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Resilient infrastructures: managing risks from water-related hazards. The Storm Alex case study

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ABSTRACT

Storm Alex hit Western Europe from 1 to 7 October 2020, becoming one of the most extreme climatic events in the current decades. The storm caused widespread destruction, especially in France and northern Italy. In Piedmont exceptional rainfall triggered landslides, floods and the collapse of numerous critical infrastructures including bridges and state roads, highlighting serious territorial and systemic vulnerabilities.

The aim of this thesis is to analyse the damage and effects of Storm Alex in Italy, to understand if there have been success stories of risk mitigation when the (partial or total) failure of an infrastructure occurred and to understand if it is possible to learn from past experiences to improve the resilience of structures and communities.

The first section of this thesis aims to analyse the event with particular focus on the most affected areas in Piedmont, through a multidisciplinary approach that combines hydro-meteorological analysis, reconstruction of infrastructure damage, examination of the causes of failure and assessment of the responses made before and during the event.

The central part of the thesis focuses on analysing the role of spatial planning and regulatory constraints (in particular hydrogeological, landscape and urban constraints), highlighting how past urbanisation and administrative fragmentation have in several cases weakened the effectiveness of prevention measures.

In the final part, the thesis examines the risk management strategies implemented pre and post-event, including improved reconstruction standards, updates to emergency plans, adoption of nature-based solutions and transnational initiatives, such as the European RITA project.

In the light of the articles examined and the evidence collected, the thesis finally proposes a reflection on the concept of systemic resilience, understood as the capacity of a territory not only to absorb the impact of extreme events, but also to adapt and improve structurally and organizationally in response to the new challenges posed by climate change.

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1. INTRODUCTION

The first winter storm of the 2020-2021 season was known as Storm Alex (or Brigitte) in central Europe and Aiden in the UK and Ireland. The storm brought destructive effects through strong winds and heavy rainfall and thunderstorms, which triggered landslides and floods across central Europe, South-East France and northern Italy. The storm lasted from October 2, 2020 until October 7, 2020 and resulted in at least 15 deaths. The storm destroyed numerous homes together with bridges and roads while disrupting rail operations. The downed trees caused power outages, telecommunication disruptions and water supply interruptions while emergency responders rescued dozens of people.

Fig. 1 shows the accumulated precipitation totals from October 1 to October 5, 2020, while *Fig. 2* highlights the stations where daily precipitation exceeded 10 mm/day between October 2 and October 3, 2020.

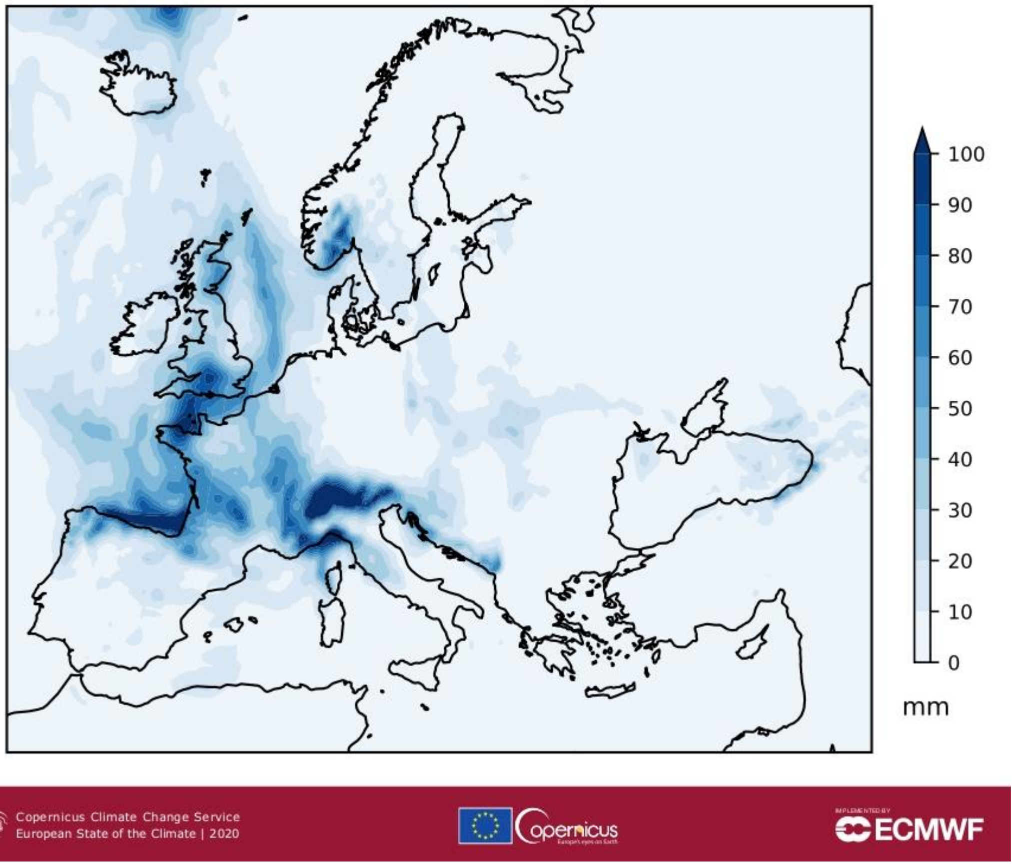

Fig. 1: Accumulated precipitation totals for the period 00:00 UTC October 1, 2020 – 00:00 UTC October 5, 2020. Data source: ERA 5. Credit: C3S/ECMWF. **[2]**

The storm broke out on October 1, 2020 over the North Atlantic west of Scotland, heading eastward. The flow from the south associated with the storm brought hot and humid air, causing intense and stormy rains in the Maritime Alps, with exceptional amounts of precipitation of about 600 mm in one day. The first landfall on mainland Europe occurred in western France in the night between October 1 and October 2, with gusts of wind up to 142 km/h.

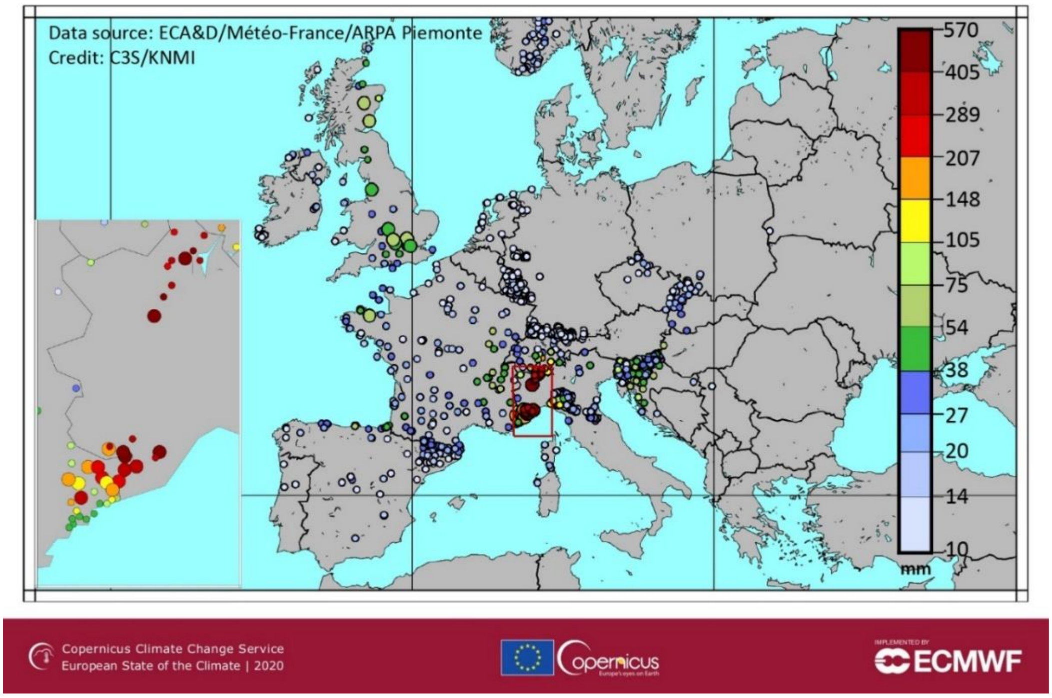

Fig. 2: Stations where daily precipitation associated with Storm Alex exceeded 10 mm/day on October 2-3, 2020.The larger circles identify stations where one-day precipitation records were broken during this event. Data source: ECA&D/Météo-France/ARPA Piemonte. Credit: C3S/KNMI. **[2]**

The first four days of October 2020 brought more than 100 mm of accumulated precipitation to central southern England and eastern Scotland. Weather stations across the country measured their highest October precipitation totals on October 3. The UK received 31.7 mm of rain on October 3, which became the most rain the country has ever recorded since 1891. The severe weather conditions led to flooding, power outages and major disruptions to road and rail transportation throughout the entire nation. The southern coastline experienced additional travel disruptions because large waves damaged coastal infrastructure.

Despite the widespread heavy precipitation associated with Storm Alex, the overall impact of flooding in the UK remained relatively limited. According to the UK Met Office, this was probably due to two key factors: the pre-existing dry soil conditions (as much of the UK had experienced below-average rainfall during September), and the steady character of the rainfall, which lacked particularly intense precipitation bands, mitigating the risk of severe flooding.

In France, severe flooding affected the French Riviera. On October 2, the region experienced exceptional rainfall, with 571 mm recorded in Mons and 500 mm in

Saint-Martin-Vésubie.[1] These amounts correspond to over three times the average precipitation typically observed in October for these locations and established a new daily rainfall record for the province. The victims were ten, while the missing are eight.[2] The municipalities seriously affected were 14, with hundreds of buildings destroyed or damaged, 50 km of road infrastructure destroyed along with 19 bridges and 6 water treatment plants, leaving 60% (13266 people) of the inhabitants of those areas without drinking water.[3] The economic damage was estimated at around €1 billion.[4]

In Italy, Piedmont recorded its highest-ever rainfall totals since meteorological records began in 1951. On October 3, the village of Sambughetto registered 630 mm of precipitation, while Limone Piemonte recorded 580 mm. The Liguria and Aosta Valley regions were also significantly affected. Several rivers in north-west Italy surpassed critical flow thresholds, including the Sesia at Borgosesia and Palestro, the Po at Valenza, the Tanaro at Garessio and Farigliano, the Toce at Candoglia, and the Roya in Ventimiglia. In most cases, these extreme hydrological conditions resulted in severe flooding.

The economic damage created by Storm Alex has been enormous: estimates vary between different sources, highlighting the complexity and magnitude of the impact of the event.

In France, according to *The Times*, damage was estimated at around €1 billion.[5] On October 20, 2020, the *Fédération Française de l'Assurance* and the *Caisse Centrale de Réassurance* estimated claims for flood and wind damage at 288 million euros,[6] while a report by *France 24* of October 8, 2020 reports that the French government allocated an initial fund of 100 million euros for the reconstruction of destroyed infrastructures.[7] Because of the extensive damage suffered, France has applied to the *European Union Solidarity Fund (EUSF)*, estimating the total direct damage at 2.373 billion euros.[8]

In Italy, according to *Artemis.bm,* preliminary economic damage has been estimated at around €1 billion,[9] with further damage to the agricultural sector. In Cuneo, local businesses have suffered serious losses: *Confcommercio* has provided

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[1] https://climate.copernicus.eu/esotc/2020/storm-alex

[2] https://www.montecarlonews.it/2024/10/02/notizie/argomenti/ambiente-1/articolo/tempesta-alex-e-trascorso-un-anno-foto.html

[3] https://fr.wikipedia.org/wiki/Temp%C3%AAte_Alex

[4] https://www.france24.com/en/business/20201008-businesses-count-cost-of-damage-from-storm-alex-in-southeastern-france

[5] https://www.thetimes.com/world/europe/article /storm-alex-causes-devastation-in-the-french-and-italian-riviera-hx3v38h5n

[6] https://www.ccr.fr/documents/35794/35839/CCR+Group+Activity+Report+ 2020.pdf/ca01c21b-2182-6f3e-1e0f-0228bdd0622b?t=1622811980707

[7] https://www.france24.com/en/business/20201008-businesses-count-cost-of-damage-from-storm-alex-in-southeastern-france

[8] https://ue.delegfrance.org/tempete-alex-l-ue-apporte-son

[9] https://www.artemis.bm/news/storm-alex-flood-wind-claims-in-france-already-eur-288m-ffa-ccr/

320000 euros of aid to more than 100 companies in the valleys of Gesso, Vermenagna and Tanaro to support post-flood recovery.[10]

In addition, the Parc des Alpes-Maritimes has estimated damages of more than 2 million euros,[11] excluding roads, and has requested funding for restoration work both from the competent regional offices and from the Ministero dell'Ambiente.

The aim of this thesis is to analyse the damage and effects of Storm Alex in Italy, to understand if there have been success stories of risk mitigation when the failure, partial or total, of an infrastructure occurred and to understand if it is possible to learn from past experiences to improve the resilience of structures and communities.

[10] https://www.cuneodice.it/attualita/cuneo-e-valli/un-anno-dopo-alex-il-racconto-delle-imprese-che-sono-riuscite-a-ripartire-dopo-l-alluvione_54264.html

[11] https://unionemonregalese.it/2020/10/09/alluvione-il-parco-alpi-marittime-stima-quasi-2-milioni-di-danni/

2. OVERVIEW ON THE CASE STUDY

2.1. Timeline of the events

From a meteorological point of view, the event began on Thursday, October 1st, when a closed low-pressure circulation detached from an Atlantic trough over the British Isles, gradually drifting towards northern France and turning into an extratropical storm. By Friday, October 2nd, the pressure minimum started channelling warm and humid air masses towards the southern French coast, Liguria and Piedmont. Initially, these air currents were pushed by libeccio winds (which is a southwesterly wind) in the lower atmospheric layers, but by the end of the day, they shifted to scirocco winds (from the southeast). This phenomenon unfolded within a very active atmospheric setup. The storm's southernmost edge was being supercharged by strong jet stream winds and it was continuously fed by moisture coming from both the Atlantic Ocean and, later on, from the western Mediterranean Sea (whose sea surface temperatures were significantly above the seasonal average, as shown in *Fig. 3*).

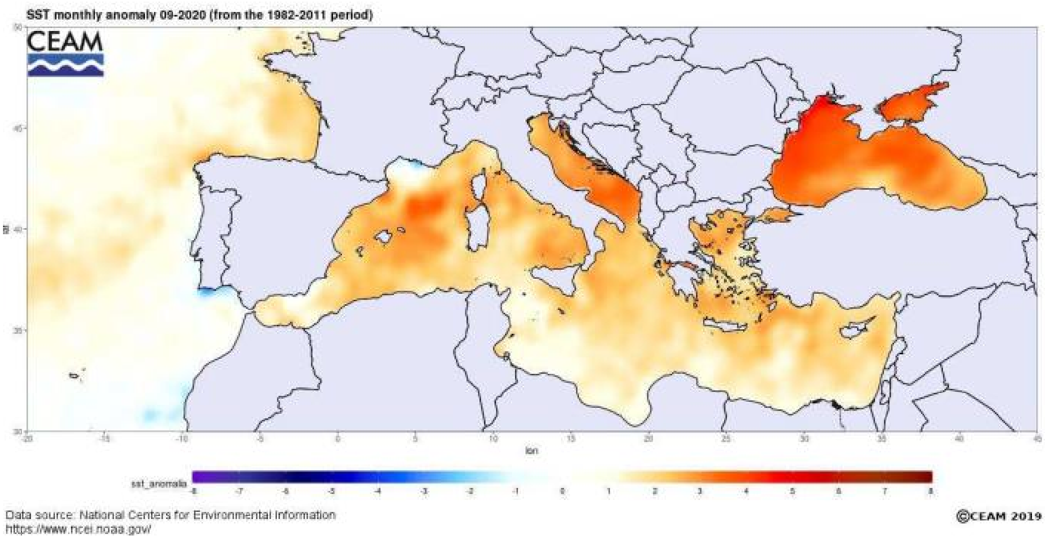

Fig. 3: Mediterranean Sea surface temperature anomaly in September 2020. **[4]**

As Friday, October 2nd, progressed into the afternoon and evening, the warm and humid airflow started to converge over the southern mountain zone of Piedmont. Because of the so-called "orographic uplift" (a phenomenon where the air is being forced upwards by the mountains), this interaction led to exceptionally intense rainfall and thunderstorms across the area between the Roya Valley and the upper Tanaro Valley. The humid flow persistently affected northern Piedmont, continuing until the early hours of the following day. The interaction between the humid flow from the south-west and the orography led to the development of a localized pressure minimum over the Cuneo province during the night between

October 2 and October 3, further intensifying wind convergence and precipitation over the upper Tanaro Valley, Sesia Valley, and Verbano province, producing record-breaking rainfall accumulations.

