Water **2013**, *5*, 1780-1796; doi:10.3390/w5041780

OPEN ACCESS

water

ISSN 2073-4441

www.mdpi.com/journal/water

Article

Impact of Damaging Geo-Hydrological Events and Population Development in Calabria, Southern Italy

Olga Petrucci [1,*], Angela Aurora Pasqua [1] and Maurizio Polemio [2]

[1] National Research Council-Research Institute for Geo-Hydrological Protection (CNR-IRPI), Unità Organizzativa di Supporto of Cosenza, via Cavour 4/6, Rende 87036 (CS), Italy; E-Mail: a.pasqua@irpi.cnr.it

[2] National Research Council-Research Institute for Geo-Hydrological Protection (CNR-IRPI), Unità Organizzativa di Supporto of Bari, via Amendola 122/I, Bari 70126, Italy; E-Mail: m.polemio@ba.irpi.cnr.it

* Author to whom correspondence should be addressed; E-Mail: o.petrucci@irpi.cnr.it; Tel.: +39-0984-841-424; Fax: +39-0984-841-409.

Received: 16 September 2013; in revised form: 25 October 2013 / Accepted: 1 November 2013 / Published: 13 November 2013

Abstract: Damaging geo-Hydrogeological Events (DHEs) are defined as the occurrence of destructive phenomena (such as landslides and floods) that can cause damage to people and goods during periods of bad weather. These phenomena should be analyzed together as they actually occur because their interactions can both amplify the damage and obstruct emergency management. The occurrence of DHEs depends on the interactions between climatic and geomorphological features: except for long-term climatic changes, these interactions can be considered constant, and for this reason, some areas are systematically affected. However, damage scenarios can change; events that occurred in the past could presently cause different effects depending on the modifications that occurred in the geographical distribution of vulnerable elements. We analyzed a catastrophic DHE that in 1951 affected an area 3700 km^2 wide, located in Calabria (southern Italy), with four-day cumulative rainfall exceeding 300 mm and return periods of daily rain exceeding 500 Y. It resulted in 101 victims and 4500 homeless individuals. The probability that a similar event will happen again in the future is assessed using the return period of the triggering rainfall, whereas the different anthropogenic factors are taken into account by means of the population densities at the time of the event and currently. The result is a classification of regional municipalities according to the probability that events such as the one analyzed will occur again in the future and the possible effects of this event on the current situation.

Keywords: Damaging geo-Hydrogeological Events; landslides; floods; Italy

1. Introduction

Periods of severe weather conditions during which damaging phenomena, such as floods, landslides, sea storms and wind, cause damage to both goods and people are defined as Damaging geo-Hydrogeological Events (DHEs) or events [1,2]. DHEs cause major damage and result in large numbers of victims in a series of circumstances related to factors such as the type of damaging phenomena, the socio-economic framework in which these phenomena happen and human behavior [3].

The occurrence of DHEs depends on the relationships between climatic and geomorphological features that, excluding long-term effects tied to climatic changes, can be considered constant; the areas where the combination of these factors is worse (downpours or prolonged rains falling on river basins characterized by unstable slopes and flash floods) are systematically affected. However, the effects of past and future DHEs can result in different damage scenarios because modifications of the distribution of vulnerable elements can occur within a relatively short period (years), especially in developed countries [4]. Both the frequency and damage of DHEs can be underestimated if data on historical cases are not available. Moreover, when analyzing the effects of a period of bad weather, there is the tendency to focus on (a) the sectors where the severest damage occurred and (b) the type of phenomena that caused major damage or resulted in many victims (e.g., floods). However, to have a realistic framework, all destructive phenomena should be analyzed together as they occur [5,6], and the effects on marginally affected areas should not be neglected.

Major DHEs consist of the simultaneous triggering of different types of phenomena in numerous locations; this situation can create problems for the agencies involved in emergency management, especially if crisis management plans are not available [7]. In addition, the interactions between the damaging phenomena and facilities can cause dangerous "cascading effects" [8], such as the interruption of roads and power supplies, that obstruct both emergency management and the post-event recovery.

This paper first describes steps to gather and elaborate the data used in the proposed approach to characterize DHEs, and then it presents a case study analyzing an historical event and assessing the potential consequences of a similar event in the current regional framework. As study area Calabria (southern Italy) has been selected, because it is frequently affected by DHEs which cause severe damage across wide areas.

2. Materials and Methods

The study of a catastrophic DHE resulting in the creation of an event scenario is based on the analysis of the triggering rainfall, the damaging effects and the anthropogenic framework at the time of the event. In the following section, we describe the data used and the procedures to acquire them.

2.1. Damage Data Collection

To find data on the damaging effects of historical DHEs, newspapers are the most commonly used data source [9–17], even if data can be found in many other types of sources [18–22]; the actual data availability generally may vary from one country to another. The restrictions affecting historical data are widely described in the literature and concern the completeness of the historical series, the exact localization in both time and space of the effects, the uncertainty concerning the number of people involved, and the reliability of the information sources [4,23–28].

Despite all of the known limitations, the usefulness of the data concerning historical events has even been recognized by authorities; according to the Directive 2007/60/EC of the European Parliament, member states shall, for each river basin district, prepare *a description of the floods which have occurred in the past and which had significant adverse impacts on human health, the environment*, *cultural heritage and economic activity and for which the likelihood of similar future events is still relevant*, *including their flood extent and conveyance routes and an assessment of the adverse impacts they have entailed*, *and a description of the significant floods which have occurred in the past*, *where significant adverse consequences of similar future events might be envisaged*.

Returning to our methodology, once the data have been collected, an *event database* must be organized. All of the information gathered from data sources is collected in this database as exact transcriptions of the original texts; then the information is distributed in a series of fields describing what and where damage happened (Table 1). Once the database has been created, one of the most severe events (for which the rain data are also available) must be selected.

Table 1. Fields of the event database.

