The cause and mechanism of Gouras stream mudflow in Epirus (W. Greece)

P. Stefanidis & D. Myronidis
Faculty of Forestry and Natural Environment,
Aristotle University of Thessaloniki, Greece

Abstract

In the current study, the investigation of the torrential potential of the "Gouras" stream in the region of Epirus (W. Greece) showed that this is affected by four basic torrential factors: climate, rocks, relief and vegetation. Conditions of mudflow are determined by the torrential potential. In other words, big mean slope of watershed, large quantities of debris, erosive geological layers, intense relief, heavy rainfalls, numerous places which produced sediment yield etc appear in its environment, something that derives also from the presence of a great landslide in the upper part of its watershed. Finally, the research of the mechanism and movement conditions of the concrete mudflow ends with the presentation of the appropriate management system and the relevant technical works that should be applied.
Keywords: torrential phenomena, landslides, mudflow, management system.

1 Introduction

Hydrology distinguishes the water currents into four categories: big rivers, rivers, torrential rivers and torrents. Torrents are characterized by the following properties:

– Sudden and intensive floods of small duration appear in the winter, while there are small or no supplies during the rest of the year

– Debris materials (especially gravel matters) are extracted, transported and deposited in their action zone.

Mud streams are torrents of mountainous areas characterized by an intense and massive transportation (mud flow) of very gravel matters and an irregular water balance.

WIT Transactions on Ecology and the Environment, Vol 90, © 2006 WIT Press
www.witpress.com, ISSN 1743-3541 (on-line)
doi:10.2495/DEB060201

Massive transportation of debris materials is created, when the matters that are swept away by the torrential currents move as mud flow, in other words they are transported in the form of lava, pulp or mud. Thus, mud flow is the main feature of the massive transportation. The massive movement of the debris materials in the form of mud flow, has generally the following results:

– an intensive rumble and vibration of the ground is provoked.
– great blocks of stones are transported downwards (ranging from 100 to 800 m^3) and also the rolling of small stones and pebbles that are found in the basis of the blocks is facilitated during their transportation.
– stones are flung as the lava is moving due to the stirring up and crushing of the materials.

In Greece, there are several mud streams and some characteristic examples of torrential action in our country are the following Kotoulas [9]:

- The secondary stream "Thodolakkas" of the torrent Velvendos in Kozani that has a watershed area of about 14 km^2, a watershed mean slope of 47.8% and a riverbed mean slope of 18.8% acts as a mud stream.
- The torrent Ormas (secondary stream «Halasmata») in Almopia that has a watershed area of about 76 km^2, a watershed mean slope of 42.5% and a riverbed mean slope of 20% creates mudflow starting from the upper part of the secondary stream Halasmata.
- The secondary stream Gouras of the torrent Theodorianon that has a watershed area of about 14 km^2 acts as a mud stream.

In the present study, the torrential potential (environment) concerning the watershed area of the torrential current Gouras that is located in the periphery of Epirus (W. Greece) is investigated. This potential is affected by four important torrential factors (climate, rocks, relief and vegetation), which are also studied together with the function of the mud stream that took place on 16 December 1981 in the above-mentioned area and which was caused by a great landslide in the mountainous region of the watershed area.

2 Study area

The study area of the present paper is the watershed area of the torrential current Gouras that is located in the periphery of Epirus (W. Greece). This extended watershed area, which is located 37 km away from the NE part of Arta, is developed around the Theodoriana village and it is surrounded by the summits of Tambouria (1390 m), Spilia (1832 m), Pliakouza (2087 m), Agathi (2393 m) and Bartzaka (2394 m).

The torrential current that drains in this watershed area (Theodorianon current) constitutes one of the most important suppliers in water and debris materials of the Acheloos River. It is characterized by an irregular, mainly rocky riverbed having a big slope and vertical gradients and whose bottom bed has a plenty big stones cover. The three main joining secondary streams that compose the Theodorianon current are «Gouras» (1), «Xistras» (2) and «Grebenitis» (3) (figure 2).

Figure 1: Location map of study area.

Our study was focused particularly on the riverbed of the secondary steam «Gouras» next to the village, which joins with secondary stream Xistras on the location Smixi and thus forming the central riverbed of Theodorianon current. The secondary stream Grebenitis flows into this bed near to its discharging point in Acheloos River.

