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EXTREME FLOODS IN GREECE: THE CASE OF 1994

M. Mimikou and D. Koutsoyiannis
Department of Water Resources, Hydraulic and Maritime Engineering,
Faculty of Civil Engineering, National Technical University of Athens, Greece

Abstract. Several regions in Greece suffer from frequent and hazardous extreme floods and flash floods. In this paper an attempt is made to present the basic characteristics of the extreme floods occurred in October 1994 and which caused severe damages and loss of lives in Athens greater area and in the Thessaly plain.

1. INTRODUCTION

Flood phenomena in Greece usually are caused by intense rainstorms whereas snowmelt is not a dominant factor in flood genesis. Most intense rainstorms are produced by the passage of depressions possibly accompanied by cold fronts (and rarely by warm fronts) approaching from W, SW or NW. A convectional weather type (characterised by a cold upper air mass that produces dynamic instability) is also responsible for many intense storms, especially in the summer period. (Mamassis & Koutsoyiannis, 1993; Maheras, 1982).

The orography of the Pindos mountain range plays an important role in rainfall and runoff regimes in Greece. Thus, the mean annual rainfall exceeds 1800 mm in the mountainous areas of western Greece whereas in eastern regions of the country may be as low as 300 mm. This does not mean that extreme floods are uncommon in the relatively dry eastern part of Greece. The maximum 24-hour rainfall depth for a 50-year return period (which can be considered as a very rough indicator of the flood severity, although the 24-hour duration is long when compared with the usual travel times of the hydrological basins in Greece) is as high as 175 mm in western Greece, reduces to about 100 mm in the eastward of Pindos mountain range, and rises again to 175 mm for the East Aegean islands (Flokas and Bloutsos, 1980). Thus, the reduction of the maximum 24-hour depth as we proceed from the west to the east of the country is not so rapid as compared to that of the mean annual rainfall. The difference at the east and west part is almost eliminated if we consider shorter rain durations such as hourly (Deas, 1994).

Deforestation and urbanisation play an important role to flood genesis. They are responsible for the increasing severity and destructive power of floods. Deforestation, also related to soil erosion, is a major problem in Greece. It is noted that the percentage of the areas covered by forest today is 18%, while at the beginning of the nineteenth century it was more than 40%. Deforestation has caused mainly from human activities such as fires, illegal land reclamation, pasturing, etc. (Kotoulas, 1980).

The areas that suffer particularly from floods can be classified into three categories (Koutsoyiannis, 1995). First are closed hydrological basins in karst areas, which normally are drained by natural sinkholes with limited drainage capacity. Second are the plains traversed by rivers as the discharge capacity of natural river beds are frequently too low to route the natural floods. Third are the urban areas where the urbanisation of natural floodplains has created a threat to both wealth and human life. In the last century the flood hazard has been considerably mitigated for the first two categories by building of major protective works such as drainage tunnels for closed karst basins and dams and levees for the rivers traversing plains. However the situation has been deteriorated in urban areas as urbanisation was seldom combined with the necessary protective works such as channel improvements and storm drainage networks.

2. THE STUDY AREAS

Our study is concentrated in two representative areas of Greece which are sensitive to flooding: the Greater Athens area and the Thessaly plain.

The Greater Athens area is the most urbanised part of Greece with a population of about four million. Without overstatement, Athens is the capital of Greece not only administratively but also in flood damages. In Table 1 some of the most severe floods causing loss of human lives in Athens are referenced. 179 lives were lost during the last 100 years, out of which 96 during the last 35 years. These figures are higher than any other part of Greece. Also the number of lives lost due to floods in Athens are greater than due to any other natural hazards. For example the 18 deaths by earthquakes were reported in the last century in the Attica area that surrounds Athens (Nicolaidou and Hadjichristou, 1995).

To explain the sensitivity of Athens in flooding we must firstly refer to climatological and geomorphological factors. The dry climate of Athens with a mean annual rainfall depth of about 400 mm and the high evaporation rate in combination with the natural relief did not lead to the formation of significant river networks; also, the cross-sections of the existing streams are small. However, as described earlier, the intense flood-producing rainstorms in Athens are almost as high as in other parts of Greece where the mean annual rainfall is 3-5 times higher and the mean runoff rate is at least one order of magnitude higher.

Table 1 Floods causing loss of human lives in Athens (adapted from Nicolaidou and Hadjichristou, 1995)†

Date	Lives lost
14 November 1896	61
23 November 1925	8
26 October 1930	2
17 October 1933	1
2 December 1933	2
22 November 1934	6
5 November 1936	2
29 October 1938	1
5-6 November 1961	40
2 November 1977	38
27 October 1980	1
5 October 1989	7
15 January 1991	1
21-22 October 1994	9

† Missing data may be in the periods 1885-95, 1897-20, 1950-60 and 1962-72.

The other reasons for the flood damages are anthropogenic. They are related to the urban development of Athens which occurred mainly in the last 50 years. The increase of residential, commercial and industrial areas and the diminution of natural parks and farm lands affected seriously the flood rate. The stream network was shrunk as many streams were converted into streets. Even buildings were constructed over the old stream beds. No priority was given to the flood protection works and the storm drainage network, which is still primitive.