Event identification	Time	Damaging phenomena	Damaged elements
Record number	Year	Landslide	People (victims injured)
Municipality	Month	Flood	Roads
Place name	Day	Strong wind	Buildings (private)
	Hour	Storm surge, *etc.*	Buildings (public)
			Services: electric/telephonic lines, aqueducts, drainage, systems, gas pipelines, embankments, dams, retaining walls.
			Productive activities: Industry, commerce and handcraft, tourism, agriculture, farming

In the literature, there is a lack of unanimity about the criteria used to classify an event's severity. The classification of a flood's severity level is described in [29], where "catastrophic flood" is defined as a *precipitation episode causing overflowing of banks leading to serious damage or destruction of infrastructure* (*bridges*, *mills*, *walls*, *and paths*), *buildings*, *livestock or crops*. Other papers define a three-level [30] or five-level [16] magnitude scale for floods, based on the extent of the inundated areas, the degree of the economic damage and the number of casualties. Often, the number of victims is considered *a measure for a catastrophic landslide event* and is used as a proxy for the landslide's impact, even if this practice can imply some limitations, especially in the cases of huge and slow landslides causing strong damage but without victims [23]. Even the severity threshold for an event to be included in international disaster databases can vary greatly. To be included in EMDAT [31], one of the criteria is based on the number of victims (>10), whereas NATHAN includes all loss events involving natural hazards that have resulted in *substantial material or human loss* [32]; other databases, such as the recent *Hazards Loss Dataset Catalogue* [33], do not clearly state the criteria characterizing catastrophic events. Taking into account that the selection of the case study among a group of catastrophic events can be biased by the weight assigned to the different types of damage, the case study should be an event in which *both landslides and floods caused major destructions of urbanized sectors and serious damage to people*.

2.2. Damage Assessment

Damage caused by a DHE at the regional level (D_{tot}) can be obtained by combining the local damage assessed at the municipal scale (D_m). Dealing with *historical data*, two limitations must be taken into account:

a. The data available mainly pertains to the *direct damage* [34], which includes the physical effects such as the destruction and changes that reduce the functionality of an individual or structure, the damage to people (death/injury), buildings, their contents, and vehicles, and the clean-up and disposal costs. The data about the *indirect* and *intangible* damage caused by old events are generally either unavailable or scattered and, thus, cannot be systematically analyzed;
b. The economic data about the direct damage are rare and can be incomplete and underestimated. These data depend on an exact appraisal of the costs based on private documents, mainly those documents reporting the damage refund, which are almost impossible to consult for old events. Even if these documents are consulted, an underestimation can arise because, in some administrative contexts, the time for the refund can span several years; it is virtually impossible to isolate a temporal section of an archive in which "all" of the refund documents are included.

For these reasons, we propose a simplified damage assessment focusing on the direct damage. The direct damage at the municipal scale (D_m) can be assessed by multiplying the relative values (set on an arbitrary scale) of the damaged elements, divided into six categories (*buildings*, *roads*, *railways*, *productive activities*, *network services* and *people*), for the level of damage that they suffered (L1 = *low damage*, L2 = *medium damage* and L3 = *high damage*). The direct damage at the regional scale (D_{Tot}) is then expressed by a non-dimensional index obtained by adding the values found for all of the municipalities damaged during the event [1,2,21,24,35].

2.3. Rainfall Data Gathering and Analysis

Based on the information about *when* and *where* the damage occurred, a selection of the rain gauges that were operating in the area at the time of the event can be performed. The proximity of the gauges to the places where the phenomena occurred is more important for landslides and flash floods than for floods in wide basins. Thus, for the selected gauges, the rainfall data must be collected.

The duration of the rain that can be considered the triggering factor of a DHE can change according to the relationships between the climate of the area and the phenomena triggered. For example, in locations where the damage was mainly caused by either deep-seated landslides or floods in wide river basins, it is probable that the rainfall reached exceptional intensities as cumulative rainfall on several days, because prolonged rain is necessary to re-mobilize deep sliding planes. However, in locations where the phenomena were either shallow landslides or flash floods in small torrent catchments, it is probable that these events were triggered by downpours having exceptional daily (or hourly) intensities because these phenomena are typically triggered by intense rain.

Based on the frequent case in which only the daily rainfall is available, to avoid an *a priori* selection of the rainfall duration to analyze, it is possible to investigate the 1-day, 3-day and 5-day cumulative rain. Based on the historical series of each rain gauge, the return periods (T) for the rain of different durations (T_{1d}, T_{3d} and T_{5d}) and the average period (T_a) can then be assessed. Thus, a measure of the probability that the rain intensities characterizing the analyzed event can occur again in the future can be assessed.

2.4. Data on the Anthropogenic Framework of the Study Area

Rainfall and damage data allows one to obtain a description of the studied event. To assess the possible effects of a similar event in the future, the framework of the affected area must be analyzed. When dealing with historical events, one must account for the fact that both the amount and the quality of available data are not comparable to the wide volume of data available for current cases, and even in favorable circumstances, the data are available at a regional scale and do not allow sub-regional differentiations.

It is necessary to select a synthetic descriptor of the human occupation of the area that is based on the accessible data. We propose to use the number of inhabitants, a figure that is widely surveyed in all of the countries; as it is measured during regular censuses, this descriptor can be used to account for the modifications that have occurred throughout time, whereas the most recent census data can be considered as representative of the current territorial framework. The population density at the municipal scale, obtained by dividing the number of inhabitants for the municipal area, can then be used to quantify the human occupation of each municipality and can be considered a proxy of the vulnerable elements' distribution. In the literature, the relationship between the increasing population and flood effects has already been used; for example, Llasat *et al.* [36] highlighted an increase of the flash-flood damage related to the population increase in the towns along the Catalan coast.

2.5. Data Analysis and Synthesis

At this point, the data concerning the risk factors related to both rain and population density variations must be analyzed to obtain two risk components for each municipality; the first component takes into account the frequency of rain events similar to the one studied, and the second component considers the modifications that occurred in vulnerable elements' locations.