3 Methodology

The accomplishment of the objectives of the study: "The cause and mechanism of Gourass stream Mudflow, in Epirus (W. Greece)" presupposes the fulfillment of a series of actions, which are further down described in detail.

The topographical maps of the Military Geographical Service having a range of 1:50.000 determined the watershed areas boundaries of the torrents of the study area. The digitization of the hydrographic network, the watershed areas boundaries and the contour lines were realized by using Geographical Systems. This was followed by the specification of the morphometric and hydrographic features using the ArcGIS 9 program.

Information concerning the land cover was taken by the National Mapping Data Base CORINE Land Cover of the Registered Property and Mapping Organization in Greece, while the data extraction took place by using Satellite data Landsat TM and remote sensing.

The types and the areas of the torrential rocky formations were determined by using geological maps (range 1:50.000) of the Geological and Mineral Research Institute and after the proper digitization and elaboration with G.I.S.

The weather data of Theodoriana meteorological station were gathered, elaborated and evaluated. Then, the four basic torrential factors (climate, vegetation, relief and geological background) were studied and according to the above elements the torrential types of the watershed areas resulted.

Furthermore, all landslides in the watershed area of the torrential current «Gouras» were recorded and the causes that resulted in the mud flow on the 16 December 1981 were analyzed. Finally, the adequate and proper water regulating system for the stability of this area is suggested.

4 Results

4.1 Generally

The torrential environment and the torrential type of the three hydrological watershed areas are defined by the combination of the four basic torrential factors as it is described below.

4.1.1 Morphometric and hydrographic features: relief

The morphometric features of the watershed area and the riverbed of the three torrential currents are shown in Table 1.

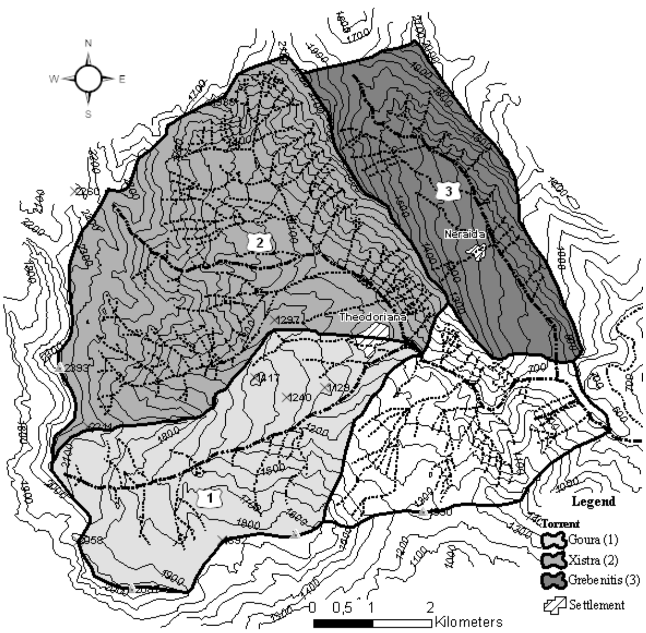

Figure 2: The hydrographic network of the water shed area.

As it results from this table the sub basin of these currents and especially of «Gouras» that concerns us, are developing in high altitudes and present an intense relief and steep slopes both in their watershed area and in their riverbed. Morphologically, they belong to the torrents type of very mountainous areas that are characterized by an intensive torrent activity.

4.1.2 Climate

The Ministry of the Environment conducts rain-measuring observations in Theodoriana village, which show that heavy rains of great intensity and duration as well as relatively low temperatures are typical in the study area of the watersheds. The mean annual rainfall was estimated to 2562.3 mm for the period 1951-1989.

Table 1: Morphometric characteristics of “Gouras" Watershed.