The second study area, the Thessaly plain, is an agricultural region with an area of about 4 000 km^2. The plain is traversed by the Pinios river whose total catchment area is 9 500 km^2. The Thessaly plain is located in central Greece (Figure 1). It is known from the geographer Stravon that the plain suffered from floods since the ancient age when several structures had been built to control Pinios river 2 500 ago. The Pinios river passes through the Tempi ravine located 18 km upstream the basin outlet. This ravine was formed after the Alpic orogenic period (1-2 x 10^6 years ago) and before that period the plain was covered by a lake. In later periods until the Neolithic age it seems that the narrow pass in Tempi was obstructed many times and the lake was formed again. Still the Tempi ravine as well as other narrow passes along the river course (such as in Amygdalea, 15 km upstream the town of Larissa) are main reasons of the flooding in the plain. Furthermore, the river natural discharge capacity is inadequate in a large part of its length. This capacity was improved 60 years ago, after the construction of levees and other protective works, but still floods remain a big problem of the region. Thus, during the last 10 years two major flood events leading to inundation of the plain occurred: on 24-27 March 1987 and 21-22 October 1994. Other reasons favouring the flood genesis in the plain are some bridges with inadequate height that have been built across the river, the vegetation of the river bed, and the construction by the farmers of “handy” barriers in the river channel for storage of irrigation water. Last but not least is the low elevation of the drainage network as compared to the flood elevation.

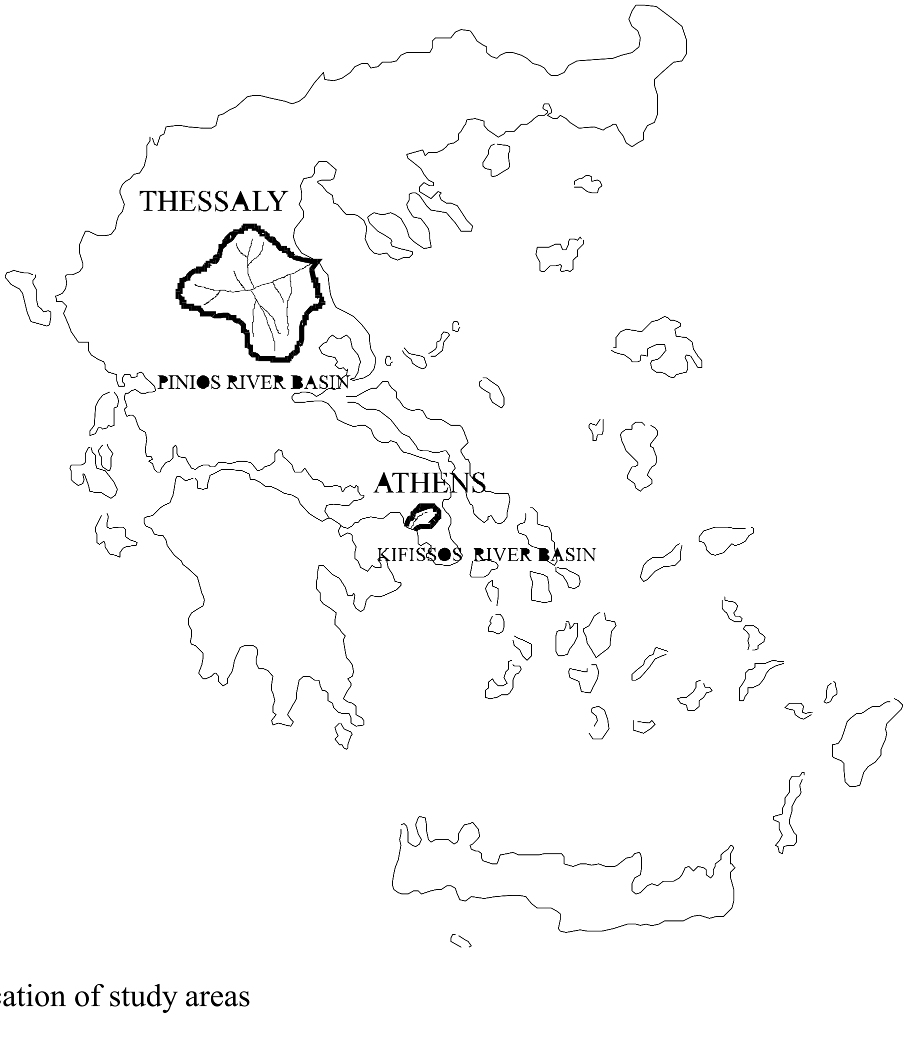

Figure 1 Location of study areas

3. THE FLOOD OF 21-22 OCTOBER 1994

Among the extreme flood events of the last 30-40 years, the event of 21-22 October 1994 is one of the most serious due to the high intensity, the large geographical extent and the significant damages. Our study will be focused on this recent event, which hit almost all country except for the Eastern Macedonia and Thrace. The event was associated with heavy precipitation and floods in urban areas and in the countryside. It had severe catastrophic consequences such as 11 deaths, and damages in agricultural property, as well as in transportation, telecommunication and energy supply.

