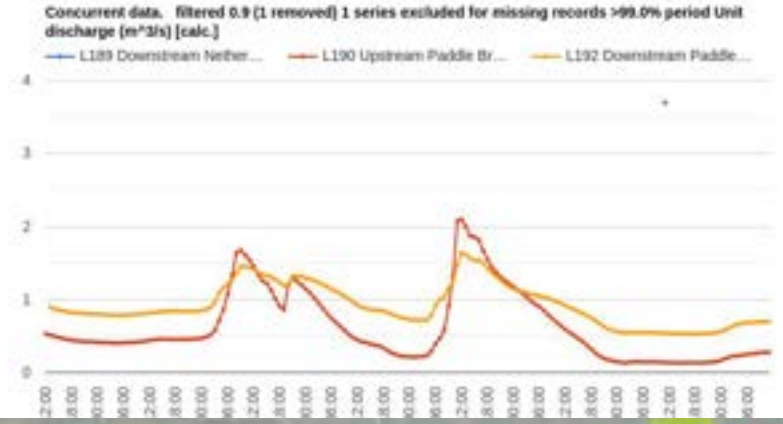
Findings: leaky dams can work if done well

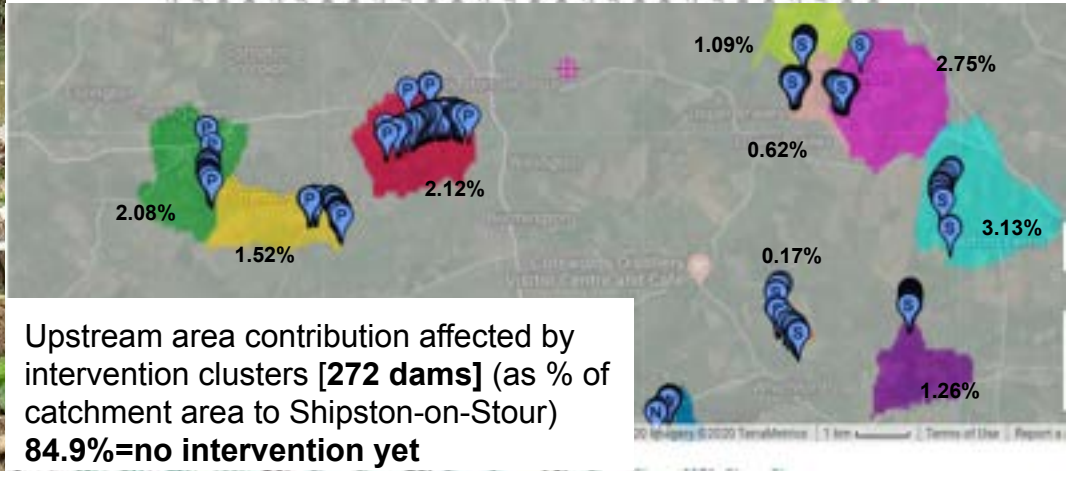
At a point NFM can be effective if assets at risk of flood are nearby downstream or if they activate flood meadows, but otherwise they have small effects (but that might still make the difference for some floods)

SAFAG/EA/DEFRA

Multiple interventions can make a difference locally eg 11 dams reduce streamflow peaks downstream (orange) and extend streamflow troughs **relative to upstream (red).**

To make a difference, this reduction of approx 25% of peak **would need to be replicated** in most tributaries that flow into the larger river which floods





Upstream area contribution affected by intervention clusters [**272 dams]** (as % of catchment area to Shipston-on-Stour)
84.9%=no intervention yet

The case of the Finchingfield Beavers

//Smart: 01/06/2020 11:45 (GMT): The beavers are currently holding back **0.462** olympic swimming pools of water.

- Finchingfield is at the junction of three streams
- The properties around the village pond flood **every few years**

- Most of the land upstream is owned by **a single farmer** Archie Ruggles-Brise

- Archie has tested a number of **NFM solutions** including engineered leaky dams and a controlled release of Eurasian Beaver

2014 flood in Finchingfield

Beaver dams

Leaky log dam

Spains Hall Estate, Finchingfield, Essex

Leaky dams stream (75.1% catchment)

Flood meadow

Beaver stream (11.2% catchment)

East stream (13.7% catchment)

Brent Hall Rd

Brent Hall Rd

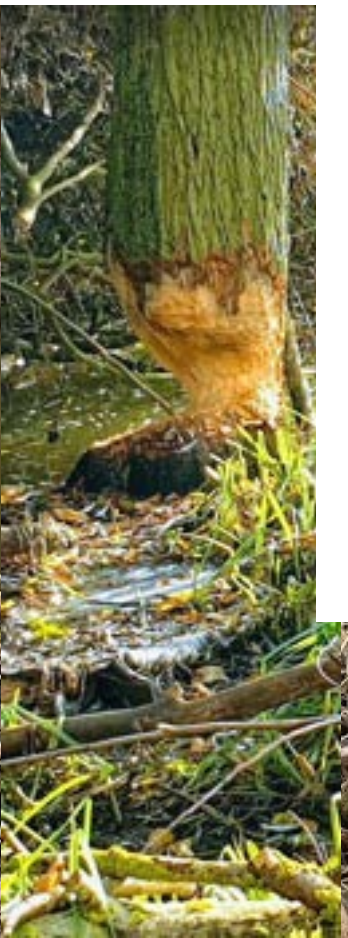
B1053

B1057

Finchingfield

Findings: beavers can make a contribution

- Beaver dams are not so leaky and are **self-building and self-maintaining**
- They have many co-benefits (for biodiversity, habitat: by creating wetlands)
- Every time it rains the beavers extend so, **unlike the leaky dams, their storage increases over time**



Spains Hall
14th Jan 2021

Original channel

Beaver pounds

Beaver pounds

Beaver pounds

//Smart: 23/03/2021 19:27 (GMT): The beavers are currently holding back **0.522** olympic swimming pools of water.

