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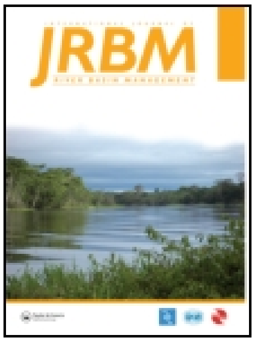

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The October 2000 flooding in Valle d'Aosta (Italy): Event description and land planning measures for the risk mitigation

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The October 2000 flooding in Valle d'Aosta (Italy): Event description and land planning measures for the risk mitigation

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ABSTRACT
On October 13–16th, 2000 heavy rainfalls in the Northwestern Italian Alps caused huge flooding and landslides with significant damages to houses and infrastructures and several life losses. In this paper a description of the main events that affected Valle d'Aosta's region and the subsequent land planning measures adopted for the risk mitigation are presented.

After a first meteorological and hydrological framing, based on the data of the regional monitoring system (that pointed out rainfalls up to 236 mm in 24 h also in high-altitude zones, because of the rise of the isotherm 0°C around 3000 m above sea level), the main effects of the event (extensive flooding, landslides, soil slips and debris flows) in the regional catchment of the Dora Baltea river are described.

Through aerial and direct surveys those effects have been transferred into a thematic cartography within two months from the event, in order to have detailed elements for the technical, administrative and political land planning decisions, and, on this basis, a new regional directive containing detailed measures for the hydro-geological risk mitigation and land safety has been adopted.

Keywords: Valle d'Aosta; flooding; land planning.

Introduction

On October 13–16th, 2000 heavy rainfalls interested the Northwestern Italian Alps from the upstream reach of the Po river to the Ticino river, causing huge flooding and landslides with significant damages to houses and infrastructures and several life losses. In particular the more affected catchments were the Toce, Sesia, Orco, Dora Baltea, Stura di Lanzo, Dora Riparia, Pellice and upper Po rivers. In Valle d'Aosta, region of the Northwestern Italy, the tributaries of the Dora Baltea river coming from the orographical right have been particularly involved, especially in the area between Rhêmes valley and Champorcher valley (southern part of the region) and in the Lys valley (eastern sector).

Valle d'Aosta Autonomous Region is the smallest of the Italian regions, with a surface of 3,262 km^2 and a population of approximately 120,000 inhabitants (average density of 37 inhabitants/km^2). A third of the residents lives in the city of Aosta (regional capital) while the remaining part in small towns across the region. Valle d'Aosta region represents the catchment basin of the Dora Baltea river, in which the main tributaries run with a prevailing direction N–S (Figure 4).

The average elevation of the region is approximately 2,100 m above sea level, while only the 20% of the whole surface is under 1,500 m above sea level: the region extends from the 340 m above sea level of the town of Pont-Saint-Martin to the 4,807 m above sea level of the Monte Bianco mountain and more than 20 mountain peaks exceed 4,000 m above sea level.

Valle d'Aosta has its own climate, protected by a chain of mountains that bounds the region sheltering it from the Atlantic weather and the winds coming from the eastern lands.

The average monthly rainfall shows a peak in Spring and another in Autumn, while its spatial distribution depends on an extreme variability of factors such as differences in elevation, the direction of the lateral valleys, the steepness and exposure of the mountainsides. Two different situation can characterize the regional climate: in the mountainous and marginal areas the range of temperatures is wide and rainfalls, and often snowfalls, are abundant (average values of 1000–1100 mm/year), while the areas along the Dora Baltea river valley line have a milder climate, with local dry winds and limited rainfalls, and are one of the less rainy place in Italy with average values lower than 600 mm/year.

In order to have a preliminary idea of the October 2000 event it can be useful to draw a comparison between the data recorded by the Hydrographic Office of Valle d'Aosta Autonomous Region in the last four years and the ones recorded during the event in two stations that are representative of the two climatic zones: the

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stations are Cogne (mountain areas) and Aosta (Dora Baltea valley line) while the parameters are the maximum daily rainfall and total monthly rainfall.

– Cogne: October maximum daily rainfall ranging from 18 to 30 mm versus 181.8 mm recorded on Saturday 14th; total monthly rainfall in October ranging from 30 to 60 mm versus 478.2 mm recorded in October 2000;
– Aosta: October maximum daily rainfall ranging from 8.6 to 29.8 mm versus 129.2 mm recorded on Sunday 15th; total monthly rainfall in October ranging from 18.6 to 70 mm versus 301.6 mm recorded in October 2000.

The maximum daily rainfall recorded during the four days of the October 2000 event is approximately equivalent to the 20% of the total rainfall normally recorded in 365 days, while the total monthly rainfall recorded in October 2000 represents almost the 50% of the annual average rainfall.

A similar approach can be used also for the Dora Baltea river water levels: taking into account two hydrometrical stations (Champdepraz and Hône) located in the lower reach of the river, before the Piedmont Region border, the maximum level recorded during the month of October in the last four years by the Hydrographic Office of Valle d'Aosta Autonomous Region in Champdepraz ranges from 0.63 to 1.52 m versus 6.13 m during the October 2000 event; in Hône it ranges from 0.54 to 1.13 m versus 8.73 m.

Meteorological analysis

The intense meteorological event of October 2000 arose on Thursday 12th when a cold front, associated with a wide and deep depression flow centred on the British Isles, reached the Western Alps (Figure 1) and attracted wet unstable air from SW towards Valle d'Aosta, causing light rainfalls on the areas adjoining Piedmont Region starting from the afternoon (Figure 2).

On Friday 13th the depression flow on the British Isles spread out towards South, accentuating the flow of southern air-currents on Valle d'Aosta; rainfalls continued becoming diffuse. Even on Friday an anticyclonic ridge settled on the Balkans, further increasing the pressure gradient between Western and Eastern Europe, with strong upper sirocco winds (Figure 3) causing a noticeable worsening of the meteorological conditions on the region and the rise of the isotherm 0°C from 2400 to 3000 m above sea level.

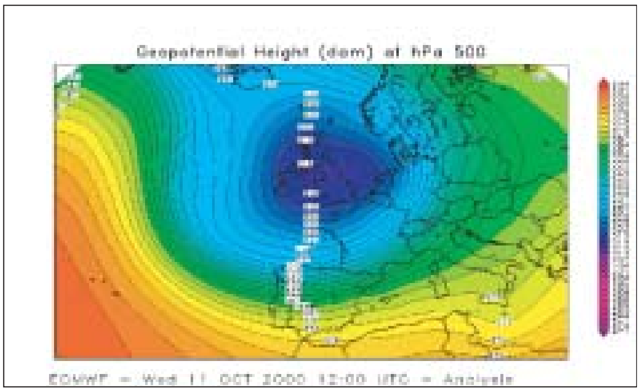


Figure 1 Geopotential height at 500 hPa (*from Piedmont Region – Prevention Technical Services Direction*).

