Temporal and spatial variations in soil structure and hydrology affect flood mitigation effectiveness of nature-based solutions

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Hydro Nation Scholars Programme

Scottish Funding Council
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1. Introduction

Temporary Storage Areas (TSAs) are nature-based solutions that store surface runoff during storms to mitigate flooding and soil erosion.

However, inundation can degrade soil structure and infiltration rates (Fig. 1), potentially reducing their effectiveness following each flood event.

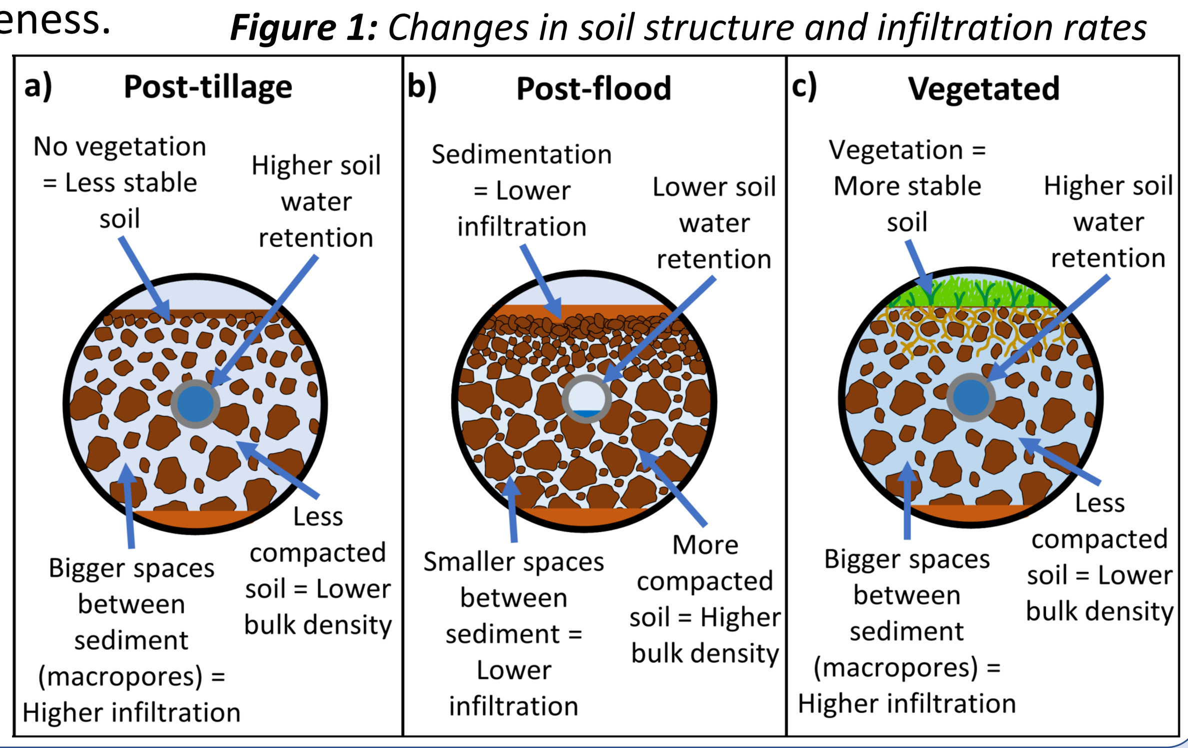
Study Aim: Investigate the impact of flooding and land management on TSA soil structure, hydrology, and flood prevention effectiveness.

TSA following Storm Babet (Oct23)

Objectives:

1. Identify changes in soil properties over time and space within TSA areas.
2. Investigate the temporal dynamics of TSAs and their impact on soil properties.
3. Discuss ways to improve TSA performance through management strategies.

Figure 1: *Changes in soil structure and infiltration rates*



2. Study sites

We explored spatial and temporal changes in soil properties at two agricultural TSAs in NE Scotland, Tarland and Invergowrie (Fig. 2 & Table 2).

Table 2: *Study site summary table.*

	Tarland	Invergowrie
TSA type	Bund	Bund
Storage (m³)	~200	~250
Land use	Winter wheat	Spring barley & Blackcurrants
Soil type	**World Reference Base:** Cambisols **Texture:** Sandy loam to sandy clay **Drainage:** Free	
Observational period	Sep 2021 – Feb 2023	Aug 2021 – May 2023

Figure 2: *Tarland and Invergowrie, NE Scotland.*

3. Methods

Intact soil cores were collected over ~2 years from three spatial zones representing different inundation levels and land management practices and at two depths (Fig. 3).

