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1994 EXTREME FLOODS IN GREECE

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Abstract. Several regions in Greece suffer from frequent and hazardous extreme flash floods. In this paper, the basic characteristics of the extreme floods that occurred in October 1994 and caused severe damage and loss of lives in Athens metropolitan area and in the Thessaly floodplain are presented. In addition, reference is made to possibilities of applying recent research results for mitigating flood impacts in the area.

1. INTRODUCTION

Flood phenomena in Greece are usually caused by intense rainstorms. 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 (characterized by a cold upper air mass that produces dynamic instability) is also responsible for many intense storms, especially in the summer period (Mamassis and Koutsoyiannis, 1993; Maheras, 1982).

The orography of the Pindos mountain range plays an important role in rainfall and runoff regimes in Greece. Mean annual rainfall exceeds 1,800 mm in the mountainous areas of western Greece whereas the eastern regions of the country recieve as low as 300 mm. This does not mean that extreme floods are uncommon in the relatively dry eastern part of Greece. The 50-year maximum 24-hour rainfall depth (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 east of Pindos mountain range, and rises again to 175 mm on 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 as pronounced when compared to that of the mean annual rainfall. The difference between east and west regions is almost eliminated if shorter rain durations, such as hourly, are considered (Deas, 1994).

Deforestation and urbanization 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 forested area is currently 18%, while at the beginning of the nineteenth century it was higher than 40%.

Deforestation has been caused primarily by human activities such as fire, illegal land reclamation, pasturing, etc. (Kotoulas, 1980).

Areas that are particularly susceptible to damaging floods can be classified in three categories (Koutsoyiannis, 1995). First are closed hydrological basins in karst areas. These areas are normally drained by natural sinkholes with limited drainage capacity. Second are the plains traversed by rivers. The discharge capacity of natural riverbeds are frequently too low to route the natural floods. Third are the urban areas. Here, the urbanization 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 major protective works including 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 that are sensitive to flooding: the Greater Athens area and the Thessaly plain. The Greater Athens area is the most urbanized 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. Table 1 lists some of the most severe floods that caused loss of human lives in Athens. On hundred and seventy nine lives were lost during the last 100 years, 96 of them occurred during the last 35 years. These figures are higher than in any other part of Greece. Flooding is also the most costly natural hazard in terms of human life. Comparatively, earthquakes only claimed 18 lives during the last century in the Attica area that surrounds Athens (Nicolaidou and Hadjichristou, 1995).

Table 1. Loss of human lives due to flooding in Athens (adapted from Nicolaidou and Hadjichristou, 1995)[†]

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

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

To explain the sensitivity of Athens to flooding, we must first 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 and unable to route high flows. However, as described earlier, the intense flood-producing rainstorms in Athens are almost as severe 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.

The other reasons for the flood damages are anthropogenic. They are related to the urban development of Athens, which has occurred mainly in the last 50 years. The increase of residential, commercial, and industrial areas and the diminution of natural parks and farmlands affected the flood rate significantly. The stream network was reduced as many streams were converted into streets. Buildings were even constructed over the old streambeds. No priority was given to the flood protection works and the storm drainage network, which are still primitive.

