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Flood mechanisms and groundwater recharge following 2023 monsoon floods

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British
Geological
Survey

Background



- In July 2023 Himachal Pradesh experienced extreme monsoon flooding.
- On 9th July rainfall was c. 400% higher than long-term daily monsoon averages.
- Flooding in HP in July caused widespread damage to infrastructure and loss of life.
- Localised flooding also occurred in some areas of Punjab.
- The initial event in July 2023 was followed by another flooding event on 14th August, causing further disruption in both states.

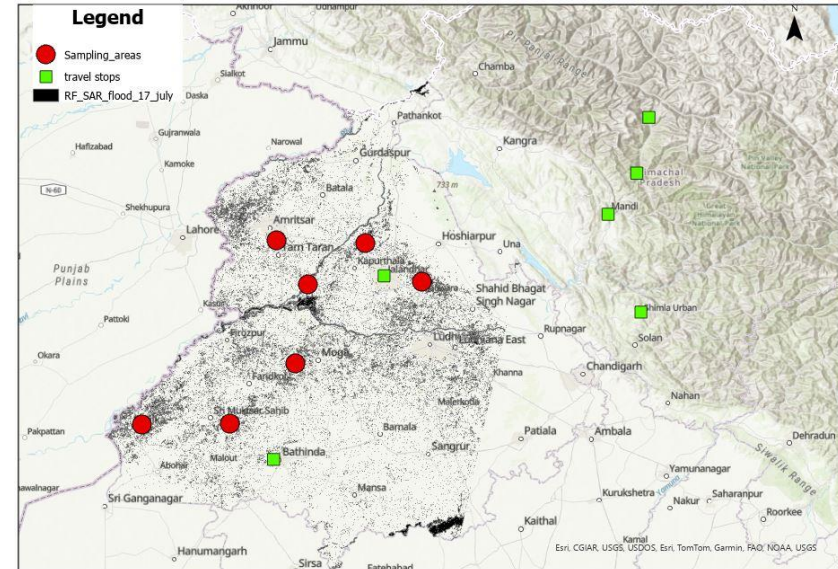
Aim

- To constrain the scale of the extreme floods in HP and Punjab in July and August 2023 and assess their cumulative impact, focusing on groundwater recharge and contamination, during the 2023 monsoon.



Objectives

- Investigate flood characteristics, processes, mechanisms and cumulative effects in the mountains and plains.
- Quantify the impacts of floods on groundwater levels and recharge in Punjab and relate this to upstream and downstream flood characteristics.
- Quantify flood impacts on water quality by collating baseline data and conducting new groundwater quality sampling and analysis.



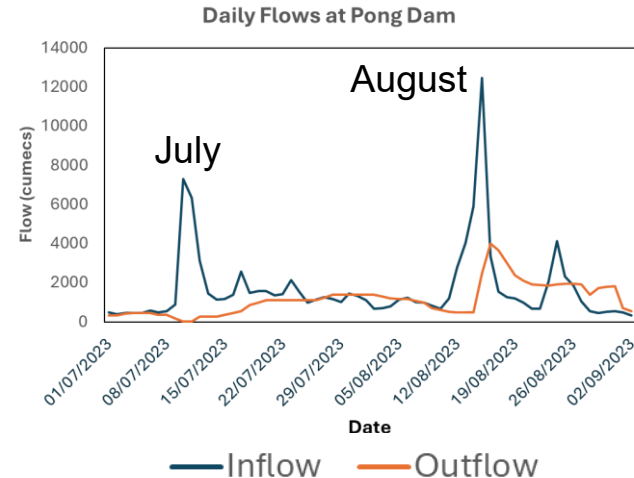
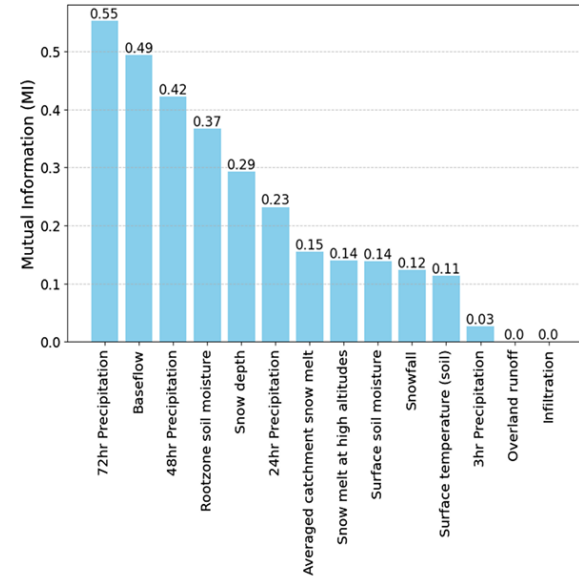
Stakeholder engagement