This event was caused by a cyclonic system with a cold front formed in the Middle Mediterranean and propagating eastward (Lagouvardos et al., 1995). As shown in Figure 3, at 18:00 UTC 21 October 1994 the low centre of the system with pressure 994 hPa was situated between Italy and Sicily while the cold front propagated toward the Ionian Sea and the Greek peninsula. An extended high pressure system of 1040 hPa was also situated in central Russia. Radiosonde observations from Athens at 12:00 UTC indicated a near-saturated environment in the whole troposphere (Lagouvardos et al., 1995). In Figure 4 is depicted a meteosat image at 18:30 UTC indicating the cloud cover over Greece.

The description of this flood phenomenon in the study areas (Athens and Thessaly) is given in the subsequent sections.

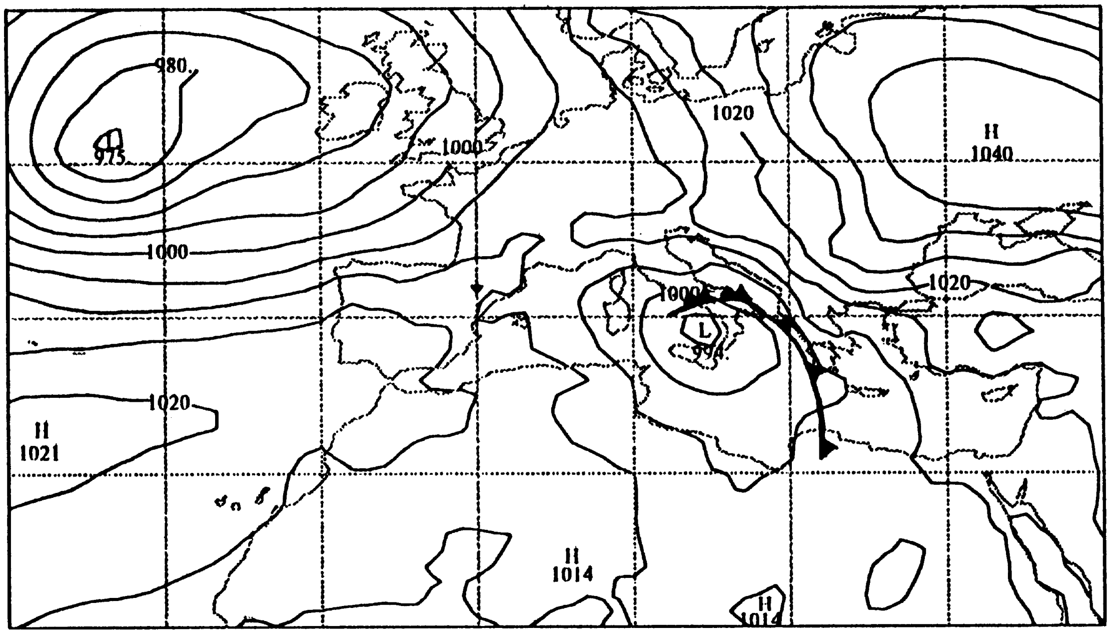

Figure 2 Surface weather map at 18:00 UTC 21 October 1994 with 5 hPa contour interval (Source: Lagouvardos et al., 1995).

