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THE DEBRIS-FLOWS MONITORING SYSTEM OF ACQUABONA TORRENT (CORTINA D'AMPEZZO, BELLUNO, ITALY)

P. SCOTTON[(*)], R. GENEVOIS[(*)], F. MORO[(*)], L. ZORZI[(*)], G. GIRARDI[(*)] & N. PRATICELLI[(*)]

[(*)] University of Padua - Department of Geosciences - Padua, Italy

ABSTRACT

The article presents a debris-flow monitoring system installed in the site of Acquabona near Cortina d'Ampezzo, in the province of Belluno, Italy.

The site, whose activity is almost annual, was equipped in the second half of the 90s, with the aim of characterizing the phase of initiation, flow and deposition of debris-flows typical of the Dolomitic areas. Three measuring stations were been realized. The power of the equipment was provided by solar panels. The field data were stored on site and recovered through inspections to the station.

The monitoring activity has proven to be, over the years, of great difficulty as a result, firstly, of the need for frequent visits to the site, sometimes long after the events occurrence, and, secondly, of the morphological changes taking place in the water course under study. In particular it was observed a progressive regression of the deposition area that was and still is affecting the two downstream stations.

The monitoring system has been, therefore, redesigned taking into account the need to move old downstream stations at a higher elevation and the will to remotely control the activity of the basin. At the moment two new stations have been realized. The first one is a weather station that collects rain, wind, temperature and humidity data. It is located further upstream than the previous upstream station and in a more apical position in the basin, to better characterize initial conditions that trigger debris flows. The second one has been realized in the flowing zone, near the deposition area. It has been equipped with an ultrasonic level meter, a video-camera served by a system of night lighting and a tipping bucket rain gauge. Geophones have been used for the activation of the monitoring system and for measuring front velocities.

Substantial changes have been introduced, in comparison with the previous installation, in the power supply of downstream station that will be reached by the main electricity grid. The power supply of the upstream weather station will be, instead, ensured by solar panels. The data coming from the two stations are collected at the downstream station (a radio link connects the upstream meteorological station with the downstream station) and are available for the download from the Department of Geosciences of Padua via mobile Internet.

***Key words**: debris-flows monitoring, field survey, debris flows, hydrologic measurement*

INTRODUCTION

The Acquabona catchment (Dolomites, Eastern Italian Alps) has an upper rock basin, with a drainage area of 0.3 km^2 formed of upper Triassic to Lower Jurassic massive dolomites and limestones. In the lower basin these rocks and the underlying red marls are covered by very thick talus deposits including heterogeneous scree, alluvium and debris flow deposits containing boulders up to 3-4 m in diameter.

The channel is mostly incised into the talus, except for a 150 m long reach where it cuts through the marls bedrock. The channel has been cut by debris flows to 30 meters maximum depth. A detailed geomorphological description of the site is available in BERTI *et alii* (1999) and GENEVOIS *et alii* (2000a).

The Acquabona catchment and the debris flows events have been studied since 1997 on the basis of a field monitoring system that changed in the years. The data collected led to a considerable amount of scientific publications.

Hydrological conditions leading to the formation of debris flows, also using collected rainfall and water pressure data, have been analyzed (GENEVOIS *et alii*, 2000b; BERTI & SIMONI, 2003; SIMONI & BERTI, 2005; ARMENTO *et alii*, 2007 and GREGORETTI & DALLA FONTANA, 2008). Front velocities, particles size and velocities distribution on the debris flow top surface, using data from induced ground vibration and recorded images have been obtained (GENEVOIS *et alii*, 2000c; TECCA *et alii*, 2003; GENEVOIS *et alii*, 2001). Relationships between flow depth, flow induced vibrations and front velocity and estimation of debris flow volumes based on the integral of measured ground vibrations have been proposed (GALGARO *et alii*, 2005). The debris-flow material has been used to perform laboratory tests in order to analyze deposition processes (DEGANUTTI *et alii*, 2003). Events detected at the site have been used to test one-dimensional numerical models (PAPA & LAMBERTI, 1999; FRACCAROLLO & PAPA, 2000) and to simulate the dynamic behaviour using one-dimensional (DAN-W) and two-dimensional (FLO-2D) models (ARMENTO, 2007; ARMENTO *et alii*, 2008). Debris-flow hazard analysis has been carried out based on the combination of field data and numerical applications (GENEVOIS *et alii*, 2009).

The installed monitoring system, that underwent numerous modifications during the years, has been completely torn up by the 2009 debris flow and, then, designed again and rebuilt.