A/a	Torrent	*Watershed Area*	*Perimeter*	*Minimum Elevation*	*Maximum Elevation*	*Mean Elevation*	*Mean slope of Watershed*	*Mainstream Length*	*Mainstream Mean slope*
		F	U	H_{min}	H_{max}	H_{med}	J_l	L	J_k
		(km^2)	(km)	(m)	(m)	(m)	(%)	(km)	(%)
1	Gouras	14,28	17,65	800	2200	1560	38,60	2.93	40,95
2	Xistras	24,09	22,79	800	2300	1612	58,05	7,16	31,23
3	Grebenitis	11,34	15,74	700	2100	1356	62,92	6.37	35,00

Moreover, the snowfalls are also important and characteristic as they start usually in November and last till April. Thus, it is obvious that severe climatic conditions prevail in the watershed area in Theodoriana village, which particularly intensify its torrential character.

4.1.3 Geological support

The geological constitution of the watershed areas is shown in Figure 3, while the distribution percentage of the rocky torrential formations is presented in Table 2. As it results from the above, the limestone formation (K) dominates in the watershed area of Gouras (50.33%) followed by sedimentary rocks (S) (44.77%), while the rest 4.9% is flysch (F).

Furthermore and in what concerns the rocky torrential formations:

-the limestone that has a platy structure occupies the higher parts of this area. It is a penetrable rock and has as typical torrential features the intense weathering and the weathering debris,

- the flysch and the sedimentary rocks occupy the lower parts and especially the central part of the watershed which is usually impermeable and have as typical torrential features the landslides, the gully and the lateral erosion.

4.1.4 Vegetation

The distribution land cover and the distribution percentages in the watershed areas are shown in Figure 4 and in Table 3 respectively. Nowadays, and as it comes out of the above, the forest cover of the watershed is not only very restricted but it also has a bad structure and that is why it has a very limited protective and hydrological effect in the area. It mainly constitutes from fir clusters that are greatly affected by human interventions. In the old days, dense fir clusters that were cut 150 years ago covered the watershed area.

4.1.5 Torrential environment

The under study torrential environment of the mountainous watershed areas that were studied is particularly rough and has the following water regulating effect:

The lack of an adequate and proper vegetation cover and especially of a water regulating forest in the watershed area leaves their geological background to be severely affected by many and heavy precipitations whose action is greatly intensified due to the intense relief. As a consequence of the above is the creation of many intensive torrential phenomena (weathering debris, deep gully erosion and landslides) that supply the torrential beds with abundant gravel debris materials. Additionally, the permeable limestones, which occupy the higher peripheral parts of the watersheds, are affected by the many precipitations and especially the snowfalls, a great part of which penetrates into their interior and it is infiltrated to the deeper layers. The presence of an impermeable flysch and sedimentary rock in the lower central parts creates the proper hydrogeological background on which the infiltrated waters are gathered. Large water carrying layers are formed next to the contact boundaries of these two rock types and a great number of springs discharges and supplies the torrential currents throughout the year. During the rainfalls period, the number of springs increases due to the enrichment of the water-carrying layers and the creation of other temporary discharges.

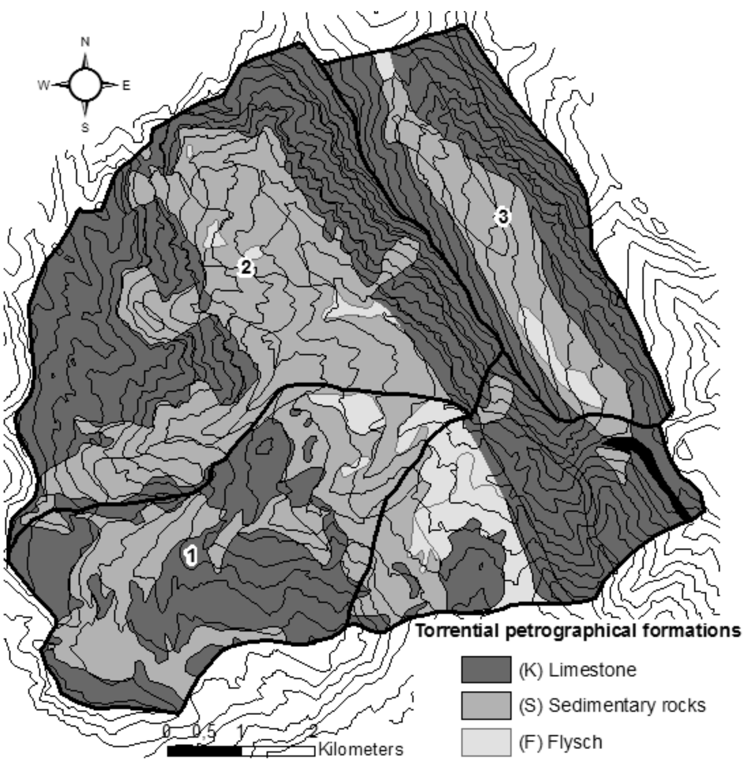

Figure 3: The torrential petrographical formations of the study area.