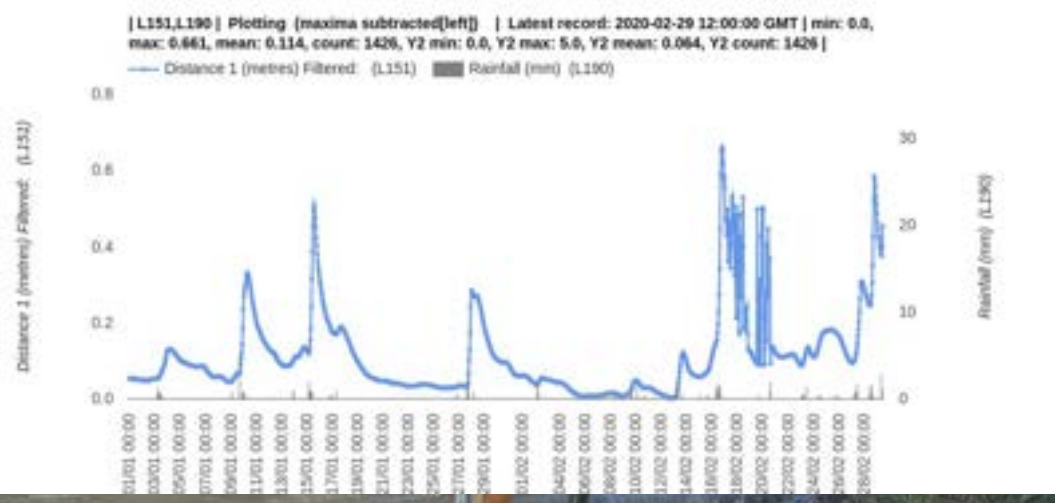
Photo: Archie Ruggles-Brise

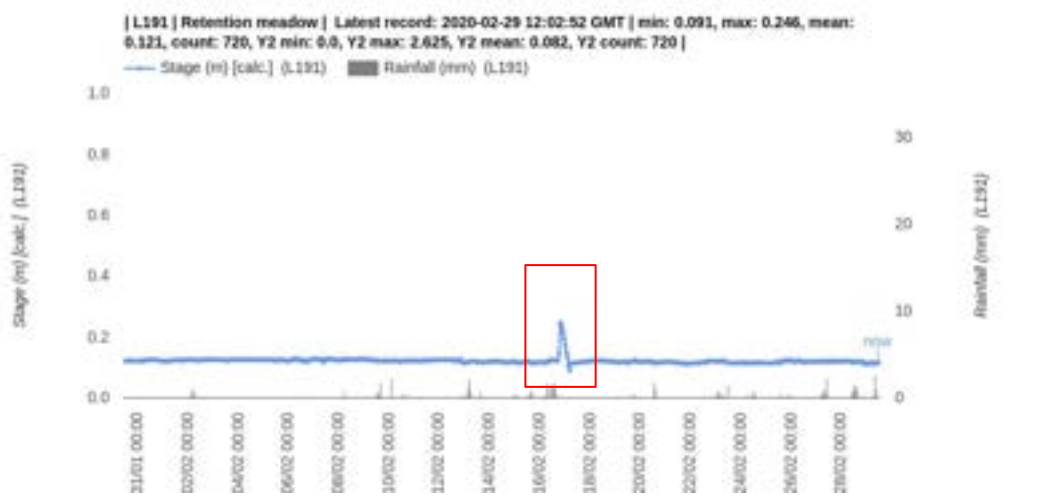
Performance of the interventions: leaky dams

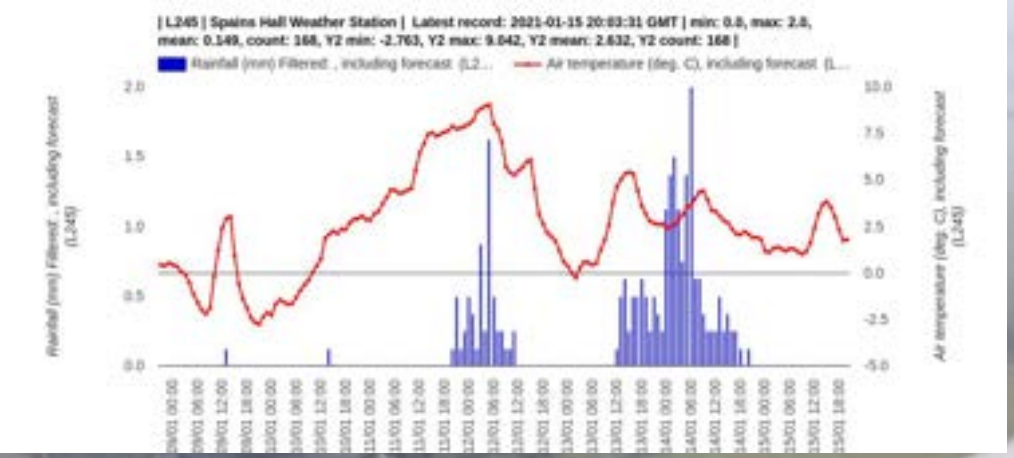
Photo: Archie Ruggles-Brise

- Leaky dams on large streams have to be very leaky, thus they **'fill' and 'drain' very quickly (top)**

- They slow the flow but do not store significant quantities of water unless they **activate a flood meadow (as here)**