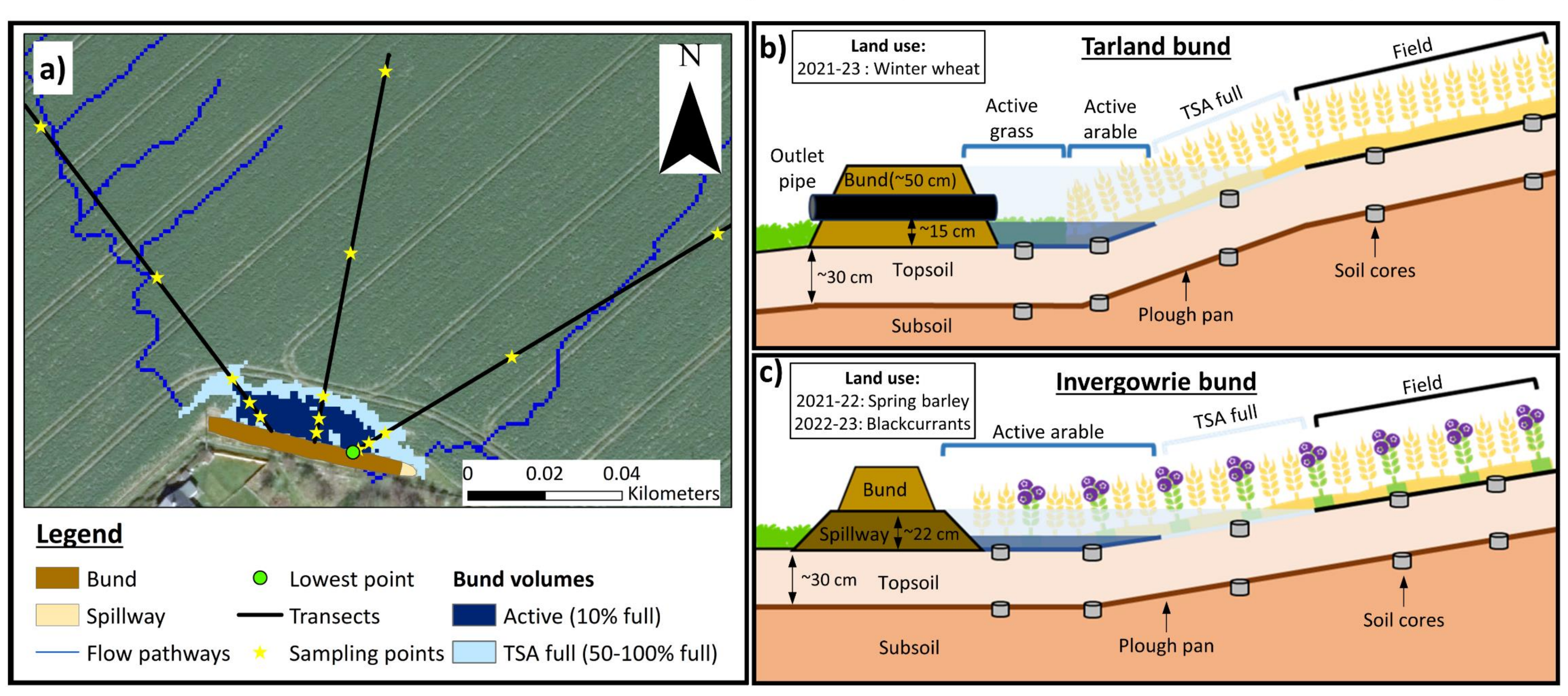


Figure 3: *Field sampling design. a) Spatial zones within the TSA footprint and contributing area (aerial imagery © Getmapping plc), b) Tarland bund schematic, c) Invergowrie bund schematic.*

Soil cores were analysed for: **Bulk density** (soil compactness), **Macroporosity** (large pore volume), and **Saturated hydraulic conductivity** (the rate water flows through a fully wet soil).

4. Results

Degraded soil structure = Higher bulk density (high compaction) | Lower macroporosity | Lower saturated hydraulic conductivity → **Lower soil infiltration**

Enhanced soil structure = Lower bulk density (low compaction) | Higher macroporosity | Higher saturated hydraulic conductivity → **Higher soil infiltration**

Key findings:

- We found topsoil structure and hydrology changed in both space and time at both sites.
- Significant differences in time occurred post-flooding and post-tillage.
- Flooded soils within the TSA footprint were more degraded than non-flooded field soils.
- Fully vegetated grass soils within the TSA footprint were more resilient to flooding.