Table 2: Distribution of the torrential petrographical formations.

A/a	Torrent	Flysch (F)		Limestone (K)		Sedimentary rocks (S)	
		(km^2)	(%)	(km^2)	(%)	(km^2)	(%)
1	Gouras	0,70	4,90%	7,19	50,33%	6,39	44,77%
2	Grebenitis	0,49	4,32%	7,31	64,43%	3,54	31,25%
3	Xistras	0,30	1,23%	12,93	53,67%	10,86	45,10%

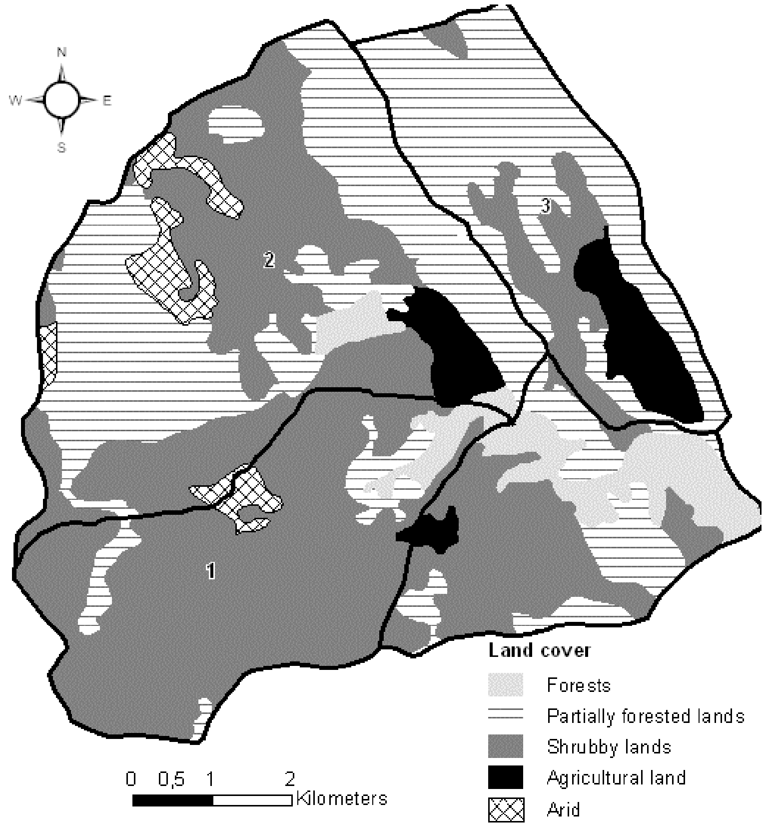

Figure 4: Land uses in the study area.

4.1.6 Torrential types

According to the recent classifications of the torrential currents Kotoulas [7] [8], all the above mentioned torrential currents («Gouras», «Grebenitis» and «Xistras») are classified into the mixed torrential type: Gouras: $K_{(50)}$, $S_{(45)}$ – III, Grebenitis: $K_{(65)}$, $S_{(31)}$ – III, Xistras: $K_{(54)}$, $S_{(45)}$ – III.

The mixed torrential type K-S-III, which is composed of limestone and sedimentary rocks and belongs to the Torrential attitudinal zone III (2000-3000 m), presents intensive torrential phenomena.

Table 3: Distribution of the land uses in the study area.