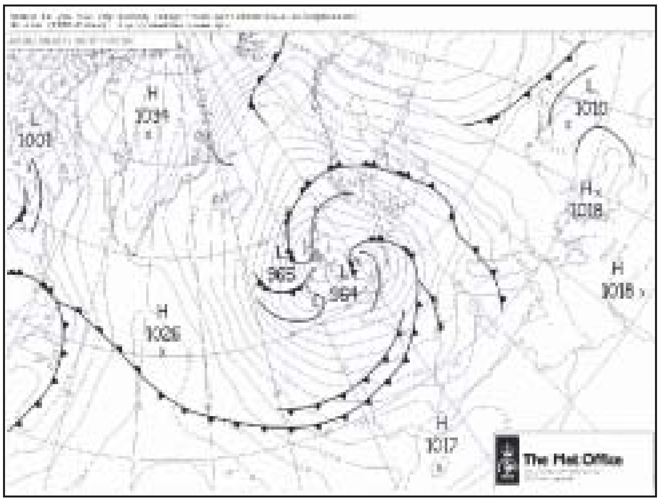


Figure 2 Depression flow on Friday 13th (*source: Bracknell Meteorological Office, UK*).

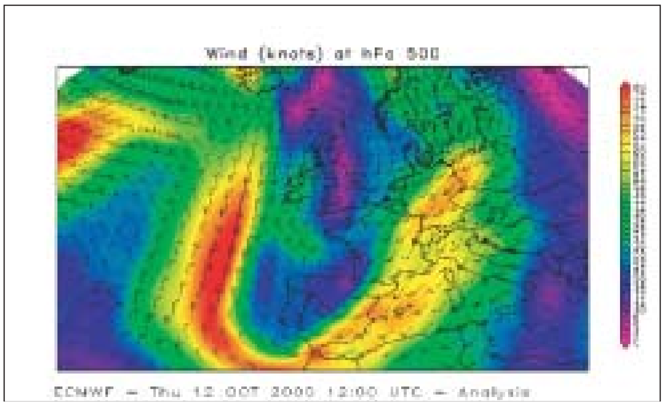


Figure 3 Wind at 500 hPa (*from Piedmont Region – Prevention Technical Services Direction*).

On the afternoon of Friday 13th a high depression flow closed on the Balearic Islands and a pressure minimum at ground level on the border between Tunisia and Algeria started to develop; therefore the flow in the lower layers set from E to SE, with an intensification of the phenomena; rainfalls involved the whole Valle d'Aosta, and especially Champorcher valley (170 mm/day, with a maximum of 20 mm/hour) and Cogne (80 mm/day, with a maximum of 8 mm/hour) in the southern part of the region.

On Saturday 14th a strongly baroclinic depression structure developed with the height minimum on the Balearic Islands and the minimum at ground level between Sardinia and Tunisia, causing a strong flow from SE in the height and from E in the lower layers, further intensifying the rainfalls.

A widespread increase of the rainfalls occurred during the night between Saturday and Sunday, especially in Champorcher and Cogne areas. In the late afternoon of Sunday 15th the phenomena started to attenuate, with a decreasing rainfall intensity between 1 and 6 mm/hour.

During the night between Sunday and Monday the minimum moved towards central Europe, determining a pressure level increase, and therefore rainfall intensity gradually decreased until Monday 16th afternoon, when rainfalls definitively ceased.

Pluviometrical analysis

The following pluviometrical analysis is based on the processing of data recorded during the event at the stations showed in Figure 4:

The pluviograms (Figure 5) show that:

– Champorcher and Cogne (southern sector of the region) are the stations where the maximum rainfall during the whole event have been recorded (about 600 and 450 mm respectively);

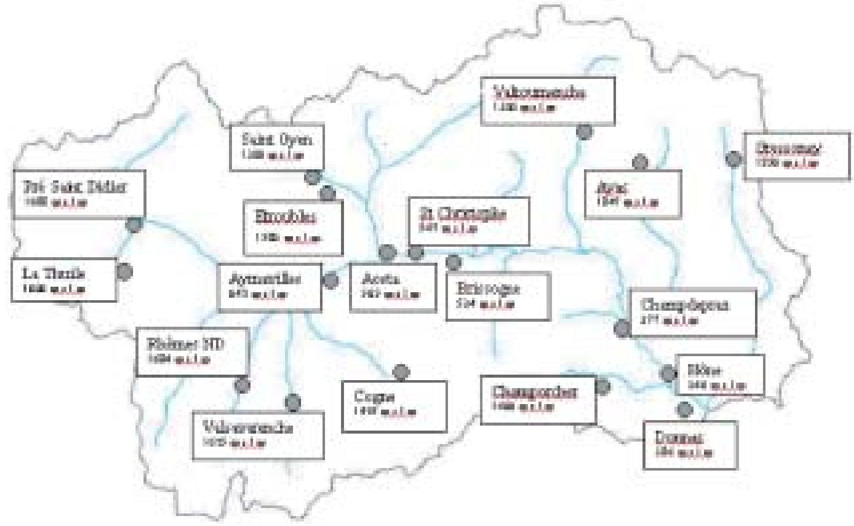


Figure 4 Valle d'Aosta stations – localisation, name and height above sea level.