4. Results

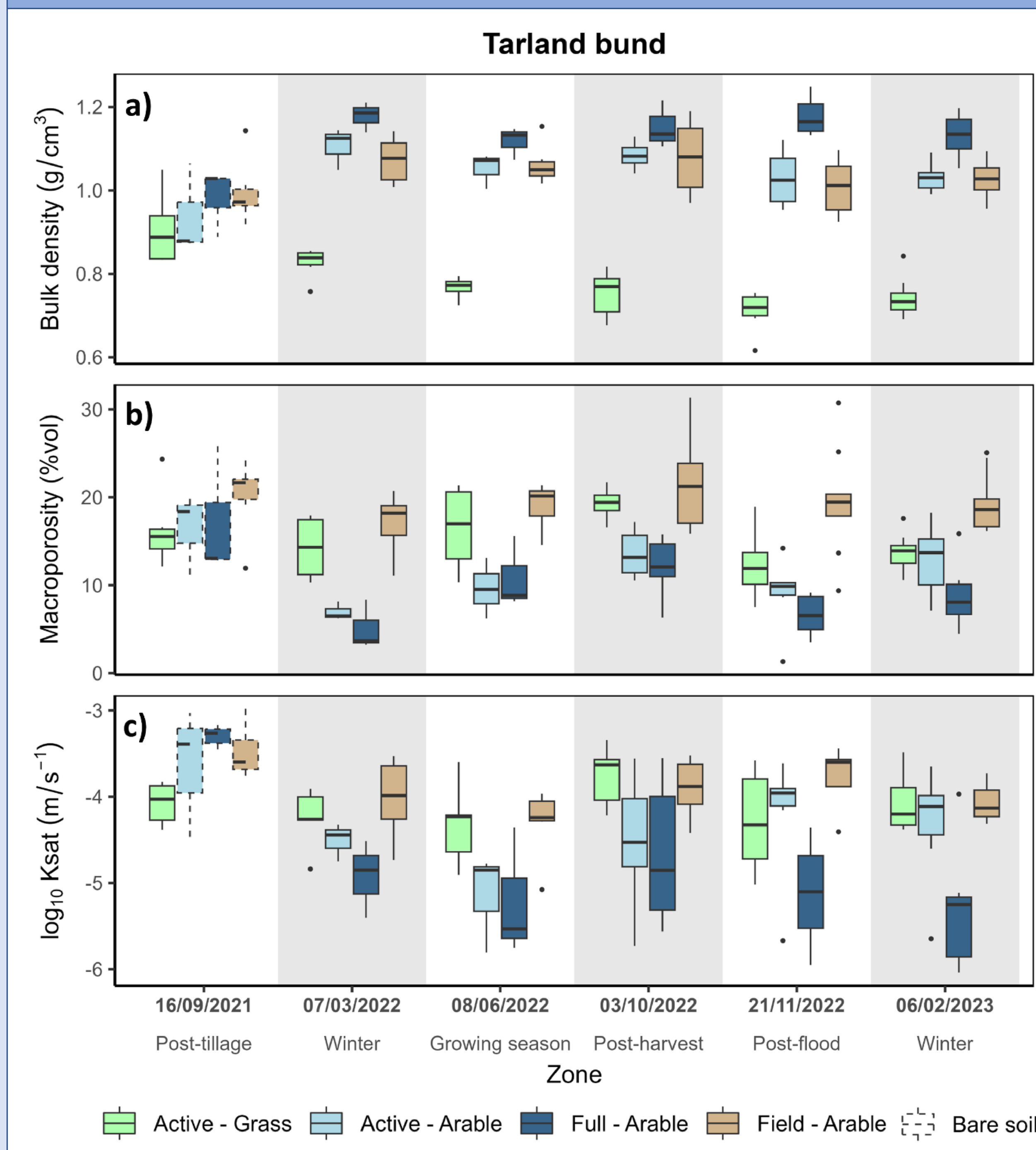


Figure 4: *Tarland bund topsoil (0-10 cm) spatial and temporal boxplots. a) Bulk density, b) Macroporosity and c) Saturated hydraulic conductivity (Ksat). Dashed boxplots represent zones that had bare soil following tillage.*

Figure 4 highlights:

- **Tillage resets soil structure:** No spatial variability in Sep 2021.
- **Soil degradation following inundation:** arable soils within the TSA footprint are most affected (blue boxplots in Mar 22).
- **Vegetated soils more resilient to flooding:** Less variability for fully vegetated grass soils within the TSA footprint (green boxplots).