Well placed leaky dams help activate floodplain

Well placed leaky dams help activate floodplain

Spains Hall
14th Jan 2021

Photo: Archie Ruggles-Brise

Challenges with point interventions

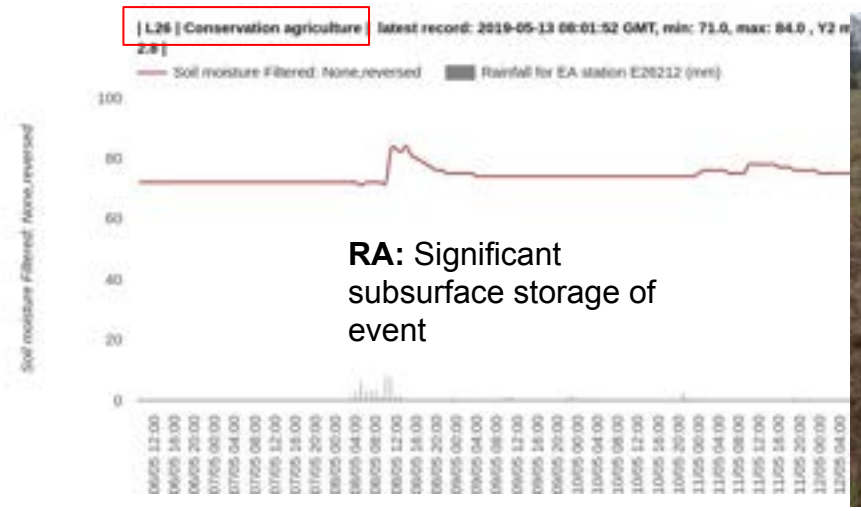
- Leaky dams and retention ponds are difficult and expensive to build
- They require maintenance, particularly after extreme events.
- They clog up with trash and become less leaky and more vulnerable to failure
- Some designs are better than others and design must be adjusted for local hydrological setting
- Scaling point interventions to be significant for larger rivers is expensive in capital and recurrent expenditure

Findings: regenerative agriculture trumps all

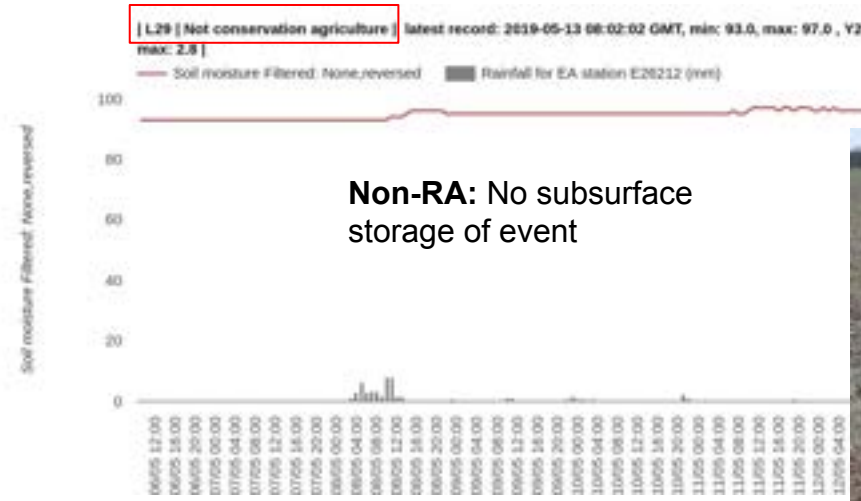
- These two fields are neighbouring on same soil, geology, climate **top under RA for ~9yr**, bottom conventional

- The **RA field clearly has much greater water infiltration during rainfall (top)** whereas the Non-RA (bottom) infiltrates little and ponds water which generates runoff

- **Over the infiltration period** 30ha of land under RA would be capable of changing flow in a river the size of the Thames at Oxford by max. **0.8%** (max. **~0.03 Mm^3**) compared with the same land under conventional tillage