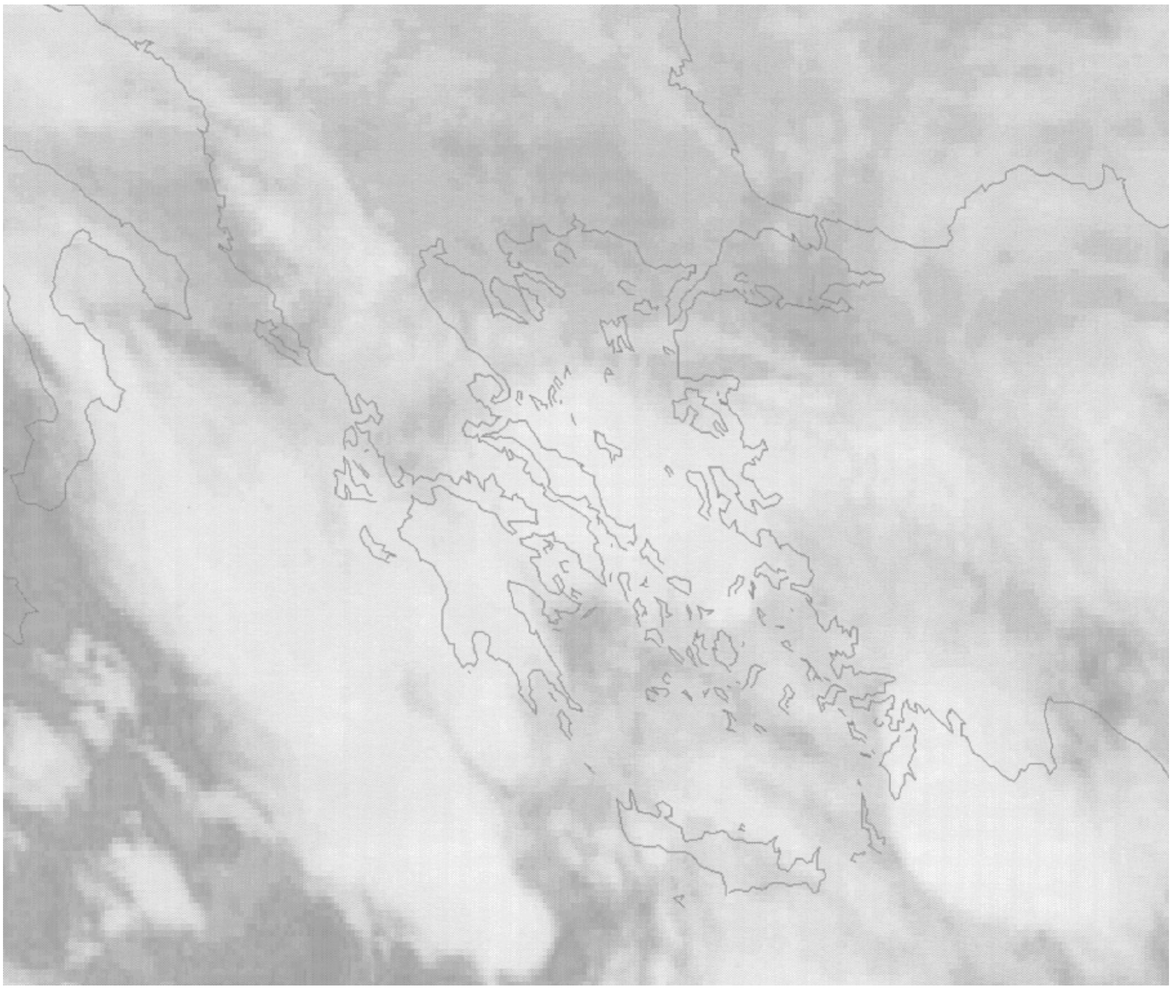

Figure 3 Meteosat image at 18:30 UTC 21 October 1994 (Source: National Meteorological Service of Greece).

4. THE FLOOD IN ATHENS

As there do not exist any runoff measurement data in the Greater Athens area, our analysis is based on rain-recorder data only. We have used data of the stations Hellinikon Airport (to the south-east of Athens, elevation 10 m), Nea Philadelphia (to the north of Athens, elevation 136 m), as well as the NTUA Campus at Zografou (to the north-east, elevation 219 m).

In Figure 4 we have plotted the storm hyetographs in hourly time scale for the recording stations Nea Philadelphia and NTUA Campus. The hyetograph for Hellinikon that is not shown in the figure was very lower in intensity. We observe a similarity in the temporal evolution of the recording in the two locations. The hourly maximum depths were 42.7 mm and 67.7 mm for Nea

Philadelphia and NTUA Campus, respectively, whereas the 10 minutes maxima (not shown in the figure) were 26.0 mm and 17.5 mm respectively.

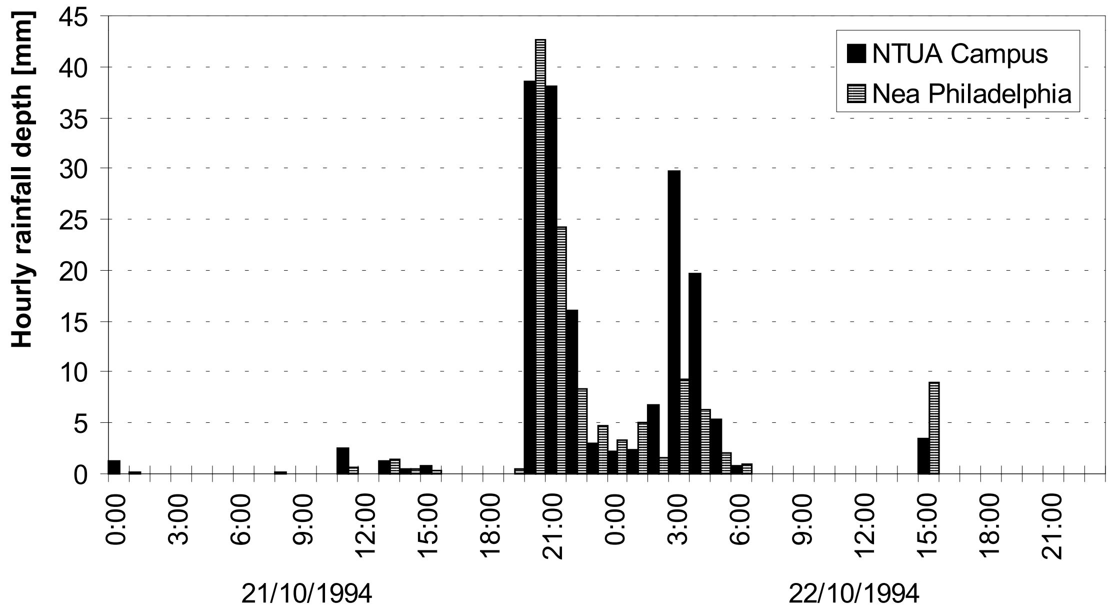

Figure 4 Hourly hyetographs of the storm of 21-22 October 1994 at two locations in Athens (Data source for Nea Philadelphia: Hellenic National Meteorological Service; for NTUA Campus: National Technical University of Athens).

