IESO 2026 TURIN

WRITTEN TEST 4 — TOO MUCH WATER, TOO FAST

Hydrosphere, geological hazards and interactions among Earth systems — The May 2023 flood in Emilia-Romagna

Time: 90 minutes • Questions: 35 • Score: 35 points • Read all the data before answering. Only one correct answer for all questions.

This test explores the interconnections among atmosphere, hydrosphere, geosphere, biosphere and anthroposphere following the principles of the Earth System through the analysis of a real catastrophic event.

SECTION 1 — The meteorological event and the hydrological cycle — Questions 1–8

Between 1 and 17 May 2023, Emilia-Romagna was hit by two extreme rainfall episodes only two weeks apart over the same territories. The first (May 1st – 3rd) brought over 200 mm in 48 hours to the central-eastern Apennines. On May 16th to 17th a low-pressure system stationed over central Italy channeled moisture-laden air masses from the Adriatic (Sirocco wind, from SE) and from the north (Bora wind, from NE) onto the Apennine slopes. Orographic uplift intensified rainfall over the same area for many hours, striking already saturated basins. Instrumental hydro-meteorological data, whose official recording began between 1916 and 1918, and the historical and archival sources, which report chronicles covering a period from the Middle Ages (about 500 years ago) to the early 1900s, do not report any such event, defined as "never recorded in historical times".

Table 1 – Rainfall by station

Station	Elev. (m)	1–3 May (mm)	16–17 May (mm)	May total (mm)	May mean (mm)
Trebbio (Modigliana)	480	205	405	610	85
Brisighella	350	185	393	578	80
Tredozio	520	178	350	528	82
S. Benedetto in Alpe	620	195	330	525	90
Forlì (plain)	35	110	275	385	72

Table 2 – Climate data

Parameter	Value	Anomaly vs 1991–2020
Mediterranean sea-surface temperature	20.8 °C	+1.6 °C
Mean air temperature, May 2023	17.8 °C	+2.1 °C (record)
Winter–spring 2023 rainfall	–	−25% (deficit)
May 2023 rainfall	250.7 mm	+230%

Question 1

Based on the given information, what is the approximate return period of a combined event such as the Emilia-Romagna May 2023 event?

A. Between 50 and 100 years, consistent with the rainfall of the first isolated event.
B. Between 100 and 200 years, consistent with availability of the instrumental hydro-meteorological data.
C. Between 200 and 500 years, considering the historical and archival sources.
D. Greater than 500 years, in accordance to the available reports.

Question 2

Based on the atmospheric conditions described above, which mechanism best explains why rainfall remained intense over the Apennine slopes?

A. Compression between the two wind masses warmed the air causing heavy condensation.
B. Converging winds produced persistent descending air over the slopes.
C. The temperature contrast generated brief, isolated but intense thunderstorms.
D. Orographic uplift forced by the convergence of Sirocco and Bora moist winds.

Question 3

The atmosphere can hold about 7% more water vapour for each degree of temperature increase: higher sea temperatures mean more evaporation and more moisture available for precipitation. Sea temperatures were +1.6 °C above average. The most direct consequence is…

A. a reduction in evaporation, because the warm sea stably stratifies the atmosphere.
B. an increase in atmospheric moisture that makes more intense rainfall possible.
C. a negligible effect, because the wind regime matters more than sea temperature.
D. a warming of the coastal air that prevents condensation and cloud formation.