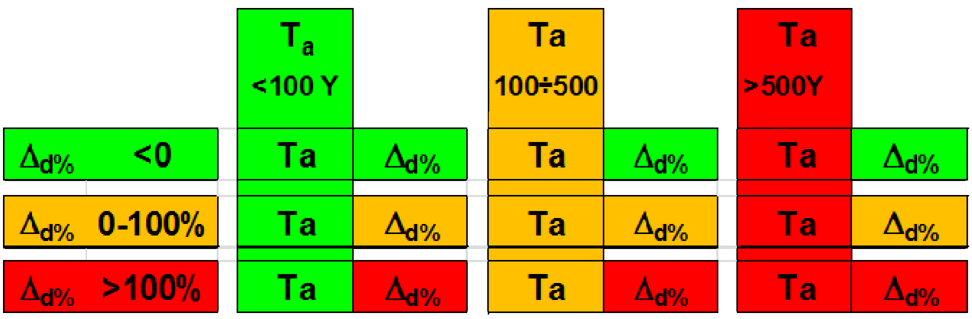
The return period is assessed using the historical series of rain gauges; thus, this evaluation takes into account the climatic trend and assesses the probability that events such as the one analyzed could occur in the future. For each municipality, T_a can be easily assessed by superimposing, in a GIS environment, the T_a map and the boundaries of the affected municipalities. In the cases in which a municipality covers an area characterized by two T_a values, the value of T_a covering the majority of the municipal area can be used as representative. For each municipality, the values of the population density, assessed both at the time of the event and currently, seemingly take into account the increase or decrease of the vulnerable elements prone to be damaged by future events. To express such a variation, a parameter named Δ_d can be defined as in Expression (1):

$$\Delta_d = [(D_m \times Density\ Pop_{DHE}) - (D_m \times Density\ Pop_{present})/Density\ Pop_{DHE}] \times 100 \quad (1)$$

D_m is the damage caused by the analyzed DHE in a selected municipality, assessed using the approaches published in previous papers; $Density\ Pop_{DHE}$ is the population density at the time of the event; and $Density\ Pop_{present}$ is the current density population. The result is then expressed as a percentage of the population density at the time of the studied DHE. Δ_d is a measure of the level of damage that could be caused, within the current population arrangement, by an event similar to the study case. This parameter can be negative, corresponding to a population density decrease during the years between the event and the present day, or positive, corresponding to an increase in the population density during the same period.

Using this double criterion, the combinations of possibilities are illustrated in Figure 1; here, the most dangerous condition is represented by both T_a and Δ_d colored in red. This is the case for municipalities where two conditions occur: (1) since the time of the analyzed DHE, the population density has been increasing; (2) during the studied event, the damage was caused by rain having an unexceptional return period, compared to the other value assessed in the surroundings, that most likely will occur again. However, green cells for both T_a and Δ_d, represent municipalities where two different conditions occur: (1) since the time of the DHE, these areas have been depopulating; and (2) the rain that triggered the damage in the studied event can be considered extremely rare with a very low probability of occurrence. All of the other cases represent intermediate situations, having one factor more dangerous than the other; these factors can either be combined to obtain a score summarizing the situation or can be analyzed separately to correctly address countermeasures. For example, where the more dangerous condition is the increasing urbanization, after a local analysis of places that were historically damaged, it is possible to introduce limitations on the creation of new settlements in the most dangerous areas. However, for locations in which the most dangerous condition depends on the rain, it should be more effective to rely on non-structural measures and take into account the possible worsening of the rain regimen because of climate changes.

Figure 1. Possible combinations of risk features related to rain, expressed by T_a (years), and to population density variations, expressed by Δ_d (green: low; yellow: intermediate; red: high).



3. Introduction to the Case Study

The described approach was applied to Calabria (southern Italy), a region frequently affected by DHEs. Calabria (15,230 km^2) has a mean altitude of 418 m and a maximum of 2266 m. The climate is

Mediterranean in the coastal zones, with mild winters and hot summers characterized by few rains. The East side, affected by air masses coming from Africa, shows higher temperatures with short and heavy rains; the West side is influenced by western air masses and has milder temperatures and frequent rain. The average regional annual rainfall is 1151 mm; heavy rainfall is frequent during autumn and winter and often triggers DHEs.

The region is made up of crystalline rocks (Palaeozoic–Jurassic) piled during the middle Miocene over carbonate rocks. Neogene flysh fills tectonic depressions. Since the beginning of the Quaternary Period, Calabria has been subjected to a still-active uplift. The regional morphology is rugged; only 10% of the territory is plain, whereas the remaining area shows either hilly or mountainous structure. Administratively, the region is divided into five provinces, which are further divided into 409 municipalities, with a population of 2,011,391 [37].

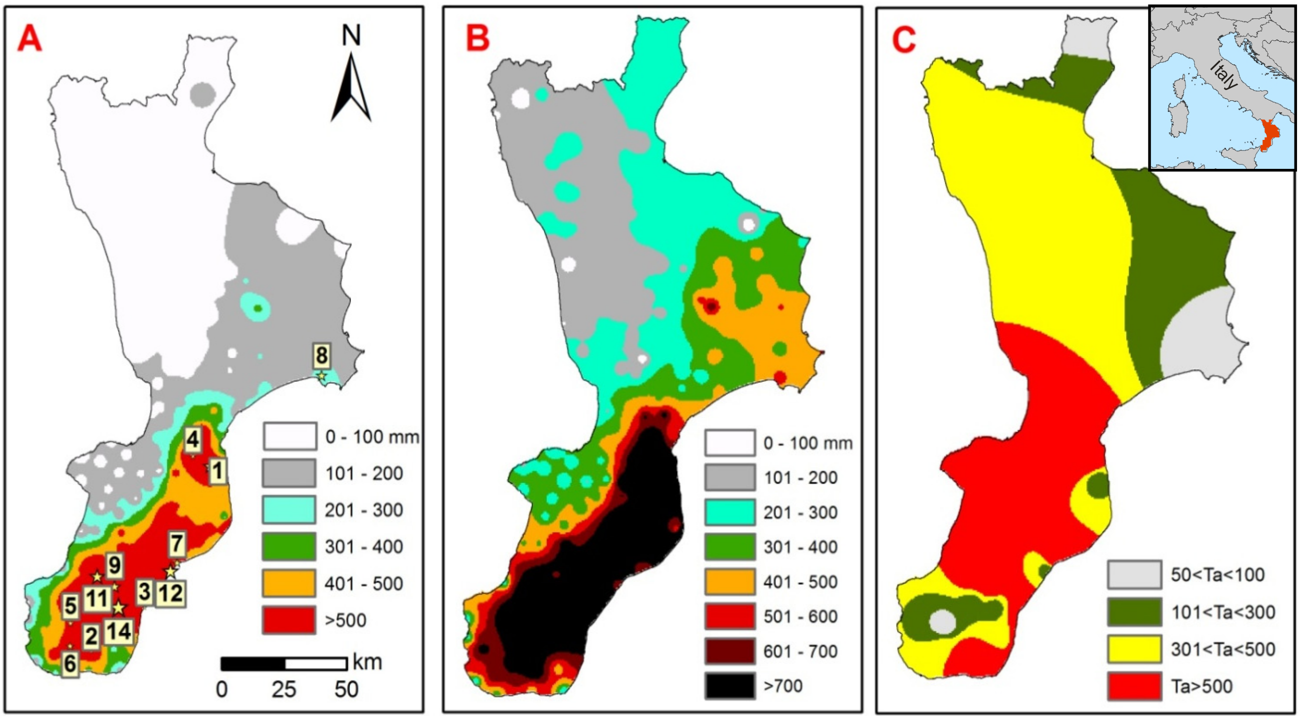
The historical research performed in recent years allowed us to implement an event database of approximately 11,000 records collecting the effects caused by the DHEs that occurred throughout the XIX, XX and XXI centuries [38–43]. The case study was selected by examining the database and looking for events characterized by widespread and serious effects and for which rainfall data were available. In this way, we chose the 1951 event, during which devastating precipitation affected the SE sector of Calabria between October 16 and 19. Floods and landslides started to manifest, causing damage that dramatically increased until the end of the month. The final balance was 101 victims, 100 municipalities damaged (24% of the total), 4500 homeless individuals, approximately 1700 houses disrupted or heavily damaged, huge damage to agriculture, 26 broken bridges, 77 damaged aqueducts and countless road interruptions, such that communications between coastal villages were possible only by sea [44,45].