In Figure 5 we show an indicative plot of the storm severity. More specifically, we have calculated the maximum observed depths for a range of durations from 10 minutes to 24 hours and plotted them, after conversion into intensity, against duration in a logarithmic plot. We have also plotted for the same range of rain durations the maximum mean intensities observed in the available historic records of the Hellinikon and Nea Philadelphia stations. Finally, we have plotted the intensity-duration-frequency (idf) curves for the Athens region for return periods 2, 10 and 50 years. To construct these curves we have used historic data of Hellinikon and Nea Philadelphia originated from the archive of the Hellenic National Meteorological Service that were published by Deas (1994). Also, we have used indirectly data from other non-recording stations located in the Greater Athens area in order to compose representative curves for the whole area (Kozonis, 1995). For the entire analysis we have used the Gumbel distribution of maxima.

Comparing the different groups of curves in Figure 5, we observe that for durations greater than 1 hr, the observed intensities of the storm of October 1994 are greater than all respective intensities recorded in the last 25-30 years, and, also, lie above the idf curve of 50-yr return period. This indicates that indeed the storm of October 1994 was very severe. Fortunately, the intensities are somehow less severe for durations smaller than 1 hr, which are more critical for the Athens area that is covered by small watersheds with small runoff concentration times.

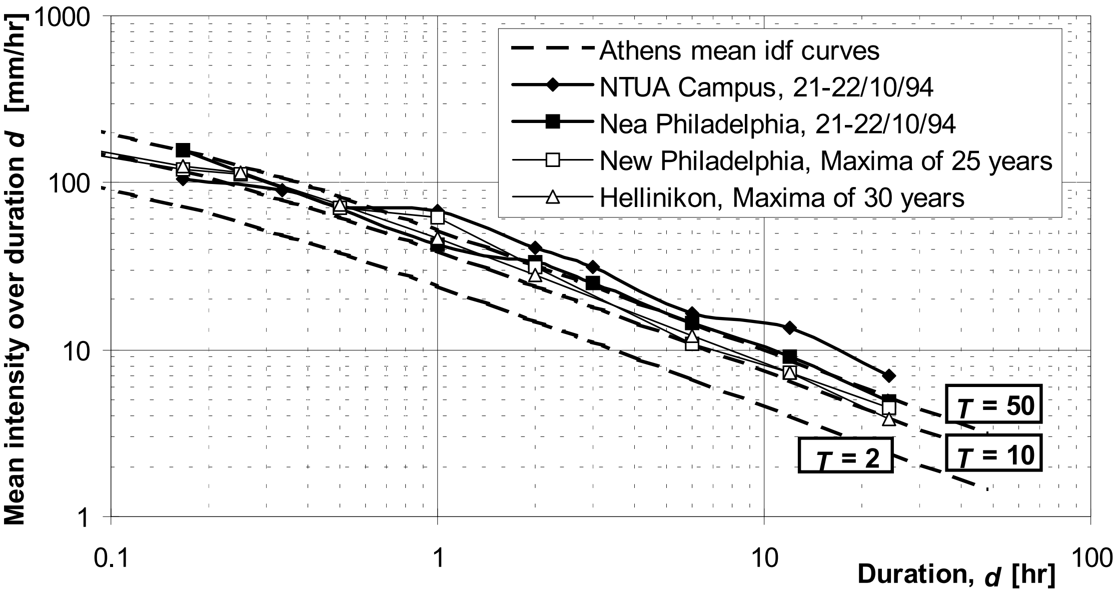

Figure 5 Indicative graph of the severity of the storm of 21-22 October 1994 in Athens.