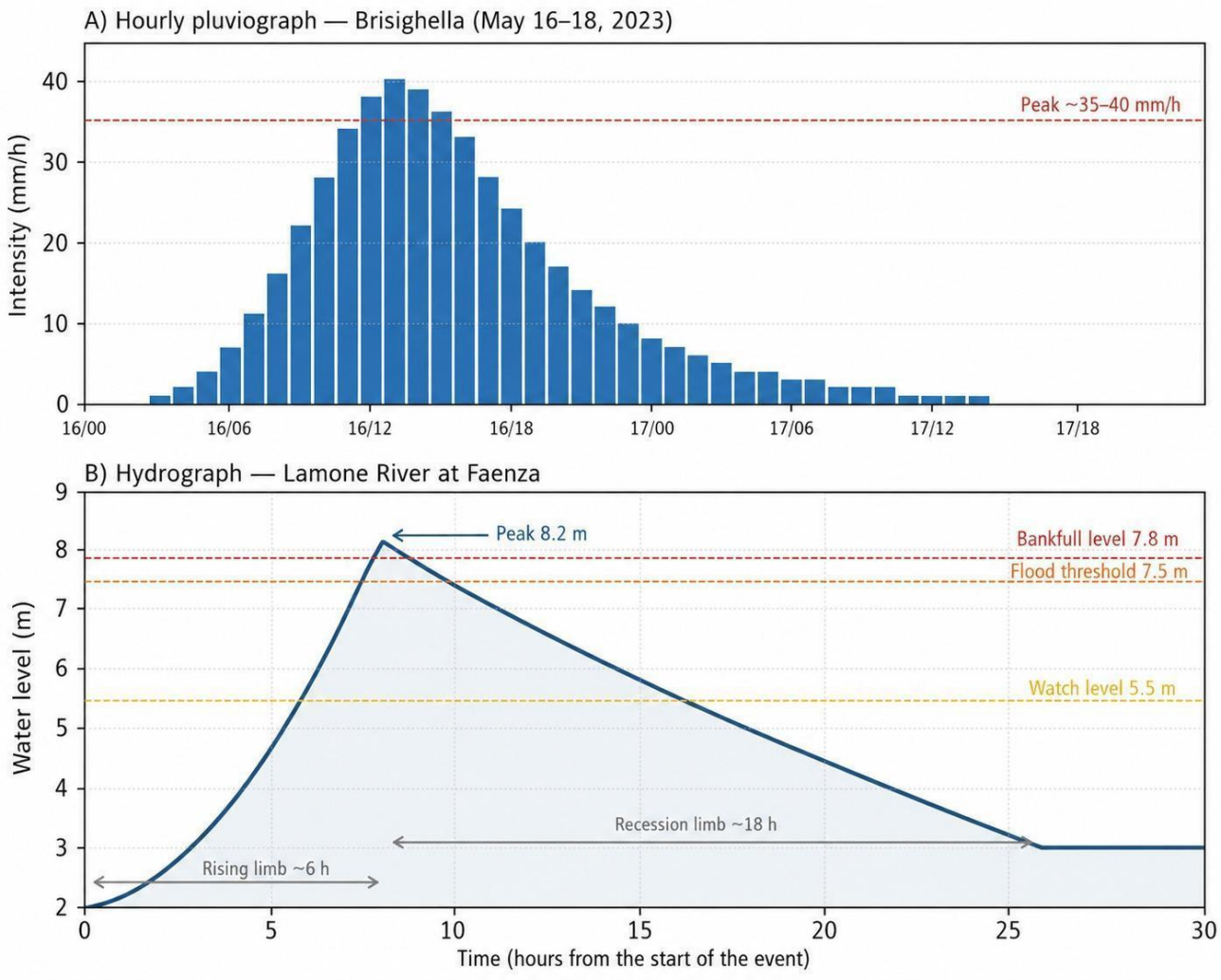

Figure 1 – Hourly pluviograph at Brisighella (A) and hydrograph of the Lamone at Faenza (B), 16–18 May 2023.

Question 4

Based on Figure 1B, which interpretation best explains the steep rising and slower falling of the Lamone hydrograph?

A. The hydrograph asymmetry can be explained by the elongated shape of the basin.
B. Continuous infiltration produced a fast rise, followed by slow channel emptying.
C. Rapid runoff from the slopes entered the river, while backwater effects slowed down drainage.
D. The basin continued to receive water inputs from upstream even after the local rainfall peak.

Question 5

Which sequence best describes how water moved through the Earth systems during the flood?

A. Atmosphere, then surface geosphere and slopes, then river hydrosphere and plain.
B. Deep geosphere, then underground hydrosphere, then atmosphere by capillary rise.
C. Marine hydrosphere, then atmosphere, then biosphere, then river hydrosphere.
D. Biosphere by transpiration, then atmosphere, then geosphere by deep infiltration.

Question 6
Winter–spring 2023 rainfall was 25% below normal, yet soils were saturated on May 15th. How can this be explained?

A. Clayey soils retain the previous winter's moisture regardless of rainfall.
B. The deficit kept soils dry, but water tables rose through lateral inputs from other basins.
C. The late melting of Apennine snow compensated for the spring rainfall deficit.
D. The intense rainfall of May 1st– 3rd rapidly saturated the clayey soils, levelling out the deficit.

Question 7
Rainfall totals range from 610 mm to 385 mm between stations just 40 km apart. Which factor explains this variability?

A. The different efficiency of rain gauges under intense rainfall and strong wind.
B. The consistent distribution of convective storms, typically very localised in the Mediterranean.
C. The different elevation and exposure to moist winds, which modulate orographic enhancement.
D. The greater distance of mountain stations from the sea, which progressively reduces moisture supply.

Question 8
Which statement MOST correctly describes the relationship between this event and climate change?