3.1. Rainfall Analysis

Daily rain data were extracted from the web archive managed by ARPACal, a regional environmental agency [46]. By interpolating the data recorded by 166 gauges that were working at the time of the event, we obtained the map of the cumulative rain for the days between October 16 and 19, during which the daily intensity reached the maximum value (Figure 2A). The affected areas, approximately 3700 km^2 wide, recorded the cumulative rainfall, which, in four days, exceeded 300 mm; in the same days, a sector of approximately 850 km^2 inside this area recorded more than 500 mm. Figure 2B is a map of the total rain that fell in October 1951; in approximately 3700 km^2, the monthly rain was greater than 600 mm, with peaks of 1770 mm and 1350 mm. The hourly and sub-hourly rain was not systematically collected at that time; nevertheless, some spare data are available. The highest value reported was 82.2 mm/h, followed by several cases of approximately 50 mm/h [47].

We selected 14 gauges that during the event recorded the maximum daily rain of their historical series (still currently unmatched) and used these gauges to describe the rainfall characteristics. The maxima of the daily rainfall were exceptionally high (Table 2); for 10 out of 14 gauges, these values reached more than double of the average monthly rainfall. In all of these gauges, the ratio of the October 1951 monthly rain to the October monthly average was greater than 5, reaching a maximum value of 10. The higher values of the daily rainfall (D) were recorded on October 18 (the highest value, 534.6 mm/day, was recorded at gauge No. 11); on average, the daily rainfall of that day was 2.30 times the average October monthly rainfall. In all but one case (No. 8), October 1951 was the rainiest October of the entire historical series (averaging seven times the October monthly average), and the monthly rain in some cases was greater than the yearly average (up to 124% of the average yearly rain).

Figure 2. (**A**) The classification of Calabria according to the accumulated rain of October 16–19, 1951 (mm); (**B**) The accumulated rain recorded in the region during October 1951 (mm); (**C**) The regional classification according to the return period of the rain (average value T_a) and the location of the study area.



To assess the exceptionality of the event, we analyzed the cumulative rain that fell over 1, 3 and 5 days. Using the Gumbel distribution and assessing the parameters using the moments method [48], we evaluated the return periods of the rainfall that fell on these gauges during the listed durations (T_{1d}, T_{3d} and T_{5d}) and the average of these three values (T_a). The results were sorted into four classes (Class 1: $50 < T_a < 100$ years; Class 2: $101 < T_a < 300$ years; Class 3: $301 < T_a < 500$ years; and Class 4: $T_a > 500$ years); we then used these values to classify the regional territory (Figure 2C).

Of the 14 analyzed gauges, 12 gauges showed similar values or return periods, whereas gauges No. 5 (maybe overestimated because of the short length of the observations) and No. 8 were the only two cases characterized by relatively low return periods ($50 < T_a < 100$ years). For the other gauges, the highest values were mainly recorded for 3–5 days, and these values affected the average value (T_a), which is greater than that for 500 years for a large sector of central-south Calabria (Figure 2C).

Table 2. Rain at the gauges that recorded the maximum daily rain during the event, indicated by stars in Figure 2A. Classified values of return periods are indicated with T_{1d} (for 1-day rain recorded during the event), T_{3d} (for 3 days), and T_{5d} (for 5 days), whereas T_a is the average of T_{1d}, T_{3d} and T_{5d}.

No.	Rain gauge	Altitude (m) [*H*]	Length of the series (years) [*L*]	Max event daily rain (mm) [*D*]	Max event daily rain/ Oct monthly average [*D*/*Ma*]	Oct 1951 monthly rain/ Oct monthly average [*M*/*Ma*]	Oct 1951 monthly rain/average yearly rain [*M*/*Ya*]	T_{1d}	T_{3d}	T_{5d}	T_a
1	Badolato	250	30	371.2	2.09	8.22	1.24	1	3	3	2
2	Bova S.	800	58	261.4	2.08	6.96	1.06	2	4	4	4
3	Bovalino M.	8	38	462.9	3.29	5.22	1.00	4	4	3	4
4	Chiaravalle C.	550	60	436.1	2.72	9.03	1.09	2	4	4	4
5	Croce Romeo	1350	10	250.4	1.48	6.06	0.81	1	1	1	1
6	Croce S.Lorenzo	425	36	274.3	2.10	5.83	0.93	2	3	3	3
7	Gioiosa Ionica	125	60	303.1	2.54	6.59	0.92	3	4	4	4
8	Isola C. Rizzuto	96	54	179.6	1.76	5.35	0.81	1	1	1	1
9	Plati'	310	60	373.3	1.96	7.12	0.83	3	4	4	4
10	S. Sostene	475	47	417.1	2.15	8.37	1.15	2	4	4	4
11	S. Cristina	510	57	534.6	3.11	10.29	1.28	2	4	4	4
12	Siderno M.	7	55	271.2	2.41	5.46	0.92	2	2	3	2
13	Santuario Polsi	786	37	410.2	1.93	7.23	0.81	1	2	2	2
14	S. Luca	250	57	410.2	2.63	5.60	0.83	1	3	3	2