The aim of this paper is to: i) summarize the history of the monitoring system installed in the debris-flow prone basin of Acquabona (Cortina d'Ampezzo) in Eastern Italian Alps, from the original one (1997); ii) illustrate the new system installed after the 2009 disastrous debris flow.

THE JULY 18TH, 2009 DEBRIS FLOW

Resting on the local inhabitants and drivers, early in the morning (5:00 and 7:00 a.m.) of July 18th 2009, a debris flow happened on the Acquabona basin, triggered by a heavy pluviometric event affecting the entire Dolomites area.

Two different surges have characterized the event: a first one, with a total volume of about 2.000-3.000 m^3, reached the retention basin at the channel outlet, depositing part of its solid loading in the lower part of the channel. A second surge, with an estimated volume of about 20.000-22.000 m^3, overflowed both left and right banks at an elevation of 1150-1160 m a.s.l. where they had their minimum height (Fig. 1). Most likely, the deposit of the first surge raising the channel bed facilitates the lateral overflows.

The deposits on the hydrological right extend from 1160 m a.s.l. to the n. 51 State Highway below that has been completely overflowed.

The main fan has a principal axis of about 300 m in length, and a maximum width of about 70 m. The thickness of the deposit is variable along the fan, with a mean value of about 1 m, also considering the mud - film covering the foot of the tree trunks (Fig. 2). The volume of the flooding mass relative to this sector is about 20.000 m^3.

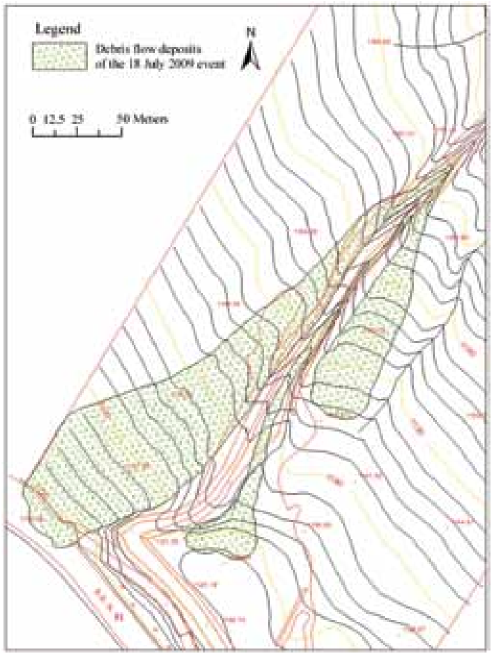

Fig. 1 - Geomorphological map of the July 18th 2009 debris

The second fan, on the left side, is smaller. Grain size distribution and texture of the deposit are similar to those of the main fan, except for a lower percentage of fines which are concentrated only on the upper part of the fan. Unlike the main deposit, there is a decrease in the grain size heterogeneity from the apical part to the toe of the fan: in fact, close to the toe of the fan the deposit is made only by gravel and pebbles, with only a local presence of the fine debris.

Pluviometric data, registered at the Mt. Faloria meteorologic station (no more than 1 km away and more or less at the same elevation), show a series of rainfall peaks between midnight and 7:00 a.m. (Fig. 3), three of which within the above mentioned time - interval. One of these certainly triggered the second main surge, but it is possible that the first small surge was triggered by one of the rainfall peaks between the 0:00 a.m. and 1:30 a.m.

Fig. 2 - Debris flow deposits with transported trees and mud on tree trunks

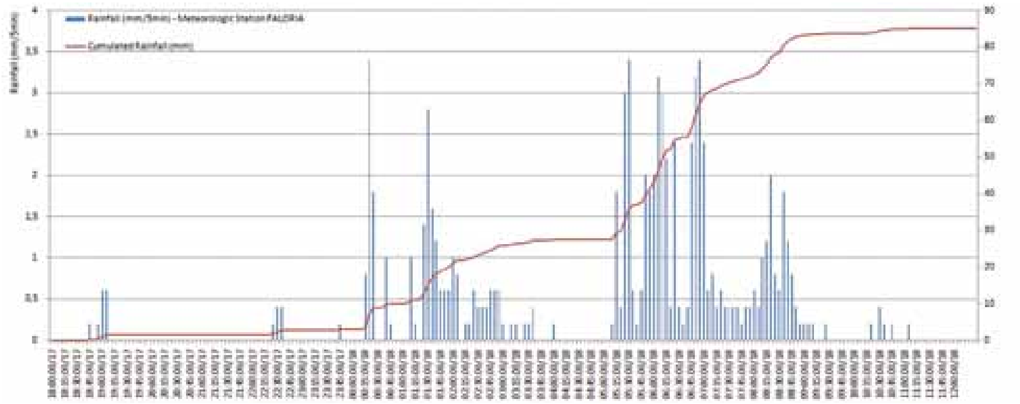

Fig. 3 - 5 minutes rainfall and cumulative 5 minutes rainfall at Mt. Faloria meteorological station (source: ARPA Veneto - Italy)