The simultaneous presence of a deep and highly active barometric structure dynamically influenced by cold polar air, strong pressure gradients and intense winds alongside a persistent, warm and moisture-laden Atlantic and Mediterranean airflow, funnelled southward by the pressure minimum, constituted a highly unusual meteorological configuration for this latitude. This pattern was very different from typical flood-producing systems in the region. Storm Alex was anomalous in terms of both intensity and seasonality, ranking among the most severe storms that have affected Western Europe in recent history.

Fig. 4 shows the arrival on the European continent of Storm Alex at 00:00 UTC of October 2, 2020.

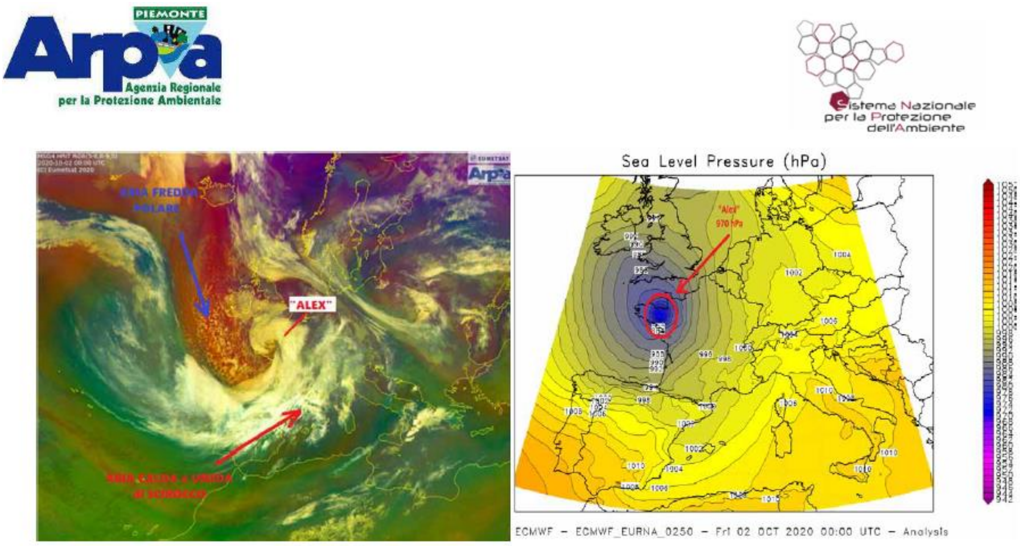

Fig. 4: Image from Meteosat satellite at 00:00 UTC of October 2, 2020 (copyright Eumetstat) highlighting the type of air masses over Europe (left) and the sea level pressure situation in the ECMWF (right). **[4]**

On Thursday, October 1st, the Functional Center of ARPA Piemonte issued an orange alert for Friday, October 2nd, covering almost the entire Piedmont except for the western area, where it issued a yellow alert. In the bulletin released on October 2, the orange alert was confirmed, as rainfall intensities were expected to increase further particularly from the Verbano area to Biella and upper Canavese, where significant cumulative rainfall totals were anticipated. The most intense phase of the storm occurred on October 2, with the heaviest precipitation affecting the northern sector of the region and the upper Tanaro Valley near the Ligurian border. On October 3, the precipitation continued to affect the Verbano area, with notable localized accumulations.

Additionally, on October 2, storm-force winds affected the southern mountain ranges, with gusts exceeding 120 km/h recorded at Rocca dell'Abisso (2753 m a.s.l.) and Colle San Bernardo (980 m a.s.l.), while Rifugio Mondovì (1760 m a.s.l.) registered wind speeds over 100 km/h[12].

For what concerns the precipitation patterns, extraordinary high areal rainfall totals were recorded on October 2 across the Sesia (325 mm), Cervo (222.8 mm), and Toce (368.3 mm) river basins. Strong extreme rainfall accumulations were also recorded in Valstrona (VB) and in Mergozzo (VB), exceeding respectively 650 mm and 600 mm. In the upper Tanaro Valley, the Limone Piemonte (CN) weather station registered nearly 600 mm of rainfall, almost entirely recorded in a single day (October 2). Similarly, Garessio (CN) recorded over 400 mm, representing more than 50% of the average annual precipitation at these locations. *Tab. 1* shows the total rainfall in millimetres on the days of the event.

Bacino	Precipitazione [mm]				
	1 ottobre	2 ottobre	3 ottobre	4 ottobre	Totale
Alto Po	0	64	3	2	69
Pellice	0	59,6	8,4	2,2	70,2
Varaita	0	61,7	3,3	0,9	65,9
Maira	0	64,4	4,5	0,5	69,4
Residuo Po confluenza Dora Riparia	0	65	2,6	2,6	70,2
Dora Riparia	0	49,3	14,6	1,9	65,8
Stura di Lanzo	0,1	94,5	42,6	4,5	141,7
Orco	2,8	118,4	53,4	8,4	183
Residuo Po confluenza Dora Baltea	0,2	73,3	8,1	4,3	85,9
Dora Baltea	1,2	83,2	44,7	5,3	134,4
Cervo	1,4	**222,8**	22	11	**257,2**
Sesia	1,4	**242,2**	68,3	13,1	**325**
Residuo Po confluenza Tanaro	0	109	2,8	6,7	118,5
Stura di Demonte	0	131,9	9,4	1,1	142,4
Tanaro	0	164,9	6,2	1,7	172,8
Bormida	0,1	114,7	9,1	5,2	129,1
Orba	0,9	86,9	21,9	18	127,7
Residuo Tanaro	0	75,6	1,5	2,3	79,4
Scrivia Curone	11	50,1	24,9	12	98
Agogna Terdoppio	0,1	107,8	6,4	13,4	127,7
Toce	6,6	**231,5**	106,8	23,4	**368,3**
Ticino svizzero	3,2	152,1	67,7	44,5	**267,5**
Bacino del Po a Ponte Becca (PV)	**1,5**	**111,9**	28,8	11,8	**154**

Tab. 1: Total rainfall in millimetres on the days of the event. **[4]**

[12] https://www.regione.piemonte.it/web/media/27777/download

At the most affected weather stations, the estimated return periods for 12-hour and 24-hour rainfall durations exceeded 200 years. The stations of Limone Piemonte (CN) and Sambughetto (VB) recorded extreme values across all durations (1, 3, 6, 12 and 24 hours), highlighting how exceptional Storm Alex was. Consequently, this intense rainfall led to extraordinary flood waves affecting both the primary and secondary river networks in the region. Water level rises were abrupt, and even in the downstream sections of extensive catchments, peak flow conditions were reached in a maximum of 12 hours. *Fig. 5* shows the cumulated rainfall from October 1 to October 4, while *Fig. 6* highlights the daily average rainfall on Piedmont observed from January 2020 to October 2, 2020, with a comparison between the actual data and the climatology of the last 60 years.

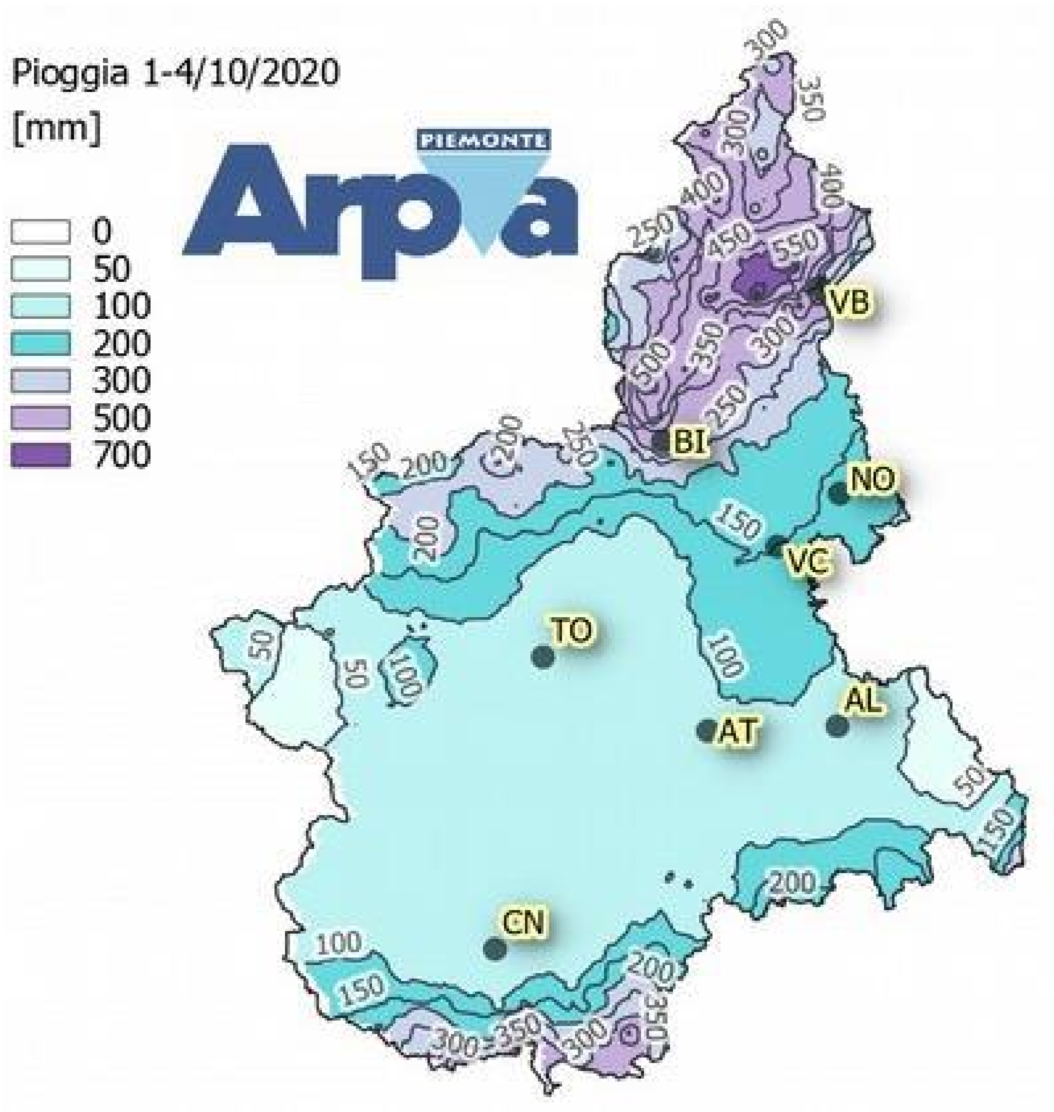

Fig. 5: Cumulated rainfall from October 1 to October 4. **[3]**

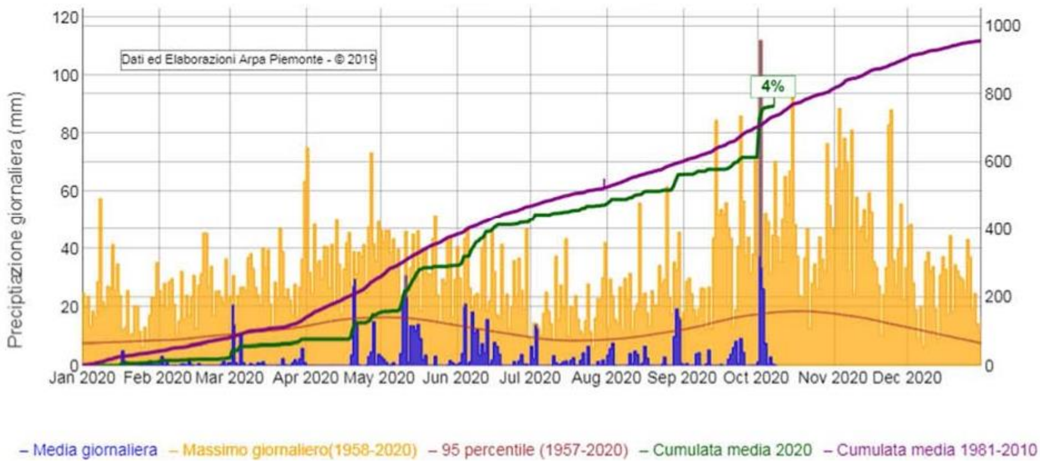

Fig. 6: Daily average precipitation in Piedmont (2020). **[4]**

All along the Toce River basin, water levels passed critical thresholds throughout the entire main river channel. The inflow from the Toce River and its tributaries into Lake Maggiore caused a moderate water level increase, mainly because the lake itself did not experience several days of continuous heavy precipitation. Unprecedented peak flows were also recorded along the Sesia River, from its source to its downstream reaches, setting new records since the installation of ARPA Piemonte's automatic monitoring stations. At Borgosesia (VC), the water level overpassed the danger threshold by more than 4 meters, with a discharge over 3000 m^3/s.[13] Significant flood peaks were also recorded in the Canavese area, where the Dora Baltea, measured at the Tavagnasco (TO) hydrometric station, came close to the critical threshold of peak discharge of approximately 1400 m^3/s.[14]

Along the Po River, water level increases were more contained. However, at Valenza (AL), the river still reached the danger level, with a discharge of approximately 6100 m^3/s.[15] Downstream, at Isola S. Antonio (AL) (the closing section of the Po River basin in Piedmont), the alert level was exceeded with a flood peak of around 7200 m^3/s.[16]

Fig. 7 shows the trend of the water level recorded on the Sesia at Palestro (PV) where the last hydrometer of the regional monitoring network is located upstream of the confluence with the river Po.

[13] https://www.regione.piemonte.it/web/media/27777/download
[14] https://www.arpa.piemonte.it/sites/default/files/media/2024-07/rapporto_evento_02_ottobre_2020_.pdf
[15] https://www.arpa.piemonte.it/sites/default/files/media/2024-07/rapporto_evento_02_ottobre_2020_.pdf
[16] https://www.arpa.piemonte.it/sites/default/files/media/2024-07/rapporto_evento_02_ottobre_2020_.pdf

Fig. 7: Cumulated rainfall from October 1 to October 4. **[3]**

Storm Alex was classified as an extreme hydrological event, with a return period exceeding 200 years in the upper Tanaro basin, approximately 200 years in the Sesia basin and around 50 years in the Toce basin, where flood magnitudes were more moderate. In the Dora Baltea, Orco, and Stura di Lanzo basins, return periods were slightly below 20 years, while flood severity was lower along the Po River and the lower Tanaro River.