	Gouras (1)		Grebenitis (2)		Xistras (3)	
	(%)	(km^2)	*(%)*	(km^2)	*(%)*	(km^2)
Forests	*4.45*	0.63	*0.04*	0	*2.52*	0.61
Partially forested lands	*7.64*	1.09	*64.38*	7.28	*45.28*	10.89
Shrubby lands	*85.21*	12.14	*21.54*	2.44	*41.74*	10.03
Agricultural land	*0.54*	0.08	*14.34*	1.62	*4.24*	1.02
Arid	*2.40*	0.34	-	-	*6.41*	1.54

4.2 The landslides in the study area

The landslides constitute a typical torrential feature of the areas that are composed of flysch and sedimentary rocks Kronfellner-Kraus [11] Kotoulas [8] [10]. The watershed area of «Gouras» represents a characteristic example where this phenomenon takes place. The study showed that the following landslides are developed in the general watershed area of the torrential current (fig. 5).

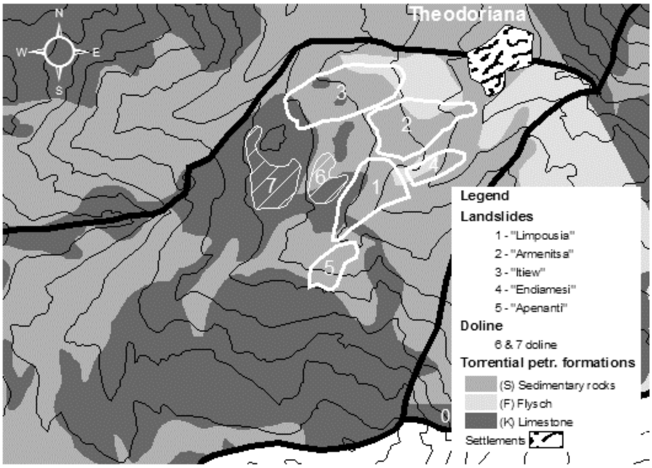

Figure 5: The landslides in Gouras watershed area.

The great landslide or "Limpousia" (1): it is developed on the right side of Gouras in a distance of about 1200 m upwards the village (fig. 6).
It is a general and abrupt collapse of an elongated significant slope, whose voluminous geomasses created mudflow and caused serious problems in the area of this current.

The landslide "Armerista" (2): It is developed in higher altitudes than the village (Figure 7). Although the first land sliding took place here in 1926, the great landslide happened later in 1963.

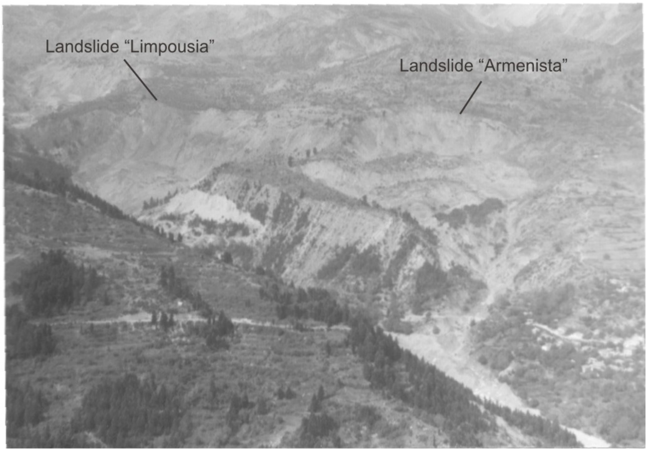

Figure 6: The landslides «Limpousia» and «Armenista».

The landslide “Itiew” (3): It is developed next to Armerista.

The “intermediate” landslide (4): It is about a limited elongated landslide, which is developed in the gradients area between the landslide “Limpousia” and the village and alongside to Armerista.

The “Apenanti” landslide (5): It is developed opposite to the great landslide, it is combined with precipitations and it is directed sideways to the central bed and supplies the Gouras current with debris materials.

As a result of the way that the above landslides are developed and arranged in the area (Figure 6), there is an impression that they comprise partial landsliding occurrences of a united landsliding whole, which is extended to the center of the watershed area of Gouras current and dangerously surrounds the Theodoriana village (Fig. 7).

Figure 7: The Theodoriana village, the mainstream of the torrential current Gouras and the landsliding phenomena.