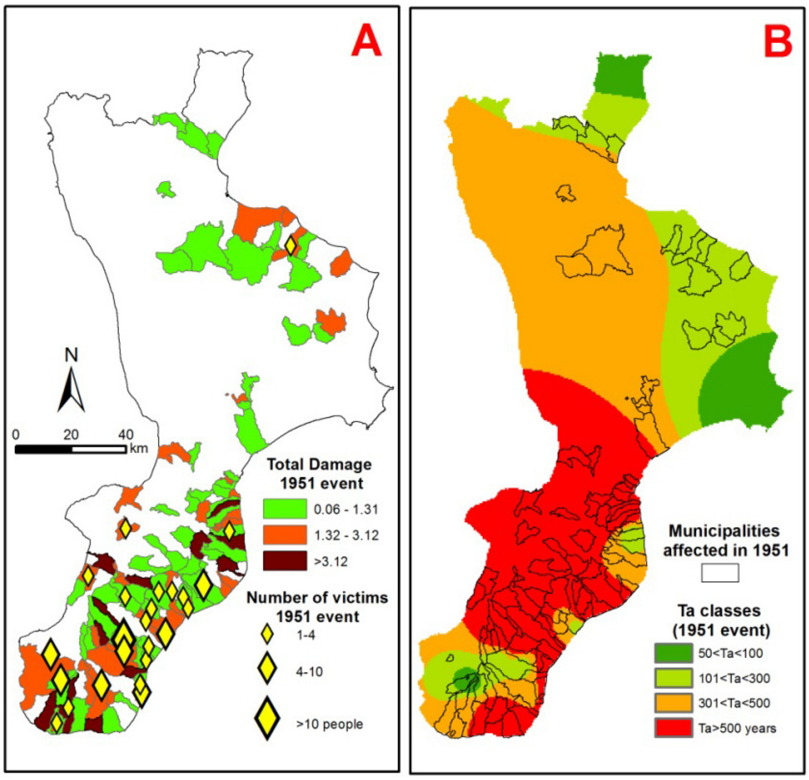
3.2. Damage Analysis

According to the great amount of rain that fell in a short period, destructive flash floods affected the small basins typical of the Mediterranean climate and characterized by steep courses and torrential regimen [49,50]. Because of the intermittent regimen, the flow in this area is not systematically measured, and no discharges data are available. Nevertheless, the huge river's flow can be inferred from the number of broken bridges that reached a total of 26. The water discharge, mixed with the debris coming from the numerous landslides triggered by the rain and channeled into the river network, became a powerful liquid-solid mass that eroded river beds and, in a sort of *domino effect*, increased the mass's power, destroying settlements and bridges along the path towards the sea. In several cases, the flow was so large that rivers changed their path, breaking the embankments and flowing into villages located along the river banks. Moreover, heavy rain triggered both shallow and vast deep-seated landslides that affected villages; people were forced to abandon their houses, which were strongly damaged or completely destroyed, as in the cases of Casalinuovo di Africo and some hamlets of Careri and Caulonia villages.

The damaging phenomena were mainly landslides (42%) and floods (42%); followed by urban flooding and wind. The higher number of damage records concerned buildings (26% of the cases of damage, 5% of which affected public buildings), roads (23%), services (14%), productive activities (14%) and people (11%).

The mean value of D_m was 1.5, the minimum was 0.06, and the maximum value was observed in the Plati' municipality on the east coast where there were 18 victims in total, and damage to houses, services and roads occurred. The severest damage was concentrated on the southeast sector, and a few municipalities located on the northeast sector were also hit (Figure 3A). By comparing this image to the regional classification based on the return period of the rainfall event [(average of $T_{1d} > T_{3d}$ and average of $T_{1d} > T_{5d}$)], the majority of the affected municipalities (more than 60%) are located in the area classified with the highest rainfall return period (>500 years) (Figure 3B).

Figure 3. (**A**) Classification of the Calabrian municipalities according to the total damage caused by the 1951 event and the number of victims that suffered (yellow rhombuses); (**B**) Classification of the regional territory according to the return period of rainfall that occurred during the 1951 event and the boundaries of the affected municipalities.



3.3. The Anthropogenic Framework of the Study Area

At the time of the event, the regional number of inhabitants surveyed was 1,995,084; by comparing this value to the number of inhabitants surveyed in 2010, an increase of approximately 0.81% in 59 years can be noted [37]. The modal value of the number of inhabitants per municipality strongly decreased (from *1604* in 1951 to *538* in 2010), according to the migration of people from mountainous villages towards coastal towns or abroad, which occurred during the second half of the 20th century. As a result, the population trend decreased in 75% of the municipalities and increased in 25% of them (Table 3).

Table 3. Comparison between the Calabrian population data recorded in 1951 and 2010 [37]. Nh: number of inhabitants; (M): per municipality; PD: population density (Inhabitants/km^2).

Inhabitants	Year 1951	Year 2010
Regional Nh	1,995,084	2,011,391
Min Nh (M)	883	291
Max Nh (M)	140,734	186,547
Mean Nh (M)	4,878	4,918
Modal value of Nh (M)	1,604	538
Median of Nh (M)	3,035	2,251
Min PD (M)	8	9
Max PD (M)	1,923	1,868
Mean PD (M)	157	144
Modal value of PD (M)	94	156
Median of PD (M)	121	79

3.4. Discussion

Based on the proposed approach, all of the regional municipalities affected during the event have been labeled according to the two parameters taking into account both the rain and the population (Table 4). The great depopulation affecting the majority of Calabrian villages is clear, even in several cases in which the 1951 event produced victims. Only two municipalities show the worst combination of rain and a variation of the population density (both cells in red), whereas in 10 cases, both factors assume a medium value. As a result, in almost all of the cases where the population factor is either high (six cases) or medium (21 cases), an analysis of the damage scenario at a municipal scale can be useful to assess the local effects of an extreme DHE.

A similar municipality's classification can appear rough, but it must be noted that we address a framework realized at a regional scale, and this is the right scale to obtain a synoptic view of both the damage and the rain triggering DHEs. Moreover, even at this scale, a more detailed classification can be tuned by simply setting more than three classes for both Δ_d and T_a.

A limitation is related to the use of the population density to express the evolution of the vulnerable elements on the territory. In this case, the choice has been forced by the unavailability, at the regional scale and especially for the time of the studied event, of more detailed data. The use of population data allows the application of this approach to regions, such as Calabria, where data concerning the evolution of elements such as urbanized settlements, road networks and infrastructures are scarce and not systematically collected through both time and space.