2.2. Infrastructures involved

From a temporal perspective, Storm Alex was an extraordinary event for its unusual rapidity (typical of Alpine torrents, but generally of limited catchment areas), but moreover for its devastating impacts on the ground, with roads wiped out, bridges severely damaged and inhabited areas heavily affected. The most severe consequences occurred in settlements located near riverbeds, where land use over the years has restricted the natural floodplain, preventing rivers from expanding during flood events without causing destruction.[17]

The areas most affected by the precipitation were a southwest-northeast oriented foothill sector, extending from the northeast of the Canavese area to Lago Maggiore (impacting the provinces of Turin, Biella, Vercelli, Novara, and Verbania) and a southern sector of the region, including the southernmost part of the Cuneo province, near the French and Ligurian borders.

In addition to the intense rainfall, the passage of flood waves from both secondary streams and major rivers, such as the Toce and Sesia in northern Piedmont and the Tanaro, Vermenagna, Gesso, Corsaglia, Mongia, and Casotto in the southwest, caused widespread damage.

[17] https://www.sigeaweb.it/documenti/gda-supplemento-4-2021.pdf

The main categories of damage recorded include:

- Damage to communication and transportation infrastructure (municipal, provincial and national roads).
- Bridge collapses.
- Damage to technological service infrastructure (power outages, telecommunication disruptions, aqueducts and sewage systems)
- Damage to private buildings and property.
- Damage to longitudinal flood protection structures, including levee breaches and embankment wall collapses.
- Damage to economic and industrial activities, as well as tourism facilities.
- Damage to public service structures and facilities.

The municipalities affected by the events were more than 350 out of about 1200 (30% of the total).[18] *Tab. 2* shows the distribution of municipalities by province, while *Fig. 8* represents a map of the affected municipalities that reported damages.

Provincia	Numero Comuni
Torino	27
Verbano – Cusio - Ossola	74
Novara	45
Vercelli	85
Biella	74
Cuneo	47
Totale	**352**

Tab. 2: Distribution by province of the municipalities affected. **[3]**

[18] https://www.regione.piemonte.it/web/media/27777/download

Fig. 8: Affected municipalities reporting damages. **[3]**

The following pages will be devoted to a territorial analysis, by province, of the damages caused by Storm Alex.

2.2.1. Province of Cuneo

Even though Storm Alex hit relatively small areas within the Province of Cuneo, (which by the way spans approximately 7000 km^2), the damage was devastating. This was mainly due to a couple of factors: severe flooding along the main rivers that affected populated areas, and intense torrential activity along both main rivers and their tributaries in the mountainous parts of the basin. The outcome was widespread destruction of essential infrastructure, including roads, aqueducts, sewage systems, gas pipelines, telephone lines and electricity supply networks.

The upper Tanaro Valley was struck by the extreme precipitations and the consequent flooding of the Tanaro River and its tributaries (the Vermenagna and Corsaglia torrents), which reached incredibly high levels. Along the Tanaro River, peak water levels exceeded the danger threshold in different monitoring stations, such as Ponte di Nava, Garessio, Piantorre, Farigliano and Alba. In particular, at the Ponte di Nava and Garessio hydrometers were recorded respectively 5.32 m and 5.93 m, surpassing historical records from 2016. Severe damage was reported to municipal, provincial and national roads, residential buildings, industrial facilities and service infrastructure such as gas pipelines, telephone networks and aqueducts. [19]

In Ormea, near the Ligurian border, over 1000 residents were completely isolated due to the blockage of the national road at Cantarana (upstream) and Isola Lunga (downstream). Additionally, two road bridges collapsed.[20]

Garessio, a town of 4000 inhabitants, suffered severe damage from the flooding of the Tanaro River in Borgo Ponte and the town centre, leaving residents without water and electricity. The flood hit infrastructure, businesses, homes, and cellars. Even the cemetery in the Trappa district, situated near the riverbank, was devastated as the floodwaters swept away numerous coffins.[21]

In Bagnasco, the town was left without gas and, in some areas, without water.[22] The catastrophic impact of the flood is attested by the collapse of several arches of the town’s iconic roman bridge, as shown in *Fig. 9*.

[19] https://www.regione.piemonte.it/web/media/27777/download
[20] https://www.arpa.piemonte.it/sites/default/files/media/2024-07/rapporto_evento_02_ottobre_2020_.pdf
[21] https://www.regione.piemonte.it/web/media/27777/download
[22] https://www.sigeaweb.it/documenti/gda-supplemento-4-2021.pdf

Fig. 9: Collapsed arches of the roman bridge in Bagnasco. **[1]**

Nucetto, a town between Ceva and Bagnasco, was completely overwhelmed by the massive influx of water and mud, which inundated streets and homes. The town also suffered a significant power outage, with half of it left without electricity and a gas pipeline rupture occurred in one of the hamlets. One entire family was forced to evacuate their uninhabitable home, while approximately twenty houses were inundated by floodwaters.[23]

In Ceva, the Tanaro River overflowed in the Rotonda area, leading to numerous garages being flooded with water and mud. The headquarters of the Croce Bianca emergency services was completely inundated, together with the local school.[24]

The Vermenagna Valley experienced some of the most severe destruction in Limone Piemonte. Here, the intense torrential activity of the Vermenagna River and its tributary (Rio di San Giovanni) caused widespread damage. Over 70 buildings were either destroyed or flooded, while another 15 underground structures were completely or partially inundated.[25] The main road suffered multiple interruptions, while secondary roads were also heavily damaged. Many homes were left without electricity and gas, as landslides ruptured multiple gas pipelines and the flooded rivers swept away power lines and pylons. Several hamlets became completely isolated, forcing 35 residents to evacuate for their safety.[26] As shown in *Fig. 10*, a large mudslide and debris damaged a ski resort, demolished buildings and invaded the parking area, while *Fig. 11* shows the design inefficiencies of the Odasso Bridge in facing flood events.

[23] https://www.regione.piemonte.it/web/media/27777/download

[24] https://www.arpa.piemonte.it/sites/default/files/media/2024-07/rapporto_evento_02_ottobre_2020_.pdf

[25] https://www.regione.piemonte.it/web/media/27777/download

[26] https://www.regione.piemonte.it/web/media/27777/download

Fig. 10: Chairlift wiped out in Limone Piemonte. **[3]**

Fig. 11: Odasso Bridge. The light of the three arches has always proved to be insufficient for the outflow of the extraordinary flows, also due to the presence of considerable floating material. **[1]**

In the municipality of Limone Piemonte, the activity of the main and secondary lattice has caused widespread damage to the territory, by either undermining the foundations of numerous buildings, or invading many areas with water and debris, involving numerous dwellings as well as the camping out of the country. The most obvious phenomenon is a collapsed building in Rio San Giovanni (*Fig. 12*).

Fig. 12: House collapsed in the riverbed of the river San Giovanni in the municipality of Limone Piemonte. **[1]**

Storm Alex did not just affect individual towns, but also regional connectivity and economy. The SS 20, a crucial route for tourism and commerce that connect Liguria, the lower Piedmont area and France, was severed due to extensive damage in multiple sections of the Italian roadway.[27]

Even more impactful was the damage to the French side leading to Colle di Tenda. This mountain pass is a key gateway connecting Cuneo Province with the French part of the Roya Valley, and its disruption had an immeasurable impact on Piedmont's tourism industry. The most affected was certainly Limone Piemonte, a ski resort with 80 km of slopes, which relies heavily on tourists from France, Liguria and lower Piedmont. The closure of this route was a major economic setback for the town. Beyond the financial repercussions, many families were evacuated from Limone, Vernante, and Priola. The extensive damage and ongoing safety concerns meant that many of the residents faced an extended period away from their homes.

Fig. 13 highlights the devastating effect of the flood for the houses built nearby the bank of Tanaro River.

[27] https://www.regione.piemonte.it/web/media/27777/download

Fig. 13: Houses flooded by the Tanaro, a few meters from the bank. **[1]**

2.2.2. Province of Verbano – Cusio – Ossola

The extreme intensity of the precipitations led to widespread flooding of roads and underpasses, along with numerous landslides and mudslides. This caused severe disruptions to transportation and damage to infrastructure. In major towns like Verbania, Omegna, and Domodossola, fallen trees and debris made several municipal roads impassable, especially those leading to mountain villages.

Furthermore, the Toce River overflowed in multiple areas, affecting the municipalities of Mergozzo, Ornavasso, Premosello, Chiovenda and Pieve Vergonte. As a safety precaution, evacuations were carried out in Mergozzo, Cesara and Pieve Vergonte, where about twenty homes had to be temporarily abandoned due to safety concerns.[28]

2.2.3. Province of Biella

The Alta Val Cervo was one of the most severely affected area in the Province of Biella. In the municipality of Piedicavallo, only one of the seven bridges remained intact, while the other six collapsed or were severely damaged.[29] Both provincial and municipal roads were interrupted in multiple locations due to landslides and flooding.[30] Moreover, numerous power pylons were knocked down, leaving many villages without electricity.[31] Across the entire province, significant damage was

[28] https://www.sigeaweb.it/documenti/gda-supplemento-4-2021.pdf
[29] https://www.regione.piemonte.it/web/media/27777/download
[30] https://www.arpa.piemonte.it/sites/default/files/media/2024-07/rapporto_evento_02_ottobre_2020_.pdf
[31] https://www.regione.piemonte.it/web/media/27777/download

reported to water intake structures along the main hydrographic network, especially along the Cervo, Elvo, Strona, and Sessera torrents.[32]

In Biella, the Fondazione Pistoletto experienced flooding, and tragically the riverbank protections that had been built after the devastating flood of June 2002 were completely swept away. Several private buildings, including historically significant ones, suffered severe damage.[33]

Lastly, in Campiglia Cervo, the sheer force of the Cervo torrent's floodwaters eroded and washed away a long stretch of the SP100 road in a section known as Malpensà, as shown in *Fig. 14*.

Fig. 14: Malpensà area in Campiglia Cervo. **[3]**

2.2.4. Province of Novara

In the province of Novara, the bridge connecting Romagnano Sesia and Gattinara, which spans the Sesia River**,** collapsed (*Fig. 15*).[34] This viaduct, managed by the Province of Novara, was a key transportation route, essential for traffic heading towards Alta Valsesia and for connecting the towns of the lower valley, particularly Gattinara**.**

[32] https://www.arpa.piemonte.it/sites/default/files/media/2024-07/rapporto_evento_02_ottobre_2020_.pdf
[33] https://www.regione.piemonte.it/web/media/27777/download
[34] https://www.regione.piemonte.it/web/media/27777/download

Fig. 15: Collapsed bridge connecting Romagnano Sesia with Gattinara. **[1]**

In the mid-section of the Sesia River, near the municipality of San Nazario S., a section of a rural road was eroded.[35] The severe weather also battered the Borgomanero area, Lower Valsesia, and Cusio, leaving behind extensive damage. Almost every town in the region experienced fallen trees, leading to multiple road closures. In Briga Novarese, Ghemme and Cavaglio d'Agogna, a multitude of downed trees completely obstructed the road that crosses the hills.[36] Along the Agogna stream, multiple overflows of its embankments were reported.[37]

2.2.5. Province of Vercelli

In the lowland area of the Vercelli province, persistent rainfall caused exceptionally high river discharges, exceeding the 200 year return period and approaching the 500 year return period along the Cervo Torrent and the Sesia River,[38] leading to numerous overflows and levee breaches, particularly in the municipalities of Motta dei Conti, Caresana, Balocco, and Vercelli (*Fig. 16*).[39] Severe flooding affected the eastern part of the city of Vercelli, especially in the southern

[35] https://www.regione.piemonte.it/web/media/27777/download
[36] https://www.sigeaweb.it/documenti/gda-supplemento-4-2021.pdf
[37] https://www.regione.piemonte.it/web/media/27777/download
[38] https://www.regione.piemonte.it/web/media/27777/download
[39] https://www.sigeaweb.it/documenti/gda-supplemento-4-2021.pdf

area, where the Cappuccini district was inundated, with water levels exceeding one meter inside homes.[40]

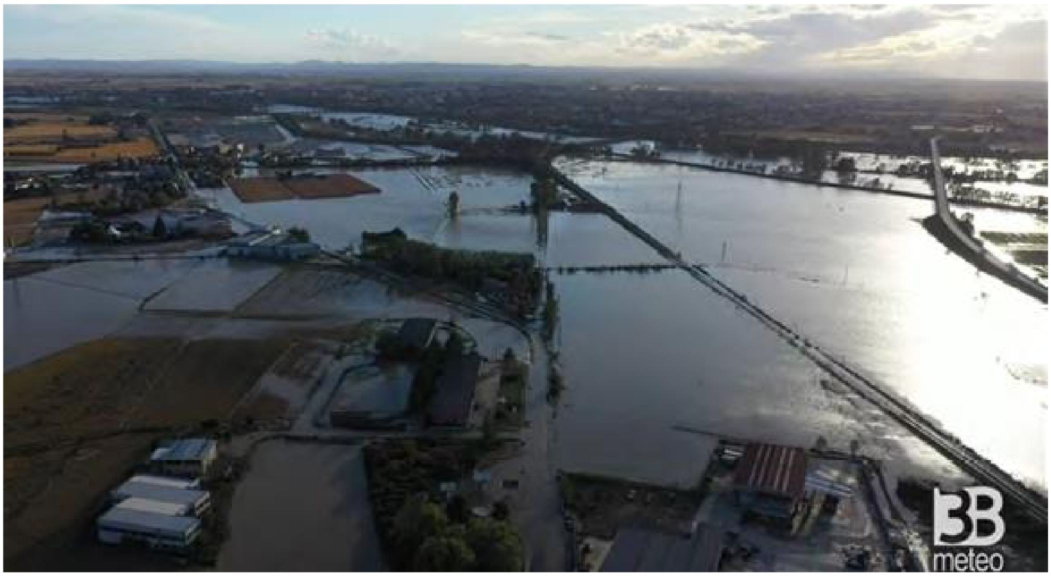

Fig. 16: The extensive flooding that has affected the hamlet Bivio Sesia, the railway line Vercelli-Novara and the provincial roads 11 and 11 bis. Source: 3BMeteo. **[1]**

In the upper part of the province, Valsesia, the intense rainfall unleashed torrential flows that washed away numerous crossings, cutting off several hamlets and towns. In the municipalities of Piode and Campertogno, significant erosion was observed along riverbanks in certain areas, destroying the protective embankments.[41]

A massive landslide severely damaged the road network in Val Mastallone: the road leading to Cravagliana was cut off for approximately 300 meters, isolating four municipalities. These communities were left without electricity, running water, and telephone connections.[42]

In Varallo, within the Camasco valley, the Rio Nono caused extensive damage to infrastructure, destroying roads and bridges.[43]

Tragically, in Quarona, a man lost his life after being swept away by the floodwaters of the Sesia River.[44]

[40] https://www.regione.piemonte.it/web/media/27777/download
[41] https://www.arpa.piemonte.it/sites/default/files/media/2024-07/rapporto_evento_02_ottobre_2020_.pdf
[42] https://www.regione.piemonte.it/web/media/27777/download
[43] https://www.regione.piemonte.it/web/media/27777/download
[44] https://www.lastampa.it/vercelli/2020/10/03/news/ritrovato-il-corpo-senza-vita-del-36enne-di-quarona-finito-nel-fiume-sesia-in-auto-col-fratello-1.39379643/

The heavy overnight precipitations resulted in power outages affecting 55,000 users across the region. They were distributed as follows: 11,599 in Cuneo, 14,200 in Novara, 14,000 in Verbano-Cusio-Ossola, 6,700 in Vercelli, and 4,500 in Biella.[45]

2.2.6. Province of Torino

The Canavese area also faced significant challenges, with reports indicating fallen trees, landslides and flooding of the Dora Baltea River. The river's height reached danger levels at the Tavagnasco hydrometer.