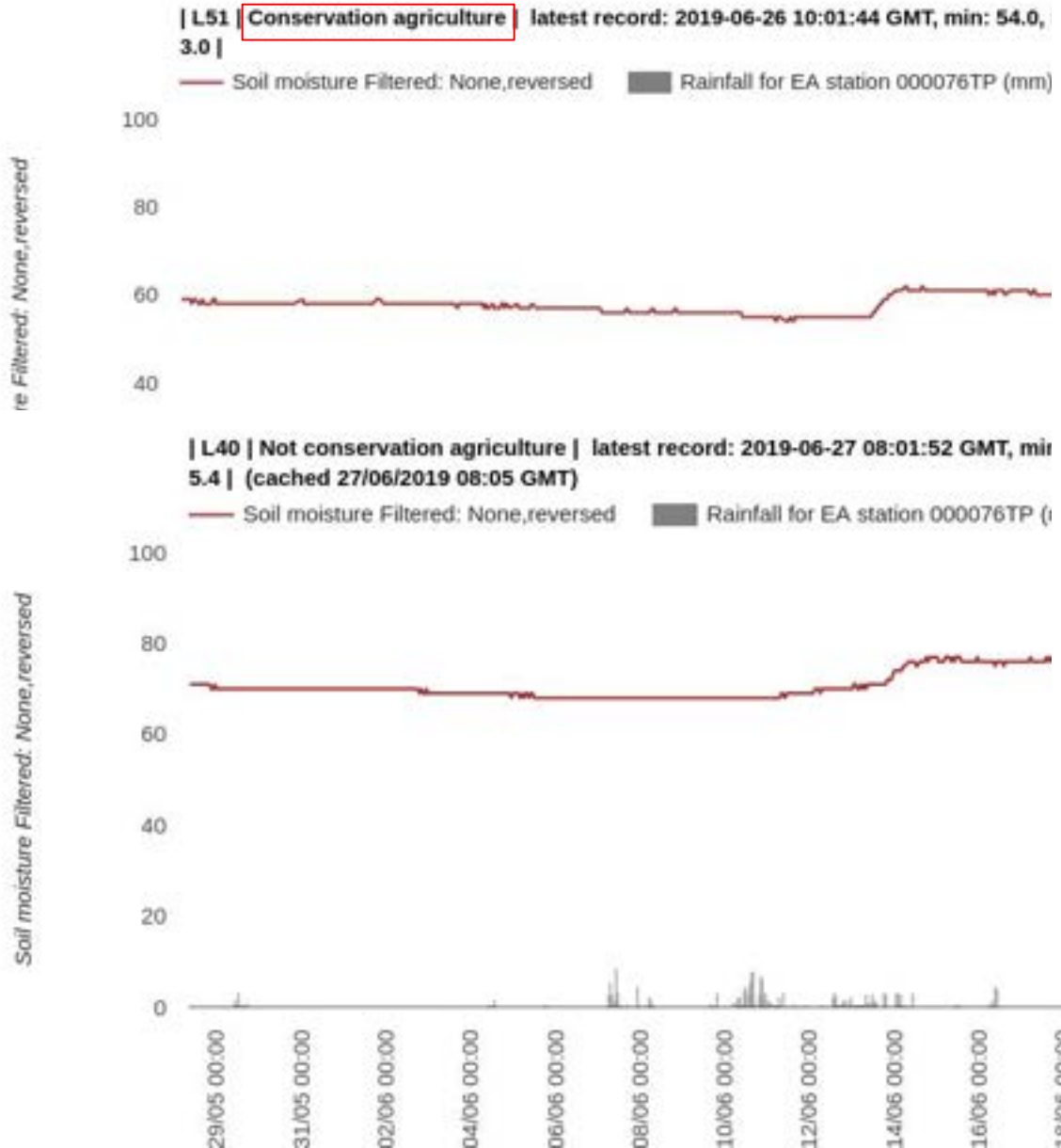


RA: Significant subsurface storage of event

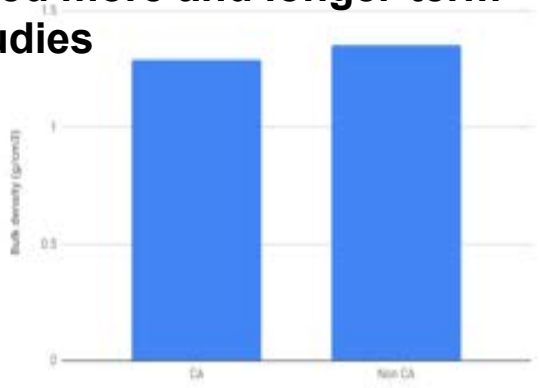


Non-RA: No subsurface storage of event

But, the RA effect is **not consistent** everywhere and takes time to build so not a silver bullet



- Bedfordshire, RA **(3 years, zero till)** vs non RA
- Behaviour of RA vs non-RA **very similar even though bulk density higher on non-RA.**
- **Soil type, rain type and age since change of management are important factors on how RA affects soil hydrology (and thus flood mitigation)**
- **Need more and longer-term studies**



Findings: monitoring is difficult and can be inconclusive

Assessing the impact of NFM is challenging

- There is often no baseline or **counterfactual** to compare with pre-NFM
- **Estimating discharge** is difficult without building flow control structures
- NFM also store **water below ground**, which needs to be measured

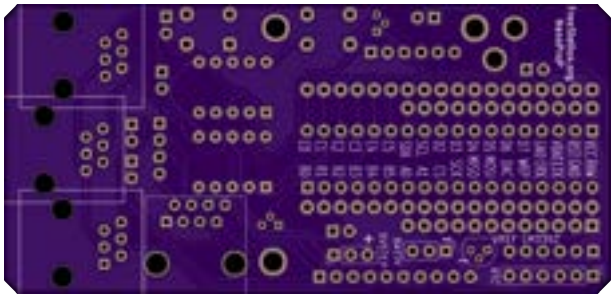
- Most of the time you are measuring flat lines. You only really get interesting data d**uring big storms** and the equipment is at risk then
- Comparing flows upstream and downstream of a network of dams is subject to the **impact of side flows**
- Comparing either side of a single dam doesn't help understand the impact of **networks of dams**
- Retention ponds (and especially Beaver dams) are **bathymetrically complex** so difficult to get accurate volumes

- Each dam in each location seems to behave differently so **extrapolation is challenging**

Setting up your own monitoring system

Components of a datalogger

Printed circuit board - links all the components together



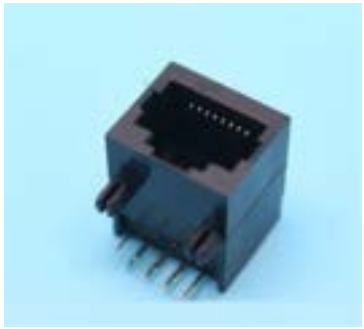
Programmable microprocessor - the brains and measurement centre

Local data storage eg SDCARD

Local battery backed up clock

Local human interface device eg screen or multi-colour LEDs

Sockets for connecting sensors



Sensors

Protective enclosure/shield

Power:

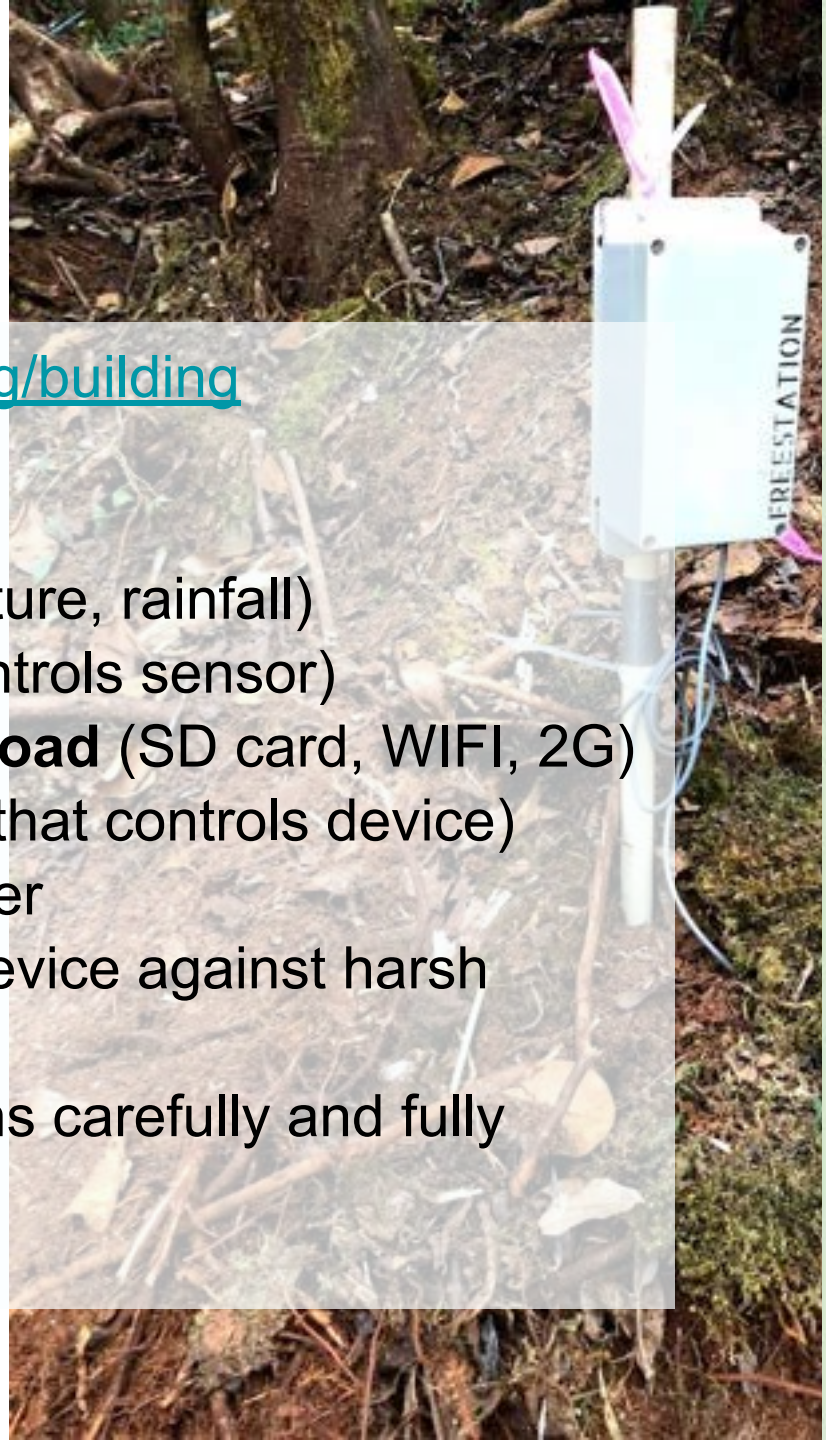
What can I build?