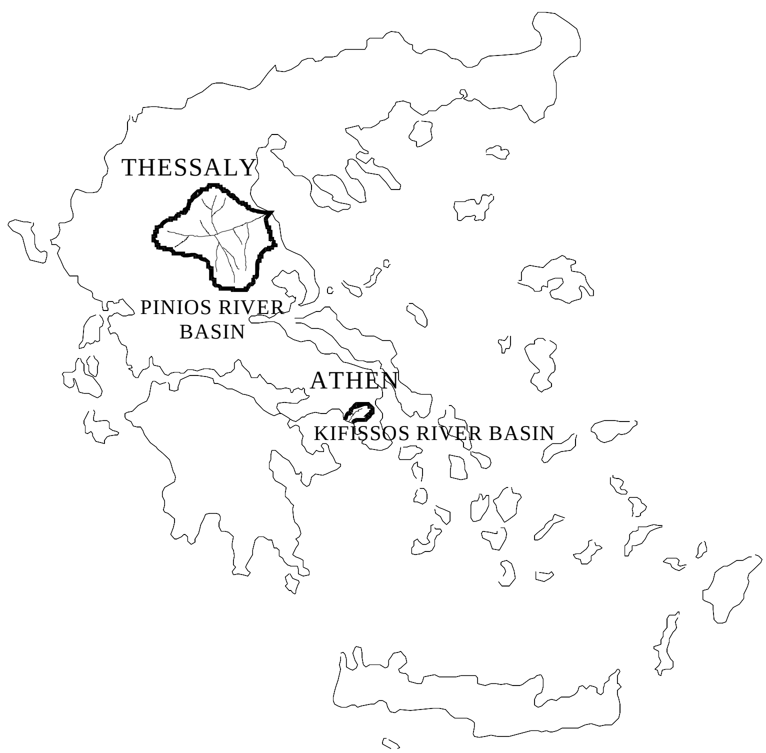

Figure 1. Location of study areas

The second study area is the Thessaly plain. Located in central Greece (Figure 1), the plain is an agricultural region with an area of about 4,000 km^2. The Pinios River, which has total catchment area of 9,500 km^2, traverses the Thessaly plain. Geographer Stravon noted that the plain suffered from floods since the ancient age when several structures had been built to control the Pinios River 2,500 years ago. The Pinios River passes through the Tempi Ravine located 18 km upstream from 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 reformed again. Still the Tempi Ravine, as well as other narrow passes along the river course (such as in Amygdalea, 15 km upstream from the town of Larissa), are primary causes of the flooding in the plain. Furthermore, the river's natural discharge capacity is inadequate in a large part of its length. This capacity was improved in the 1930's, through the construction of levees and other protective works, but floods such as those occurred during March 24-27, 1987 and October 21-22, 1994, has remained a big problem in the region. Other factors favouring the genesis of floods in the plain are, the presence of some bridges with inadequate height, the vegetation of the river bed, the construction of "handy" barriers in the river channel by local farmers to store irrigation water, and the low elevation of the drainage network as compared to the flood elevation.

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 focus on this recent event, which hit almost the entire country except for Eastern Macedonia and Thrace. The event was associated with heavy precipitation and floods in urban areas and in the countryside. It had catastrophic consequences including 11 deaths, damage to agricultural property, and damages to 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 2, at 18:00 UTC 21 October 1994 the low center 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 1,040 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). Figure 3 depicts 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.

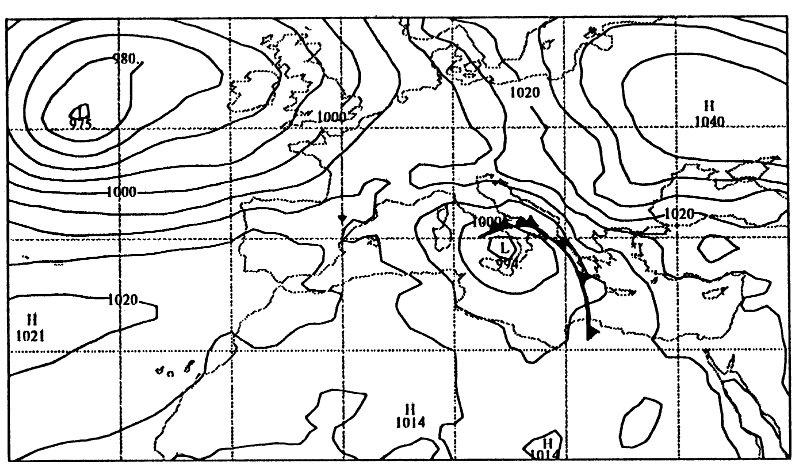

Figure 2. Surface weather map at 18:00 UTC 21 October 1994 with 5 hPa contour interval (Source: Lagouvardos et al., 1995).