A. Warming increases the energy and moisture in the system, making extreme events more probable.
B. The event directly proves that the regional climate has changed relative to the recent past.
C. Climate change can be evaluated only over decadal trends and has no relation to a single weather event.
D. Climate change determines new trajectories of the low-pressure system in the Mediterranean.

SECTION 2 — Hydrological response and river dynamics — Questions 9–17

The considered area is characterized by the Argille Scagliose (scaly clay complex), where the infiltration capacity after the first event had dropped below 5 mm/hour. With rainfall of 35 mm/hour in the second event, almost all the water turned into surface runoff. Twenty-three rivers overflowed simultaneously.

Table 3 – Discharge of the main rivers (May 16th - 17th)

River	Basin (km²)	Peak (m³/s)	May mean (m³/s)	Peak/mean	Time to peak (h)
Lamone	620	1,850	15	123	7
Senio	270	850	8	106	5
Montone	580	1,520	12	127	8
Savio	650	1,350	18	75	6
Reno	4,060	2,800	45	62	18

Previously, between 1950 and 2023, the rivers were embanked for 800 km, straightened with a 30–50% reduction in width, and gravel extraction lowered the riverbed by 2–4 m. Impervious surface on the coastal plain rose from 5% to 43%, wetlands fell from 15% to 2%.

Table 4 – Basin characteristics

Basin	Area (km²)	Max elevation (m)	Mean slope (%)	% Argille Scagliose	% Forest	Rain May 16th–17th (mm)
Lamone	620	960	8	55	68	380
Senio	270	850	10	45	72	350
Montone	580	1,100	7	50	65	330
Savio	650	1,250	9	48	75	310
Reno	4,060	1,500	5	35	55	280

Question 9
What is the probable causal connection between the two events that led to the environmental disaster described?

A. The first event removed the riparian vegetation, eliminating the natural protection of the banks.
B. The second event eroded river channels already compromised by the first event.
C. The first event drastically reduced infiltration capacity during the second.
D. The second event struck valley-floor sediments compacted by the first, causing runoff toward unprotected areas.

Question 10
If rain falls at 35 mm/h on soils with an infiltration capacity of 5 mm/h, how much water becomes surface runoff each hour?

A. 40 mm, because saturated soils reject even the water previously infiltrated into the pores.
B. 30 mm, equal to the difference between rainfall intensity and the soil's residual infiltration capacity.
C. 15 mm, because about half the water is retained by vegetation and litter anyway.
D. 5 mm, corresponding only to the component that cannot drain deeper through the macropores.

Question 11
The times to peak (Table 3) range from 5 to 18 hours. Using info from Table 4 which factor, among others, seems to have a more direct effect on the different time response of the rivers?

A. The basin areas that collect rainwater from converging tributaries.
B. The extensive forest cover that channels water along the trunks down to the underlying soil.
C. The steepness of the slopes of the Apennine basins that accelerate surface runoff downslope.
D. The percentage of scaly clay in the substrate that influences drainage.

Question 12
Twenty-three rivers overflowed simultaneously. Why did the simultaneity worsen the disaster?

A. It made the flood waves converge downstream, with combined higher and longer water levels.
B. It caused an anomalous rise in the Adriatic Sea level due to the excess of fresh water.
C. It saturated the absorption capacity of the plain soils in a much shorter time than usual.
D. It diluted the discharge of the individual rivers, reducing the height of each flood wave.

Question 13
The Reno River has a time to peak of 18 hours, much longer than the others. Why?

A. The May mean discharge of the Reno River is higher, and this delays the moment of overtopping.
B. The Reno flows over more permeable ground due to reduced scaly clay content.
C. Rainfall over the Reno basin hit at a higher elevation, taking more time to reach the outlet.
D. Waters from different areas of a broader basin reach the outlet at different times.

Question 14
Levee overtopping of the Lamone river began at 7.8 m, while the flood peak reached 8.2 m. Which conclusion is directly supported?

A. The flood peak unexpectedly exceeded the levee system design.
B. The levee level had lost height through local erosion.
C. The levee failed structurally before water reached its crest.
D. The levee was designed for a specific return period not expected by the available data.

Question 15
During the flood, intense erosion and sediment transport occurred. In which phase is transport capacity greatest?

A. At peak discharge, when velocity and turbulence reach their maximum values across the whole section.
B. In the rising phase, when the acceleration of the flow begins to mobilise the bed sediments.
C. During low flow, when prolonged contact with the bed mobilises the fine particles.
D. In the recession phase, when the flow slows and concentrates the sediment in the centre of the channel.

Question 16
Impervious surface on the coastal plain rose from 5% to 43%. What effect does this have on hydrology?