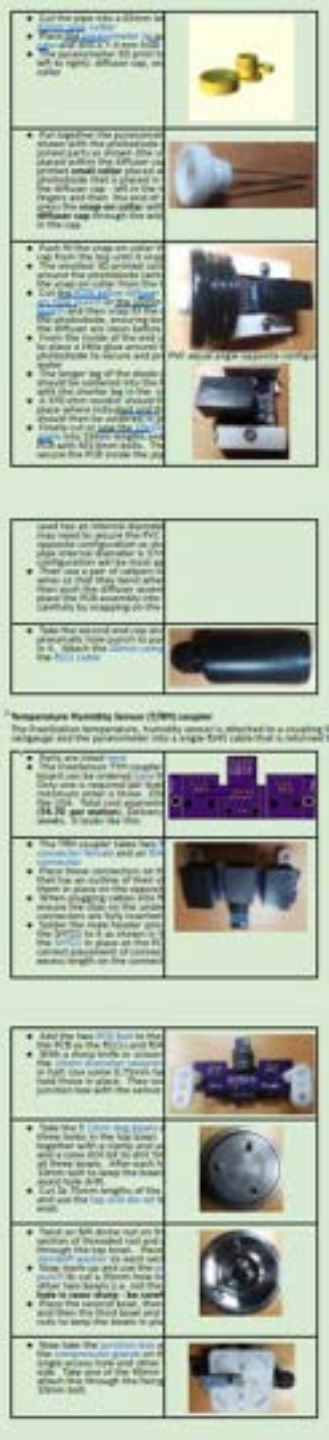
- Weather stations
  - Rain, fog, wind driven rain
  - Air temperature, humidity
  - Solar radiation
  - Photosynthetically active radiation
  - Wind speed and direction
- Soil moisture and drainage loggers
- Water quality loggers
- River stage, flow and discharge loggers
- Logging: surface temperature, weight, surface wetness, UVA, particulates, tilt, rotation, acceleration, liquid temperature, soil temperature, Visible, IR light, vibration, turbidity, GPS, noise
- Sap flow

How do I start?

- http://www.freestation.org/building

- Key parts:
  - **Sensor** (eg temperature, rainfall)
  - **Microcontroller** (controls sensor)
  - **Data storage/download** (SD card, WIFI, 2G)
  - **Firmware** (software that controls device)
  - **Batteries**, solar power
  - **Housing** (protects device against harsh environments
  - Follow the instructions carefully and fully
- Step by step





What do I need?

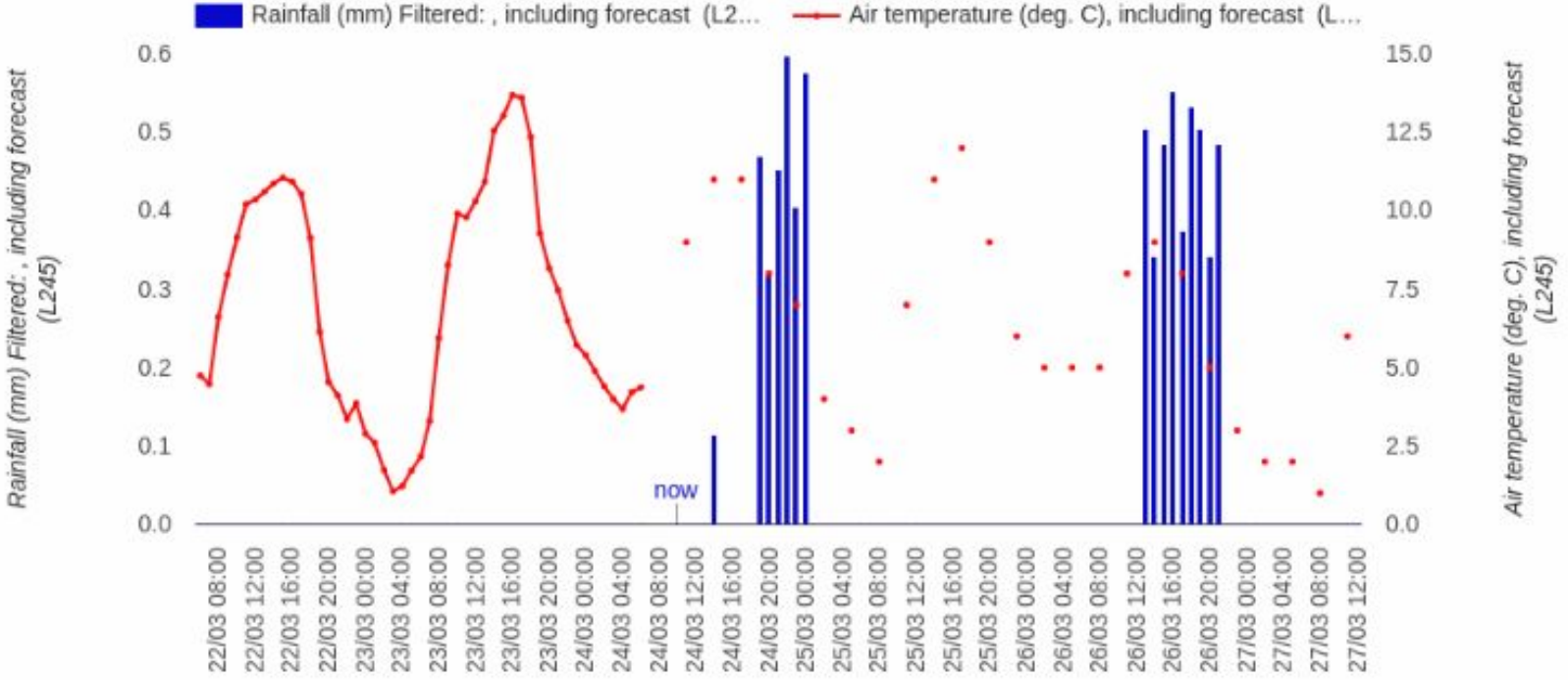
- Simple bench, workshop (or shed)
- A few tools -->
- A soldering iron
- Steady hands, safety gloves, protective glasses
- An ability to carefully follow instructions
- An ability to problem solve at home and in the field
- Recognition that if it does not work you have done something wrong or you have a faulty part. There is no magic in electronics and there will be a reason if it does not work.
- Time to fully test what you have built