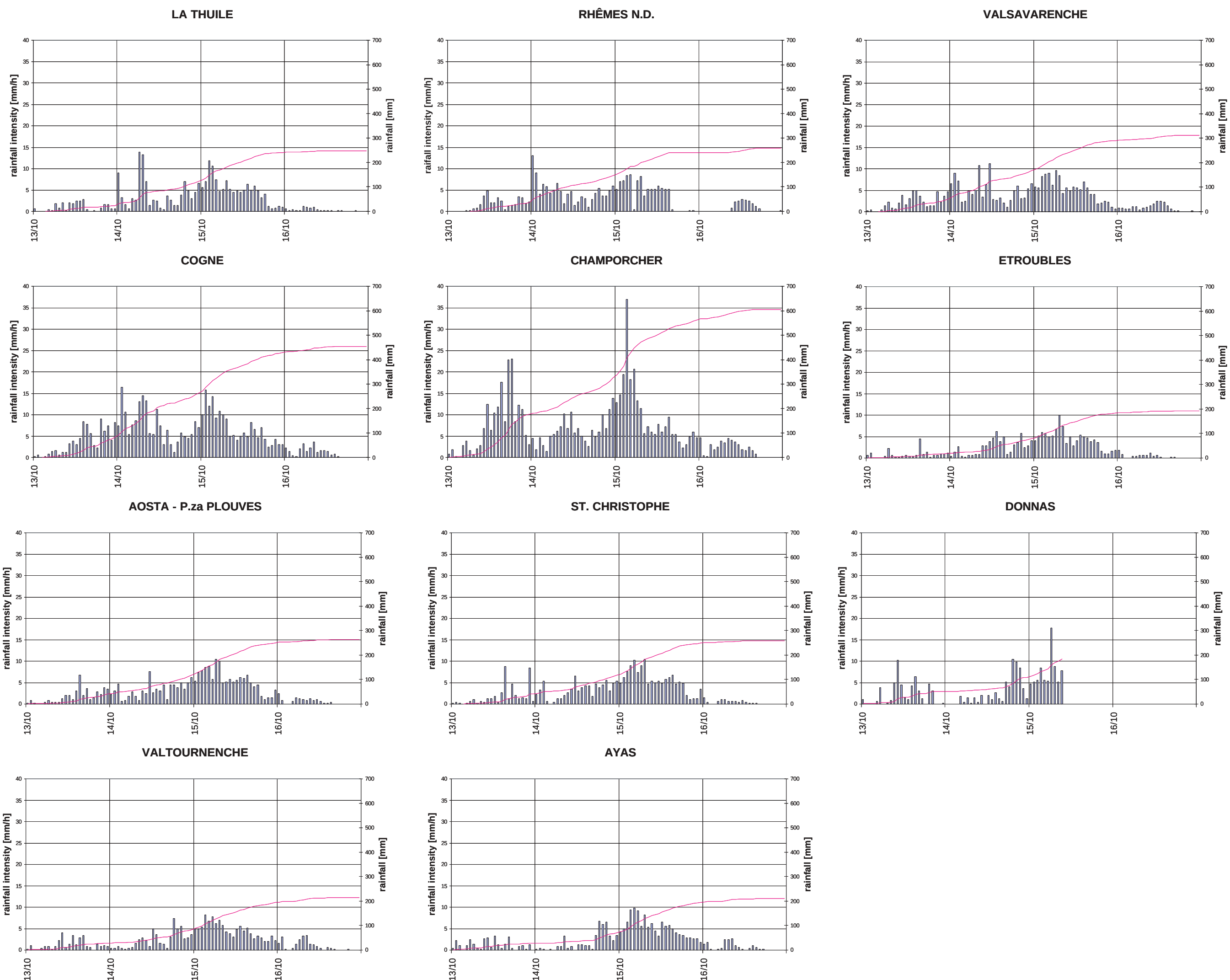
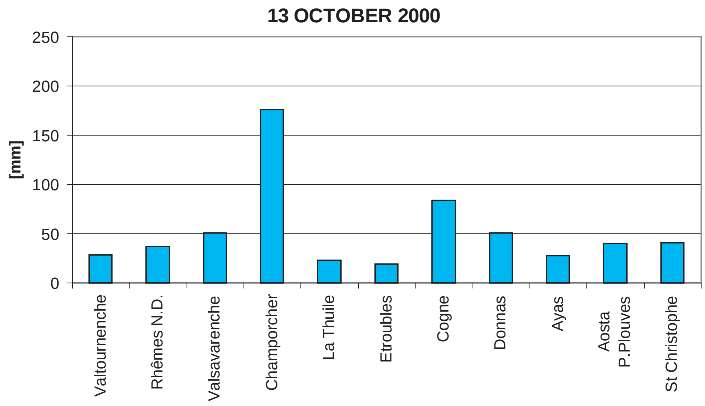
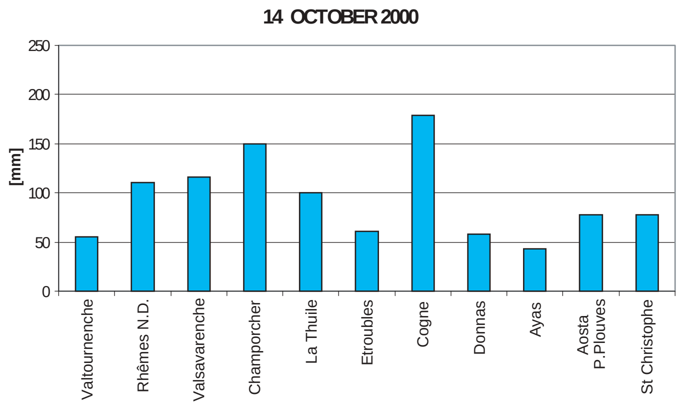


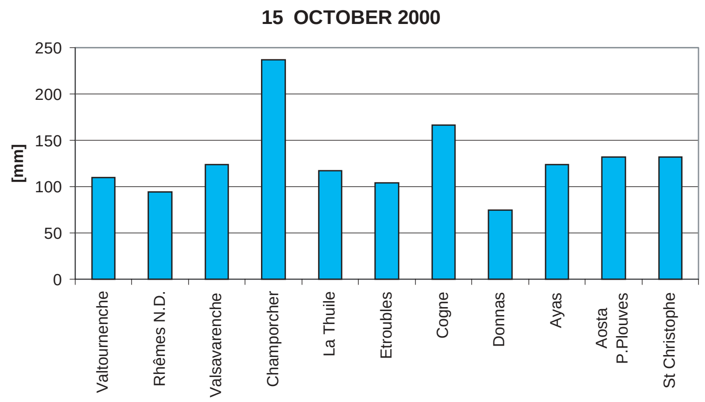
Figure 5 Pluviograms.