A. It improves river drainage thanks to networks that convey water in a more controlled way.
B. It reduces evapotranspiration, leaving more water available to recharge the underground systems and increasing the wetlands.
C. It reduces infiltration and increases runoff volume, anticipating and raising flood peaks.
D. It can significantly reduce erosion when associated with straightening of river courses.

Question 17

Gravel extraction lowered some riverbeds by 2–4 m. Which consequence is most directly associated with this channel incision?

A. Permanent elimination of flood risk along the incised reaches.
B. Undermining of structures such as the foundations of bridges and levees.
C. Increased groundwater recharge throughout the basin.
D. Greater deposition of fine sediment downstream.

SECTION 3 — Geology, rocks and mass movements — Questions 18–25

The affected area lies where the Northern Apennines meet the Po River Plain. The Apennines are a fold-and-thrust belt formed during the Alpine orogeny.

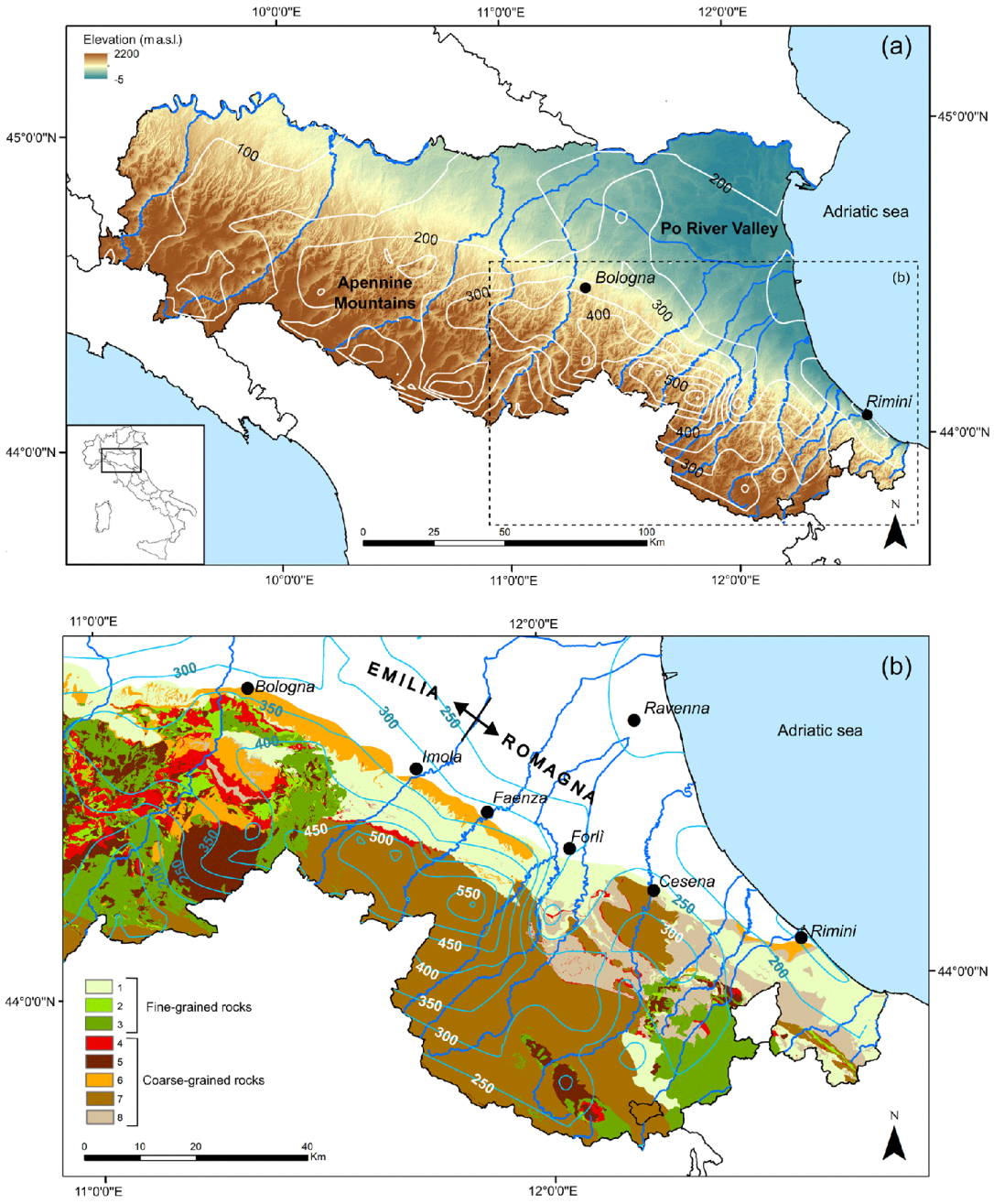

Figure 2 – (Top) Map with elevation and cumulative isohyets and (bottom) simplified geological map with isohypses.