Figure 5 highlights:

- **No spatial variability during 1st year:** No flood events occurred during this time.
- **Post-flood 22:** Spatial variability between the blackcurrants (2) freshly tilled field and inundated TSA soils.
- **May 23:** Spatial variability despite secondary tillage. Most likely due to increased sedimentation following erosion in Nov 23.

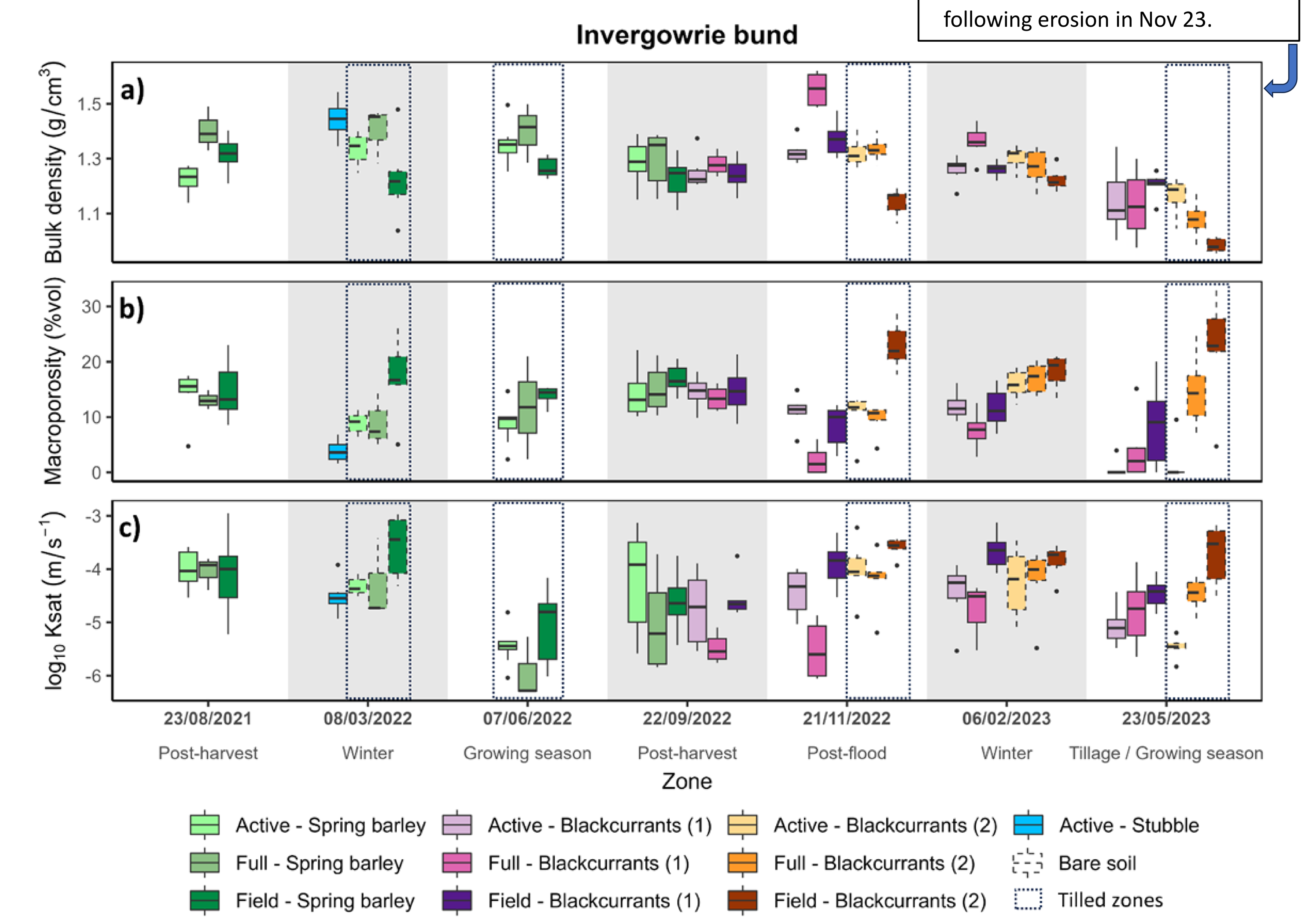


Figure 5: *Invergowrie bund topsoil (0-10 cm) spatial and temporal boxplots. a) Bulk density, b) Macroporosity and c) Saturated hydraulic conductivity (Ksat). Blackcurrants (1) were planted in spring 2022 (grass margin). Blackcurrants (2) were planted in autumn 2022 (bare soil).*