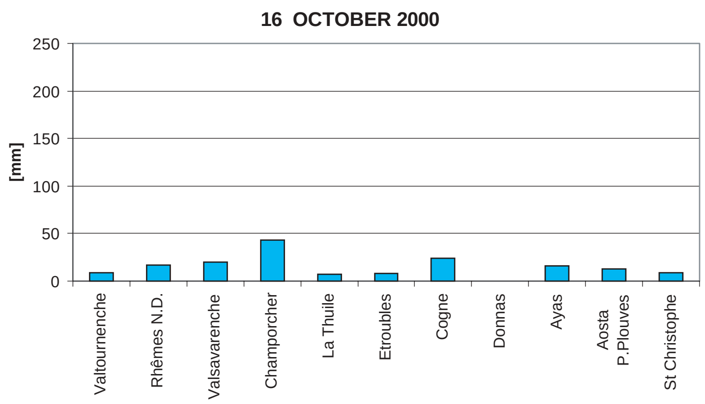
Station	Total [mm]	Max.[mm/h]
Valtournenche	28,6	4,0
Rhêmes N.D.	36,6	4,8
Valsavarenche	51,0	5,0
Champorcher	**176,0**	**23,0**
La Thuile	23,2	2,8
Etroubles	19,0	4,4
Cogne	83,8	9,0
Donnas	51,0	10,2
Ayas	27,8	3,2
Aosta P.Plouves	39,8	6,8
St Christophe	40,4	8,8



Station	Total [mm]	Max.[mm/h]
Valtournenche	55,0	7,4
Rhêmes N.D.	110,4	13,0
Valsavarenche	116,2	11,2
Champorcher	149,4	13,8
La Thuile	100,2	13,8
Etroubles	60,6	6,2
Cogne	**179,2**	**16,4**
Donnas	57,6	10,4
Ayas	43,2	6,8
Aosta P.Plouves	78,0	7,6
St Christophe	77,4	6,6



Station	Total [mm]	Max.[mm/h]
Valtournenche	110,0	8,2
Rhêmes N.D.	94,0	8,6
Valsavarenche	123,4	9,6
Champorcher	**236,8**	**37,0**
La Thuile	117,4	11,8
Etroubles	104,2	10,0
Cogne	166,8	15,8
Donnas	74,4	17,8
Ayas	123,8	9,8
Aosta P.Plouves	132,2	10,4
St Christophe	132,0	10,4



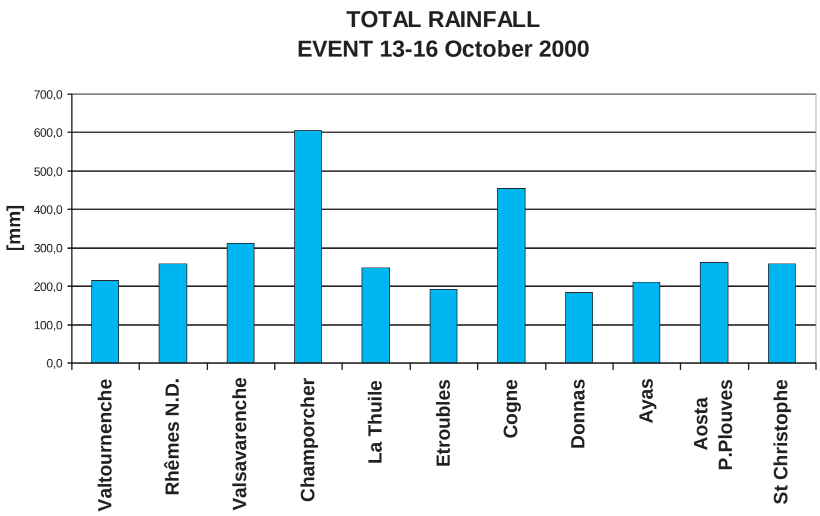
Station	Total [mm]	Max.[mm/h]
Valtournenche	8,4	1,4
Rhêmes N.D.	17,0	2,8
Valsavarenche	20,2	2,4
Champorcher	**42,8**	**4,6**
La Thuile	7,4	1,2
Etroubles	8,0	1,8
Cogne	24,0	3,6
Donnas	-	-
Ayas	15,6	2,6
Aosta P.Plouves	12,6	2,4
St Christophe	8,4	1,4

Figure 6 Daily rainfall histograms and tables.

- two different peaks have been recorded (Saturday 14th morning and first hours of Sunday 15th);
- Donnas station (south-eastern sector of the region) stopped its recording on Sunday 15th morning being damaged by the Dora Baltea river flooding.

Analysing the rainfall data showed in the tables and daily rainfall histograms of Figure 6, the following elements can be pointed out:

- Champorcher and Cogne are the stations where the higher daily rainfall has been recorded both on Friday 13th and Saturday



Station	Total [mm]
Champorcher	605,0
Cogne	453,8
Valsavarenche	310,8
Aosta P.Plouves	262,6
St Christophe	258,2
Rhêmes N.D.	258,0
La Thuile	248,2
Valtournenche	214,4
Ayas	210,4
Etroubles	191,8
Donnas	183,0

Figure 7 Total rainfall.