Fine-grained units 1–3, with Argille scagliose = unit 3; coarse-grained units 4–8, with Marnoso-Arenacea = unit 7

Additional information

- Argille Scagliose complex (scaly clays; Cretaceous–Paleogene): chaotic clay matrix with embedded blocks of limestone, sandstone and ophiolite. Extremely low permeability; high landslide susceptibility when saturated. Soils on the Argille Scagliose: clay-rich, shallow (20–80 cm), infiltration <5 mm/h when saturated
- Marnoso-Arenacea Formation (Miocene): flysch, rhythmic alternation of sandstone and marl beds. Prone to translational slides along the bedding planes. Soils on the Marnoso-Arenacea: silty-clayey, deeper (50–120 cm), infiltration 10–30 mm/h.
- Epi-Ligurian Succession (Oligocene–Miocene): sandstones and conglomerates more resistant to erosion; forms the highest ridges.
- Quaternary deposits: colluvium on the slopes, alluvial fans, plain alluvium.

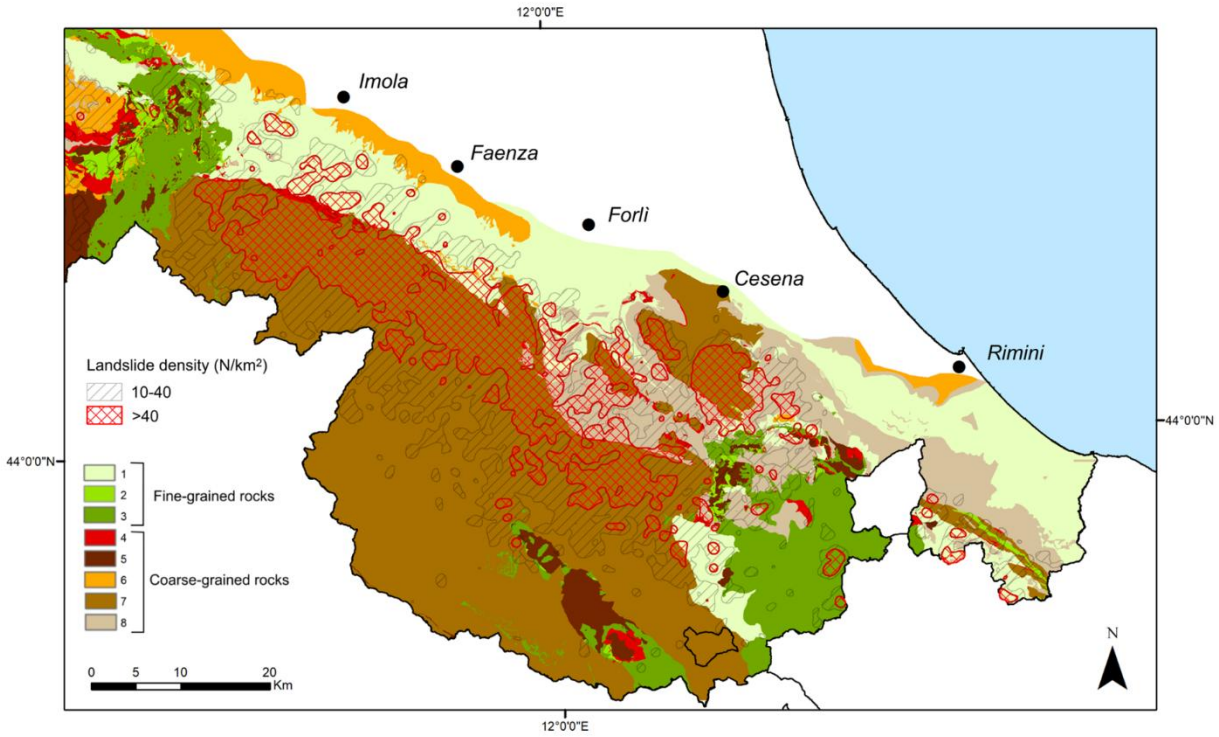

Figure 3 – Soil saturation and landslide distribution (landslide-density map over the geology).

Source: Berti, M. et al. (2025), Earth System Science Data. © The authors, licensed under CC BY 4.0, https://doi.org/10.5194/essd-17-1055-2025.