- March 2024: Workshop in Shimla attended by project team. Overview of project aims and objectives presented.
- March 2024: Workshop in Punjab attended by project team. Overview of project aims and objectives presented.
- July 2024: Additional workshop in Punjab specifically presenting the aims and objectives to a more focussed group of stakeholders.
- Final workshop Chandigarh March 2025.



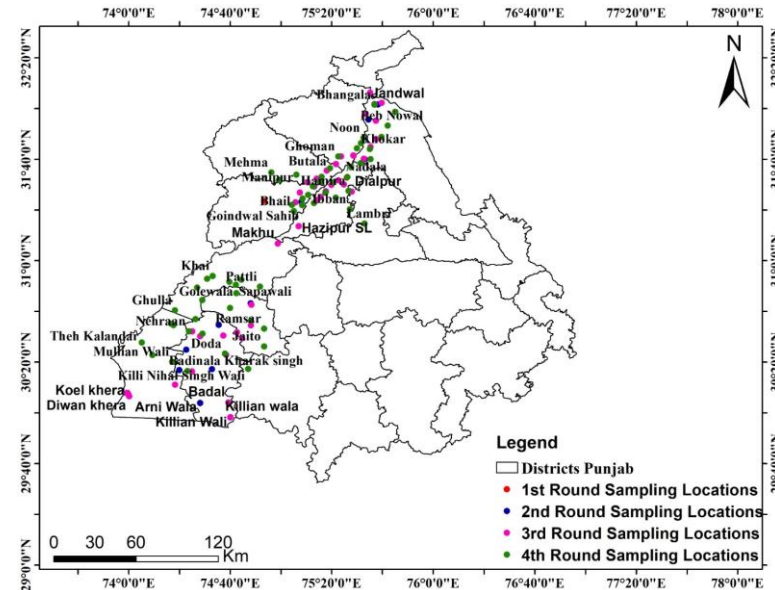
Hydrometeorological analysis

- Precipitation anomalies of 268.7 mm (9 July) and 248 mm (10 July) in HP and Punjab exceeded the 1981–2010 climatological mean for July–August.
- Total monsoon precipitation did not deviate significantly from long-term averages.
- Rain-on-snow, elevated soil moisture leading to reduced infiltration capacity, increased surface runoff and higher inflows were drivers of the floods in July & August 2023.
- Dams played a vital role in regulating the movement of water, protecting downstream communities but limiting the likelihood of increased groundwater recharge.