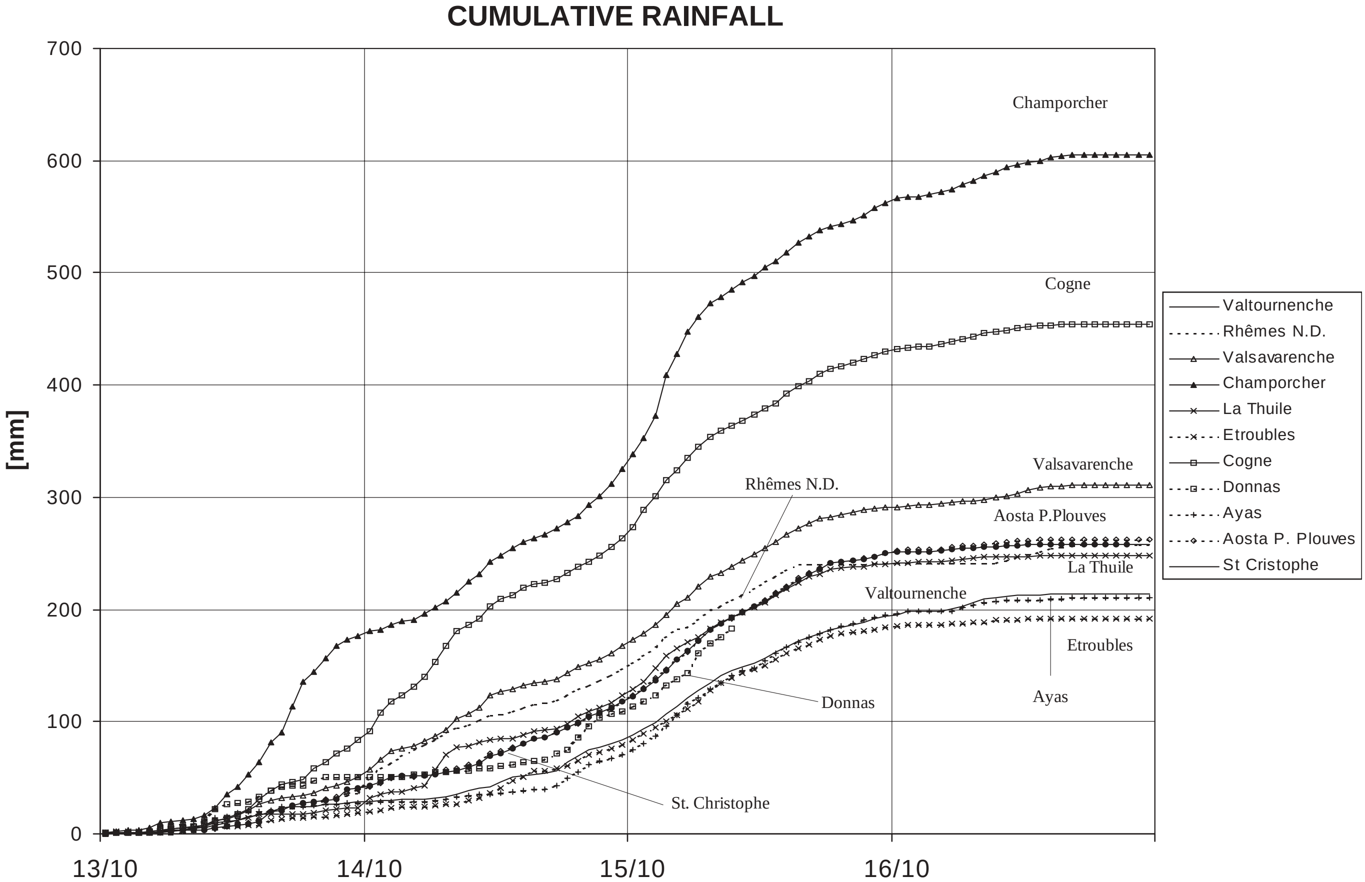


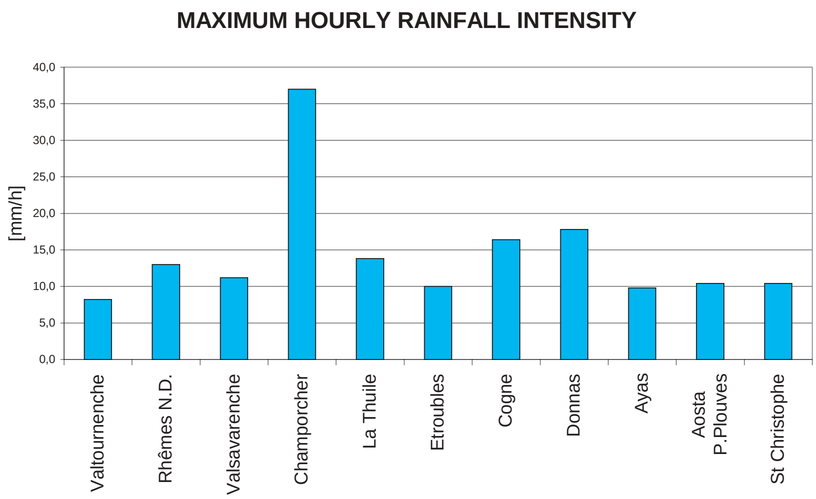
Figure 8 Cumulative rainfall.

14th; in 6 stations out of 11 a maximum intensity of more than 10 mm/hour has been recorded;

- once again on Sunday 15th the higher rainfall recorded values are at Champorcher and Cogne stations; all the other stations (excluding Donnas that ceased its activity at 10:00 a.m. anyway recording the second higher value of hourly intensity with 17.8 mm) recorded a daily rainfall higher than 100 mm/day with a maximum intensity higher than 10 mm/hour;
- on Monday 16th the rainfalls gradually faded.

Taking into account the whole event of October 13–16th, from the values of the cumulative rainfalls (Figures 7 and 8) and of the maximum hourly intensity (Figure 9) it is clear that:

- Champorcher and Cogne stations (and so the southern sector of Valle d'Aosta) recorded maximum total values exceeding 450 mm;
- the other stations anyway recorded maximum total values higher than 200 mm;
- 7 stations recorded the maximum of hourly intensity between the 03:00 a.m. and the 08:00 a.m. of Sunday 15th;
- 4 stations recorded the maximum of hourly intensity between the 00:00 a.m. and the 07:00 a.m. of Saturday 14th.



Station	Max intensity [mm/h]	Day
Champorcher	37,0	15/10
Donnas	17,8	15/10
Cogne	16,4	14/10
La Thuile	13,8	14/10
Rhêmes N.D.	13,0	14/10
Valsavarenche	11,2	14/10
Aosta P.Plouves	10,4	15/10
St. Christophe	10,4	15/10
Etroubles	10,0	15/10
Ayas	9,8	15/10
Valtournenche	8,2	15/10

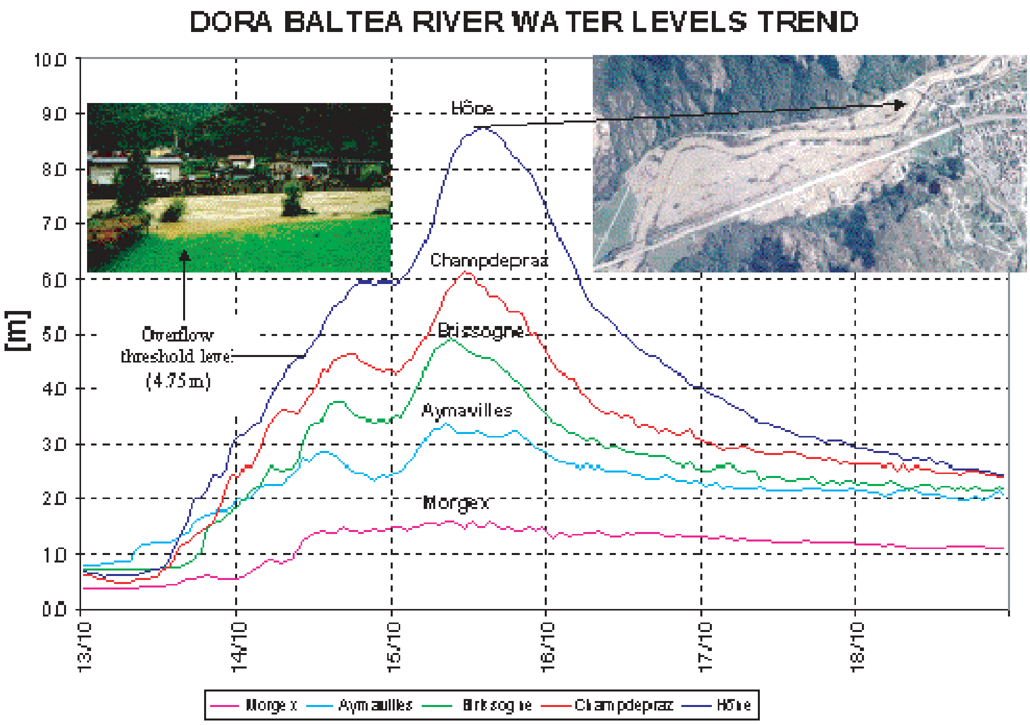
Figure 9 Maximum hourly rainfall intensity.