The lithology and grain size of the whole 18th July's deposits indicates that the debris flow was not generated as usual at the closure of the rock basin, just upstream of station S1 M1 (Fig. 4), as it is confirmed by the lack of Raibl Formation debris and the absence of boulders larger than 1 m^3, present almost only at higher elevation, let presume that the event was triggered below an altitude of 1440 m. The debris flow was then triggered at the elevation of Station S2 M1 (Fig. 4) or just a little above.

As a consequence of the critical stability conditions of the right side of the channel in this area, it can be assumed that a series of small slides could have happened, damming the channel and increasing the available debris subsequently mobilized.

THE FIRST MONITORING SYSTEM, 1997

The first monitoring system was designed in the late 90s (Fig. 4), in collaboration with the USGS - Cascades Volcano Observatory. Three measurement stations have been realized (Simoni, 1998).

The upstream station was located in the initiation area of the debris flow phenomena at the elevation of approximately 1565 m a.s.l. This station was equipped with a tipping bucket rain gauge, a geophone for the activation of the monitoring system at the events, four water pressure transducers distributed in the surface layer of the bottom, a water pressure transducer located at a larger distance from the surface, two cameras and two VHS video recorders that were activated in case of overcoming of the trigger threshold of the geophone.

The middle station was positioned in the flowing zone, at the altitude of about 1310 m a.s.l. The station was equipped with three geophones separated from each other about 100 m, the first of which acted as recording trigger at the events, and an anemometer.

The downstream station was located at the end of the sliding zone, at the altitude of about 1175 m a.s.l.. This station was equipped with three geophones, separated from each other about 100 m. As in the previous station the upstream geophone have the function to trigger the fast data acquisition mode. An ultrasonic sensor was mounted for measuring the distance from the bed surface, a total pressure measurement system was located in the channel (surface dimension of 0.2 m x 0.3 m, measuring range from 0 to 300 kPa), a water pressure transducer and a VHS camcorder were installed.

Each station was powered by a 12 V solar panel battery and was equipped with a data logger and a radio receiver and-transmitter. The radios allow connection to a data collection station located in Socol area, located about 1.3 km from Acquabona village. The radio connection also allowed the remote control of the proper functioning of instrumentation and possible modification of the instrumentation setting. The data from the stations were collected continuously at a frequency of 0.0033 Hz (one acquisition every five minutes) in normal conditions, and at the frequency of 5 Hz at event mode.

The monitoring system has been designed taking into account the relatively low data rates provided by radio link and the required electrical power to activate the equipment, in particular the large absorption sensors: camcorders and ultrasonic meter. To reduce the amount of data to transmit, the acquisition frequency varied from normal conditions to event mode as described and video data were stored locally on video tapes. To reduce the energy required to operate all the equipment, instrumentation with high power consumption was only activated in event mode.

Important information about events of Acquabona catchment were obtained from the event of June 12th, 1997 (estimated volume of 6.000 m^3), when the monitoring system had not yet been activated. The monitoring system was active instead at the events of July 25th and 27th, 1998 (estimated volume of deposit of less than 1000 m^3) and August 17th, 1998 (estimated volume of deposit of the order of 10.000 m^3).

Alongside the wealth of information gathered, the system also showed some drawbacks. The use of geophones as sensors for the activation of event mode was effective at the upstream and downstream station and ineffective at the middle station, despite the lowering of the threshold consequently the non-activation after the events of July 1998. The system for the measuring of the total pressure located at the downstream station operated during the first event in July 2008 and was swept downstream during the second event, showing the considerable difficulties of designing this type of instrumentation.