Groundwater data collection

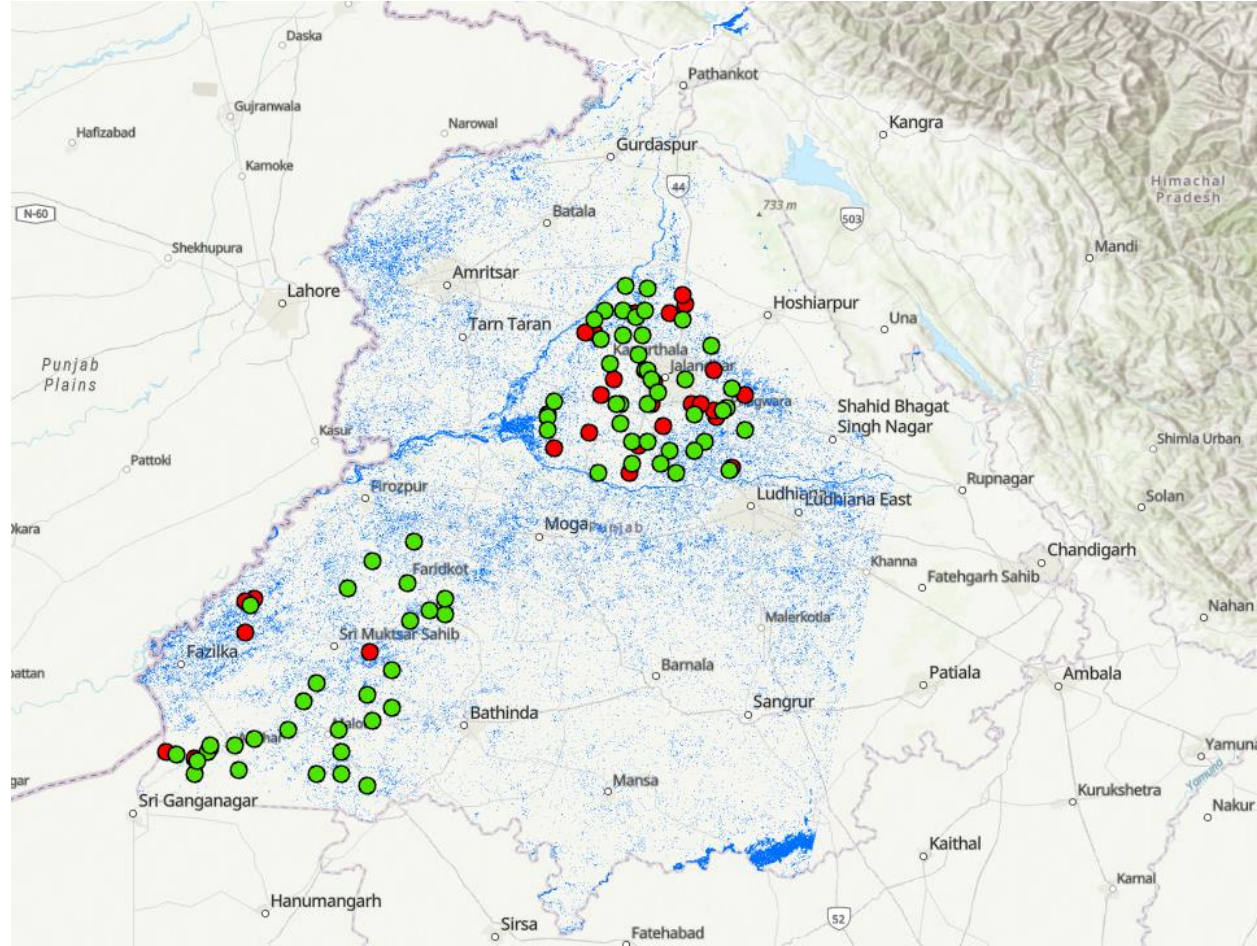
- Groundwater level data:
 - Water resource department (WRD), 130 sites, telemetered 15-minute sampling, 2023-2024
 - CGWB, 169 sites, manual four times per year, 2013-2024
- Environmental tracers:
 - Stable isotopes – 144 Punjab + 42 HP
 - Natural tracers (CFC, SF6, tritium) – 55 Punjab
 - Fluorescence – 77 Punjab + 42 HP
- Water chemistry samples:
 - Major ions – 146 Punjab + 42 HP
 - Trace metals – 46 Punjab + 6 HP
 - Pesticides/fungicides – 77 Punjab



Groundwater level (GWL) responses to flood events

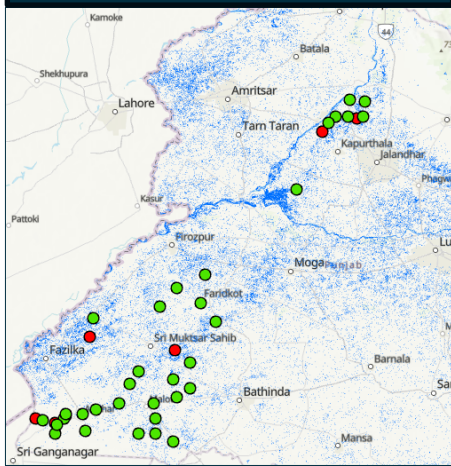
Blue areas – extend of
flooding on 17th July,
2023