Hydrometrical analysis

Figure 10 shows the trend of the water levels in the hydrometrical stations of the regional Hydrographic Office along the Dora Baltea river. In order to have an idea of the event dimensions it is sufficient to look at the water levels of the Hône station, few kilometers upstream the Dora Baltea river's last section in Valle

Table 1 Flood peak transit.

Reaches	Distance [km]	Transit time	Transit velocity [m/s]
Aymavilles–Brissogne	15	1 h	≅4.2
Brissogne–Champdepraz	28	3 h 10 min	≅2.5
Champdepraz–Hône	10	2 h 30 min	≅1.1



Station	Peak level [m]	Peak level day/hour	Max hourly level increase [m]	Max hourly level increase day/hour
Morgex	1.63	15/10 h:9-10	0.21	14/10 h:10-11
Aymavilles	3.38	15/10 h:8-9	0.24	15/10 h:5-6
Brissogne	4.94	15/10 h:9-10	0.44	13/10 h:19-20
Champdepraz	6.13	15/10 h:11-12	0.36	13/10 h:22-23
Hône	8.73	15/10 h:14-15	0.45	13/10 h:23-24

Figure 10 Recorded water levels – referred to the zero of the discharge scale of each station.

d'Aosta, before the Piedmont Region border. The flood peak was reached on Sunday 15th at 14:00 p.m. with a water level of 8.73 m, while the Dora Baltea river had already overflowed the left bank in the morning of Saturday 14th with a measured level of 4.74 m: in 24 h the water had risen to 4 m above the overflow threshold level, despite the drastic widening of the flow area width (from 40 to 200 m at the hydrometrical station, and from 40 to 500 m in the upstream areas).

In Table 1 are showed the distance and the time interval for the flood peak transit between two consecutive hydrometrical stations on Dora Baltea river (central and lower reaches in Valle d'Aosta). Being unavailable maximum discharge's measures or values, it has been assumed as approximation that the transit of the flood peak coincided with the transit of the maximum discharge (even if in reality the last transits later): with this assumption, the flood transit velocity has been approximately calculated (last column).

Looking at the velocity values it is clearly noticeable the flood lamination effect. The drastic reduction of the velocities is due to the fact that Dora Baltea river, starting from the reach immediately downstream the rocky narrows of Montjovet (town located between Brissogne and Champdepraz), started to overflow its banks inundating vast areas, involving the whole valley line from the right to the left versant.

Photo 1 Hône – Dora Baltea river .

Photo 2 Hône – Ayasse torrent.

Phenomena description

The October 13–16th, 2000 event turned out particularly severe because of the conjunction of the following factors:

- rainfalls involving the whole region;
- presence, within the event, of several time intervals with particularly intense rainfalls, especially in the first hours of Sunday 15th;

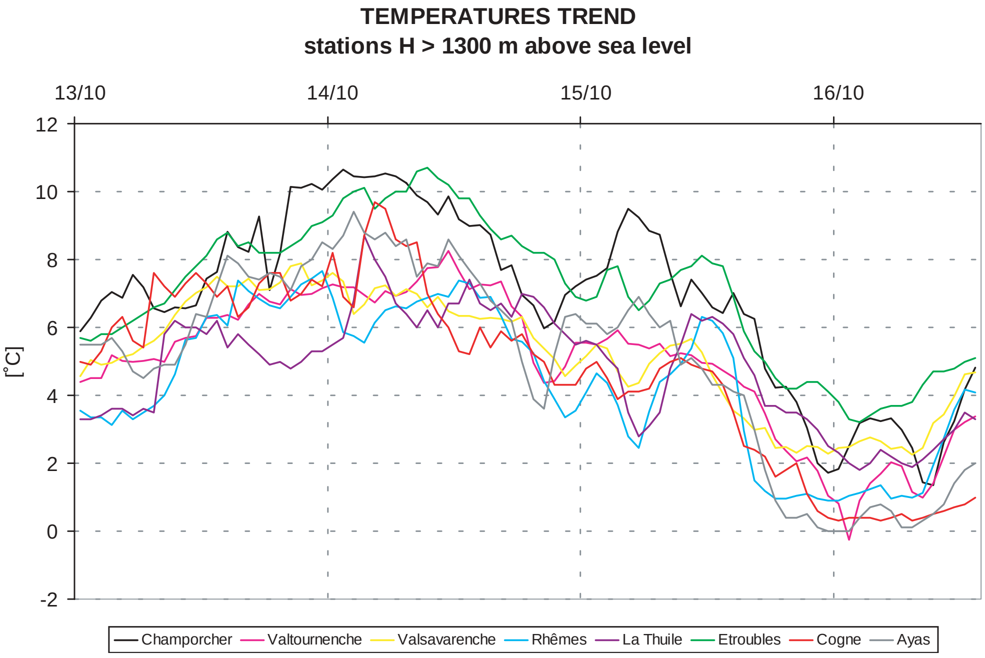


Figure 11 Temperatures recorded at stations located at an altitude of more than 1300 m above the sea level.

Photo 3 Cogne – Epinel Arpisson torrent. (*author: local media*).

Photo 4 Pollein – Effects of debris flow (*author: local media*).

Photo 5 Fénis – Debris flow deposit.

Photo 6 Nus – Soil-slip.

Photo 7 Nus – Solid transport of St. Barthélemy Torrent.

Photo 8 Gressoney-St-Jean – Debris flow.

– drainage basin widening due to the rise of the isotherm 0°C from 2400 to 3000 m above sea level caused by sirocco winds as attested by the temperature values recorded between Friday 13th and Monday 16th at the stations located at an altitude of more than 1300 m above sea level (Figure 11);
– contribution of the snow previously fallen that melted during the event;
– ground already partially saturated because of intense rainfalls occurred from the end of September and the first days of October, when in all the stations more than 60 mm were recorded, with several values higher than 100 mm, and up to 200 mm at Donnas and Champorcher stations (south-eastern sector of the region).