The FreeStation //Smart: system

//Smart: [L245], deployed: 31/12/2019 16:00:00, last reset: 31/12/2019 16:00:00. Gen. 2 (Particle). Live station. AWS, Spains Hall **Status:** Deployed

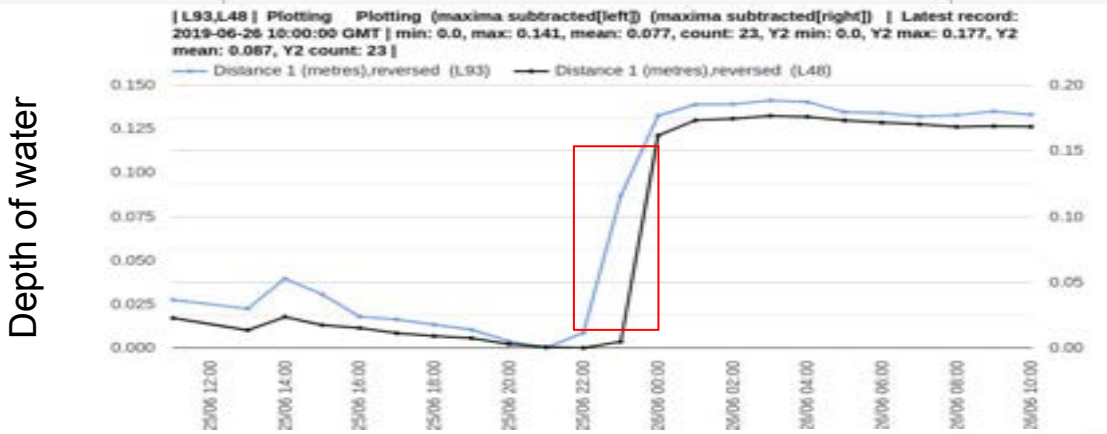
< 2021 Hour, Day, Week, Month, Year, ≤ ≥ | ±	**Download:** View, All **Tools:** Display Manage Config, Analyses (Refresh)	**Options:** Fixed range, No calibrate, No-filter, No-remove, Scatter	**Info:** RE:117, D:0, M:31%, R:0%, F:0%, B:75%	Rainfall (mm) LX /RY	Wind speed (m/s) LX/RY	Wind direction (deg. from N) LX/RY	Air temperature (deg. C) LX/ RY	Humidity (%) LX/RY	Pressure (mb) LX/RY	Solar radiation (W/m^2) LX/RY	Battery status (%) LX/RY	

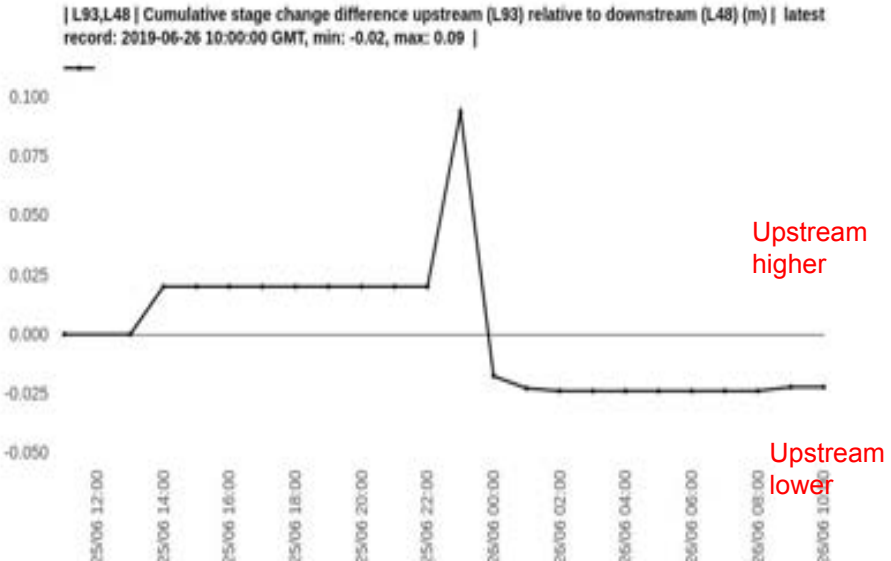
| L245 | Spains Hall Weather Station | Latest record: 2021-03-27 12:00:00 GMT | min: 0.0, max: 0.599, mean: 0.057, count: 124, Y2 min: 1.0, Y2 max: 13.691, Y2 mean: 6.796, Y2 count: 74 |