The most severe disruptions occurred in Pont Canavese, Alpette, and Vico Canavese, where several hamlets lost electricity.[46]

Due to the Dora Baltea overflowing, the A5 Torino-Aosta highway was closed as a precaution measure between Ivrea and Quincinetto.

In Ivrea, specifically in the Via delle Rocchette area, the river swept away vehicles, flooded basements and inundated the lower floors of several buildings.[47]

As the Dora Baltea's flood crest moved through, it caused major disruptions to both railway lines and roads.

2.2.7. Province of Asti and Alessandria

The Tanaro River flood crest passed through Asti and Alessandria, remaining below danger levels. However, power outages in the Province of Alessandria still caused significant disruptions for residents.

In Casale Monferrato, in the Terranova district, 600 people had to be evacuated because the Sesia River and its tributaries overflowed their banks.[48]

In the municipalities of Pasturana and Tassarolo (AL), an obstruction affected the course of the Riasco stream. The blockage consisted of a large accumulation of earth material, which collapsed from the left orographic wall, approximately 40 meters high, that defines the overlying alluvial terrace. The accumulation, stretching about 40 meters along the riverbed with a thickness of approximately 10 meters, completely blocked the water flow, causing an ephemeral reservoir that overflowed the road crossing located 150 meters upstream by approximately 50

[45] https://www.arpa.piemonte.it/sites/default/files/media/2024-07/rapporto_evento_02_ottobre_2020_.pdf
[46] https://www.regione.piemonte.it/web/media/27777/download
[47] https://www.regione.piemonte.it/web/media/27777/download
[48] https://www.arpa.piemonte.it/sites/default/files/media/2024-07/rapporto_evento_02_ottobre_2020_.pdf

cm. The estimated volume of the deposit was between 3,500 and 4,000 cubic meters.[49]

On the evening of Sunday, October 4th, around 8:30 PM, in Lu Monferrato, the bell tower of the historic 15th-century Church of San Biagio collapsed, probably due to the bad weather of those days. This church was an important landmark in the area.[50]

Fig. 17 shows the geolocation of the impacts described in the previous pages and the damaged and/or collapsed infrastructures. The map was created with QGIS, using OSM Standard as background and pointing the geolocation of the affected infrastructures on the territory of Piedmont.

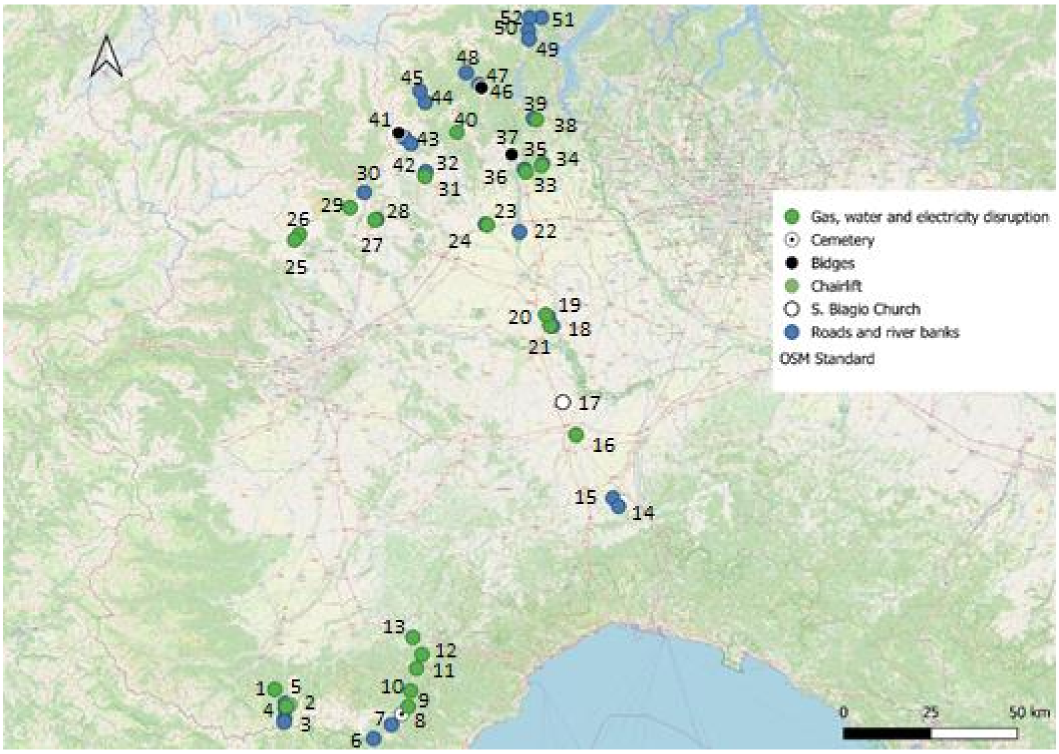

Fig. 17: Map of impacts and damaged and/or collapsed infrastructure.

Below is a description list of the points represented on the map.

- **1: Vernante.** Many families were evacuated due to the flood.
- **2, 3, 4 and 5: Limone Piemonte.** The extreme torrential activity of the Vermenagna River and its tributary, Rio di San Giovanni, caused the destruction or flooding of over 70 buildings, while another 15 underground structures were inundated. The main road suffered multiple interruptions,

[49] https://www.sigeaweb.it/documenti/gda-supplemento-4-2021.pdf

[50] https://www.lastampa.it/alessandria/2020/10/04/news/lu-crolla-il-campanile-nel-centro-del-paese-nessun-danno-alle-persone-1.39382633/

while secondary roads were heavily damaged. Many homes were left without electricity and gas because landslides broke multiple gas pipelines and the flooded rivers swept away power lines and pylons. A large mudslide and debris damaged a ski resort, demolished buildings and invaded the parking area.

- **6: Cantarana.** The national road suffered blockage due to the presence of mud and debris.
- **7: Trappa.** The cemetery, situated near the riverbank, was devastated as the floodwaters swept away numerous coffins.
- **8: Garessio.** Severe damage was caused from the flooding of the Tanaro River, leaving residents without water and electricity. The flood hit infrastructure, businesses, homes and cellars.
- **9: Priola.** Many families were evacuated due to damages to homes, gas pipelines and infrastructures.
- **10 and 11: Bagnasco.** The town was left without gas and, in some areas, without water. The flood also caused the collapse of several arches of the town's iconic roman bridge.
- **12: Nucetto.** The town suffered a significant power outage, with half of it left without electricity and a gas pipeline rupture occurred in one of the hamlets. Approximately twenty houses were inundated by floodwaters.
- **13: Ceva.** The Tanaro River overflowed, leading to numerous garages being flooded with water and mud. The headquarters of the Croce Bianca emergency services was completely inundated, together with the local school.
- **14 and 15: Tassarolo and Pasturana.** An obstruction affected the course of the Riasco stream, completely blocking the water flow and causing an ephemeral reservoir that overflowed the road crossing located 150 meters upstream.
- **16: Alessandria.** Power outages caused significant disruptions for residents.
- **17: Lu Monferrato.** The bell tower of the historic 15th century Church of San Biagio collapsed.
- **18, 19, 20 and 21: Motta dei Conti and Caresana.** Overflows and levee breaches.
- **22: San Nazario Sesia.** A section of a rural road was eroded.
- **23 and 24: Balocco.** Overflows and levee breaches.
- **25 and 26: Alpette and Pont Canavese.** Several hamlets lost electricity.
- **27 and 28: Ivrea.** Due to the Dora Baltea overflowing, the A5 Torino-Aosta highway was closed as a precaution measure between Ivrea and Quincinetto. The river swept away vehicles, flooded basements and inundated the lower floors of several buildings
- **29: Vico Canavese.** Several hamlets lost electricity.
- **30: Tavagnasco.** The Dora Baltea's height reached danger levels at the Tavagnasco hydrometer.
- **31 and 32: Biella.** The Fondazione Pistoletto experienced flooding and riverbank protections were completely swept away. Several private buildings, including historically significant ones, suffered severe damage.

- **33, 34, 35 and 36: Ghemme.** A multitude of downed trees completely obstructed the road that crosses the hills.
- **37: Romagnano Sesia.** The bridge connecting Romagnano Sesia and Gattinara, which spans the Sesia River, collapsed.
- **38 and 39: Briga Novarese.** A multitude of downed trees completely obstructed the road that crosses the hills.
- **40: Coggiola.** Several hamlets lost electricity.
- **41: Piedicavallo.** Only one of the seven bridges remained intact, while the other six collapsed or were severely damaged.
- **42 and 43: Campiglia Cervo.** The sheer force of the Cervo torrent's floodwaters eroded and washed away a long stretch of the SP100 road in a section known as Malpensà.
- **44 and 45: Piode and Campertogno.** Significant erosion was observed along riverbanks in certain areas, destroying the protective embankments.
- **46 and 47: Varallo Sesia.** The Rio Nono caused extensive damage to infrastructure, destroying roads and bridges.
- **48: Cravagliana.** A massive landslide severely damaged the road network in Val Mastallone: the road leading to Cravagliana was cut off for approximately 300 meters, isolating four municipalities. These communities were left without electricity, running water, and telephone connections.
- **49, 50, 51 and 52: Gravellona Toce.** The extreme intensity of the precipitations led to widespread flooding of roads and underpasses, along with numerous landslides and mudslides. This caused severe disruptions to transportation and damage to infrastructure.

2.3. Comparison with the past

In the geomorphological study of an area, historical documents concerning landslides and floods are very useful tools: the analysis of past information can offer a valuable contribution to the prediction and prevention of instability phenomena.

Looking at the history of floods in a given watercourse can highlight how river sections subject to flooding and areas flooded by water tend to repeat themselves over time. What is also clear from historical analysis is that when an area that is never flooded before suddenly is inundated, it is frequently because new human-made structures have altered the landscape and changed how the river naturally behaves.[51]

This highlight why it is essential to analyse the changes that have occurred in an area over the years. By doing so, it is possible to identify which areas are potentially vulnerable to future flooding. When the available historical data are sufficient, it is possible to perform statistical evaluations of how these physical

[51] https://www.sigeaweb.it/documenti/gda-supplemento-4-2021.pdf

processes have changed over space and time. This kind of in-depth processing provides key information for further informed spatial planning.

This approach allows decisions to be based on not only the current conditions of the area, but also on a dynamic and evolving framework that covers a long time span.

The following images (*Fig. 18*, *Fig. 19*, and *Fig. 20*) show how the phenomena of erosion have affected several times the same valleys and towns.

Fig. 18: Postcard concerning the flood of the Tanaro at the Odasso bridge on November 21, 1926. **[1]**

Fig. 19: Aerial view of Garessio on November 9, 1994 following the flooding of the Tanaro. **[1]**

Fig. 20: Memorial plaque of the Tanaro flood of November 10, 1886, Ceva. The line is located 37 cm from the ground. **[1]**

2.4. Impacts on the society

As stated in the past pages, Storm Alex caused widespread damage, both direct and indirect, severely influencing the affected community. This event did not just disrupt daily life, but affected the region's economic infrastructure and inflicted significant harm on local businesses. The scale of destruction was immeasurable. Tragically, the human toll was quantifiable: at least 550 persons were displaced and there were 20 victims (three in Italy, all linked to river dynamics), including 10 individuals who were never found.

Among those who perished, a 36-year-old man in the province of Vercelli tragically died when a section of the Doccio-Crevola road collapsed under the force of the water. His body was later recovered in the Bettole hamlet of Borgosesia, on the banks of the Sesia River.[52] A few days after the disaster, rescuers also found the body of a herdsman who was overwhelmed by water while walking with his brother in Vievola, a hamlet in Tende, on the French side of the Colle di Tenda.[53] Additionally, a 77-year-old hunter went missing in Lomellina (Palestro, PV) after being caught by the overflowing Sesia River while inside a hunting cabin.[54]

In response to the immense devastation, *Specchio dei tempi*, the charitable foundation of *La Stampa*, which has long supported local communities, launched a fundraising campaign to assist those affected. Their initiative aimed to not only gather financial resources but also to identify and address the most urgent needs to provide immediate support.

[52] https://www.lastampa.it/vercelli/2020/10/03/news/ritrovato-il-corpo-senza-vita-del-36enne-di-quarona-finito-nel-fiume-sesia-in-auto-col-fratello-1.39379643/

[53] https://torino.repubblica.it/cronaca/2020/10/05/news/non_e_del_malgaro_cuneese_il_corpo_recuperato_ieri_in_val_roya_riprendono_le_ricerche-269499875/

[54] https://www.ansa.it/sito/notizie/topnews/2020/10/03/maltempo-disperso-un-cacciatore-nel-pavese_5ffa46d9-b32c-4d0e-a91f-639e817b63b9.html

3. CAUSES OF FAILURE

In the Ligurian Alps, there are large formations of carbonate rocks, characterized by the presence of numerous underground water circuits that feed sources with variable flows. In these areas, aquifers have high permeability, so rainwater infiltrates into the bedrock and re-emerges to the springs after generally longer times than direct surface runoff.

During intense flood events, these underground aquifers absorb a significant amount of the rainfall, which helps reducing the volume of water flowing to the surface. However, the data collected during the last alluvium episodes affecting various sectors of the Ligurian Alps indicate that even in areas with carbonate rocks, the flows of the main watercourses have reached exceptionally high values.

In the following pages, the thesis will focus on analysing the hydrogeological and karst factors that influence the regime of surface watercourses, taking into consideration the Tanaro Valley, affected by the presence of extensive outcrops of carbonate rocks.

3.1. Hydrogeological factors

The high basin of the Tanaro Valley is characterized by the presence of numerous karstic massifs, within which important underground circuits develop that, thanks to consistent infiltrative contributions, feed sources with high flows. These karstic systems are characterized by large absorbent areas, with extensive depressions of tectonic-karstic origin, and for a superficial karst without cover, rich in microforms that favour a very rapid infiltration of the meteor waters and of nival fusion. *Fig. 21* and *Fig. 22* shows a terrain's section to better understand the karstic system.