Nevertheless, an in-depth analysis can be realized at the municipal scale, where the evolution of urbanized sectors can be imported in a GIS environment by simply comparing air photos of urbanized sectors at the time of the event to those of today. At this scale, all of the data collected from the event scenario can be used to add information to both flood and landslide maps that are usually available at the municipal level to understand, using the real example of an event that actually occurred, the way in which landslides or rivers can cause damage and even the circumstances in which people died.

Table 4. The Calabrian municipalities affected by the 1951 event. The colors represent the values of the Δ_d and T_a classes, as in the legend; the numbers represent victims in each municipality in the 1951 event.

Municipality	Δ_d	T_a	Municipality	Δ_d	T_a
ACQUARO			LONGOBUCCO		
ACRI			LUZZI		
AFRICO	9		MAMMOLA	4	
ALBI			MANDATORICCIO		
ANTONIMINA	2		MARINA DI GIOIOSA IONICA	2	
ARDORE	1		MELICUCCO		
BADOLATO	1		MELITO DI PORTO SALVO	1	
BAGALADI			MILETO	1	
BELVEDERE DI SPINELLO			MONTAURO		
BENESTARE			MONTEBELLO IONICO		
BIANCO	2		MONTEPAONE		
BIVONGI			NARDODIPACE		
BOVA			OPPIDO MAMERTINA		
BOVA MARINA			PALIZZI		
BOVALINO	2		PALMI		
BRUZZANO ZEFFIRIO			PENTONE		
CACCURI			PETRIZZI		
CAMPANA			PIETRAPAOLA	2	
CANOLO	3		PLATI'	18	
CARDETO	7		POLISTENA		
CARDINALE			PORTIGLIOLA		
CARERI	10		REGGIO DI CALABRIA		
CASABONA			RIACE		
CASIGNANA			ROCCELLA IONICA		
CATANZARO			ROGHUDI		
CAULONIA	10		ROSARNO		
CERCHIARA DI CALABRIA			ROSSANO		
CHIARAVALLE CENTRALE			S. GIORGIO MORGETO		
CINQUEFRONDI			S. LORENZO	1	
CITTANOVA	3		S. LORENZO BELLIZZI		
CONDOFURI			S. LORENZO DEL VALLO		
COSOLETO			S. LUCA		
CROPALATI			S. SOSTENE		
CROSIA			S. CATERINA DELLO IONIO		
CRUCOLI			S. CRISTINA D'ASPROMONTE		
CURINGA			S. ALESSIO IN ASPROMONTE	7	
DAVOLI			S. ANDREA AP. DELLO IONIO		
DELIANUOVA			SATRIANO		
FABRIZIA			SCIDO		
FOSSATO SERRALTA			SERRA SAN BRUNO		
GALATRO			SIDERNO		
GASPERINA			SOVERATO		

Table 4. *Cont.*

Municipality	Δd	Ta	Municipality	Δd	Ta
GERACE			STIGNANO		
GIOIA TAURO	1		STILO		
GIOIOSA IONICA	2		TAURIANOVA		
GROTTERIA	2		TORRE DI RUGGIERO		
GUARDAVALLE			VARAPODIO		
ISCA SULLO IONIO			VAZZANO		
JACURSO			VIBO VALENTIA		
LOCRI	10		VILLAPIANA		

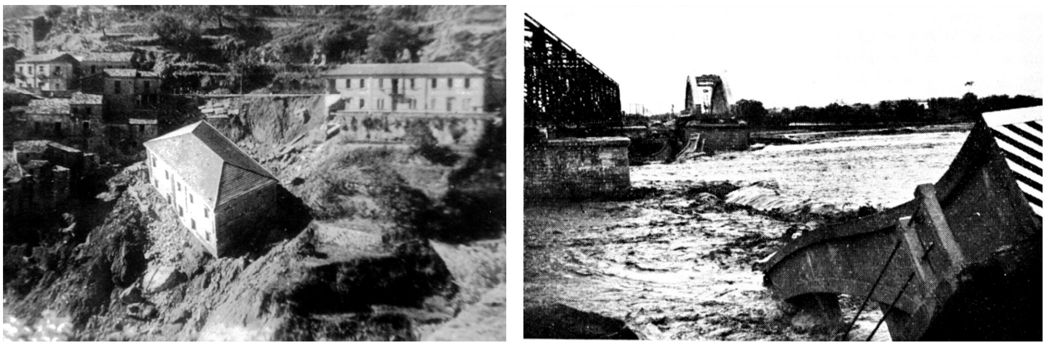
Notes: Δ_d Classes: <0, 0–100, >100; T Classes: <100, 100–500, >500.

The idea of studying such a severe event, caused by rain with a return period greater than 500 years, is a choice depending on the fact that, during the last 10 years, the number of DHEs that have been affecting Calabria is increasing. For this reason, even taking into account that rain measurements are not available for the period before 1921, the current observation of the increasing frequency of rain capable of causing damage should lead us to review our concept of an "exceptional" event because if these events occur more frequently, they can no longer be considered exceptional.

4. Conclusions

The paper presents the analysis of major DHEs that occurred in 1951 in a region of southern Italy, both in terms of the triggering rainfall and the resulting damage (Figure 4). The probability that a similar event will happen again in the future is assessed using the return period of the triggering rainfall, whereas the different anthropogenic factors are taken into account by means of the population density at the time of the historical event and currently. The result is a classification of regional municipalities according to the probability that events such as the one analyzed will occur again in the future and the possible effects of such an event in the current situation. The usefulness of these results depends on the fact that the phenomena causing damage during these events are generally analyzed separately, instead of all together as they actually occur.

Figure 4. Damage caused by the analyzed DHE. (**A**) The city-hall of Grotteria village (Reggio C.), moved from the top of a hill because of a landslide (photo from the newspaper *L'Unità*); (**B**) The broken bridge on the Careri river, in Reggio Calabria province (after Gulli, [51]).



(**A**) (**B**)

The approach is built at a regional scale but can help project planners to recognize the most dangerous situations and make decisions about how to address those situations. Moreover, especially for the most dangerous cases, by using historical data, knowledge gaps at the municipal scale can be filled, and a more detailed framework of the places where urban expansion must be forbidden can be obtained. Because of the long return period of major DHEs, the density of the vulnerable elements in historically hit areas may currently be greater than in the past, which increases the risk conditions. Moreover, it is possible to verify where historically damaged points are still damageable (if no defensive measures have been undertaken) and to identify the major causes of injures to people, which will be useful in information campaigns for people.