Fig. 4 - The position of the stations of the monitoring systems for debris-flow events installed at the Acquabona basin. The first monitoring system (1997, M1) was composed of three stations in-site (S1 M1, S2 M1, S3 M1) and a station off-site (SOCOL). In the second (2000, M2), a new station was built in the deposit basin (S3 M2) and the intermediate station of the previous system (S2 M1) no more activated. The nowadays system (m^3) is composed of two stations (S1 m^3, S2 m^3)

THE SECOND MONITORING SYSTEM, 2000

The second monitoring system has been developed to the early 2000s (Fig. 4) in collaboration with a local company for the design and the management of the system of instrumentation control. Again three measuring stations have been equipped (Galgaro, 2002).

The position of the upstream station was the same of the monitoring system described above. A rain gauge, a geophone for the activation of the monitoring system at the events, four surface water pressure transducers, a VHS camcorder activated in case of overcoming of the geophone trigger threshold, have been installed.

A second station was located, approximately, at the position of the downstream station of the previous system. The station was equipped with four geophones, an ultrasonic sensor, a measurement system of the total load on the bottom of the channel (anchored to a concrete structure embedded in the river bed), a piezometer and a video camera with video recorder.

The third station was located at the altitude of about 1120 m a.s.l., within the retention basin designed to contain the solid volume mobilized by debris flows. This station was equipped with an ultrasonic distance meter, a total load measuring system, a water pressure transducer and a VHS camcorder.

The stations were equipped, as before, with a local power system and a local data collection system, with a radio receiver - transmitter (transmission speed 1200 baud) connected with the Socol station. Here a radio modem (data rate 56 kB) allowed remote data transfer.

THE NEW MONITORING SYSTEM, 2009

The current monitoring system (Fig. 4) has been implemented by the Department of Geosciences, University of Padua, as a result of damage suffered by the existing installation during the event in July 2009.

The quoted event has been particularly heavy and interested the national road 51. During the same meteorological event other debris flows occurred on slopes nearby. In Cancia Village, little far from Acquabona, an immature debris flow caused some victims caught in their sleep in the room invaded by the flow.

The structure of the monitoring system being developed is simpler than previous systems, even if the possibility of expansion is assured. Some instruments that have proved unreliable and difficult to manage have not been included in this phase. Major changes have been introduced in the power supply and in the data transmission in order to increase the transmission speed and to allow remote real time monitoring. Monitoring stations under construction are two.

The upstream station is located upstream the sediment catchment feeding the debris flows (Fig. 5), at an altitude of about 1715 m a.s.l., in an area not involved in the slope erosion processes that are close to reaching the location where the previous upstream station were placed.

The elevation is higher than the elevation of the downstream station of the previous system to take into account the processes of deposition and reduction of the slope, in place in recent years, in the final reach of the flowing zone.

At the upstream station (Fig. 7) a weather station is installed that allows data acquisition of liquid precipitation, wind speed and direction, air temperature, barometric pressure and relative humidity, in order to characterize some metheorological properties of the site.

The downstream station (Fig. 6) is located at the altitude of about 1185 m a.s.l., on a big boulder on the left bank.

The obtained data have the form of ASCII strings through the RS232 port of the device. They are stored by a Rabbit RCM4000 microcontroller which in turn routes them, through its serial port, to a radio transmitter having a power of 0.1 W and a carrier frequency of 2.4 GHz.

Fig. 5 - The upstream station of the new monitoring system. From the left to the right: the Vaisala metheorological station; the antenna for downstream data transmission; the solar panels

Fig. 6 - The support structure of the instrumentation of the downstream station. The arm length is 6 m. The current elevation over the bottom, at the center of the section, is about 3.5 m

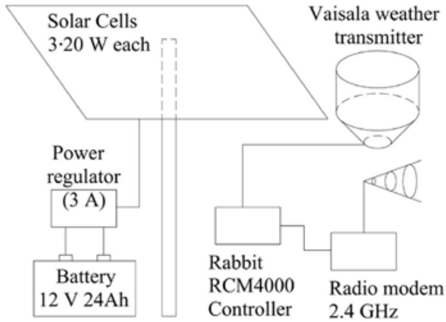

Fig. 7 - The scheme of the new upstream station

Power is supplied by three solar panels of 20W each that charge a battery 12 V/24 Ah through a 3A power regulator. All equipment is supported by galvanized steel poles.

Because of the considerable difficulties in accessing the site, the installation was achieved through the use of the helicopter to transport the material a short distance from the mounting area and through the creation of a path made safe for installation and maintenance of equipment.