Table 5 – Landslides by province and geology in the 2023 May event (*data: Berti et al., 2025*)

Province	Area (km²)	N. slides	Density (/km²)	% Arg. Scagl.	% Marn.-Aren.	Prevalent type
Bologna	3,700	22,000	5.9	55	35	Shallow translational
Forlì-Cesena	2,380	28,500	12.0	45	40	Flows + translational
Ravenna	1,860	11,000	5.9	50	35	Shallow translational
Rimini	860	5,500	6.4	48	38	Shallow translational
Reggio Emilia	2,120	13,000	6.1	35	30	Mixed

Question 18

Looking at Figure 3, which geological formation has the lowest permeability?

A. The Quaternary plain alluvium, made of alternating and stratified sands and clays.
B. The Argille Scagliose complex, with its destructured clay matrix.
C. The flysch of the Marnoso-Arenacea formation, with its impermeable marl beds between the sandstones.
D. The sandstones and conglomerates of the Epi-Ligurian Succession, compact and well cemented.

Question 19.
The Marnoso-Arenacea formation is a 'flysch' with alternating sandstone and marl. In which environment did it probably form?

A. In a continental plain crossed by braided rivers with cyclic sedimentation.
B. On the shallow continental shelf, by the action of tidal and storm currents.
C. In a rift lake basin, with alternating arid and humid phases controlling deposition.
D. In a deep-marine environment, by deposition from sediment-laden turbidity currents.

Question 20
The Argille Scagliose are considered an intrinsically unstable formation, subject to landslides and recurrent reactivations. Which property explains this?

A. Their clay content makes them nearly impermeable: when saturated through slow water intake they lose strength.
B. Their very old age has made them brittle through repeated cycles of tectonic loading over millennia.
C. The embedded ophiolite blocks create internal weakness surfaces that favour sliding when saturated.
D. The sparse vegetation cover on clayey ground exposes the slopes to concentrated rainfall erosion.

Question 21
The hilly belt contains abundant Argille Scagliose and Marnoso-Arenacea, whereas Epi-Ligurian units form many ridge tops. Which interpretation best explains the concentration of landslides at 200–600 m elevation?

A. Runoff from the rocky peaks accumulates in the hilly belt, increasing local saturation.
B. Rainfall is more intense at intermediate elevations due to partial orographic uplift.
C. Less resistant, landslide-prone formations dominate the hill slopes.
D. The ridge tops control slope instability because of the more recent lithology.

Question 22
60% of the landslides were 'shallow translational'. These slides are characterised by…

A. a thin layer of soil sliding parallel to the slope along a planar surface.
B. a deep, curved rupture surface involving large volumes of rock or soil.
C. an extremely slow movement developing progressively over decades.
D. a sudden detachment of compact rock blocks that roll down the slope by free fall.

Question 23
A translational slide in the Marnoso-Arenacea formation has its slip surface…

A. through intact rock, following tectonic fractures oriented at random.
B. at the contact between the surface soil and the bedrock, independently of bedding.
C. along the bedding planes, where the marl beds act as weak, slippery surfaces.
D. along deep, curved rupture surfaces involving large volumes of compact rock.

Question 24
During the event, some saturated landslides changed into rapidly moving debris flows. Which process best explains this transition?

A. Increase of moisture created cohesion among fine particles and accelerated the movement.
B. Additional water reduced internal friction and allowed the failed material to flow.
C. Coarse clasts increased gravitational acceleration and sliding.
D. Pressurized bedrock increased pore water flows.

Question 25
Earth flows concentrated in areas with Argille Scagliose. Why?

A. The Argille Scagliose occur at elevations where slope gradients are on average steeper.
B. The clayey colluvium produced by the Argille Scagliose liquefies easily when hydrated.
C. The Argille Scagliose contain ophiolite blocks that weather rapidly, generating debris.
D. The Argille Scagliose occur at lower elevations where rainfall was more abundant.

SECTION 4 — System interactions, human factors and risk management — Questions 26–35