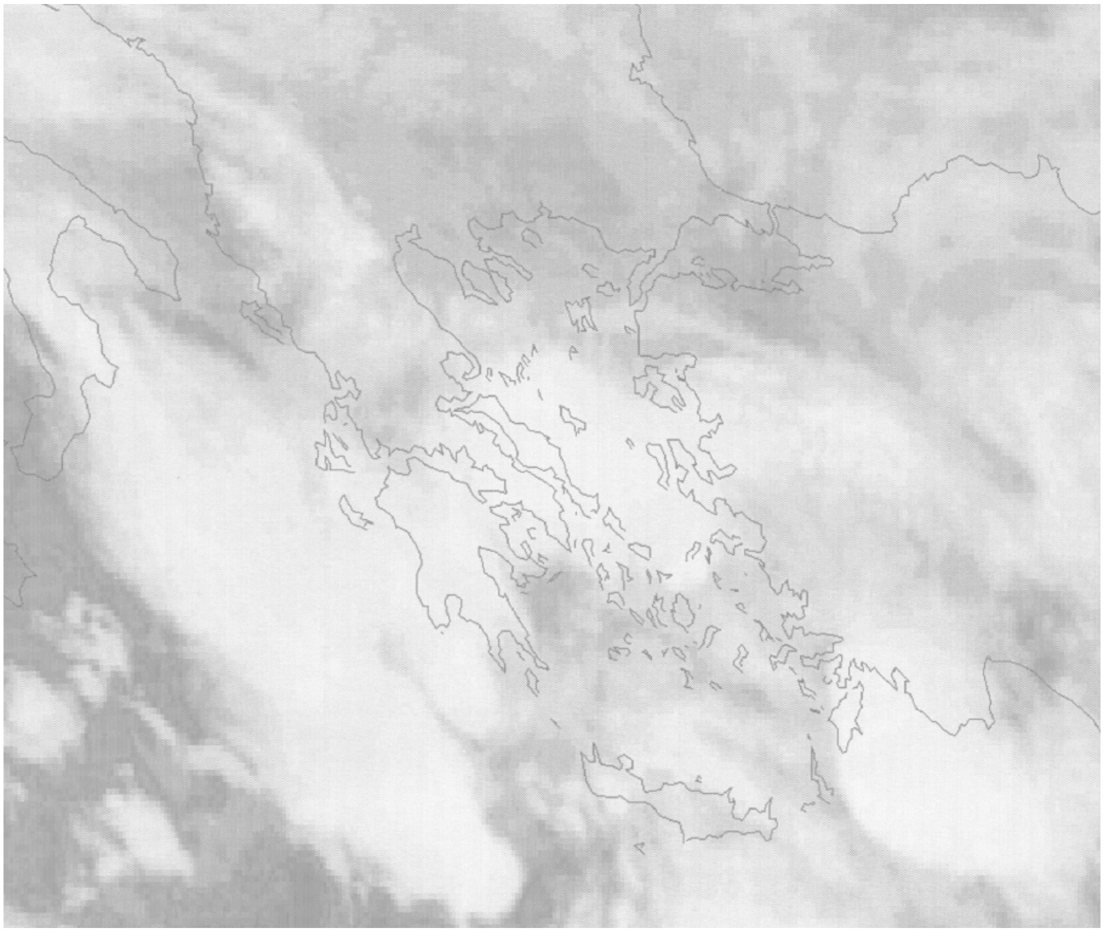

Figure 3. Meteosat image at 18:30 UTC 21 October 1994 (Source: National Meteorological Service of Greece).

4. THE FLOOD IN ATHENS

As there are no runoff measurement data in the Greater Athens area, our analysis is based on rain-recorder data only. We have used data of stations at Hellinikon Airport (to the south-east of Athens, elevation 10 masl), Nea Philadelphia (to the north of Athens, elevation 136 masl), and NTUA Campus at Zografou (to the north-east, elevation 219 masl). In Figure 4, we have plotted the storm hyetographs in an hourly time scale for the recording stations at Nea Philadelphia and NTUA Campus. The hyetograph for Hellinikon, not shown in the figure, was very low in intensity. We observe a similarity in the storm's temporal evolution at 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.

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 scale. We have also plotted the same range of rainfall durations versus 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 the Hellinikon and Nea Philadelphia stations that were published by Deas (1994) and originated from the archive of the Hellenic National Meteorological Service. Also, we have indirectly used 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.