At the downstream station the equipment has been mounted on a reticular structure anchored to a big boulder (Fig. 8). The length of the arm of the support structure is about six meters and can reach the central area of the section. The instrumentation is mounted at a distance from the bottom of the channel of about 3.5 m. In order to make the assembly, disassembly and maintenance of the equipment easier, the support structure can be rotated around the anchorage vertical axis about ninety degrees to align with the left bank of the channel. On the described support a tipping bucket rain gauge, an ultrasonic distance meter, a digital video camera with a nocturnal lighting system and a radio receiver, compatible with the upstream radio transmitter, have been mounted.

Upstream the station, along the left bank of the watercourse, three geophones have been buried spaced roughly 100 m each other. Downstream the station, at the same distance, another geophone has been placed.

The station is powered by connection to the main electricity grid. The power provided is 3 kW.

The measured data are collected by a single board computer and stored locally. The processor and the local mass storage can be managed remotely via access to high speed internet (up to a maximum of 7.2 Mbps), recently available.

THE INSTRUMENTATION

VAISALA WEATHER STATION

The Vaisala Weather Station WXT520 (Fig. 9), operates in the temperature range between -52 °C and +60 °C.

It can be powered in DC 5-32 V with a typical power consumption of 3 mA when powered at 12 V. The station allows the measurement of the following physical quantities: the liquid precipitation, wind speed and direction, air temperature, barometric pressure and relative humidity.

The rainfall is measured as accumulated liquid starting from a manual or automatic reset. The declared output resolution is 0.1 mm, while the accuracy is 5%. The instrument provides a value of cumulative accumulation every 10 seconds in the presence of precipitation. The intensity of precipitation is provided as an average over a minute. The measurement range varies from 0 mm/h to 200 mm/h (for higher intensity the accuracy decreases).

The wind speed is measured in the range 0-60 m/s. The response time is equal to 250 ms and the accuracy is equal to 3% up to 35 m/s and 5% between 35 m/s and 60 m/s. The resolution is equal to 0.1 m/s. The azimuth of the wind direction is measured. The response time is 250 ms, the accuracy is ±3° and the resolution is ±1°.

The air temperature is provided in the range from -52 °C to +60 °C with an accuracy that varies with temperature from ± 0.2% at -52 °C to ± 0.7% at +60 °C. The resolution is equal to 0.1 °C.

Barometric pressure is measured in the range 600-1100 hPa with an accuracy of ± 1.0 hPa between -52 °C to +60 °C; the resolution is equal to 0.1 hPa.

The relative humidity is measured in 0-100 %RH. The accuracy is 3 %RH in 0-90 %RH and 5 %RH in 90-100 %RH. The output resolution is equal to 0.1 %RH.

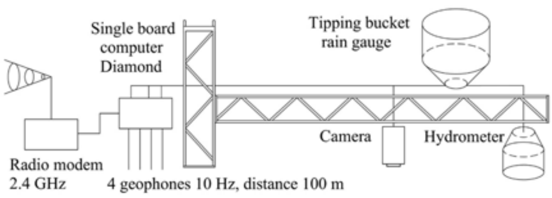

Fig. 8 - The scheme of the downstream station

Fig. 9 - The Vaisala weather station, model WXT520

RADIO MODEM

The connection between the upstream and the downstream station is done by radio-modem. Its use ensures access to data even in case of failure of direct access to the internet at the upstream meteorological station. The model used is the Xstream-PKG RF (2.4 GHz). The transmission range is up to 5 km. There are several options for data interface: the interface RS-232/422/485 serial, USB and telephone. The data transmission rate is selectable at 9.600 bps or at 19.200 bps. 10 V power is supplied. The current consumption is about 200 mA in transmission and about 100 mA in receive mode. The instrument works in the temperature range between -40 °C and 85 °C.

LEVEL TRANSMITTER

The level transmitter is the model 522 Smart Ultrasonic of LTH Electronics Ltd. It allows to measure distances up to 15 m under ideal conditions of perfectly reflective surface. The analog output is in the interval 4 - 20 mA. It can be powered by 24 V DC or 230 V AC. The dissipated power is 6 W. The minimum distance measured is equal to 0.7 m. The sensor is temperature compensated through a thermal resistance sensor, PT100, in the temperature range -30/+60 °C. The resolution of the instrument is 3 mm. Its use has proved suitable for field operating conditions in the previous installations.

TIPPING BUCKET RAIN GAUGE

The measurement of the precipitation at the downstream station is performed by the use of a tipping bucket rain gauge. The diameter of the funnel is equal to 28 cm (area equal to 616 cm^2). The overturning of the bucket occurs every 13.8 grams of water (the value has been obtained by calibration) which corresponds to 0.22 mm precipitation height.