Because of the previous factors the event was characterised not only by the extension but also by the typological variety of the phenomena.

In fact the whole Valle d'Aosta (excluding the north-western sector where less damages have occurred) was interested by extensive flooding, landslides, soil slips and debris/earth flows on the alluvial fans with damages to houses and infrastructures for more than 500 million euro and several life losses in the population (14 persons died).

Photo 9 and 10 Hône – Donnas. Dora Baltea river flooding (*author: local media*).

Photo 11 Donnas. Dora Baltea river flooding.

Photo 12 Donnas. Dora Baltea – Flood effects (*author: local media*).

Photo 13 Issime. Lys torrent – Flood effects.

Photo 14 Gressoney-St-Jean. Lys torrent – Flood effects (*author: local media*).

Photo 15 G.S. Bernardo valley – Citrin landslide.

In chronological order the rainfalls effects were:

- A drastic increase of the water levels in all the regional watercourses, with the Dora Baltea river already reaching its overflow threshold levels since Saturday 14th (Photos 1 and 2).
- Debris/earth flows, landslides and soil slips activation between Saturday 14th (Cogne area) and Sunday 15th morning from 07:00 to 09:00 a.m. (in the rest of the region) (Photos 3–8).

Photo 16 Becca di Nona landslide (*author: Ketty Carere*).

- Dora Baltea river flood, even through its peak was recorded on Sunday 15th between 09:00 a.m. (central region) and 14:00 p.m (lower region) (see Photos 9–11), already caused serious damages on Saturday 14th.
- Surveys on the damages along the watercourses during the days after the flood transit (Photos 12–14).
- Activation/reactivation of landslides phenomena involving broad areas and huge volumes, some of them still developing nowadays (Photos 15–16).

Event thematic cartography

On October 18–19th the areas involved by the event were surveyed through aerial photography. The survey was focused on the Dora Baltea river valley line and adjoining mountainsides, and the valley lines of the main tributaries. Then a team of 4 experts (3 geologists and 1 informatics) of the Cartography and Hydrogeological Asset Service, worked for two months in order to draw a first estimate of the event. The work was carried out through the following steps:

- through aerial photography interpretation techniques a thematic cartography in scale of 1 : 5000 and 1 : 10 000 has been produced, highlighting the main typologies of hydrogeological phenomena identified;
- the produced thematic cartography has been digitized and georeferenced in order to allow an integrated use with information of different type and provenance;
- the thematic cartography has been updated and corrected as a result of numerous direct surveys.

Table 2 Summary of the event's effects.

Phenomena	Number	Interested areas [m^2]
Landslides	385	1,642,418
Debris/earth flows	259	4,281,562
Dora Baltea tributaries flooding	—	5,039,968
Dora Baltea river flooding	—	6,738,353

In this way the event thematic cartography has been defined and disclosed within two months (two examples are showed in Figures 12 and 13: comparison aerial photograph-thematic cartography). On the one hand it gave a first estimate of the event's effects (Table 2), and, on the other hand, has been afterwards used as a fundamental backing element for the technical, administrative and political land planning decisions. Figure 14 shows all the areas involved by hydro-geological phenomena during the event that have been included into the thematic cartography (in the Figure are outlined the sites of Figures 12 and 13). The cartography covers approximately 2/3 of the whole region (excluding only the western part, less severely interested by the event).

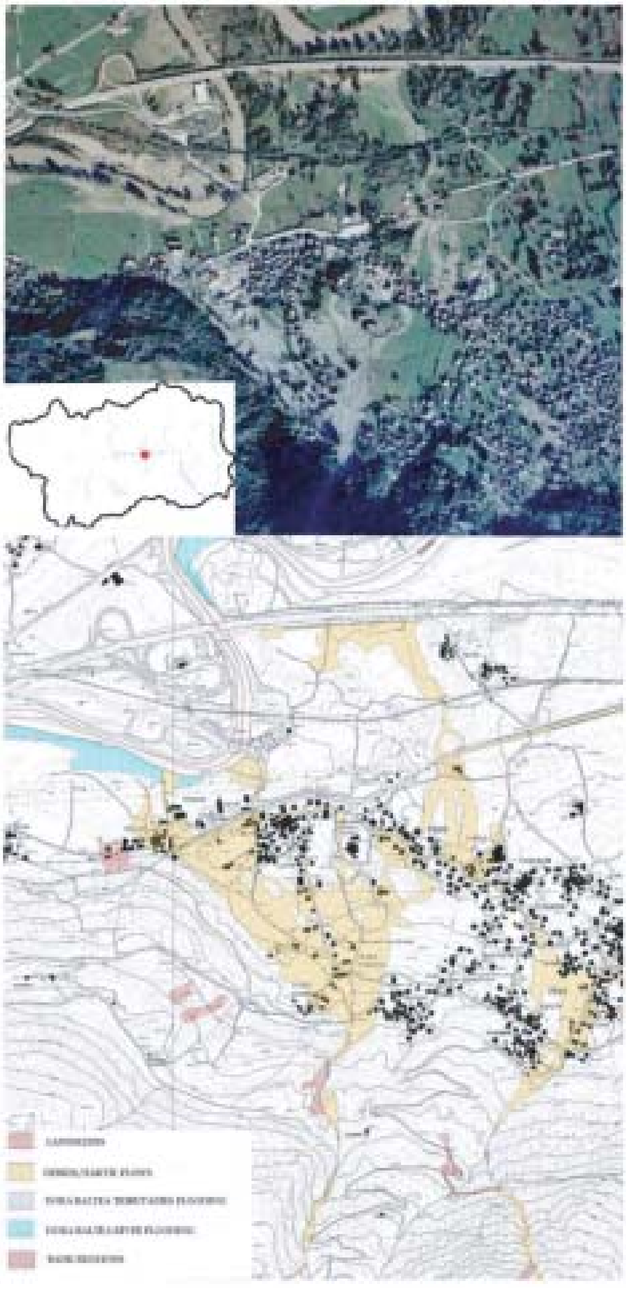


Figure 12 Fenis. Biolley torrent debris flow – comparison aerial photograph-thematic cartography.

Measures for the hydro-geological risk mitigation and land safety

Valle d'Aosta Autonomous Region and in particular its technical bodies on the one hand, and administrative and political bodies on the other hand, immediately reacted to the event through the planning and the setting up of structural and non-structural interventions.

Figure 13 Donnas. Dora Baltea river flooding – comparison aerial photograph-thematic cartography.