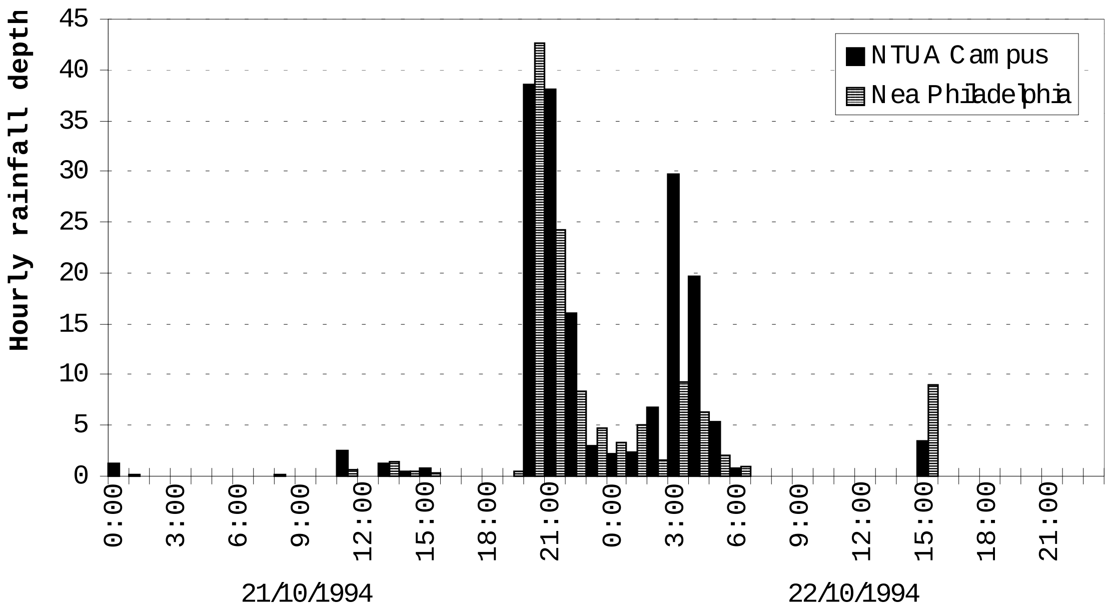

Figure 4. Hourly hyetographs of the storm of 21-22 October 1994 at two locations in Athens: NTUA Campus (source National Technical University of Athens) and Nea Philadelphia (source Hellenic National Meteorological Service).

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 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 were less severe for durations smaller than 1 hr, which are critical for the Athens area since it is covered by small watersheds with small runoff concentration times.

Consequences of the storm included the extensive inundation and damage of streets, houses, commercial and industrial areas, as well as the overflow of water courses in a major part of Athens (Figure 6). An estimate of the damages caused by the flood is 13 MECU for commercial and industrial properties and 1 MECU for houses (Nicolaidou and Hadjichristou, 1995).