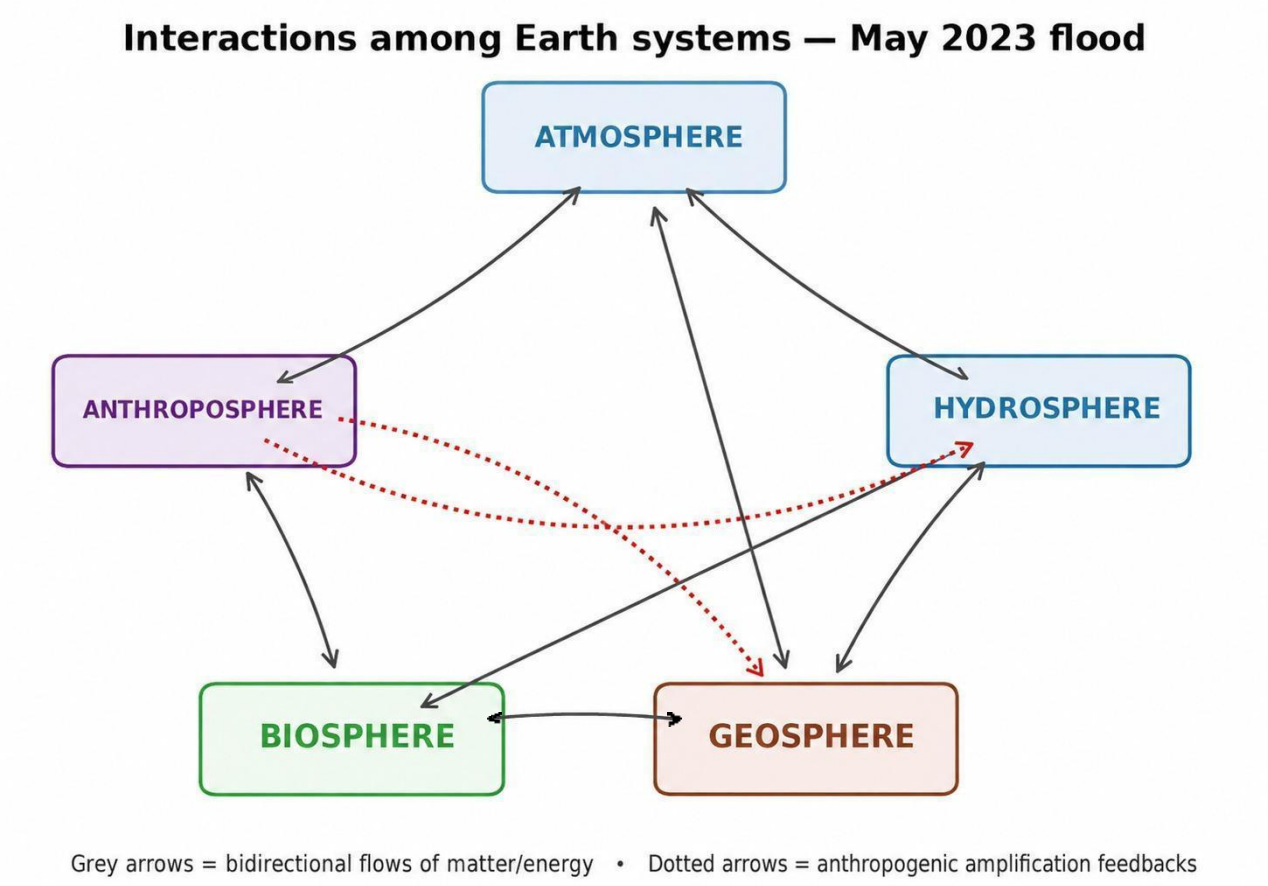

Figure 4 – Diagram of the interactions among the Earth subsystems during the May 2023 event.

The May 2023 event shows how all the Earth subsystems are interconnected: the atmosphere supplied the water, the geosphere conditioned where landslides were triggered, the hydrosphere transported water and sediment, the biosphere suffered habitat damage, and the anthroposphere had modified the territory in the decades before the event. Consequences: 17 fatalities, over 20,000 displaced, damage exceeding 10 billion euros, 45,000 hectares of farmland flooded.

Question 26

The correlation between the percentage of Argille Scagliose and landslide density presented in Table 5 is not direct. Which factor described in Table 4 helps explain the differences?

A. The different elevation and the area of each monitored province.
B. The percentage of forest cover, which stabilizes slopes through roots.
C. The different lengths of each river course, which might reduce the effect.
D. The mean slope of the hillsides and the amount of rainfall received during the event.

Question 27

What was the main physical triggering mechanism of the 80,000 landslides of May 2023?

A. The increase in pore-water pressure that reduced the shear resistance in the saturated slopes.
B. Mechanical vibrations produced by the passage of flood waves along the Apennine valley floors.
C. Toe erosion of the slopes by the flooding rivers, which removed the basal support.
D. The removal of vegetation cover by the strong wind associated with the storm.

Question 28

What interaction between landslides (geosphere) and rivers (hydrosphere) produced an immediate effect on the biosphere?

A. The sediment input created new habitats favourable to colonisation by pioneer species.
B. The deposition of sand on the fields caused agricultural damage.
C. The excess of sediment deposit altered river habitats and ecosystems.
D. The increased water discharge revitalized the drying out coastal wetlands.

Question 29
River straightening and embankment were meant to improve the river system. Which one of the following is NOT a probable reason for the unexpected effect of amplification of downstream flooding?
A. They accelerated downstream sedimentation, silting up the outlet channels toward the sea.
B. They increased the energy of the flow in narrow channels.
C. They prevented the rivers from spreading into upstream floodplain areas.
D. Reduced riverbed cross-section concentrated water within the channel system.