4.2.1 Description, evolution and consequences of the great landslide

The torrent Gouras was always characterized by an intense transportation of materials in the form of lava. Landsliding phenomena took place in the past during the decade 1900-1910 and in December 1963. As a consequence of the above, it is concluded that the area of the great landslide always presented a significant landsliding action, which usually took place after the autumn rainy period (December).

The morphology of the great landslide «Limpousia» of the Gouras torrential current is considered to have an undulated form Kotoulas [8] [10] and it is characterized as multiple (Bunza [2], Hutchinson [6]).

The great landslide happened on 16 December 1981. The descriptions of the eyewitnesses make obvious that the ground of the landslide indicate creeping that resulted in a "waving" shape of the surface a few days before the event. Thus, small cavities were created and were filled with rainwater. The main landslide took place during the noon on 16.12.81. The movement of the geomass was abrupt. Great bulks of materials collapsed downwards to the gradient and vertically to the water flow, fell on the torrent's bed, blocked it and created an earth dam.

A lake was formed from the blockage of the torrent's bed. At 12.25' on 16.12.81 the earth dam, which in the meantime had been pulped due to its saturation with water and its high hydrostatic pressure, was put in motion. This resulted to the first mudflow on the torrent's bed that was followed by a great rumble and strong vibration of the ground. The height of its "head" was about 30 m and its speed was estimated to 100 km/h according to eyewitnesses (Fig 8).

Figure 8: The mudflow movement on the bed of Gouras torrential current.

More than 20 similar waves took place and moved till about 3.00' in the morning the materials of which were discharged in River Acheloos. However, their traces still remain in the gradients, while bulky stones can still be found on the riverbed giving evidence of the above-mentioned event.

The day after 16.12.81, the area of the great landslide presented a relative stability. During the winter of 1982-83, only small parts of the land sliding surface were put in motion. The morphology of the area and the pre-land sliding phenomena upwards from the landslide show that in the future new and intense landsliding movements should be expected.

4.2.2 The cause of the great landslide: analysis of the causes

According to the specific bibliography (Stiny [13], Emmanouloudis and Pavlides [5], Bernard [4], Strele [14], Weber [17], Terzaghi and Peck [15], Aulitzky [1], Skempton [12], Bunza [2], Veder [16], Kronfellner-Kraus [11], Kotoulas [9] [10], the causes of the landslides should be mainly searched in the favorable formation concerning the geology and relief of the area, in the great impregnation of the area with water and thus to the factors that provoke it, in the extraordinary natural events like earthquakes and in the human interventions. The study of these factors in the Theodoriana village came up with the following results:

Structure of the geological background: The area of the great landslide presents no particularity in what concerns its geological structure. The area mainly composes of flysch and sedimentary rocks that favor the development of landslides.

Human interventions: No such interventions were discovered in the area like the opening up of new roads or other technical works.

Precipitation and impregnation of the area: The great landslide was put in motion in the mid-December after a significant rainy period preceded something that was also observed in former cases. Precipitation measurements taken from the weather station in Theodoriana reveal that the rainfall was rather small at the day that the landslide happened (13.5 mm) (sχ.1). However, a long rainy period preceded that lasted more than two months with a total precipitation height of 1101.9 mm before the movement of the geomasses. As a consequence of this, the ground was fully impregnated and this was further intensified by the fact that intense rainfalls that caused extreme runoffs followed heavy snowfalls. As it arises from the above and before the landslide took place, there had been:

- an intense impregnation of the area for a long period, which is considered to be a prerequisite of landslides according to Kronfellner-Kraus [11] and
- a six-week period between the impregnation and the landslide as well as a 14 days period between heavy rainfalls and the landsliding movement that are considered to be the cause according to Baumgartiger [3]. Thus, the long-lasting and complete impregnation of the geological background of the watershed before the landslide was the main cause of this.

External formation of the landslide: Regarding this point of view, the area favors the landslides since it is a high and steep gradient.

Groundwater and springs: An important number of springs rich in water discharges in the land sliding surface all year long. Five of these springs are present almost in the middle of the land sliding gradient, about 50 m above the riverbed. Two other springs discharge about 7-15 m lower than the secondary bed that is formed between the landsliding gradient and the discharging hill. A typical feature of the rainy period is the appearance of a big number of temporary springs covering nearly all the surface of the gradient and the surrounding area. The presence of all these springs reveals the existence of rich groundwater layers upwards of the great landslide. During the rainy period, these layers are extended and cause an intense, local impregnation of the area with rainwater coming from distant supplying regions.