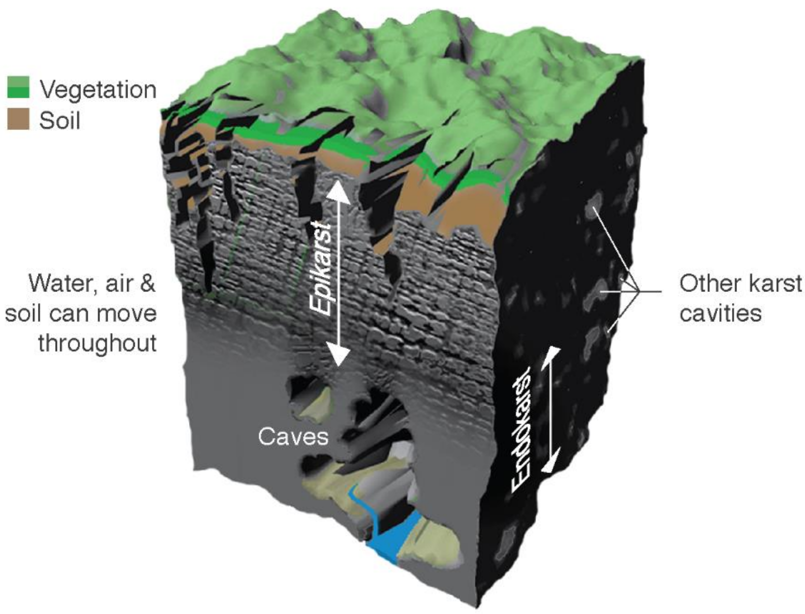

Fig. 21: Exokarst, Epikarst and Endokarst components of the Karst system. **[82]**

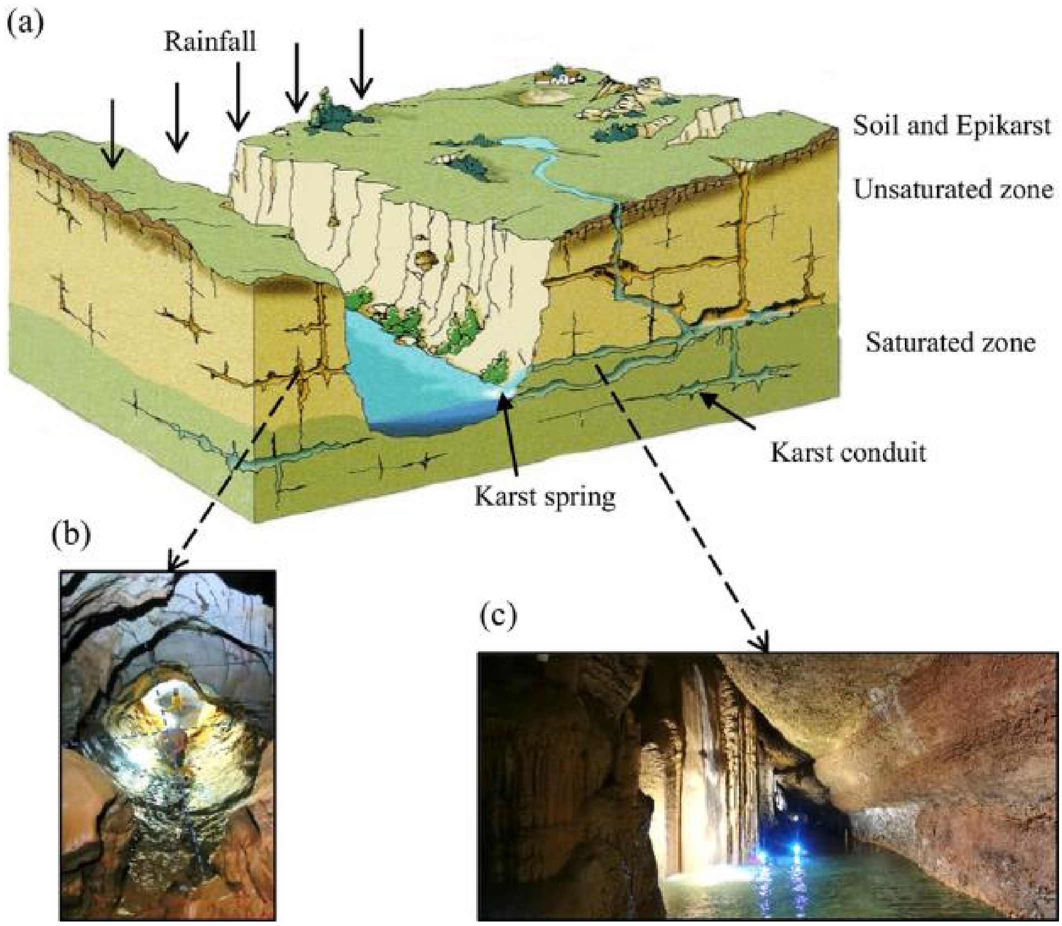

Fig. 22: (a) Conceptual model of Karst system (modified from Donsimoni et al. 2008); (b) example of karstic conduits developed along an inception feature; (c) a Karst underground river. **[83]**

Numerous tests with artificial tracers, conducted along the margins of these hydrostructures, have confirmed the existence of direct links with the sources mentioned, also showing very high flow velocities, above 7,000 meters per day; calculated by automatic scanning.[55]

The karst system develops inside large pipelines set "full load", which cross the river bed and resurface on the opposite side.

The main morphometric parameters for these river basins are listed in *Tab. 3*. Among these, the drainage density is one of the most significant indicators, as it expresses the capacity of the basin to dispose of surface water. This parameter can provide information both on the predisposition of the reservoir to water storage and on the degree of infiltration of water into the substrate.

The form factor, which expresses the degree of sinuosity of the main river boom, can instead provide information on the response times of the basin following weather-rainfall events. Finally, the circularity ratio has also been calculated

[55] https://www.sigeaweb.it/documenti/gda-supplemento-4-2021.pdf

which, together with the form factor, helps to define the development of the drainage system in relation to the extension of the basin area.

Corso d'acqua	Formula	T. Vermenagna complessivo	Rio Panice	T. San Giovanni complessivo	T. Almellina	Rio Milliboro
Superficie sottesa (km^2)	A	35,4	9,76	20,97	6,74	1,95
Quota max (m s.l.m.)	qMax	2755,9	2204	2381	2300	1950
Quota min (m s.l.m.)	qmin	975	1110	970	1050	1000
Reticolo idrografico (km)	Σ lungh	223,2	142,8	225,7	121,9	18,7
Lunghezza asta principale (km)	L	9,04	4,89	7,28	4,28	3,43
Densità di drenaggio	Dd= Σ Σ lungh/A	6,30	14,63	10,76	18,1	9,59
Perimetro bacino (km)	P	28,13	13,3	23,07	13,18	8,52
Fattore forma	$F_f = A/L^2$	0,43	0,41	0,40	0,37	0,17
Rapporto di circolarità	$R_c = 4\pi A/P^2$	0,56	0,69	0,49	0,49	0,34

Tab. 3: Morphometric elements of the basins draining the territory of Limone Piemonte. **[1]**

3.2. Urban development of the territory

The town of Ceva, located on the banks of the Tanaro River, has suffered numerous floods throughout its history. An analysis of the urban development of the last 150 years shows how the settlement has progressively extended into natural areas of water expansion, often ignoring the hydraulic risk, despite the frequent "warnings" provided by the Tanaro and its tributary, the Cevetta.[56] *Fig. 23* was made using Google Earth and represents the geolocation of Ceva in Piedmont.

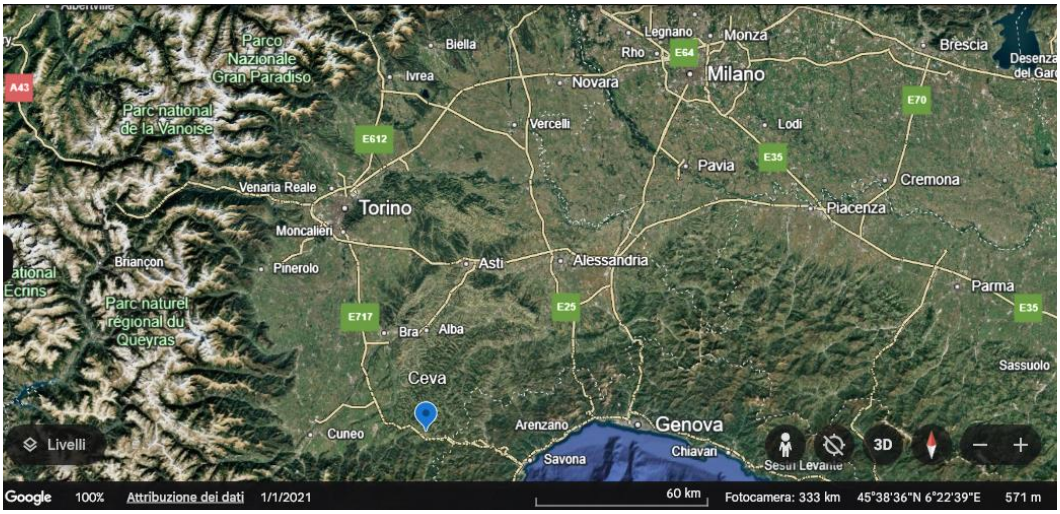

Fig. 23: Geolocation of Ceva in Piedmont. Made using Google Earth.

[56] https://www.sigeaweb.it/documenti/gda-supplemento-4-2021.pdf

The last three most significant flood events occurred on November 5 and November 6, 1994 (the most severe),[57] November 24 and November 25, 2016,[58] and October 2 and October 3, 2020. These incidents have caused extensive damage, aggravated by the presence of settlements in the most vulnerable areas.

Despite destructive alluvium events already occurred in the past (documented by historical sources and maps of the time), the expansion of construction, especially in the second post-war period, has affected areas already affected by previous floods. In particular, the southern sector of the historic centre (*Fig. 24*), near the bridge on the Strada Provinciale, is located on a wide alluvial plain frequently invaded by the waters of the Tanaro during floods.

Fig. 24: Positioning of the historic centre of Ceva on an alluvial plain.

Until the 1960s, the area was sparsely urbanized, except for a few farms. Later, however, there was a constant expansion of construction, with the edification of villas, houses, workshops, shops, an oratory and two schools. Those buildings were all heavily damaged during the flood of 1994, and to a lesser extent also in 2016 and 2020.[59]

57 https://cri.it/piemonte/2019/11/05/la-grande-alluvione-del-1994/
58 https://datimeteoasti.it/articoli-alluvioni/analisi-evento-alluvionale-24-25-novembre-2016-piemonte/
59 https://www.sigeaweb.it/documenti/gda-supplemento-4-2021.pdf

Proper land-use planning, especially in densely populated urban contexts, must necessarily take into account the information derived from historical research, the morphological evidence of the territory and the presence of recent infrastructure. Only through an accurate evaluation of the interactions between these components and river dynamics, hydraulic risk can be effectively reduced.

Tab. 4 shows the urban development of the town of Ceva, derived from the comparison between historical maps, while *Fig. 25* represents a graph describing how, with the increasing of the urbanized area of Ceva, increases also the area affected by a large flood such as that of November 1994.

Anno	Area urbanizzata (ha)	Incremento (ha)	Periodo in anni intercorsi	Incremento annuo (ha/anni)
Prima del 1852	2,77			
1902	3,39	0,62	50	0,01
1930	6,83	3,44	28	0,12
1971	12,44	5,61	41	0,14
1994	18,80	6,36	23	0,27
2020	19,17	0,37	26	0,01

Tab. 4: Ceva's urban development derived from historical maps. **[1]**

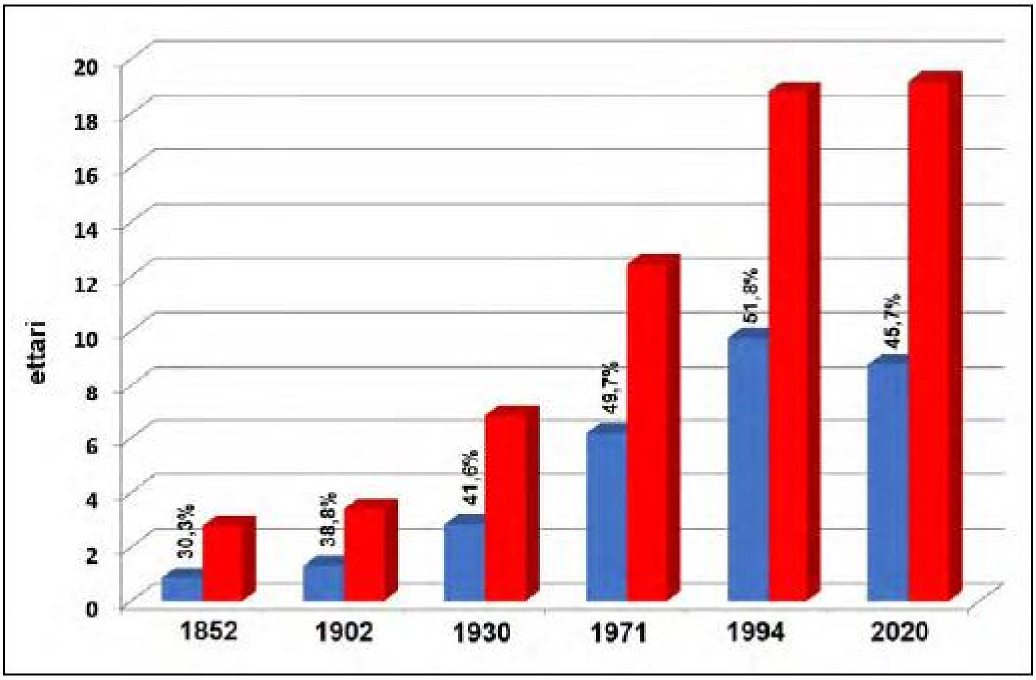

Fig. 25: In red: urbanized area of Ceva drawn from different historical maps. In blue: percentage affected by a large flood such as that of November 1994. **[1]**

The analysis of the effects and consequences of Storm Alex, as described in the previous paragraphs, raises questions about how such a scenario could have occurred. One of the hypotheses often more accredited by public opinion is certainly that of building abuse, but, in the context of Piedmont, this can be considered a marginal phenomenon from a quantitative point of view. When present, it is mostly manifested in the form of irregularities related to the construction or finishing of buildings, often limited to internal modifications, generally without relevance in terms of hydrogeological risk.

In view of this, it is legitimate to ask why the many constraints existing in the field of land management and planning, even those at a higher level than municipal planning, have not been able to limit urbanization, in particular in mountain areas, thus avoiding such extensive damage.

3.2.1. Hydrogeological constraint

Analysing the main constraints to the urbanization of the territory, the first normative reference, in chronological order, is represented by the so-called "hydrogeological constraint". These are rules governing land use and planning, not only for urban development purposes but also in relation to agricultural and forestry-pastoral uses. However, these provisions do not apply uniformly throughout the national territory, but only in specific and limited areas.

In the 1920s, the introduction of the hydrogeological constraint was preceded by a careful study of the territory, conducted not only in geological and hydrogeological terms, but also through a survey of land use and vegetation cover. The boundaries resulting from these studies are the result of a meticulous work carried out by the supervisors of the current Corpo Forestale dello Stato, which, with the means available at the time, made a real "photograph" of the degree of instability and hydrogeological vulnerability of Italy at that time.

In the specific case of Piedmont, and in particular of the mountain area of Limone Piemonte, the areas subject to hydrogeological constraints cover almost the entire surface, with the exception of some valley bottoms, particularly where they are more extensive. It is important to specify that the hydrogeological constraint does not have absolute character: in fact, it is possible to intervene in the restricted areas, if appropriate precautions are taken and after the necessary authorizations have been issued, often accompanied by specific requirements defined on a case-by-case basis.

At the regional level, the application and management of the hydrogeological link, especially in the last decades of the twentieth century, have been characterized by a fruitful collaboration between the technical offices of the Regione Piemonte, competent in the field of geology, and the Corpo Forestale dello Stato, responsible for forestry aspects. This synergy has made it possible to deal with the authorisation investigations with well-established technical skills.

In recent years, Regione Piemonte has established its own offices also competent in the field of forestry, directly taking over the management of practices related to the most important interventions. For minor interventions (less than 5000 m^2 of extension or 2500 m^3 between excavations and carry-over), instead, the legislation has provided for the sub-delegation of powers to the municipalities. However, many municipal administrations do not have the necessary technical expertise, resulting in a reduction in the effectiveness of the "permission filter". This has sometimes allowed the construction and urban development in areas not suitable from a geo-hydrological point of view.