- no response in GWL
- response in GWL



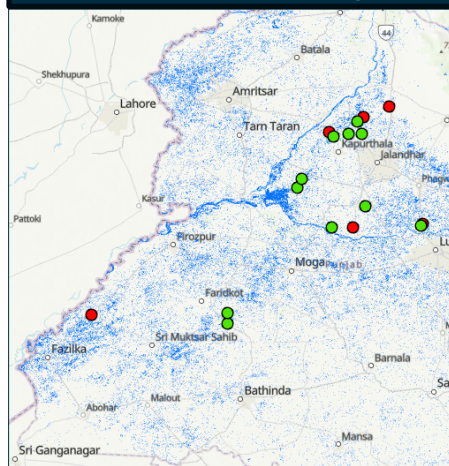
GWL response by depth to groundwater

GWL 0-10 m bgl



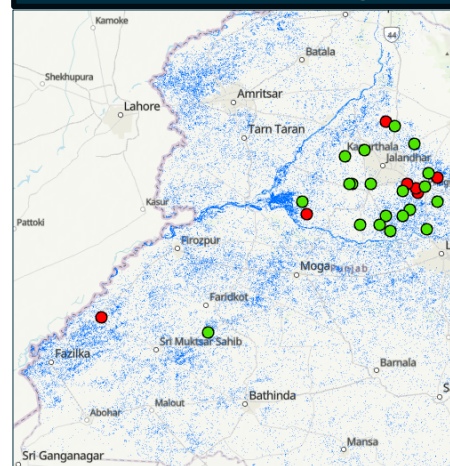
88% GWL response

GWL 10-20 m bgl



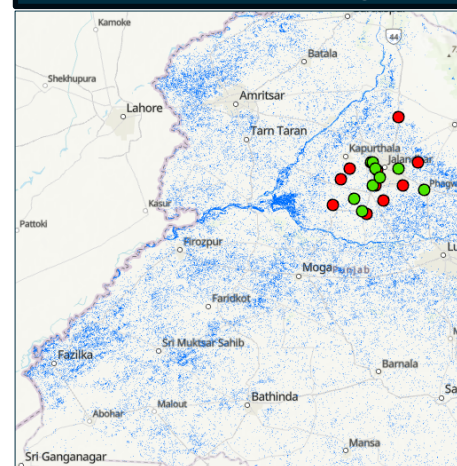
67% GWL response

GWL 20-30 m bgl



68% GWL response

GWL 30-40 m bgl