Morphology of the general area: The study of the area's relief around of the great landslide showed that certain cavities (dolines) are formed upwards and supply abundantly the groundwater of the geomass, thus contributing to the initiation of the landsliding phenomena in the area.

As a conclusion of the above, it is understood that the **general causes** of the great landslide are the favorable geological background, the steep slope of the landsliding gradient and the strong impregnation of the ground due to the heavy rainfalls that preceded. However, the **specific cause** is the rich groundwater layers that flow through the geomass and which are supplied by big dolines that are located upwards of the landslide.

4.3 Objectives and management systems of the great landslide and the mudflow

The objective of the management system in Theodoriana is focused on the stabilization of the great landslide by reducing the land sliding forces that act in this area and by increasing the resistance of the geomass. From a torrential point of view the action area of Gouras torrent can be divided into three partial correction parts: A, B and C (Figure 9):

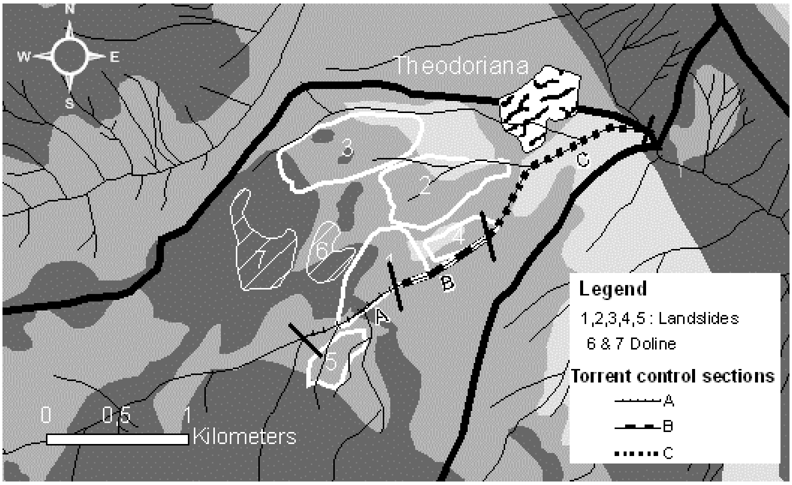

Figure 9: The central bed of Gouras torrent and the separate management system parts: A, B and C.

The determination of the correction system and the necessary works in every part was based on the specific torrential features of each part. That's why the area was initially investigated on the spot and then general plan, longitudinal section and cross-sections were used for each part and were drawn up based on torrential criteria after the land survey of the area, were used for each part.

The correction system should comprise the following for each part:

Part A: In this part of the riverbed, the stability and the drainage of the landsliding area should be accomplished so as to avoid the creation of a new mud flow. This can be achieved by constructing a basic stabilizing dam of the bed and as well as retaining the debris materials, by terracing the bed with small dams and by constructing effluent that will drain the dolines.

Part B: In this part, the detainment of the mud flow that might be created, should be accomplished in order to be transformed into regular (bedload transporting) sediment discharge, before it reaches the village. This can be achieved by constructing selection dams and by retaining the material in proper locations that will be creating extended discharging positions upwards of them.

Part C: In this part, the securing of the riverbed against the gully erosion can be achieved by constructing a bed stabilizing dam downwards of it.

5 Conclusions

The torrential problem in Theodoriana is due to an undulated landslide of an extremely large bulk of materials upwards the village and which created an earth dam on the bed of the Gouras torrent and thus led to the formation of mud flow. The main cause of the landslide was the strong impregnation of the geomass because of the heavy rainfalls and snowfalls that preceded and lasted for two months. The mud flow was created by the strong impregnation of the materials in the earth dam and by the hydrostatic pressure that the water of the lake acted on this.