3.2.2. Environmental and landscape constraints

As with the hydrogeological constraint, the landscape constraint does not imply an absolute ban on the transformation of the territory, but simply requires the prior obtaining of a specific authorisation. Such authorisation may only be granted if the proposed intervention does not "harm the protected landscape values". The competent administration, in the analysis of the application, has the task to verify that the intervention complies with the requirements contained in the landscape plans, verify the compatibility with the values protected by the link and the consistency with the management criteria of the area or property, as well as the coherence with the landscape quality objectives.

In the present case, the numerous disturbances observed at Limone Piemonte near the hydrographic network, a critical situation emerges: when intervention projects are presented adjacent to watercourses, the preliminary assessments focus exclusively on landscape aspects, completely neglecting water and geomorphological issues.

It is important to remember that the primary intention of the legislation on landscape protection is to protect watercourses from the impacts of human activities, and not vice versa. However, even with regard to this constraint, in the Piedmont context there has been a process of administrative decentralization: in recent years, in fact, responsibility for the investigation and the issue of landscape permits has been entrusted to individual municipalities, which use the so-called "Commissione Locale per il Paesaggio".

This choice, if on the one hand aims at a more direct and capillary management, on the other hand has led to some critical issues. The administrative fragmentation and small size of many municipalities has often prevented adequate scientific and technical support. Consequently, as already observed in the case of the hydrogeological link, there was a lesser effectiveness in the "authorization filter" of the investigative procedures, making it possible to carry out urban development in areas that are particularly sensitive from the environmental and geomorphological point of view.

3.2.3. Local constraints

At local level, in addition to the constraints of nature such as hydrogeological and landscape, there are other urban constraints that can be introduced by municipal administrations to address hydrogeological problems. Through the tools of urban and territorial planning, in particular the Piano Regolatore Generale (PRG), the municipalities can in fact establish restrictions on construction in relation to the intrinsic danger of the territory.

In order to identify and delimit the unbuildable areas, the municipal territory is generally divided into homogeneous zones according to the level of hydrogeological and geomorphological hazard and the consequent suitability for urban use. This classification follows a "traffic light" approach, divided into three main classes:

- **Class I:** includes those parts of the territory where the danger is such as not to place particular constraints on urbanization. These areas are, therefore, buildable in compliance with urban regulations and in the absence of other superordinate constraints.
- **Class II:** includes areas with "moderate" danger, which can be overcome by "modest technical measures" applicable to the individual lot. In these cases, the construction is subject to the prior execution of specific surveys that allow a more detailed assessment of the site characteristics and identify the technical measures to be taken to enable the safe implementation of interventions.
- **Class III:** includes areas where the geomorphological or hydrogeological hazard is so high that they are "unsuitable for new settlements", therefore unbuildable. This class is itself divided into two subclasses:

    - **Class IIIa**, for areas without human settlements;
    - **Class IIIb**, referring to areas already built on the date of classification.

In the latter case, the legislation provides for the implementation of "land-use planning measures", without which no "increase in anthropogenic load" is allowed. However, the interpretation of this last concept has given rise to many difficulties, since the expression "anthropogenic load" is not explicitly defined in the current town planning legislation, nor have clear operational indications been provided.

Despite the theoretical implementation of these regulations, the effectiveness in fighting urbanisation in risk areas has in fact proved rather limited. This is due, in large part, to the complexity of the Piedmont’s territorial context, strongly shaped by centuries of human presence and activity. In fact, authorities often have to deal with established and long-standing settlements, located even in hilly and mountainous areas now considered at high risk.

In many cases, these are historical buildings, even of great architectural or cultural value, sometimes under protection, even by international bodies such as UNESCO, and which would be unbuildable today according to modern criteria. Particularly relevant are the urbanizations carried out in the second post-war period, during the so-called "economic boom" of the 1950s and 1960s, a period during which rapid building development often neglected environmental and geomorphological issues, generating risk situations that today seem difficult to resolve retrospectively.

4. RISK MANAGEMENT MEASURES

Prior to the Alex storm, several risk management measures had been designed and implemented in areas of potential hydrogeological risk, with the aim of mitigating the effects of extreme flood events. These measures included:

- Early Warning Systems: ARPA Piemonte had installed meteorological monitoring systems to predict and alert to adverse weather conditions. Despite accurate forecasts, however, the intensity of precipitation has exceeded design standards, making some warning measures less effective.
- Hydraulic Defence Infrastructure: banks, dams and drains were built to control the flow of watercourses and prevent flooding. The exceptional amount of rain, however, has exceeded the design limits of these structures, leading in some cases to their collapse.
- Municipal Emergency Plans: municipalities such as Limone Piemonte had developed emergency plans to deal with crises. However, the magnitude of the event necessitated improvised evacuations and revealed gaps in the design of emergency plans. The Municipal Emergency Plan currently in force for Limone Piemonte (in inter-municipal form) dates back to January 13, 2020. Following the events of Storm Alex, there is no trace of a complete new drafting of the plan, but incremental actions and "emergency orders". The Municipality has in fact issued several emergency orders from 2020 to 2024 for urgent work on the territory, schools, connections and infrastructure affected by the flood. Examples of those emergency orders are punctual safety measures, such as the repair of the Rio San Giovanni with a regional funding of € 2.65 million,[60] and the reconstruction of the symbol bridge inaugurated in 2023.[61]

The analysis of these pre-event measures reveals that, although risk mitigation strategies had been adopted, the extraordinary intensity of Storm Alex exceeded the expected capacities of these measures, underlining the need to review and strengthen risk management strategies to address increasingly frequent extreme weather events.

The next pages of the thesis will be dedicated to analyse the damages caused by Storm Alex to the most affected municipalities, the response interventions, and the improvements proposed to face the hydrogeological risks.

[60] https://www.cuneo24.it/2024/07/265-milioni-per-la-messa-in-sicurezza-del-rio-san-giovanni-a-limone-piemonte-246714/

[61] https://www.rainews.it/tgr/piemonte/video/2023/06/alluvione-2020-limone-piemonte-garessio-ricostruzione-83388eb5-5e01-476f-b431-d18db3a6d3e2.html

4.1. Event response and evaluation of the effectiveness of measures

According to the testimonies, early warning measures were activated promptly: on October 2nd, ARPA Piemonte issued a red alert for hydrogeological and hydraulic risk to the south-west of the region. Although the location and intensity of the event were correctly predicted, the speed at which the floods occurred reduced the local authorities' ability to respond effectively. The Protezione Civile system has been activated for evacuations and real-time monitoring, but the situation has degenerated very quickly, blocking preventive action in many cases.

Several press publications highlighted how the inter-institutional solidarity was a crucial factor during the response to the event. In fact, municipalities, regions, Protezione Civile and volunteers collaborated in assisting displaced persons and in distributed aid, although logistical difficulties caused by the size of the event have slowed down many operations.

In summary, despite the advanced warning system and the existence of local emergency plans, the exceptional nature of the event showed that many structural and organizational measures were not designed to address such a residual risk.

4.2. Post event strategies and implemented improvements

As discussed in the previous pages of this thesis, Storm Alex caused damage in many areas of Piedmont. The most affected municipalities were those in the province of Cuneo. Below is a list of the proposed improvement strategies to address the hydrogeological risks in these municipalities.

- Limone Piemonte: located in the Valle Vermenagna, it has suffered significant damage to infrastructure, with damages estimated at more than 20 million euros. Two years later, in 2022, the municipality had received only about 5.8 million of the 21 promised,[62] with Regione Piemonte contributing its own funds. In addition to infrastructure interventions, the municipality has organized commemorative events such as "Inondazione" to raise awareness and raise funds for reconstruction.[63]
- Garessio: located in the province of Cuneo, the damage reported was significant, including infrastructure such as bridges and roads and necessitating reconstruction. The funds received by the municipality have

[62] https://www.rainews.it/tgr/piemonte/video/2022/10/limone-alluvione-danni-tenda-61d6b1a1-c521-4ee1-9b17-ec3c8d114999.html

[63] https://www.lavocedialba.it/2022/09/28/leggi-notizia/argomenti/attualita-14/articolo/limone-ricorda-i-tragici-eventi-dellalluvione-2020-con-la-2a-edizione-di-inondazione.html

been lower than promised, causing problems to the restoration of damaged infrastructure.[64]

- Ormea: this municipality has been isolated for days because of the damage to communication routes. Here too, the damage has exceeded €20 million, with funds received below initial promises.[65]
- Valdieri: infrastructures along the Gesso River have been particularly damaged. Regione Piemonte has allocated funds for urgent interventions, including the removal of debris, road rehabilitation and reconstruction of shore defences.[66]
- Entracque: it has seen the destruction of roads and trails in the Maritime Alps. The municipality worked with the Ente di gestione delle Aree Protette delle Alpi Marittime and others to start reconstruction work to restore roads and trails for access to refuges and hiking trails, with the aim of reopening tourist areas in time for the summer season.[67]

Following the event, there was a strong need to learn from the tragedy and make improvements to risk management strategies, both organisational and structural. National and local administrations, together with technical bodies such as ARPA, ISPRA and Protezione Civile, have launched post-event analysis processes with the aim of strengthening the resilience of infrastructures and communities.[68]

One of the main interventions was the initiation of reconstruction procedures with upgrading criteria compared to the pre-existing condition, avoiding simple repair. For example, as reported by *France24* in a 2021 article, the French government has allocated more than 200 million euros for the reconstruction of communication routes in the Roya Valley, integrating sustainability and resilience criteria into projects.[69] In Piedmont, on the other hand, according to a report by ARPA drawn up in 2020, work was financed for the arrangement of riverbeds, the reinforcement of bridle and the profiling of embankments, especially in the Tanaro and Vermenagna basins.[70]

At the same time, updates of local Protezione Civile plans were proposed, including updated simulations based on more frequent extreme events, greater involvement of the public in prevention and planning activities, and strengthening

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[64] https://www.rainews.it/tgr/piemonte/video/2023/06/alluvione-2020-limone-piemonte-garessio-ricostruzione-83388eb5-5e01-476f-b431-d18db3a6d3e2.html

[65] https://www.targatocn.it/2022/10/02/leggi-notizia/argomenti/attualita/articolo/due-anni-dalla-tempesta-alex-simonelli.html

[66] https://www.cuneodice.it/varie/cuneo-e-valli/valle-gesso-inaugurata-la-nuova-sede-della-pro-andonno_51157.html

[67] https://www.areeprotettealpimarittime.it/news/1683/la-ricostruzione-nelle-alpi-marittime-dopo-la-tempesta-alex

[68] https://windpress.info/it/press-release/365475/un-nuovo-ecosistema-difesa-soccorso-e-protezione-cosa-emerso-da-forum-pa-sicurezza

[69] https://www.france24.com/en/20201004-france-italy-step-up-rescue-efforts-after-deadly-storm-alex

[70] https://www.gazzettadalba.it/2022/11/interventi-contro-il-dissesto-idrogeologico-dal-pnrr-arrivano-158-milioni-per-il-piemonte/

real-time monitoring systems using sensors, weather radar and hydrological models.

Together with these improvements, ecosystem approaches have been introduced into planning: the need to adopt Nature Based Solutions (NBS) such as renationalisation of river beds, creation of rolling zones, restoration of wetlands as a natural buffer or the transfer of critical infrastructure from high-risk areas were discussed. These measures, although still at an early stage, are entering regional planning and could become key tools for future risk management, but although these initiatives have been discussed and voted as of fundamental importance, to date there is no evidence of implementation.

At the regulatory level, Storm Alex has given impetus to a broader reflection on climate change and the need to integrate its effects into spatial plans and building codes. The concept of "systemic resilience", understood as the ability not only to resist but also to adapt and improve after an impact, has entered more strongly into the technical and political debate.

As regards structural measures, Regione Piemonte has undertaken measures to restore and improve damaged infrastructure, including the reconstruction of the bridge over the Vermenagna River with greater resilience, securing unstable slopes and watercourses in the affected municipalities and, finally, using ERDF and PNRR special funds for hydraulic works.

In France, on the other hand, the Roya Valley has been the subject of a massive reconstruction and reorganization plan, thanks to the support of the Government and the French Civil Protection. Adaptive design criteria have been adopted, considering extreme events as a reference for new infrastructure.

Further notable initiatives were the push to strengthen cooperation between local and regional authorities, greater involvement of citizens in risk awareness through exercises and public campaigns and the digitisation of emergency plans with the use of mobile alert systems like SMS, apps and social media.

The Storm Alex, therefore, highlighted the need to shift from a simple reactive approach to a proactive one. This means focusing heavily on prevention and adaptation to climate change. The strategies put in place after Storm Alex demonstrate how an extreme event, as devastating as it was, can actually become a catalyst for change.

5. RECOVERY AND RESILIENCE

Resilience, in the context of water risk management, refers to the capacity of territory and communities to resist, adapt and recover from extreme events. This concept plays a key role in climate change adaptation policies and the prevention of natural disasters. In this context, resilience is not only referred to the ability to return to pre-disaster conditions, but implies the ability to learn from events and to improve risk management and mitigation measures.

Following flood disasters such as Storm Alex, several strategies could be put in place to improve the resilience of water risks in Piedmont. The following is a list of the main and most widely implemented strategies around the world to cope with extreme water events. For what regards the Piedmont case, some adaptation strategies have been put in place, while others are still under discussion or awaiting funding.

- Structural interventions: reinforcement of riverbanks, improvement of drainage systems and construction of rolling basins to reduce the risk of floods.

  The reinforcement of riverbanks refers to hydraulic engineering operations aimed at consolidating riverbanks in order to contain floods.[71] These may include the raising of existing embankments (as illustrated in *Fig. 26*), the construction of new defences (e.g. shore walls or sheet piles, as shown in *Fig. 28*) or the use of nature engineering techniques (e.g. restoration of riparian vegetation as shown in *Fig. 27*). The effectiveness of embankments depends on their height, strength and maintenance.