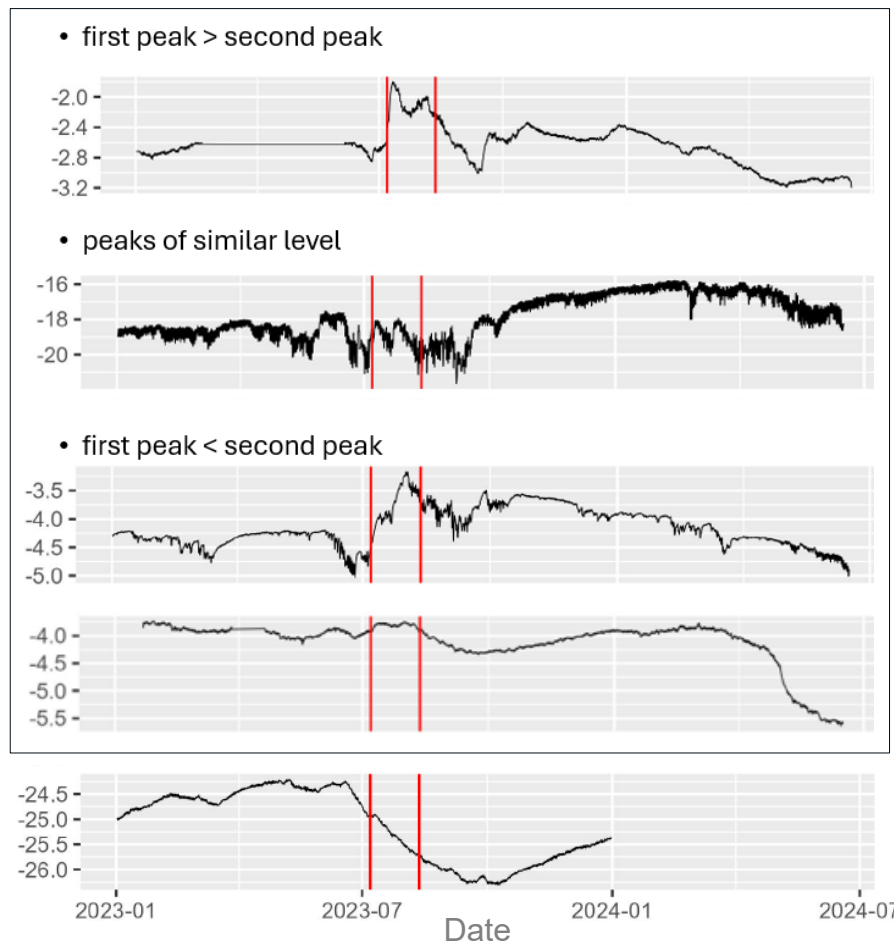
37% GWL response

GWL responses to flood events

Effect from flooding observed – 69% →

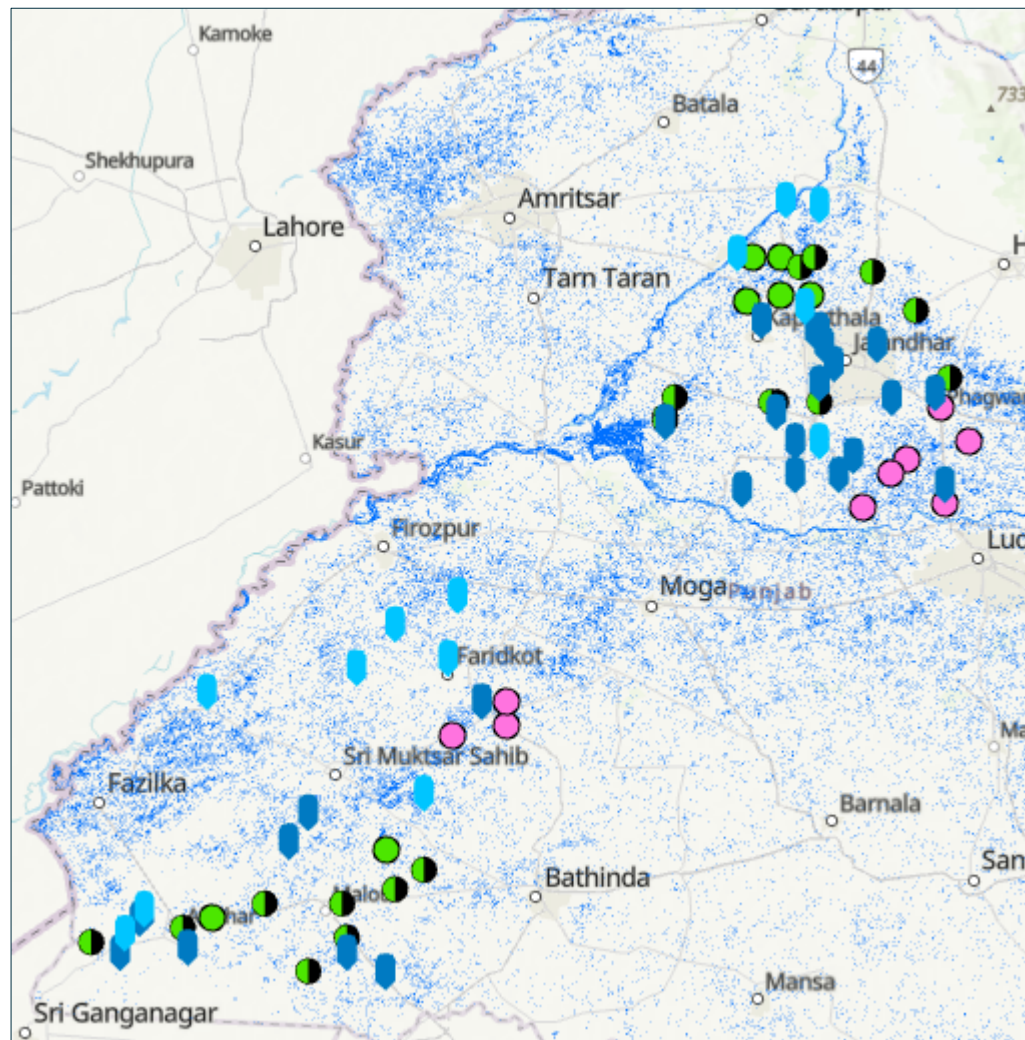
- bimodal peak
 - first peak > second peak – 36%
 - peaks of similar level – 25 %
 - first peak < second peak – 18%
- unimodal peak (and other) – 21%