Acknowledgments

This study has been carried out within the Subproject *Tipizzazione di eventi naturali ed antropici ad elevato impatto sociale ed economico*, as part of the Project *Rischi naturali*, *ambientali e antropici*"—Department *Terra e Ambiente* of the Italian National Research Council (CNR).

Conflicts of Interest

The authors declare no conflict of interest.

References

1. Petrucci, O.; Polemio, M.; Pasqua, A.A. Analysis of damaging hydrogeological events: The case of the Calabria Region (Southern Italy). *Environ. Manag*. **2009**, *25*, 483–495.
2. Petrucci, O.; Polemio, M. The role of meteorological and climatic conditions in the occurrence of damaging hydro-geologic events in Southern Italy. *Nat. Hazards Earth Syst. Sci.* **2009**, *9*, 105–118.
3. Llasat, M.C.; Llasat-Botija, M.; Petrucci, O.; Pasqua, A.A.; Rosselló, J.; Vinet, F.; Boissier, L. Towards a database on societal impact of Mediterranean floods in the framework of the HYMEX project. *Nat. Hazards Earth Syst. Sci*. **2013**, *13*, 1337–1350.
4. Blahut, J.; Poretti, I.; de Amicis, M.; Sterlacchini, S. Database of geo-hydrological disasters for civil protection purposes. *Nat. Hazards* **2012**, *60*, 1065–1083.
5. Crozier, M.J. Multiple-occurrence regional landslide events in New Zealand: Hazard management issues. *Landslides* **2005**, *2*, 247–256.
6. Copien, C.; Frank, C.; Becht, M. Natural hazards in the Bavarian Alps: A historical approach to risk assessment. *Nat. Hazards*, **2008**, *45*, 173–181.
7. Petrucci, O.; Pasqua, A.A.; Gullà, G. Landslide damage assessment using the Support Analysis Framework (SAF): The 2009 landsliding event in Calabria (Italy). *Adv. Geosci*. **2010**, *26*, 13–17.
8. May, F. Cascading disaster models in post burn flash flood. In *The Fire Environment—Innovations*, *Management*, *and Policy*; Butler, B.W., Cook, W., Eds.; U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station: Fort Collins, CO, USA, **2007**, 443–464.
9. Rappaport, E.N. Loss of life in the United States associated with recent atlantic tropical cyclones. *Bull. Am. Meteorol. Soc.* **2000**, *9*, 2065–2073.

10. Agasse, E. Flooding during the 17th to 20th centuries in Normandy (Western France): Methodology and use of historical data. In *Palaeofloods*, *Historical Floods and Climatic Variability*: *Applications in Flood Risk Assessment*; Thorndycraft, V.R., Benito, G., Barriendos, M., Llasat, M.C., Eds.; In Proceedings of the Palaeo-Flood and Historical Evidence in Flood Risk Assessment Workshop, Barcelona, Spain, 16–19 October 2003; pp. 99–105.
11. Devoli, G.; Morales, A.; Høeg, K. Historical landslides in Nicaragua-collection and analysis of data. *Landslides* **2007**, *4*, 5–18.
12. Hilker, N.; Badoux, A.; Hegg, C. The Swiss flood and landslide damage database 1972–2007. *Nat. Hazards Earth Syst. Sci*. **2009**, *9*, 913–925.
13. Kuriakose, S.L.; Sankar, G.; Muraleedharan, C. History of landslide susceptibility and a chorology of landslide-prone areas in the Western Ghats of Kerala, India. *Environ. Geol*. **2009**, *57*, 1553–1568.
14. Llasat, M.C.; Llasat-Botija, M.; Barnolas, M.; Lopez, L.; Altava-Ortiz, V. An analysis of the evolution of hydrometeorological extremes in newspapers: The case of Catalonia, 1982–2006. *Nat. Hazards Earth Syst. Sci*. **2009**, *9*, 1201–1212.
15. Maples, L.Z.; Tiefenbacher, J.P. Landscape, development, technology and drivers: The geography of drownings associated with automobiles in Texas floods, 1950–2004. *Appl. Geogr.* **2009**, *29*, 224–234.
16. Adhikari, P.; Hong, Y.; Douglas, K.R.; Kirschbaum, D.B.; Gourley, J. A digitized global flood inventory (1998–2008): Compilation and preliminary results. *Nat. Hazards* **2010**, *2*, 405–422.
17. FitzGerald, G.; Du, W.; Jamal, A.; Clark, M.; Hou, X. Flood fatalities in contemporary Australia (1997–2008). *Emerg. Med. Aust.* **2010**, *22*, 180–186.
18. Brázdil, R.; Kundzewicz, Z.W. Historical hydrology—Editorial hydrological sciences. *Hydrol. Sci. J.* **2006**, *51*, 733–738.
19. Llasat, M.C.; Barriendos, M.; Barrera, A. The use of historical data in flood risk assessment, application to Catalonia (NE Spain) 14th–20th Centuries. In *View from the South*, *Environmental Stories from the Mediterranean Word*; Armiero, M., Ed.; Consiglio Nazionale delle Ricerche, Istituto di Studi sulle Società del Mediterraneo: Napoli, Italy, 2006; pp. 95–110.
20. Kirschbaum, D.B.; Adler, R.; Hong, Y.; Hill, S.; Lerner-Lam, A.L. A global landslide catalogue for hazard applications: Method, results and limitations. *Nat. Hazards* **2009**, *52*, 561–575.
21. Petrucci, O.; Gullà, G. A simplified method for landslide damage scenario assessment based on historical data. *Nat. Hazards* **2010**, *52*, 539–560.
22. Petrucci, O.; Pasqua, A.A.; Polemio, M. Flash flood occurrences since 17th century in steep drainage basins in southern Italy. *Environ. Manag.* **2012**, *50*, 807–818.
23. Guzzetti, F. Landslide fatalities and the evaluation of landslide risk in Italy. *Eng. Geol*. **2000**, *58*, 89–107.
24. Petrucci, O.; Pasqua, A.A. The study of past Damaging Hydrogeological Events for damage susceptibility zonation. *Nat. Hazards Earth Syst. Sci*. **2008**, *8*, 881–892.
25. Petrucci, O.; Pasqua, A.A. A methodological approach to characterise Landslide Periods based on historical series of rainfall and landslide damage. *Nat. Hazards Earth Syst. Sci*. **2009**, *9*, 1655–1670.