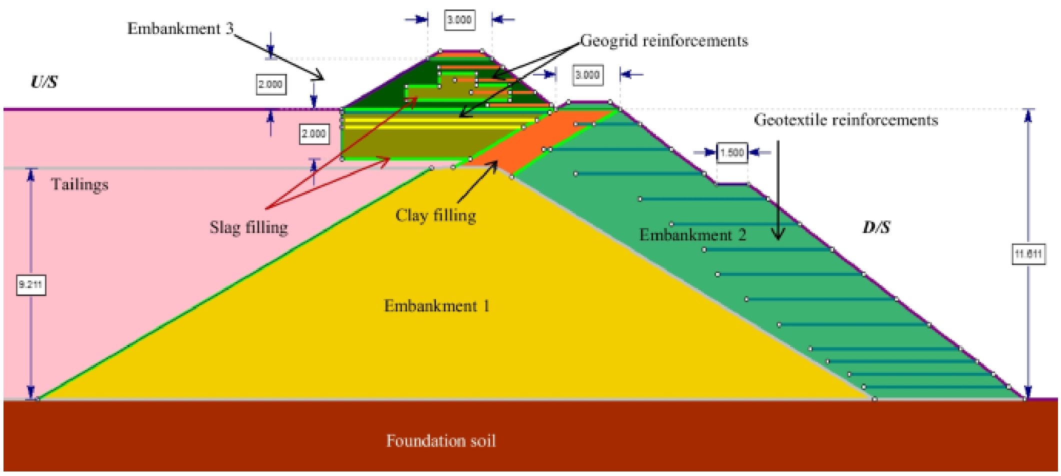

Fig. 26: Scheme of an embankment raising. **[73]**

[71] https://doi.org/10.1007/s42461-023-00772-8

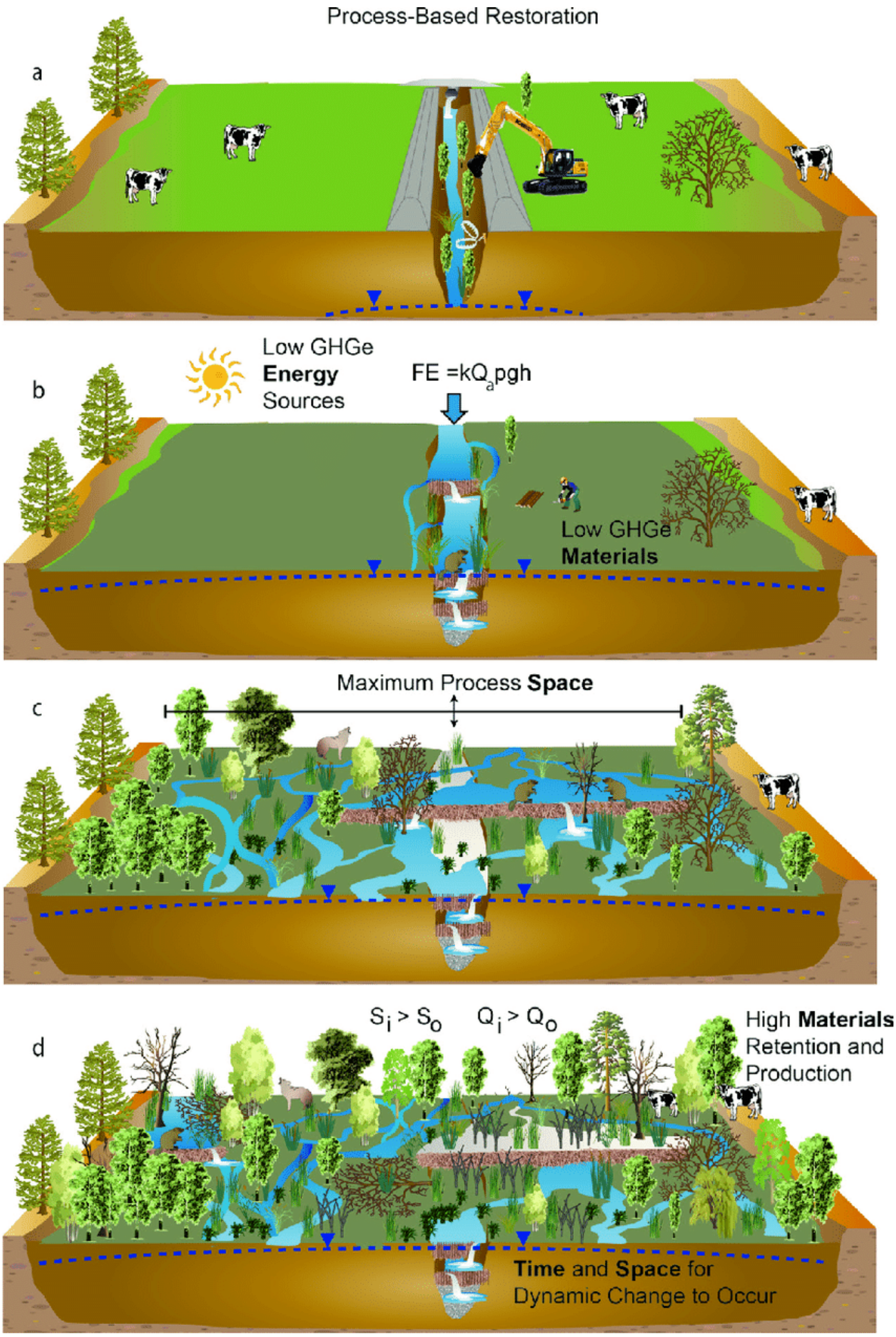

Fig. 27: Design criteria for process-based restoration of fluvial systems. **[74]**

Fig. 28: Sheet piles positioned along a river. **[72]**

As regards the improvement of the drainage systems, the focus in on the optimization of the network of canals, sewers and drainage infrastructures. In Piedmont, the 2021 Water Protection Plan has introduced measures to enhance the resilience of watercourses, including monitoring and flow management systems. The 2021 WTP is the update of the 2007 Plan. The revision was carried out with the need to formally and temporally adapt the regional strategy for safeguarding and management of Piedmont's watercourses to the substantial and significant regulatory changes, which have occurred over the years. Although, the aim of this revision is also to align the content and structure of the regional plan with the normative indications introduced by the Water Framework Directive for the elaboration of the district water management plan.[72] The aim is to ensure rainwater to rapidly runoff, especially form urban areas. This can involve activities as cleaning and maintaining existing networks, expanding drainage capacity or implementing Sustainable Urban Drainage Systems (SUDS).[73] SUDS are particularly relevant as they are designed to imitate natural water management processes, reducing the burden on traditional sewer systems and facilitating infiltration. *Fig. 29* and *Fig. 30* show some typical examples of SUDS, while *Fig. 31* represents a scheme of SUDS applied in an urban context.

[72] https://www.regione.piemonte.it/web/temi/ambiente-territorio/ambiente/acqua/piano-tutela-delle-acque-aggiornamento-2021

[73] https://www.iridra.eu/en/nature-based-solutions/sustainable-drainage-systems

Fig. 29: Typical examples of SUDS. **[75]**

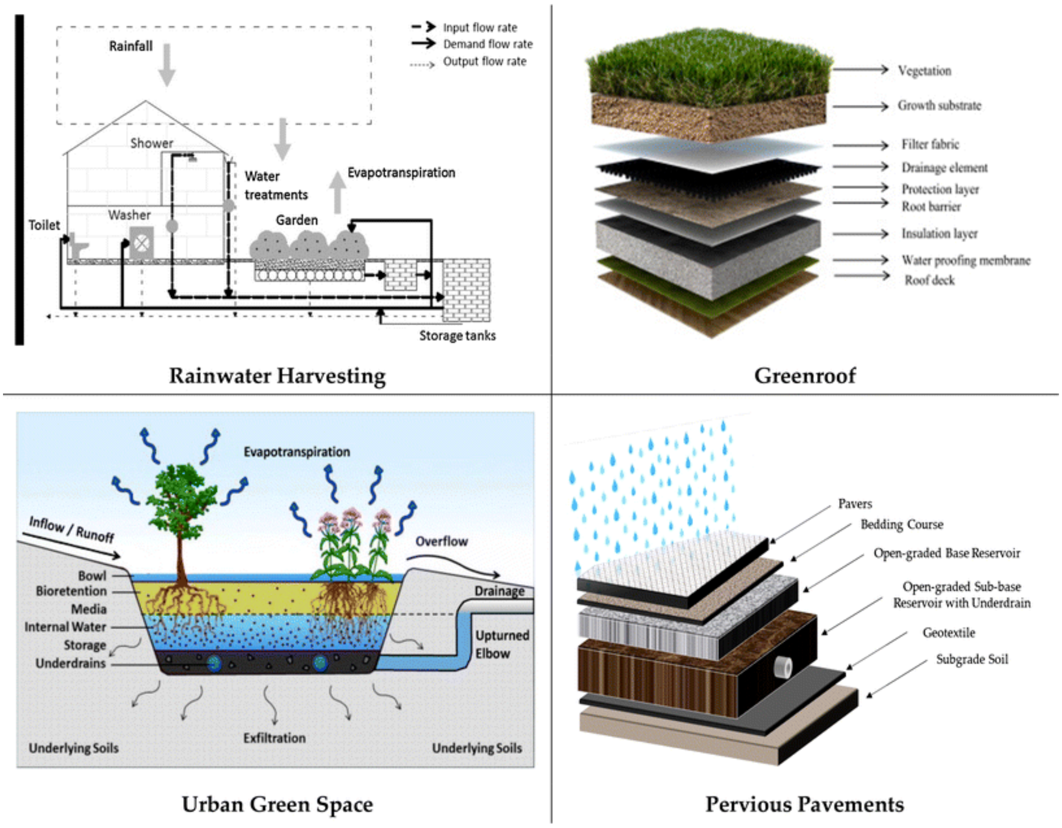

Fig. 30: Typical examples of SUDS in more details. **[76]**

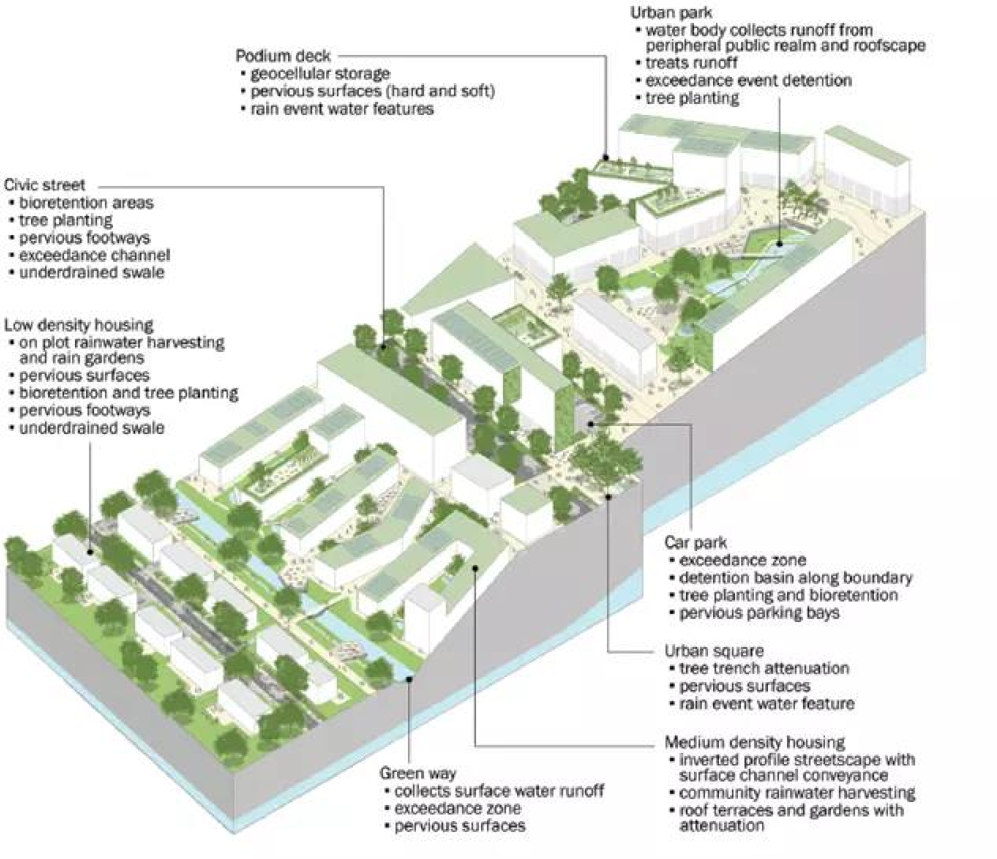

Fig. 31: SUDS applied in an urban context. **[77]**

The rolling basins are, on the other hand, works of temporary accumulation of floodwaters, carried out upstream of the areas at risk, in order to reduce the peak flow rate of watercourses.[74] They function as "sponges" that collect excess water during flood events and release it gradually. They may be open-air or underground, and their design takes into account the hydrological characteristics of the catchment area and the areas to be protected.

Fig. 32 represents a section for better understanding the functionality of rolling basins.

[74] https://www.leca.it/applicazioni/geotecnica-e-infrastrutture/bacini-di-accumulo-e-infiltrazione-interrati/

Fig. 32: Rolling basin under a public car park. **[78]**

For what concerns Piedmont, in December 2020, a regional ban for 2.7 million euros was published for projects aimed at the morphological redevelopment of rivers and lakes. The resources have been allocated to Provinces, Metropolitan City of Turin, individual or associated municipalities, managers of protected natural areas and Natura 2000 sites for interventions of morphological redevelopment of rivers and lakes.

The call also allows the financing of functional interventions for the maintenance and control of the flow in the riverbed and for the transmission of water withdrawal data, given the important contribution of these actions to the recovery of the chemical-physical and ecosystem quality of watercourses.

The maximum limit for funding was set at 125,000 euros per project and per beneficiary.[75]

- Infrastructure efficiency: reduction of water losses in distribution networks and improvement of treatment plants. The aim is to reduce the drinking water losses in distribution networks due to ruptures, cracks or insufficient maintenance of pipelines. This includes the identification and repair of leaks, replacement of obsolete network sections and implementation of advanced monitoring systems. Water leakage represents a significant waste of a

[75] https://www.regione.piemonte.it/web/temi/ambiente-territorio/foreste/tutela-bosco-territorio/programma-interventi-riqualificazione-dei-corpi-idrici-piemontesi-bando-2021

valuable resource and a cost to management companies. Technologies such as advanced sensor technology and hydraulic modelling are increasingly used.

Improving sewage treatment plants concerns the upgrading and extending wastewater treatment plants so that the water runoff, which is released directly into surface water bodies, meets increasingly stringent quality standards. This means adopting the advanced technologies to remove specific pollutants, such as nutrients and micro plastics. Better purification is crucial for keeping the aquatic ecosystem healthy and for ensuring the availability of good quality water. Modern plants also aim at the recovery of resources, such as biogas and sludge.

By the way, until today there is no evidence in Piedmont of improvements to water networks and sewage plants directly related to Storm Alex.

- Integrated water resources management: optimising water use through storage basins and wastewater reuse systems. The optimization of water use through storage basins does not only refer to rolling basins for filling, but also to reservoirs for collecting and storing water for different purposes, such as agriculture, water use and hydro power generation, ensuring availability even in drought periods and reducing the take-up from natural sources. The approach is to balance water supply and demand over time, managing water as a finite and valuable resource. *Fig. 33* represents a technical scheme of storage basins for the detention of storm water (in the upper part of the image) and for the retention of storm water (at the bottom).

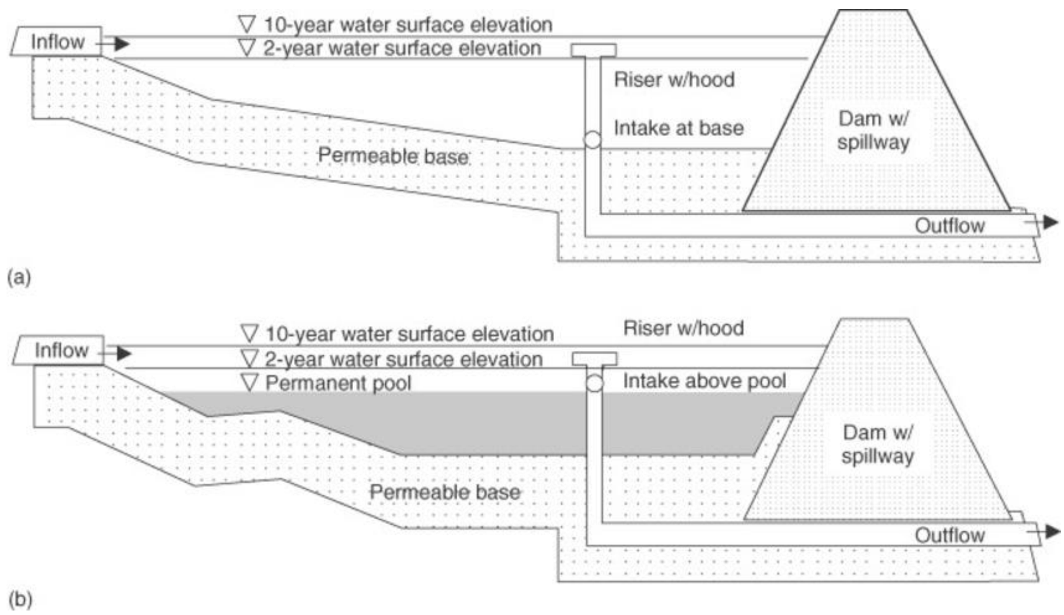

Fig. 33: Storage basins for the (a) detention and (b) retention of storm water. **[79]**

Wastewater reuse systems involve advanced treatment of wastewater (grey or black) to make it suitable for non-drinkable uses, such as agricultural irrigation, industrial use, road washing or non-drinkable civil uses, such as toilet drains. Reuse is a key strategy to address water scarcity by closing the water cycle and reducing pressure on conventional sources.