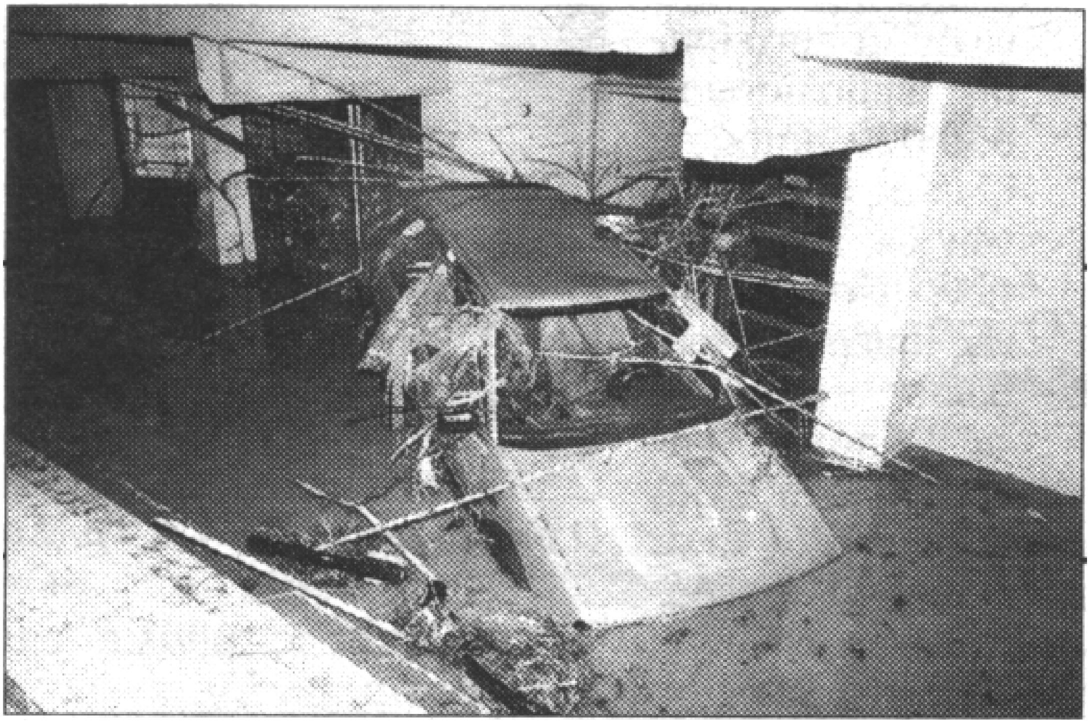

Figure 6 A picture of damages in streets, cars and buildings caused by the flood of 21-22 October 1994 in Athens (Photo from the newspaper *To Vima*).

The consequences of the storm were the extensive inundation and damages of streets, houses and commercial and industrial areas, as well as the overflow of water courses in a big part of Athens (Figure 6). An estimate of the damages caused by the flood is about 13 MECU for commercial and industrial property and 1 MECU for houses (Nicolaidou and Hadjichristou, 1995).

5. THE FLOOD IN THE THESSALY PLAIN

For the assessment of the rainfall severity that caused the flood in Thessaly we have used rainfall data of the stations Argithea (located at the west mountainous part of Thessaly at elevation 980 m) and Karditsa (located at the west part of the Thessaly plain at elevation 103 m). The latter station was very close to the geographical centre of the storm.

In Figure 7 we have plotted the storm hyetographs in hourly time scale for the above recording stations. The hourly maximum depths were 17.9 mm and 24.8 mm for Argithea and Karditsa, respectively. We observe a similarity in the temporal evolution of rainfall in the two locations. Comparing with Figure 4, we observe a longer duration, higher total depth and lower maximum intensity than the corresponding characteristics of the rainfall in Athens.

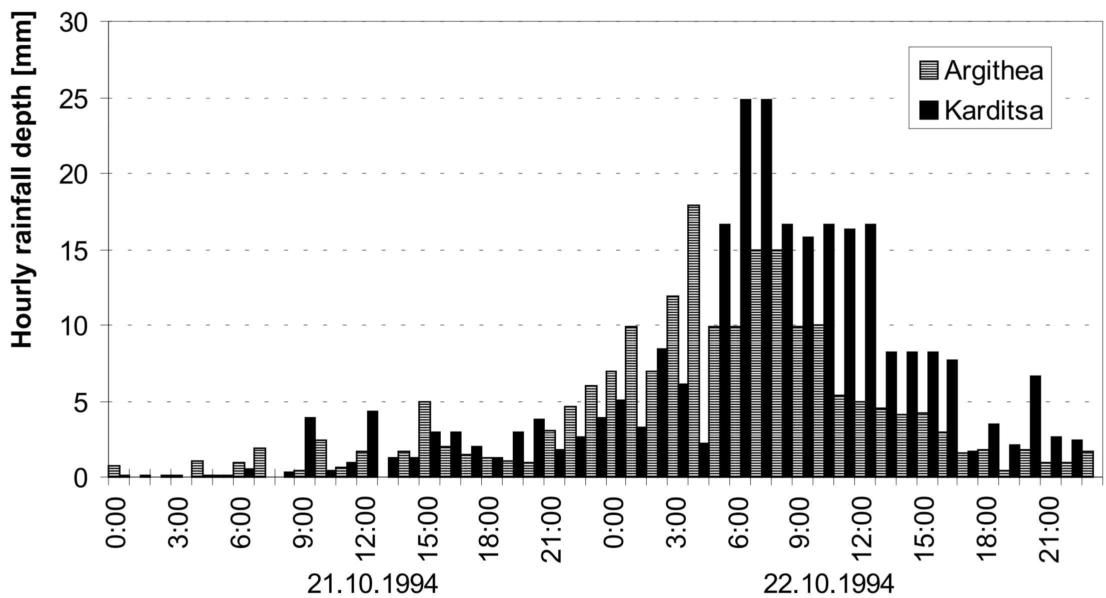

Figure 7 Hourly hyetographs of the storm of 21-22 October 1994 at two locations in Thessaly (Data source for Argithea: Public Power Corporation 980; for Karditsa Ministry of Agriculture).