No recharge until later in the year – 31%
(onset of recharge ~October) →

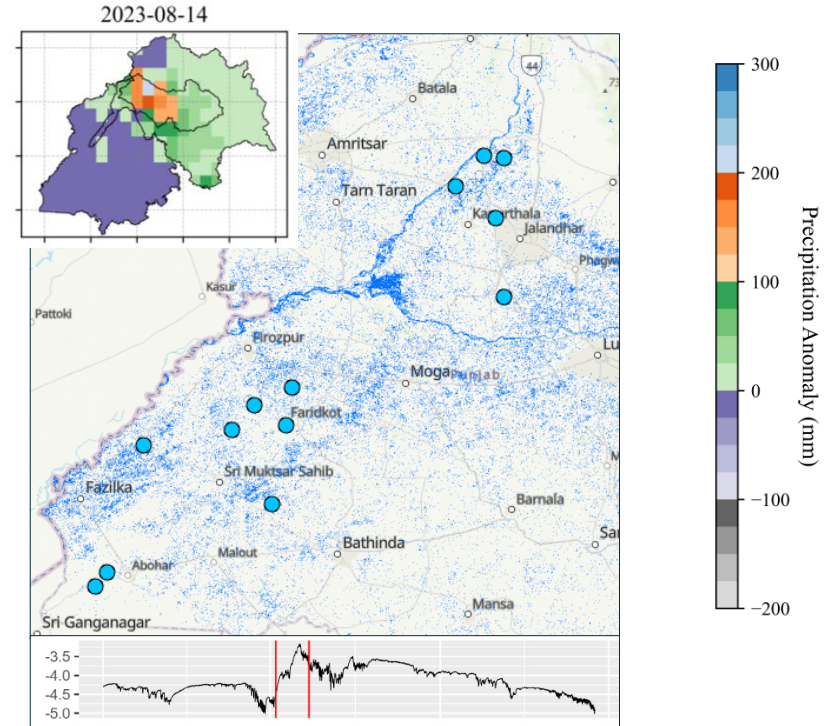
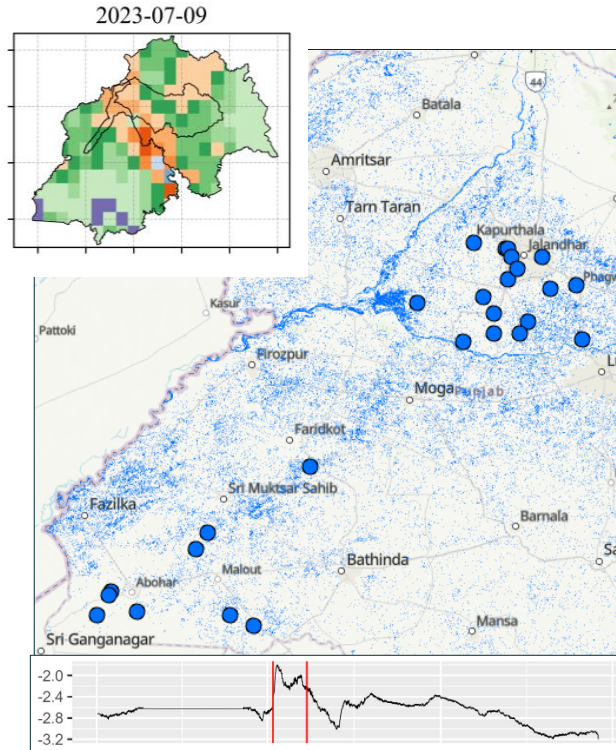


GWL responses to flood events: response type

	Type of response	% (of all affected)
	one broad peak	11%
	two peaks (similar size)	30%
	two peaks, 1 st > 2 nd	32%
	two peaks, 1 st < 2 nd	16%
	other type of rise	10%