The secondary stream Gouras of the torrent Theodorianon having a watershed area of about 14 km^2 functions as a mud stream. The mud flow that was created on 16.12.81 came from a big landslide on the right gradient of the current. This had a length of 900 m, a height that ranged between 100 to 130 m and a horizontal surface of about 0,18 km^2. The height of the head of the first lava was 30m and had a speed of 100 km/h. Totally, 20 lava waves moved, which created an alluvial deposit on the torrent's bed reaching a height of 18 – 40 m and blocked River Acheloos with their materials for at least one month. The total volume of the land sliding mass came up to 7250.00 m^3. The total volume of the deposits on the torrent's bed came up to 3644.000 m^3, while River Acheloos transported the rest downwards.

The appropriate management system that is suggested, firstly schedules the stabilization of the foot of the landslide on the lower part of the hilly deposit by constructing a basic stability dam. Secondly, it plans the control of the material in case of a new mudflow by constructing two material selection dams between the landslide and the village. Afterwards, it schedules the drainage of the dolines that supply the landslide with water, the check dam of the main and secondary riverbed in the land sliding area, the scraping of the gradients and the stabilization and drainage of their surface by applying reforestations and deforestation.

Acknowledgements

In this paper, the results that are presented concern the research program entitled: "The causes and the management system of the great landslide and the mudflow of torrent «Mouzaki» or «Gouras» in Theodoriana village in the prefecture of Arta". This was implemented in the Laboratory of Mountainous Water and Management Control of the Aristotle University in Thessaloniki in 1983. The supervisor was the today's Professor Emeritus Dim. Kotoulas and the assistant researchers that worked on this were M. Kaikis, Th. Pavlidis and P. Stefanidis. The contribution of the writers regards the use and appliance of the Geographic Information Systems in the better comprehension of the torrential potential or environment of the area.

References

[1] Aulitzky, H., *Der Enterbach* (Inzing in Tirol), WLV, 1970.
[2] Bunza, G., *Bewegungsablauf und Sanierungsm oglichkeiten von Erdstromen*, GeoPalaont. Mitt. Innsbruck, 1978.
[3] Baumgartiger, A., Einfuhrung in das Thema der Studienreise, WLV, 1979.
[4] Bernard, M., *Cours de restauration des montagnes*, Ec.Nation, des Eaux et Forets, Nancy, 1929.
[5] Emmanouloudis, D., Pavlides, Th., The Cause and the Mechanism of the Homicidal Flood in Eleftheres, Kavala, Northern Greece, *Proc. XX IUFRO World Congress, Finland, (pp. 38-48)*, 1995.
[6] Hutchison, J.N., General report, theme 3, *Proc. Symposium on Landslides and their Mass Movements*, Prag., 1977.
[7] Kotoulas, D., Das Auftretten von Hangrutschungen, Mitt. Nr.45 des Inst, f. Gebirgswasserbau der Aristot. Uni., Thessaloniki, 1972.
[8] Kotoulas, D., Die Wildbache Suddeutschlands und Griechenlands.Mitt. Nr.25, 31 der Versuchsanstalt f.Wasserbau der T.U.Munchen, 1972, 1975.
[9] Kotoulas, D., Materialerzeugung und Murenbildung dargestellt *am Beispiel einiger murfahiger Wildbache Nordgriechenlands*, Interpravent, 1980.
[10] Kotoulas, D., Theoretische Uberlegungen und allgemeine Untersuchungser-fahrungen im Rahmen der Wildbachtypologie und -geographie. Mitt, der Forstl. Bundesversuchsanstalt, Mien, 1982.
[11] Kronfellner-Kraus, G., Neue Untersuchungsergebnisse in Wildbachen – Der Talzuschub in Abhangigkeit von Niederschlagen, Interpravent, 1980.
[12] Skempton, A.M., First-time slides in over-consolidated clays, Geotechnique Vol.20, No.3, 1970
[13] Stiny, J., *Die Muren*, Innsbruck, 1910.
[14] Strele, G., *Grundriss der Wildbach-u.Lawinenverbauung*, Mien, 1950.
[15] Terzaghi, K., Peck R., *Soilmechanics in engineering practice*, New York, 1967.

[16] Veder, Chr., *Landslides and their Stabilisation*, New York, Mien, 1979.
[17] Weber, A., Mildbachverbauung, *Taschenbuch Landwirtsch*. Wasserbau von Uhden, Stuttgart, 1964.