In Piedmont, allocations and funding to remediation consortia indicate interventions aimed at integrated management. The work carried out by the Ministero dei Lavori Pubblici e della Protezione del Suolo of Regione Piemonte with the Dipartimento Nazionale di Protezione Civile has resulted in a further 6,EUR 5 million to mitigate the hydrogeological risk and to make functional public infrastructure damaged by Storm Alex. At the provincial level, it is over 1.7 million for Biella, about 1.9 million for Cuneo, 116,000 euros for Novara, 605,000 euros for Turin, over 1 million for Verbano-Cusio-Ossola, 1.2 million for Vercelli.[76]

- Ecosystem approaches: wetland restoration and reforestation to improve the natural capacity of the territory to absorb and dispose of precipitation water.

Wetlands, such as swamps, peat bogs and ponds, act like "natural sponges", absorbing excess water during the rainfall events and releasing it slowly, thus reducing the flow rate of flooding and contributing to natural water filtration. The restoration aims to recreate or revitalise these ecosystems. Wetlands are also crucial for biodiversity and natural purification. Their restoration is an example of a "Nature-Based Solution". *Fig. 34* highlights the benefit, in terms of net carbon, of restored wetland.

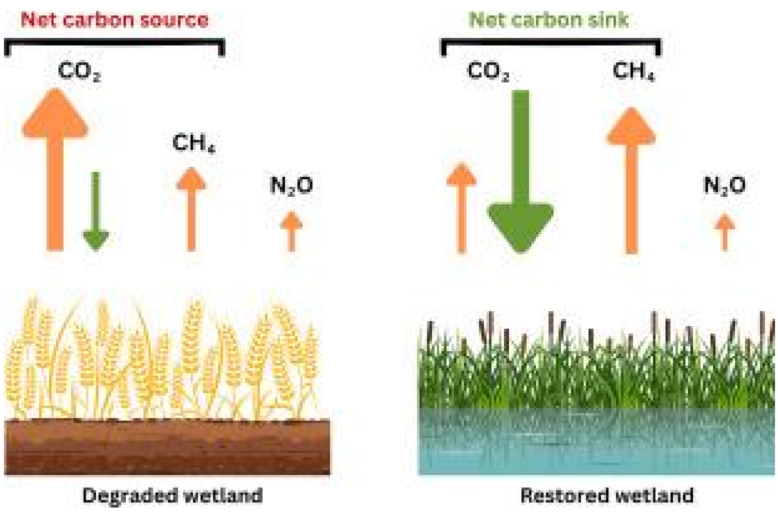

Fig. 34: Net carbon in degradated wetland (sx) VS net carbon in restored wetland (dx). **[80]**

[76] https://www.regione.piemonte.it/web/pinforma/notizie/alluvione-2020-oltre-65-milioni-per-continuare-ricostruzione

As regards reforestation, the presence of forests and tree vegetation increases the capacity of the soil to absorb rainwater, reducing surface runoff and erosion, while tree roots stabilize the soil, preventing landslides. Reforestation is not only an intervention for the hydrogeological stability, but also contributes to the counteraction of climate change through the absorption of CO2 and the conservation of biodiversity.

Fig. 35 represents a theoretical example of the reforestation process.

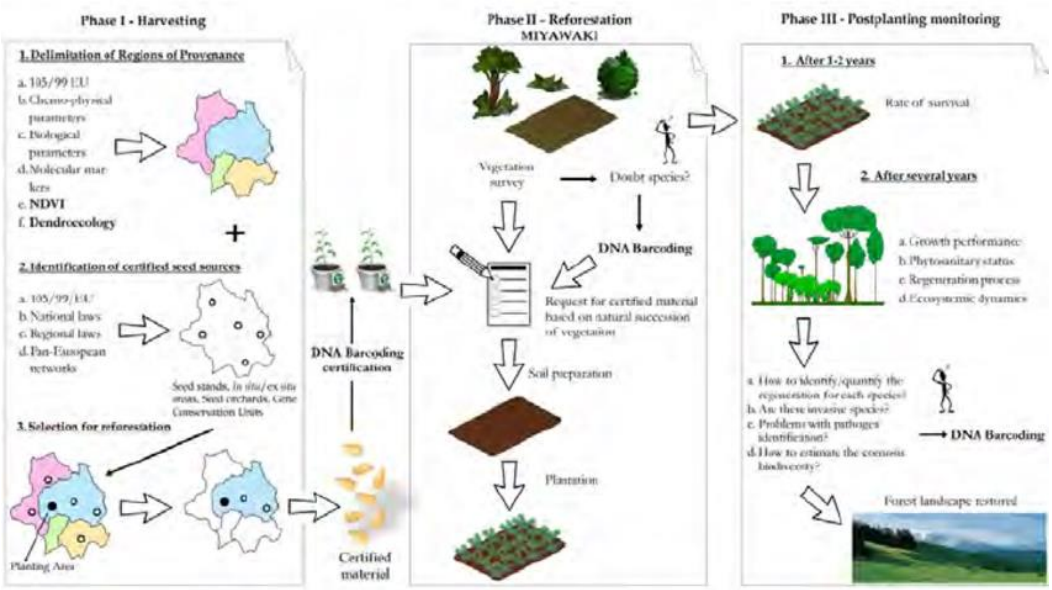

Fig. 35: Theoretical example of reforestation process. **[81]**

In 2022, the Piedmont Region has allocated funds for 11 projects to redevelop rivers and lakes, with an investment of about 2.9 million euros, aimed also at "green" and natural-based interventions such as the environmental restoration of banks. The projects that have obtained the best score are those of the Metropolitan City of Turin (with the ascent ladder of the fish fauna in Ciriè), that of the Province of Alessandria (for the environmental requalification of the river ecosystem along the streams Orba and Piota) and that of the Province of Verbano-Cusio-Ossola for the ecological and naturalistic requalification of the Fondotoce canal.[77]

- Spatial planning: introduction of urban planning regulations that limit construction in areas at hydrogeological risk and promote nature-based solutions.

[77] https://www.regione.piemonte.it/web/pinforma/notizie/finanziate-altre-11-riqualificazioni-fiumi-laghi

Limiting construction in areas of hydrogeological risk refers to the implementation of zoning regulations and zoning plans that designate areas as risk areas (for example, flood or landslide risk) where construction is prohibited or severely restricted, or subject to stringent safety requirements. This approach is preventive and aims to avoid the exposure of people and property to risk.

Promoting nature-based solutions (NBS) refers instead to integrating into spatial planning interventions that use natural processes to address environmental challenges, such as water risk management. Examples include re-naturalised river corridors, green roofs, flood parks, or permeable meadows. NBSs are increasingly recognised for their effectiveness, cost-benefit and co-benefits, such as improving air quality, biodiversity and well-being.

Ordine dei Geologi del Piemonte has called for strengthening prevention through geological studies of town planning and micro zoning. To date, around 800 municipalities have already adapted to the Piano per l'Assetto Idrogeologico (PAI), with the obligation of updating to prevent future hydraulic emergencies.[78]

- Monitoring and early warning: development of weather forecasting and emergency management systems to reduce the impact of extreme events.

  The development of weather forecasts aims at improving the accuracy and timeliness of heavy rain, thunderstorms and snowfall forecasts, using numerical atmospheric models and data from monitoring networks (radar, satellites, ground stations). The trend today is to focus more and more on probabilistic and very short-term forecasts (nowcasting).

  Emergency management systems shall provide structures and procedures to coordinate the response to flood or landslide events, including evacuation plans, relief management, communication to the population and restoration of pre-event conditions.

  In Piedmont, several projects have been implemented over the years. First of all the Project FASTER, thanks to which in 2021 Regione Piemonte experimented with drones, chatbots and 3D software to improve monitoring and emergency management, with exercises at Moncalieri.[79]

[78] https://www.quotidianopiemontese.it/2025/04/19/dopo-londata-di-maltempo-in-piemonte-i-geologi-chiedono-piu-prevenzione-e-risorse

[79] https://relazione.ambiente.piemonte.it/2023/it/territorio/risposte/rischi-naturali

In September 2024, the UAWOS project started in collaboration with CNR and AIES, which allows monitoring river areas difficult to reach, in areas such as Po, Orco and Sangone.[80]

- Community involvement: awareness raising and training programmes for local populations so that they can take preventive measures and respond effectively to emergencies. It is of fundamental importance to organize initiatives aimed at informing citizens about the hydrogeological risks of their territory, on the self-protection measures to be taken before, during and after an event, and on the importance of correct behaviour. This includes information campaigns, public meetings, exercises.

  Awareness and training campaigns are not detailed in official documents, but projects such as FASTER involve exercises with volunteers and technicians, while Ordine dei Geologi promotes extensive involvement at municipal level to apply local risk studies.[81]

It has been seen, over the years and cases, that an improvement in the resilience of the territory in water risk management brings long-term benefits to both the environment and resident communities. First, resilient management minimises the damage caused by extreme events such as floods and droughts by protecting infrastructure and housing. Secondly, adaptation strategies such as waste water reuse and water efficiency in agriculture help to preserve water resources over time and, with regard to the improvement of water quality, reducing pollution from chemicals and micro plastics ensures better water quality for human consumption and ecosystems. With regard to economic resilience, investing in water infrastructure and advanced technologies reduces the costs of managing emergencies and promotes local economic development.

An example of a resilience strategy is the RITA (Risposta Impatti Tempesta Alex) project: a cross-border initiative funded by the European INTERREG ALCOTRA Italy-France programme, designed to respond to the devastating impacts of which hit the Maritime Alps and the Aosta Valley between October 2 and October 3, 2020.

The RITA project was created with the aim of reducing the vulnerability of the territory through a combination of structural, managerial and socio-economic interventions. On the one hand, interventions have been proposed for the restoration and security of damaged infrastructures, which are essential for daily life and maintenance of essential services. On the other hand, activities aimed at improving spatial planning with a view to more effective management of future

[80] https://torinocronaca.it/news/provincia/364431/rischio-alluvioni-in-piemonte-l-allarme-lo-daranno-i-droni.html
[81] https://www.quotidianopiemontese.it/2025/04/19/dopo-londata-di-maltempo-in-piemonte-i-geologi-chiedono-piu-prevenzione-e-risorse

risks have been launched. Particular attention was also paid to the socio-economic recovery of the affected areas, with initiatives aimed at relaunching the productive and tourist fabric, seriously compromised by the event.

The technical activities carried out under RITA have been diverse and innovative. One of the key actions was the execution of high-density LiDAR surveys, which allowed a detailed reconstruction of the hydrological and geomorphologic morphology of the affected basins. At the same time, hydraulic and hydrological models have been developed to improve understanding of the response mechanisms of the territory to exceptional precipitation events. In particular, the study of the sedimentary balance in the Vésubie basin has provided fundamental insights for the design of risk mitigation measures related to solid transport.

Consistent with the most innovative approaches to risk management, RITA has also focused on the adoption of Nature-Based Solutions, aimed at combining safety and environmental sustainability. In this perspective, the project has deepened the application of techniques already started in previous projects such as RISBA[82] and RESBA[83], proposing the integration of small hydraulic interventions (such as dams and harrows) into an adaptive management framework for mountain basins.

The creation of RITA was made possible thanks to the collaboration between Italian and French institutions. The overall coordination was entrusted to the Autonomous Region of the Aosta Valley, while the scientific contribution was guaranteed by institutions such as INRAE (Institut National de Recherche pour l'Agriculture, l'Alimentation et l'Environnement) and Politecnico di Torino, through Dipartimento di Ingegneria dell’Ambiente, del Territorio e delle Infrastrutture (DIATI).

The project took place between January 2022 and May 2023, with a total budget of about 987,770 euros.[84]

RITA has thus emerged as an emblematic example of cross-border cooperation applied to hydrogeological risk management, proposing a model for action based on the integration of advanced scientific knowledge, innovative technologies and strategies for socio-territorial resilience. The results obtained have not only contributed to the restoration of security conditions in the territories affected by Storm Alex, but also provided valuable operational indications for dealing more effectively with future extreme events.

[82] https://www.regione.piemonte.it/web/temi/protezione-civile-difesa-suolo-opere-pubbliche/difesa-suolo/dighe/risba-rischio-degli-sbarramenti-artificiali
[83] https://www.regione.piemonte.it/web/temi/fondi-progetti-europei/programmi-progetti-europei/cooperazione-territoriale-europea-piemonte/resba-resilienza-sugli-sbarramenti
[84] https://www.diati.polito.it/en/content/download/8826/69261/file/RITA_Sheet_ENG.pdf

6. CONCLUSIONS

Storm Alex, in conclusion, represented a dramatic and unexpected event that was not only a meteorological anomaly in terms of intensity and timing, but also a stress test for the resilience of territorial systems. The analysis carried out in this thesis aims to highlight how the meteorological event exposed critical vulnerabilities and fragilities in the management of hydrogeological risk and land use planning, especially in the Piedmont region.

What emerges from the reconstruction of the timeline of the event and the territorial impacts is that, although early warning systems and emergency plans were in place, their effectiveness was often limited by the exceptional nature of the event and by pre-existing structural and organizational weaknesses. The rapid evolution of the floods, the fragmentation of administrative competencies, and the presence of settlements in historically flood-prone areas amplified the consequences.

One of the key point highlighted by this thesis is how urban development over the decades has ignored the hydrogeomorphological conditions, contributing to increase in exposure to risk. The overlapping of hydrogeological, landscape, and local constraints have been proved insufficient in preventing construction in sensitive areas, partly due to a lack of technical capacity in small municipalities and the inefficacy of decentralized permit systems.

However, the response after the event demonstrated a growing awareness of the need to move toward integrated and adaptive management of water risks. Post-event strategies, including structural reconstruction with enhanced standards, the adoption of NBS and the RITA project, underline a change of pace toward systemic resilience. Particularly relevant is the shift from a reactive to a proactive approach, integrating climate change considerations into land use planning, infrastructure design, and civil protection.

While several measures have been proposed and partially implemented, there remain criticalities: delays in fund disbursement, incomplete implementation of planned interventions and the need for stronger citizen involvement. Moreover, although the implementation of advanced technologies such as LiDAR and hydrological modelling for more precise weather forecasts, these tools must be accompanied by consistent political will and financial support.

Ultimately, this case study underline how resilience is not only a technical attribute but also a socio-political process. It requires coordination among institutions, interdisciplinary knowledge, community engagement and, above all, a long-term vision that embraces uncertainty as a planning paradigm. The lessons from this event should serve as a foundation for transforming emergency-driven adaptation into a culture of preparedness and sustainability.

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