Question 30
Coastal wetlands fell from 15% to 2%. Which hydrological function was altered?
A. The role of a physical barrier against saltwater intrusion into coastal aquifers.
B. The capacity to attenuate floods by absorbing and slowly releasing the excess water volumes.
C. The production of the fine sediment needed for the natural stabilisation of the river banks.
D. The generation of water vapour by evapotranspiration that fed local rainfall.

Question 31
Which statement best reflects the systemic approach needed to understand this disaster?
A. The subsystems acted in a linear sequence — first rain, then slopes, then rivers — each passing the effect to the next in a single direction.
B. The interactions and feedbacks among the subsystems amplified the effects beyond the sum of the single parts.
C. The anthroposphere was the determining factor, while the natural systems played a secondary, background role.
D. The event is the sum of the independent responses of the individual systems, each assessable and predictable separately.

Question 32
Given the stated relationship between warming and atmospheric water-vapour capacity, which future change would MOST plausibly increase hydrogeological risk in the Mediterranean region?
A. More frequent and severe weather events.
B. A seasonal shift of rainfall, with harsher precipitation events in winter.
C. More moisture available for prolonged and diffused rainfall, increasing flood and landslide potential.
D. Long-term drying clay slopes with lower stability.

Question 33
Landslide warning systems use rainfall thresholds. Which information would improve the forecasts?
A. The local atmospheric pressure, because barometric changes influence slope stability.
B. The air temperature at altitude, because landslides trigger only below certain thermal thresholds.
C. The antecedent soil moisture, because already saturated soils need less rain to trigger landslides.
D. The downstream river discharge, because river floods are the main trigger of landslides.

Question 34
Which long-term strategy BEST reduces flood risk by addressing hazard, exposure and vulnerability together?
A. Raise levees throughout the region and expand urban drainage networks.
B. Build upstream retention basins and extensive reforestation.
C. Plan restoration of floodplains and wetlands and limit anthropic development in flood-prone areas.
D. Relocate settlements and activities out of the risk areas letting nature restore hydrogeological stability.

Question 35
Based on Figures 2 to 5, which interpretation of flood risk best explains the overall relationship between inhabited area and flood response?
A. Exposure and vulnerability to floods reflect levels of inhabited areas.
B. Flood hazard reflects highly populated areas.
C. Comparisons among basins show that risk has no consistent relationship to population density.
D. Flood risk is not influenced by land use.

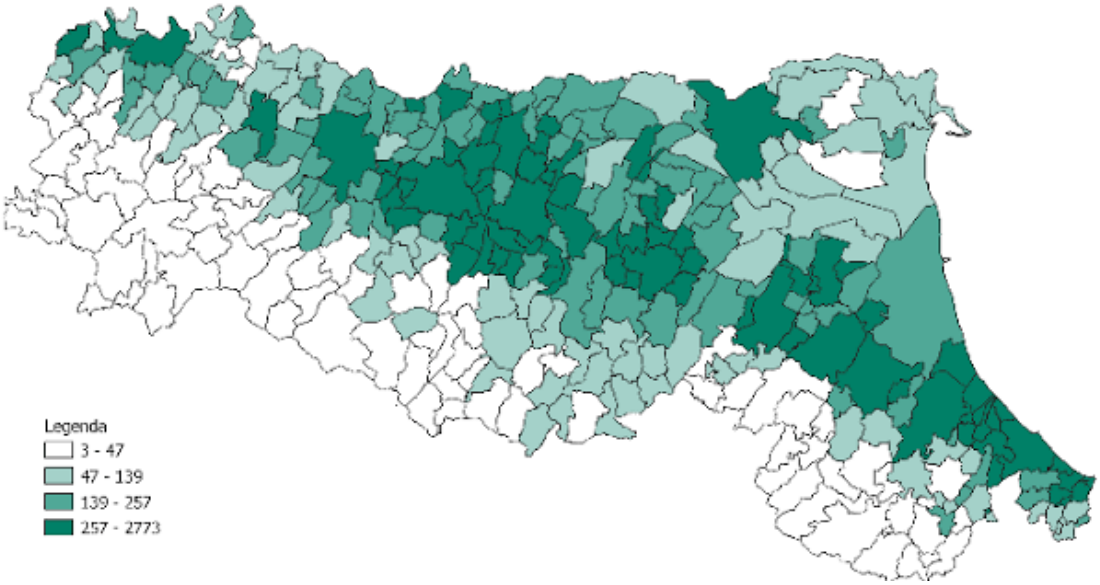

Figure 5: Population density (inhabitants/km²)