26. Petrucci, O.; Pasqua, A.A. Damaging events along roads during bad weather periods: A case study in Calabria (Italy). *Nat. Hazards Earth Syst. Sci*. **2012**, *12*, 365–378.
27. Petrucci, O. Assessment of the impact caused by natural disasters: Simplified procedures and open problems. In *Managing Disasters*, *Assessing Hazards*, *Emergencies and Disaster Impacts*; Tiefenbacher, J.P., Ed.; InTech: Rijeka, Croatia, 2012; pp. 109–132. Available online: http://www.intechopen.com/books/approaches-to-managing-disaster-assessing-hazards-emergencies-and-disaster-impacts (accessed on 12 September 2013).
28. Frigerio, S.; Blahut, J.; Sterlacchini, S.; Poretti, I. Landslides historical dataset and population distribution: Historic@, the experience of the consortium of Mountain Municipalities of Valtellina di Tirano, Italy. Malet, J.-P., Glade, T., Casagli, N. Eds.; CERG Publications: Strasbourg, France, 2010; pp. 491–497.
29. Llasat, M.C.; Barriendos, M.; Barrera, A.; Rigo, T. Floods in Catalonia (NE Spain) since the 14th century. Climatological and meteorological aspects from historical documentary sources and old instrumental records. *J. Hydrol.* **2005**, *313*, 32–47.
30. Mudelsee, M.; Deutsch, M.; Börngen, M.; Tetzlaff, G. Trends in flood risk of the River Werra (Germany) over the past 500 years. *Hydrol. Sci. J.* **2006**, *51*, 818–833.
31. The International Disaster Database Homepage. Available online: http://www.emdat.be/ (accessed on 6 November 2013).
32. Munich Re Homepage. Available online: http://mrnathan.munichre.com/ (accessed on 6 November 2013).
33. Beckman, L. An Annotated Bibliography of Natural Hazard Loss DataSets Derived from the Hazards Loss Dataset Catalog, 2009. Available online: http://www.colorado.edu/hazards/ publications/hazloss/ loss_catalog.pdf. (accessed on 12 September 2013).
34. Swiss Re. *Floods—An insurable risk*? Swiss Re: Zurich, Switzerland, 1998; p. 48.
35. Petrucci, O.; Gullà, G. A Support Analysis Framework for mass movement damage assessment: Applications to case studies in Calabria (Italy). *Nat. Hazards Earth Syst. Sci*. **2009**, *9*, 315–326.
36. Llasat, M.C.; Lopez, L.; Barnolas, M.; Llasat-Botija, M. Flash-floods in Catalonia: The social perception in a context of changing vulnerability. *Adv. Geosci*. **2008**, 17, 63–70.
37. Istituto Nazionale di Statistica Homepage. Available online: http://www.istat.it/it/ (accessed on 6 November 2013).
38. Petrucci, O.; Chiodo, G.; Caloiero, D. *Eventi alluvionali in Calabria nel decennio* 1971–1980; Available online: http://books.google.it/books/about/Eventi_alluvionali_in_Calabria_nel_decen.html?id=JqQtrxZhkpsC&redir_esc=y (accessed on 12 September 2013).
39. D'Andrea, E.; Petrucci, O. *Gli Eventi Alluvionali Calabresi di Dicembre* 2002 *Gennaio* 2003; Editoriale Bios: Cosenza, Italy, 2002.
40. Petrucci, O.; Versace, P. ASICal: A Database of Landslides and Floods Occurred in Calabria (Italy). In Proceedings of 1st Italian-Russian Workshop: New Trends in Hydrology, Rende, Italy, 24–26 September 2002; pp. 49–55.
41. Petrucci, O.; Versace, P. *Frane e Alluvioni in Provincia di Cosenza Agli Inizi del* '900: *Ricerche Storiche Nella Documentazione del Genio Civile*; Editoriale Bios: Cosenza, Italy, 2005; p. 172.
42. Petrucci, O.; Versace, P. *Frane e Alluvioni in Provincia di Cosenza Tra il* 1930 *e il* 1950: *Ricerche Storiche Nella Documentazione del Genio Civile*; Nuova Bios: Cosenza, Italy, 2007; p. 247.

43. Palmieri, W.; Petrucci, O.; Versace, P. *La Difesa del Suolo Nell'Ottocento nel Mezzogiorno d'Italia*; Rubbettino: Soveria Mannelli, Italy, 2011; p. 183.
44. Botta, G. *Difesa del Suolo e Volontà Politica*, *Inondazioni Fluviali e Frane in Italia*: 1946–1976; Franco Angeli: Milano, Italy, 1977.
45. Caloiero, D.; Mercuri, T. *Le Alluvioni in Calabria dal* 1921 *al* 1970; Consiglio Nazionale delle Ricerche: Rende, Italy, 1980, p. 161.
46. ARPACAL, Centro Funzionale Multirischi Homepage. http://www.cfd.calabria.it/index.php?option=com_wrapper&view=wrapper&Itemid=41 (accessed on 6 November 2013).
47. Servizio Idrografico. *Annali Idrologici*, *parte I e II*; Istituto Poligrafico e Zecca dello Stato: Roma, Italy, 1951.
48. Versace, P.; Ferrari, E.; Fiorentino, M.; Gabriele, S.; Rossi, F. *Valutazione Delle Piene in Calabria*; Consiglio Nazionale delle Ricerche: Rende, Italy, 1989; pp. 1–157.
49. Ergenzinger, P. A conceptual geomorphological model for the development of a Mediterranean river basin under neotectonic stress (Buonamico basin, Calabria, Italy). In *Erosion*, *Debris Flows and Environment in Mountain Regions*; IAHS Press, Institute of Hydrology: Wallingford, UK, 1992; pp. 51–60.
50. Ibbeken, H.; Schleyer, R. *Source and Sediment*: *A Case Study of Provenance and Mass Balance at an Active Plate Margin* (*Calabria*, *Southern Italy*); Springer: Berlin, Germany, 2012; p. 300.
51. Gulli, G.B. L'alluvione del 15–18 ottobre 1951 in Calabria. In *Giornale del Genio Civile*; Istituto Poligrafico dello Stato: Roma, Italy, 1952; pp.147–157.