CAMERA

The camera is a high resolution IP colour Camera, model Videoline Ep-CC480M4, CCD 1/3" Sony Super HAD, 480TVL. It supports two modes of image compression: MJPEG and MPEG4. The shutter speed can vary from 1/50 to 1/100.000. Images are captured at a maximum speed of 25 fps. The camera is powered with 5 VDC/2A. The operating temperature ranges from 5 °C to 50 °C. The relative humidity should be between 20% RH and 80% RH. The minimum illumination is 0.5 lux @ F 1.2. At low light conditions is put into operation the system of artificial lighting. The weight is about 300 g.

THE GEOPHONES

Geophones of Sercel, model L10-AR, are used for triggering the monitoring system and for determining the travelling time of the event through a section of the water course. The standard frequency range is equal to 10 - 14 Hz. Their use has proved adequate to the analysed phenomena during previous activity.

THE HELIOS PC BOARD

The monitoring system is controlled by Helios board of Diamond Systems Corporation, model HLV800-256AV, which integrates a complete embedded PC plus a full analog and digital data acquisition circuit into a single board. The processor speed is 800 MHz, a math coprocessor is present. The internal memory consists of 256 MB DDR2 RAM. It is available a 10/100 Mbps Ethernet circuit integrated in the processor chip and a connector for direct access to the Internet. There are 16 single-ended or 8 differential analog voltage inputs available, 16-bit resolution, and up to 40 digital programmable lines. It requires 5 V power supply.

THE RABBIT PC BOARD

The upstream monitoring station is controlled by the board Rabbit ZWorldCorporation, Model RCM4000, which integrates a processor Z180 8-bit and an 11 bit A/D data acquisition circuitry. The processor speed is 29.5 MHz with math coprocessor emulation function.

The internal memory consists of 512 kB of SRAM and 32 MB of flash memory. There is a 10/100 Mbps Ethernet circuit integrated on the chip of the core module and the RJ45 connector for direct access to the Internet.

SOFTWARE FOR THE MANAGEMENT OF MONITORING SYSTEM

On the Helios board of the downstream station the acquisition program is written in C language (Fig. 10). The heart of the program consists of two nested infinite loops. The internal one periodically records the analog signals of the geophones and of the ultrasonic distance meter for a period of 1 minute per hour.

In the inner loop there is a function checking the trigger signal from a digital input. If the signal exceeds a threshold value for an assigned duration the program exits the inner loop and enters the event acquisition routine. The routine is the same as before except in duration: 15-20 minutes. At the same time the camera is also turned on for recording images of the watercourse. At the end of the event recording, the program returns into the inner loop and resumes the periodic registration.

The program is also provided of a connection via TCP/IP, so it is possible to continuously monitor the proper functioning of the equipment installed and the remote download of the recorded data.

In the Rabbit board of the upstream station is mounted a code, also written in C language, which allows the management of serial communications of the Vaisala meteorological station and of the radio modem.

Data can be stored locally and sent subsequently to the downstream station, or sent directly to the downstream station by the radio modem. The method of collecting and managing data is determined from the downstream station accessing a simple user interface with a standard HyperTerminal at 9600 baud rate.

```
while(1) {
        for(;;) {
          if( ((char)kbhit()) == 'a') return;
          if(wait_for_trigger()) break;
          periodic_log();
          if( (vfp = fopen(vfilename,"a")) != NULL) {
            … }
            fclose(vfp);
          }
      }
      event_log();
}
```

Fig. 10 - The core of the software for the management of th downstream station

CONCLUDING REMARKS

This paper has presented an overview of new sensors and system employed for debris-flow monitoring at the Acquabona site (Eastern Alps), where debris flows frequently occurred in the past. The need for field monitoring of debris flow occurrence mainly follows on the consideration that many researches, both theoretical and laboratory, have been undertaken to understand debris-flow processes and the associated hazards. However, confirmation of results needs for quantitative data from natural debris flows. Despite the valuable results that can be obtained, monitoring debris flows in instrumented areas had a rather limited development mainly due to the great difficulties arising from both the morphology of mountainous regions where they occur and the characteristics of this natural phenomenon.

Data collection at the Acquabona site supported then researches on the hydrologic factors controlling debris-flow initiation, entrainment, and flow dynamics.

The previous installed monitoring system, that underwent numerous modifications during the years, was completely torn up by the 2009 debris flow and a completely new system has been planned and realized. Sensors employed are mostly the same used for warning systems that have an important role in the frame of non-structural control measures for these hazardous phenomena.

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