In Figure 7 we show an indicative plot of the storm severity, similar to that of Figure 5. Here the comparison of the storm of October 1994 is done against the observed maxima of the Argithea and Karditsa historic records, as well as the idf curves of Argithea. The latter were constructed from historic data originated from the archive of the Public Power Corporation that were published by Roti and Koutsoyiannis (1988). For the idf construction we have used the Gumbel distribution of maxima.

Comparing the different groups of curves in Figure 7, we observe that the measured intensities of the storm of October 1994 are greater than all respective intensities recorded in the past for both stations and, also, lie above the idf curve of 50-yr return period. Notable are the high intensities in Karditsa which are 2-3 times higher than those recorded in the past.

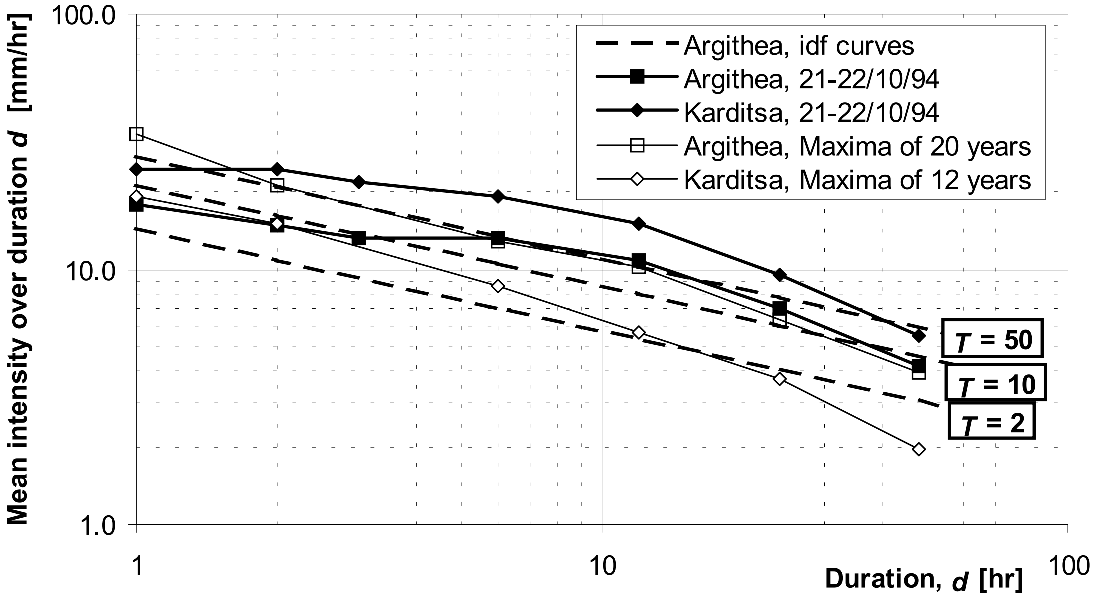

Figure 8 Indicative graph of the severity of the storm of 21-22 October 1994 in Thessaly.

The stage and discharge data in the measuring stations along the Pinios river have not been processed yet. Moreover, in some measuring stations there was lack of data due to destruction of the measuring devices and in some other stations the measured values were not reliable due to inundation. Until now, the only available hydrograph of the flood of October 1994 refers to the location Ali Efenti Bridge, which includes the west part of the Pinios subbasin (2 764 km^2) This hydrograph is given in Figure 9 and was constructed by using rainfall-runoff models rather than stage and discharge data. The peak of the hydrograph does not exceed 540 m^3/s. This is not so high compared to the previous flood (26 March 1987), in which the measured by current meters discharge at the same location was 637.3 m^3/s.

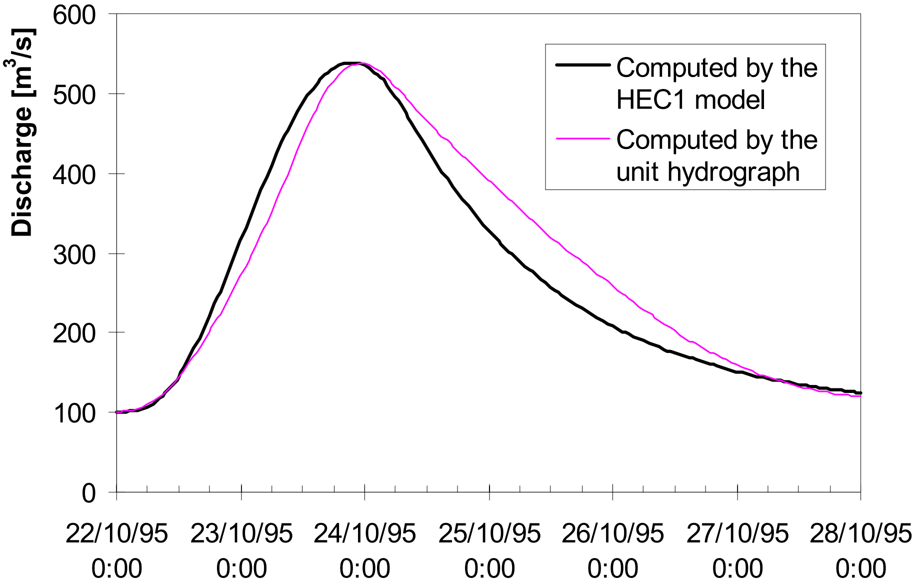

Figure 9 Reconstructed hydrograph at the Ali Efenti Bridge on the Pinios river.