Structural interventions

Besides the emergency interventions aimed at guaranteeing the minimum safety conditions while waiting for the planning and realization of flood defence definitive works, on the basis of the event's effects scenario exhaustively defined through the previous thematic cartography and the municipalities and other stakeholders consultation, on January 2001 has been approved the "*Extraordinary intervention plan for the recovery of the security conditions of the damaged public infrastructures, for the clear-out and extraordinary maintenance of the rivers bed, for the versants stabilisation and for the hydro-geological risk prevention*" whose guidelines are aimed at:

– protecting built-up areas, infrastructures, sites and environments of noticeable importance from severe flood events, in order to reduce the hydraulic risk to acceptable levels;
– taking safety measures for built-up areas and infrastructures affected by slope instability phenomena;
– adequately restoring the damaged line of communications, aqueducts and sewers, only provisionally restored immediately after the event.

Non-structural interventions

Unfortunately it has to be pointed out that in October 2000, after 22 years from the first regulations concerning the "risk cartography" for a correct land planning (1978), only 10 municipalities out of the 74 of the whole Valle d'Aosta produced and adopted their own cartography for the inundation risk, and 20 for the landslide risk.

For this reason Valle d'Aosta Autonomous Region immediately adopted a directive (D.G.R. 11-12-2000 n. 4268), locking up as "high risk sectors", and therefore classifying as non-building sites, all the areas affected by the October 2000 event included into the event thematic cartography.

The non-building restriction has been extended also to other areas that, even if not affected by the event, were classified with

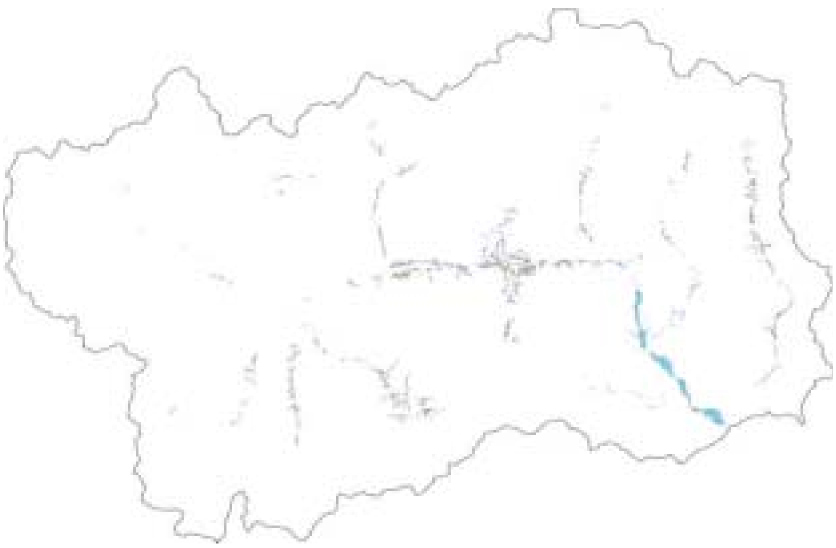


Figure 14 Areas involved by hydro-geological phenomena object of the thematic cartography.

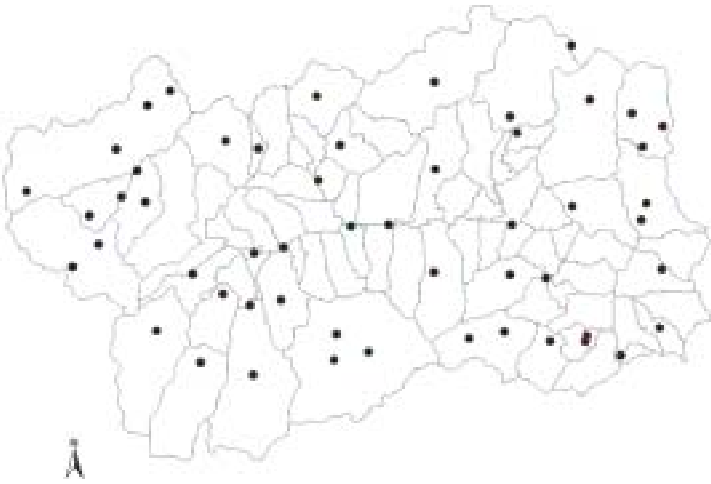


Figure 15 Current regional hydrological monitoring network.

lower risk levels on the Hydrogeological Asset Plan (PAI) produced by Po River Basin Authority in 1999 (that in 2001 entirely accepted this approach updating its cartography). The previous restriction will stand until the municipalities will produce and adopt (or upgrade) the risk cartography of their territory in compliance with the existing regulations. Because of this drastic approach in 2001 and in the first months of 2002 more than a half of the regional municipalities produced their own risk cartography, currently under examination by the competent regional offices.

Further regulations have been promulgated in the field of civil protection and land planning in order to relocate both the buildings destroyed or seriously damaged by the event and, once approved the risk cartography, those situated in high risk areas.

The previous are the main adopted measures concerning prevention. New actions have been undertaken also in the field of forecasting. In fact Cartography and Hydrogeological Asset Service is developing the regional monitoring network installing new meteo-pluviometrical and hydrometrical stations in still not covered strategic sites of the region. To the 18 existing stations operating during the event (12 managed by the regional hydrographic office and 6 by the Environmental Protection Regional Agency – ARPA) 41 new stations have been added (some of them still to be installed) obtaining an homogeneous covering of the whole region. Figure 15 shows the the situation at the end of 2002 (53 stations).

At the same time agreements have been stipulated with technical structures of other Italian Regions that are leaders in the field of forecasting, in order to obtain weather predictions for the Valle d'Aosta region and a technical advice in the organization/improvement of the alerting procedures.

Today Cartography and Hydrogeological Asset Service is undertaking a detailed analysis of the regional geological and hydrological database in order to define the landslides and soil-slips activation pluviometrical thresholds. At the same time it is planned to apply and calibrate on the whole Dora Baltea river catchment numerical models for the rainfall-runoff and flood propagation simulation, in order to forecast critical events along the hydrographical network starting from the forecasted and observed data.

These activities allow and will allow to:

- improve the forecasting phase, in order to issue hydrogeological alerting bulletins, not only based on the notification of adverse weather conditions, but also on the knowledge of the land vulnerability according to fixed rainfall scenarios;
- improve the data management during the events through the consecutive issue of bulletins to the civil protection offices, updating the measured data and their trend, allowing the decision-making processes based on the more probable scenario.

Acknowledgements

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