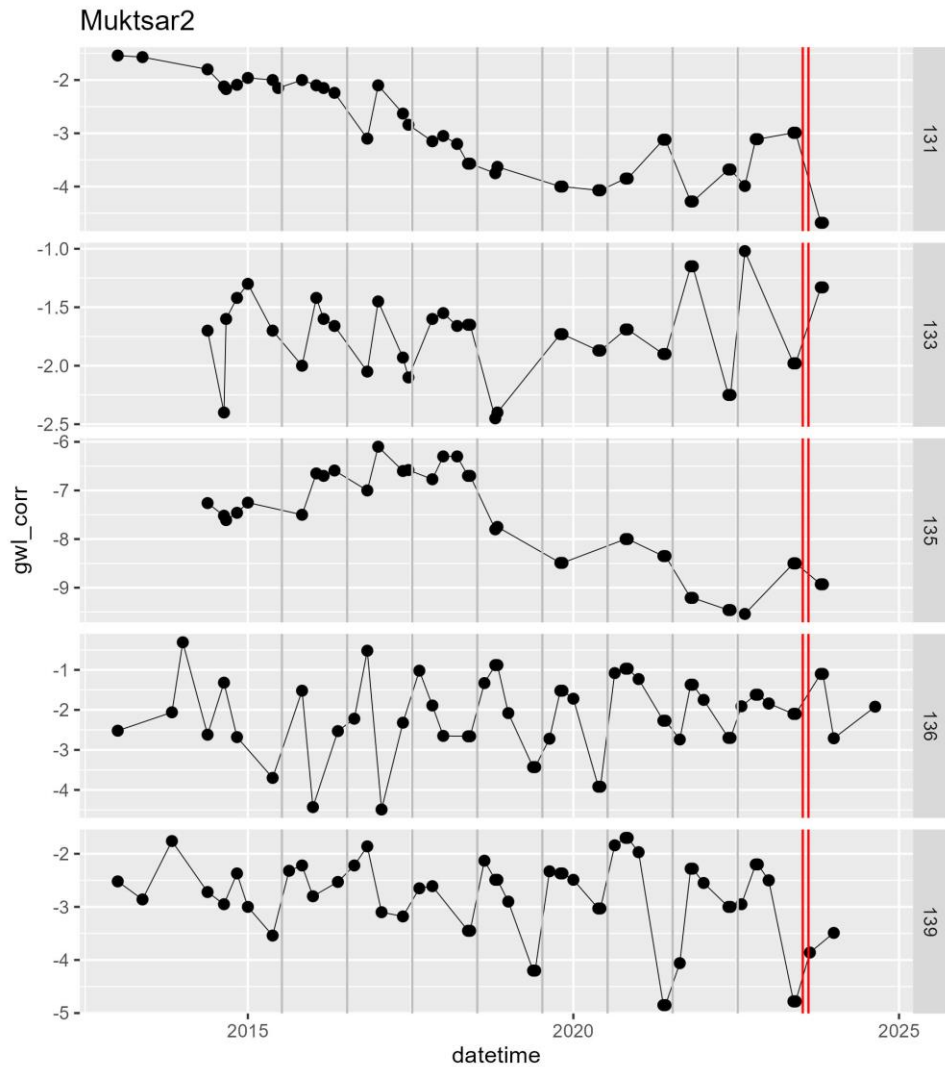


Distribution of GWL responses



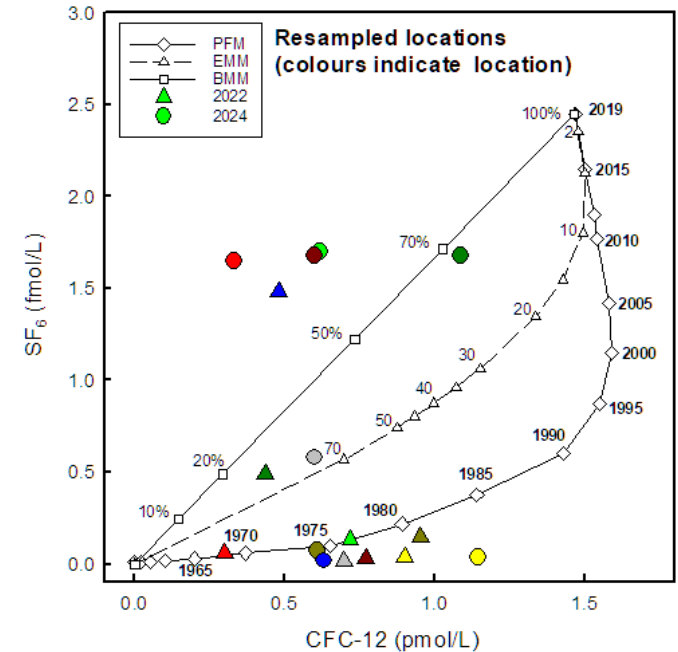
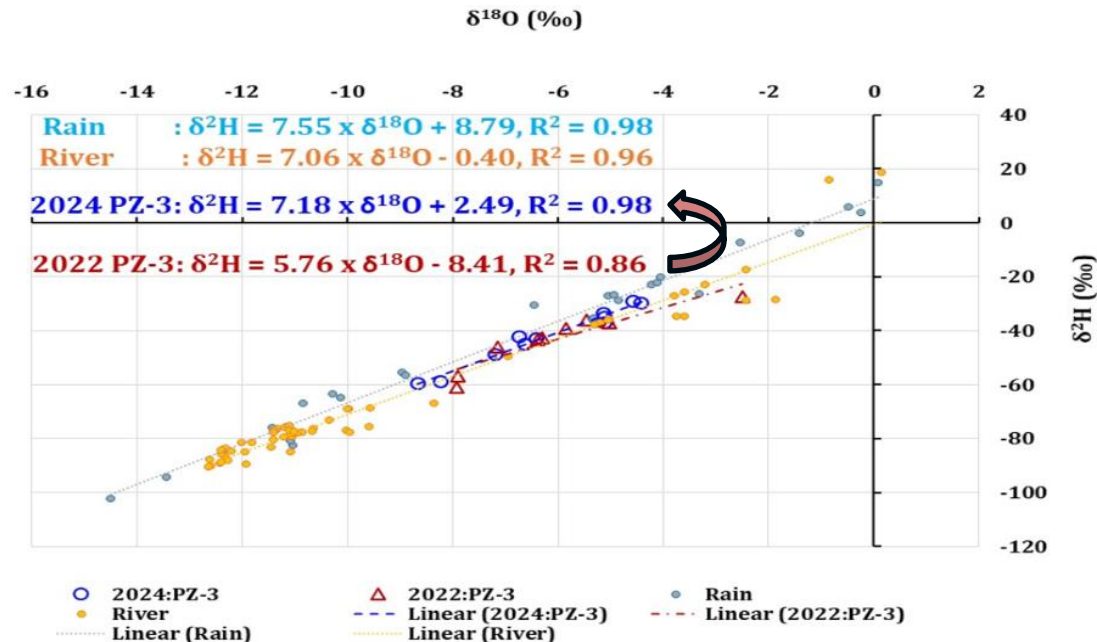
Long-term groundwater levels

- There does not appear to be a significant impact of the flooding or precipitation anomalies on long-term groundwater level trends.
- Total precipitation did not deviate significantly from long-term averages => cumulative rainfall maybe more important for groundwater level recharge than extremes.



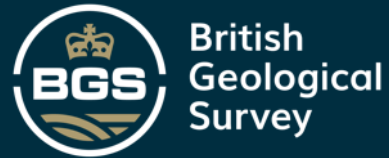
Isotope and age tracers

- Isotopes hint at influence of river and rain in groundwater in 2024 compared to 2022.
- Estimated ages in **2022: 1969-1984**. Estimated ages in **2024: 1969-2011**.
- Change in mode of groundwater recharge from piston to mixing, explained by flooding.



Conclusions

- Extreme precipitation, rain-on snow, high soil moisture => reduced infiltration capacity, increased surface runoff and higher inflows were key drivers of the flooding that occurred in HP in July and August 2024.
- Dams played a critical role in regulating flow and preventing severe flooding downstream. This also limited potential for flood groundwater recharge.
- Groundwater levels displayed short term response to both flooding events:
 - Response to the flooding was most common where groundwater levels were shallow.
 - GWLs displayed distinct responses to flooding (bi-modal peaks, unimodal peak).
 - A spatial pattern of distinct GWL responses was identified relating to the primary recharge source during the flooding (e.g. rainfall vs river flooding).
 - **Cumulative monsoon rainfall may be more important for recharge than individual rainfall events.**
- Isotope samples show a clear influence of rainfall and river water compared to pre-flood samples. Age tracer data also indicates influence of flooding.



Questions?



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