According to local authorities, more than 70 houses in about 20 communities were totally destroyed by the flood, more than 200 suffered severe damage and other 90 minor damage, whereas 80 km^2 of agricultural land (cotton fields) were flooded (Figure 10). Dalezios et al. (1995) using satellite images has determined that the damaged area was 26 km^2. Furthermore, damages were caused to the infrastructure works (roads, flood control works, etc.) estimated about 3 MECU. The cost of the total damages was initially estimated to more than 300 MECU.

6. RESEARCH TOPICS

Recently, a branch of the EU project entitled "*Storms, Floods and Radar Hydrology*" was implemented in the Thessaly plain. The project was focused on the deployment of weather radar for hydrological applications such as storm and flash flood forecasting and warning. The study included the use of a weather radar system that covers a part of Central and NW Greece, comprising basins of hydrological interest (Baltas and Mimikou, 1994; Mimikou and Baltas, 1995). More research is needed to incorporate the current results for operational use.

For the Athens region, an outline of the applied research required to mitigate the flood problem was accomplished by Xanthopoulos et al. (1995). This outline includes four stages. Stage 1 is concerned with the improvement of the raingauge network and the computational infrastructure as well as the development of experimental basins. Stage 2 includes regional analysis of recorded intense storms and construction of isorisk flooding curves. Stage 3 regards the assessment of the existing storm drainage system and the ordering of the necessary improvements by means of measures and construction works. Finally stage 4 includes the development of a monitoring, forecasting and warning system for intense storms and floods in Athens.

Figure 10 The inundation of the Thessaly plain during the flood of October 1994 (Photo by M. Thanos, Ministry of Agriculture).

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7. REFERENCES

Baltas, E. A. and M. A. Mimikou, Short term rainfall forecasting by using radar data, *International Journal of Water Resources Development*, 10(1), 1994.

Dalezios, N. R., Tsintarakis, A. M., and Zarpas, K. D., Quantitative characteristics of the flood of October 1994 in Thessaly, Proc. 2nd Conference of the Hellenic Committe for Water Resources Management (in Greek), EEDYP, Athens, 1995.

Deas, N., Construction of idf curves for the Sterea Hellas region and investigation of their space variability, Diploma thesis (in Greek), National Technical University of Athens, Athens, 1994.

Flokas, A. A. and A. A. Bloutsos, Computation of the maximum daily rainfall in Greece for various return periods, *Proc. 2nd Greek seminar on hydrology* (in Greek), 185-196, Ministry of Coordination, Athens, 1980.

Kotoulas, D. K., The anthropogenic flood genesis in torrent streams of Greece, and its prevention, *Proc. 2nd Greek seminar on hydrology* (in Greek), 185-196, Ministry of Coordination, Athens, 1980.

Koutsoyiannis, D., The flood hazard in Greece, in, *Geomorphological hazards in Europe*, edited by C. Embleton, Elsevier, 1995 (in press).

Kozonis, D., Construction of idf curves from incomplete data: Application to the Sterea Hellas region, Diploma thesis (in Greek), National Technical University of Athens, Athens, 1995.

Lagouvardos K., V. Kotroni, S. Dobrivic, and G. Kallos, The storm of 21-22 October 1994 over Greece: Observations and model results, Fifth International Conference on Precipitation, Elunda, Greece, June 1995.

Maheras, P., Synoptic situations and multivariate analysis of weather in Thessaloniki, report (in Greek), Lab. of Climatol., Univ. of Athens, Athens, 1982.

Mamassis, N. et D. Koutsoyiannis, *Structure temporelle de pluies intenses par type de temps, 6ème Colloque International de Climatologie*, Aristotle University of Thessaloniki, Thessaloniki, 1993.

Mimikou M. A., and Baltas, E. A. Flood forecasting based on radar rainfall measurements, *Journal of Water Resources Planning and Management*, ASCE 1995 (in press).

Nicolaidou, M. and E. Hadjichristou, Recording and assessment of flood damages in Greece and Cyprus, Diploma thesis (in Greek), National Technical University of Athens1995)

Roti, S. and D. Koutsoyiannis, Intensity-Duration-Frequency curves, in Hydrological investigation of the Thessaly water district, Volume 3, Report, National Technical University of Athens, Athens, 1988.

Xanthopoulos, Th., D. Christoulas, M. Mimikou, D. Koutsoyiannis and M. Aftias, A strategy for the problem of floods in Athens, *Proc. of the Workshop for the Flood Protection of Athens*, Technical Chamber of Greece, Athens, 1995 (in press).