Analysis with the //Smart: system. *Leaky dams.*

Variable	Explanation	Calculate
Difference in stage change either side of dam	Examine difference in stage change either side of leaky dam at this upstream sensor	Include drainage? (Y/N): N; L# of downstream FreeStation: L48; Type these colours ■&■ eg red&green, to indicate you are not a robot; Submit





The rate of change in stage is higher upstream (positive values) during the rising limb event and approximately equal before and after

Useful for understanding dam function

Analysis with the //Smart: system. *Inline storage.*

		Include drainage (Y/N):	Area of water body (m^2):	L# of FreeStation measuring flow at asset at risk:	..or max. downstream peak flow (cumecs):
Mitigation of flood peak by inline storage intervention	Calculate mitigation of flood risk by inline storage intervention at this sensor. Can be calculated as a volume or percentage of flow (with downstream flow volume data)	N	2500	-	1.0

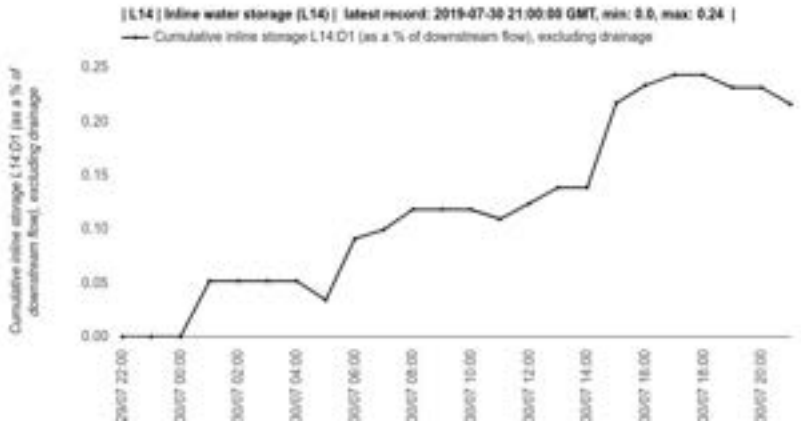
Type these colours & eg red&green, to indicate you are not a robot

Submit

Prior to the event the pond holds water equivalent to 0.05% of the river flow

During the event this rises to 0.25%

Useful for understanding significance of NFM



Analysis with the //Smart: system. *Regenerative ag.*

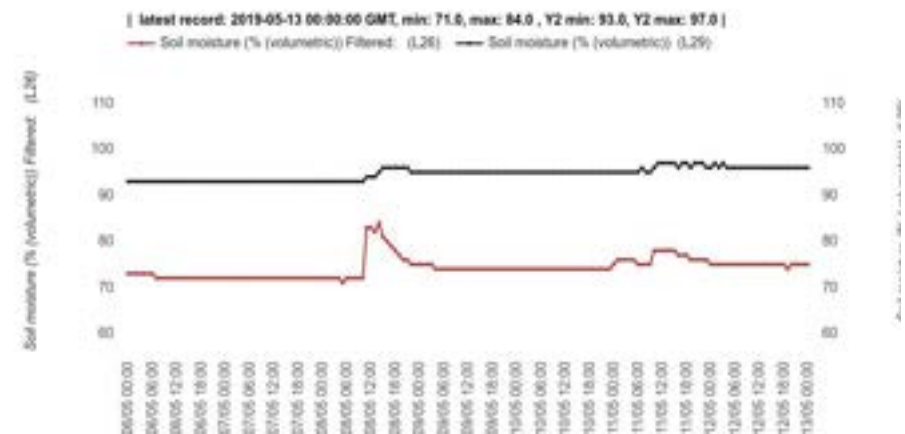
Variable	Explanation	Calculate
Mitigation of flood risk by this soil management intervention	Calculate mitigation of flood risk by the soil management intervention at this sensor, compared with a counterfactual under different management. Can be calculated as a volume or percentage of flow (with downstream flow volume data)	//Smart:Soil

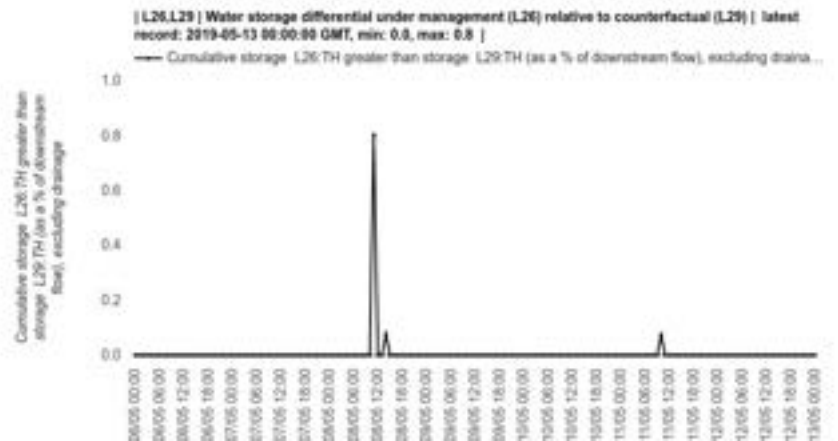
Include drainage? (Y/N):	Area of CA land (ha.):	Depth to sensor (m):	L# of counterfactual FreeStation:	L# of FreeStation measuring flow at asset at risk:	..or max. downstream peak flow (cumecs):	Cumulate? (Y/N):
N	30	1	L29	-	17.6	N