5. Summary

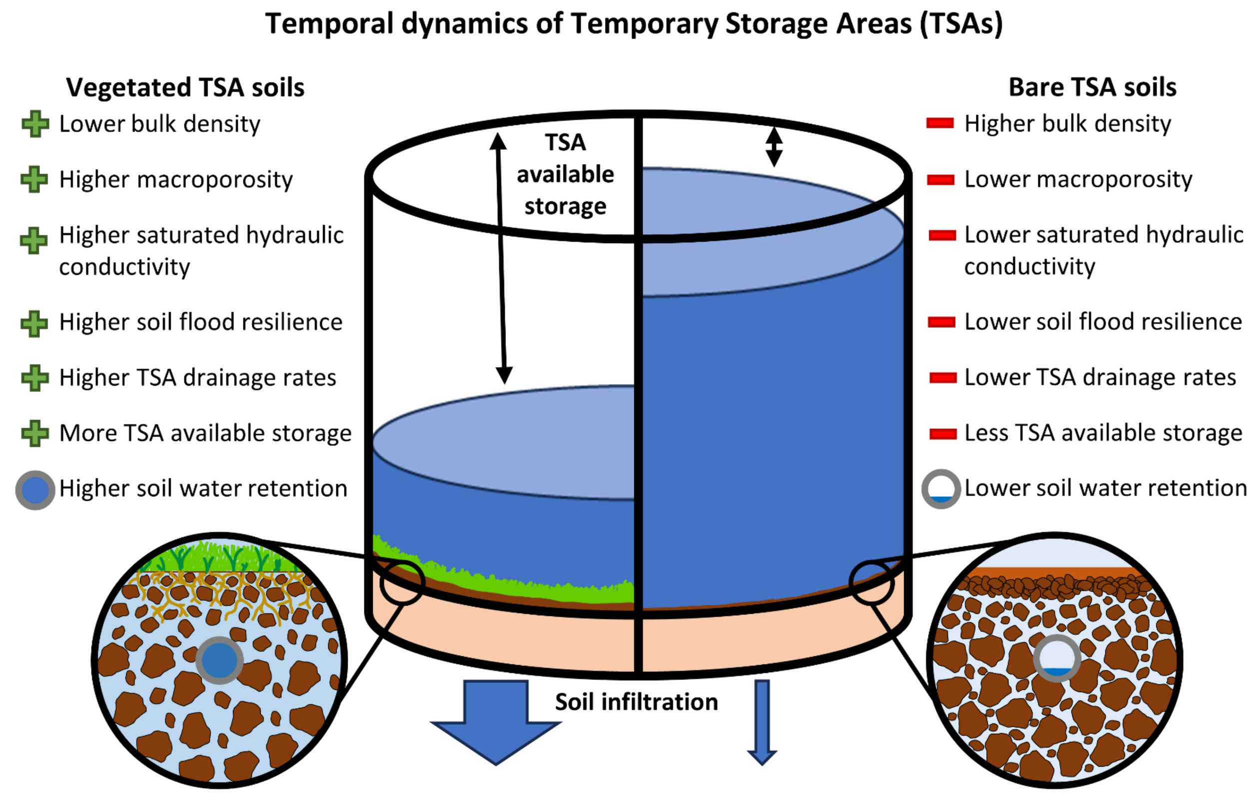


Figure 6: *Temporal dynamics of TSAs and the importance of soil structure and hydrology for TSA flood mitigation effectiveness*

- Soil infiltration rates affect the TSA volume and available storage required for attenuating surface runoff (Fig. 6).
- TSA effectiveness may decrease following flooding due to effect of inundation on soils.
- High vegetation cover within the TSA footprint during ponding months is a viable management strategy to improve soil infiltration rates and the resilience to flooding.
- Future work could model the relative importance of temporal changes in soil physical properties for TSA functioning and effectiveness.

Acknowledgements: This research was supported by The Hydro Nation Scholars Programme funded by the Scottish Government through the Scottish Funding Council and managed by the Hydro Nation International Centre and the Rural and Environment Science and Analytical Services Division (project JHI-D2-2)