Type these colours & eg red&green, to indicate you are not a robot

Submit

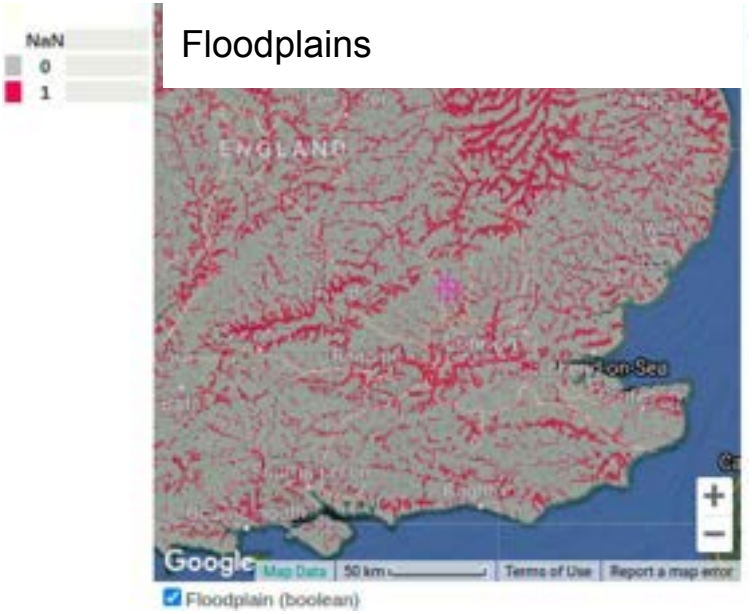
30ha of land under CA would be capable of changing flow in a river the size of the Thames at Oxford by max. 0.8% (during the peak of infiltration) over this period compared with the same land under conventional tillage.**Useful for understanding significance of NFM**



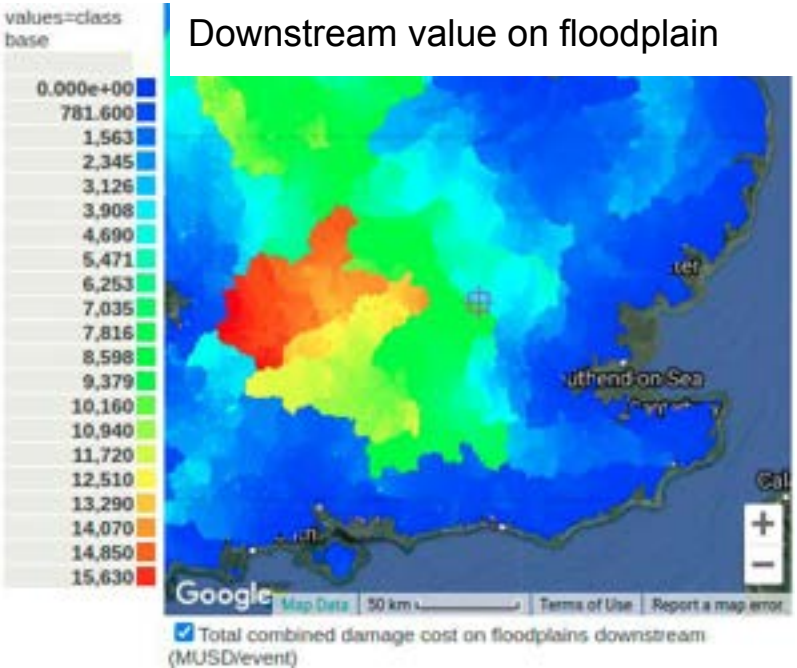


Scaling up with Eco:Actuary, shows where interventions are most important

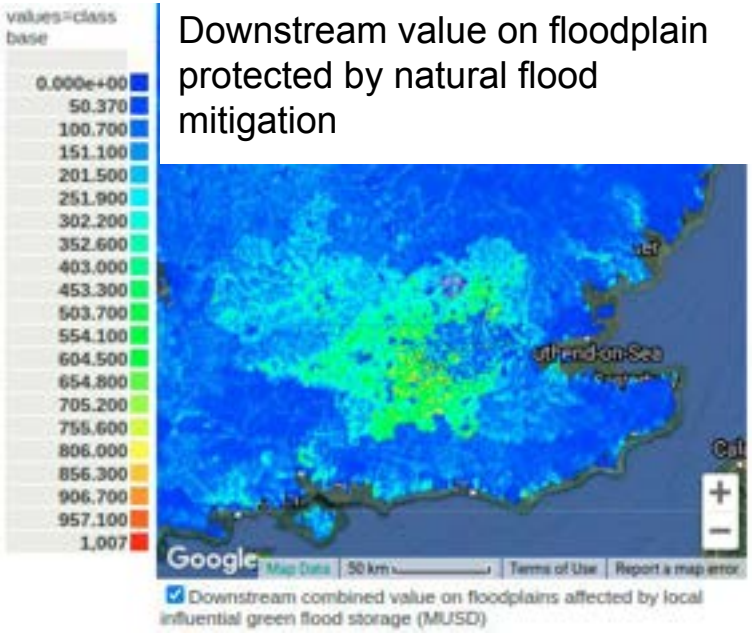
- Eco:Actuary is a **catastrophe** model of the type used by insurers to assess risk and calculate premiums
- It differs in that it also calculates the **risk mitigation value of upstream land and its management** in terms of downstream damage **losses avoided**
- Some areas are much more valuable than others: these are areas in which much damage loss could be avoided by **preventative investment** in land management rather than post-event compensation for damage losses (insurance)



Floodplains



Downstream value on floodplain



Downstream value on floodplain protected by natural flood mitigation

Conclusions

- Different types of NFM have different impacts that depend on their design and local context

- Point NFM will have to be commonplace to have a meaningful impact on significant rivers and streams

- Areal NFM, like good soil management, scale much more readily

- Low cost, DIY sensing can help measure
  - Water volume differences upstream and downstream of dams
  - Water volume stored in retention ponds
  - Water volume stored in well managed soils

..directly or as a proportion of water volume at the asset at risk.

- It is not without challenges but is low financial risk and replication begets resilience

RGS-IBG FreeStation #fieldwork course in #ThamesEstuary 26th May

- Learn about the Estuary and Estuarine environments
- See and use a whole lot more FreeStation instruments and sensors
- Have us check and troubleshoot your build and provide further advice to get you started
- Subject to COVID-19 regulations
- https://www.rgs.org/events/spring-2021/low-cost-diy-field-sensors-online/

- We'll also hold **free** courses as part of H2020 ReSET project (www.policysupport.org/reset)
- Also looking for extra sites as part of ReSET project
- **Follow @markmulligan for news on courses**