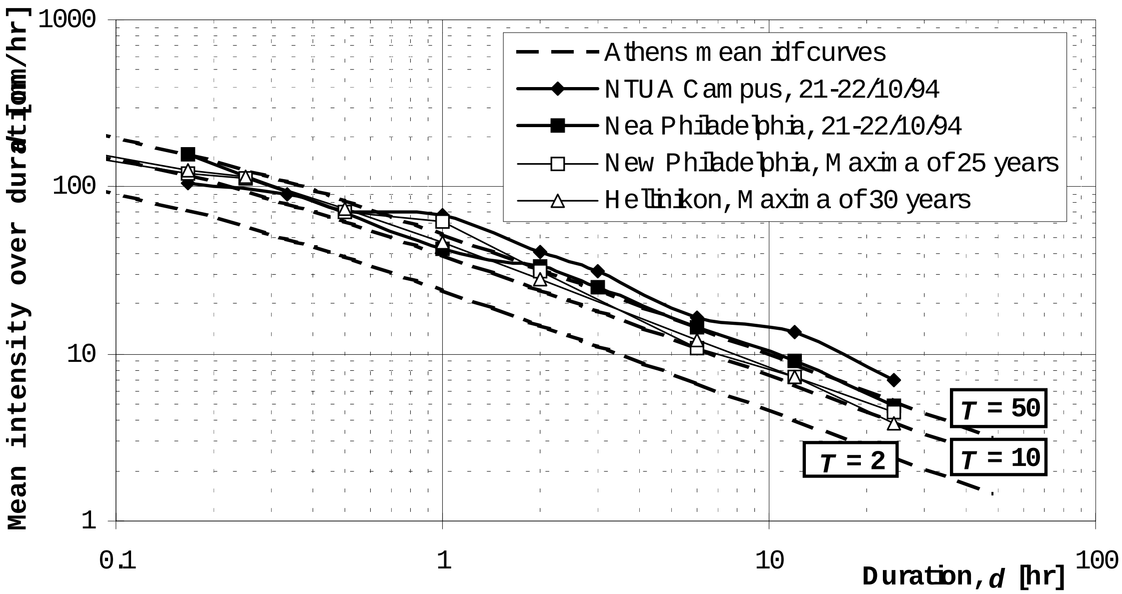

Figure 5. Indicative graph of the severity of the storm of 21-22 October 1994 in Athens, Greece.

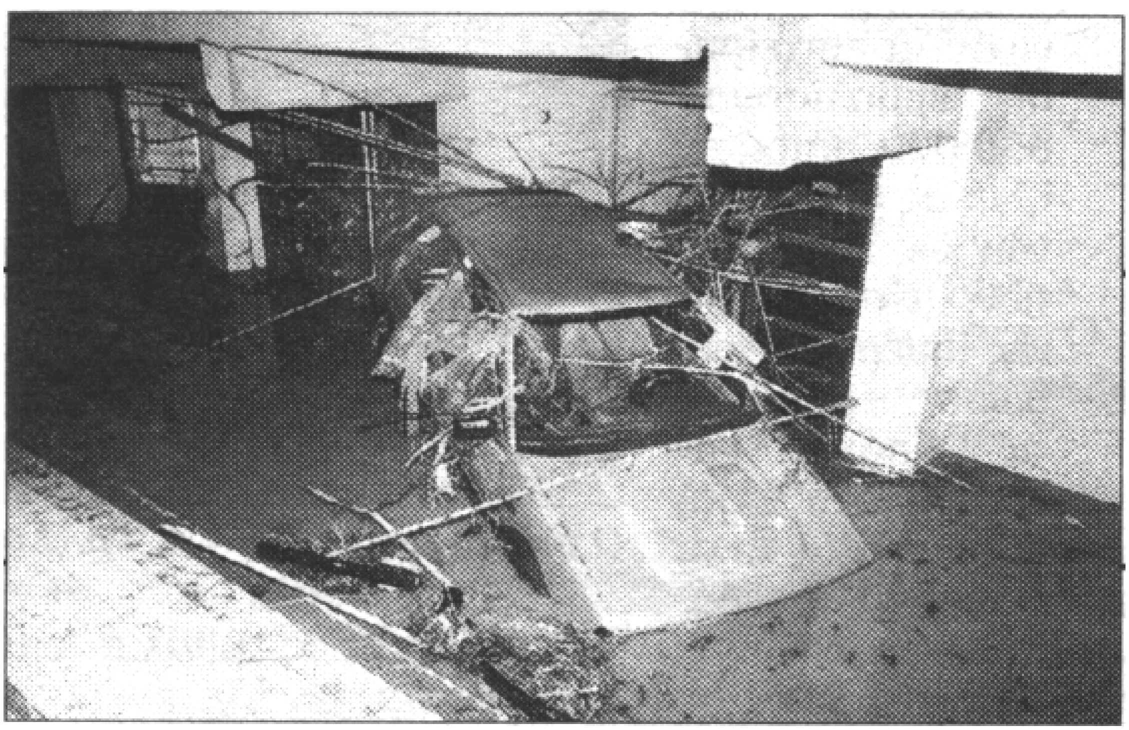

Figure 6. A picture of damages in streets, cars, and buildings caused by the flood of 21-22 October 1994 in Athens, Greece (Photo from the newspaper *To Vima*).

5. THE FLOOD IN THE THESSALY PLAIN

Rainfall data from the stations at Argithea (located at the west mountainous part of Thessaly at elevation 980 masl) and Karditsa (located at the west part of the Thessaly plain at elevation 103 masl) were used to assess the rainfall severity that caused the flood in Thessaly. The latter station was very close to the geographical center of the storm. In Figure 7, we have plotted the storm hourly hyetographs for both 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 storm's temporal evolution of rainfall at the two locations. Compared to Figure 4, we observe a longer duration, higher total depth and lower maximum intensity than the corresponding characteristics of the rainfall in Athens.

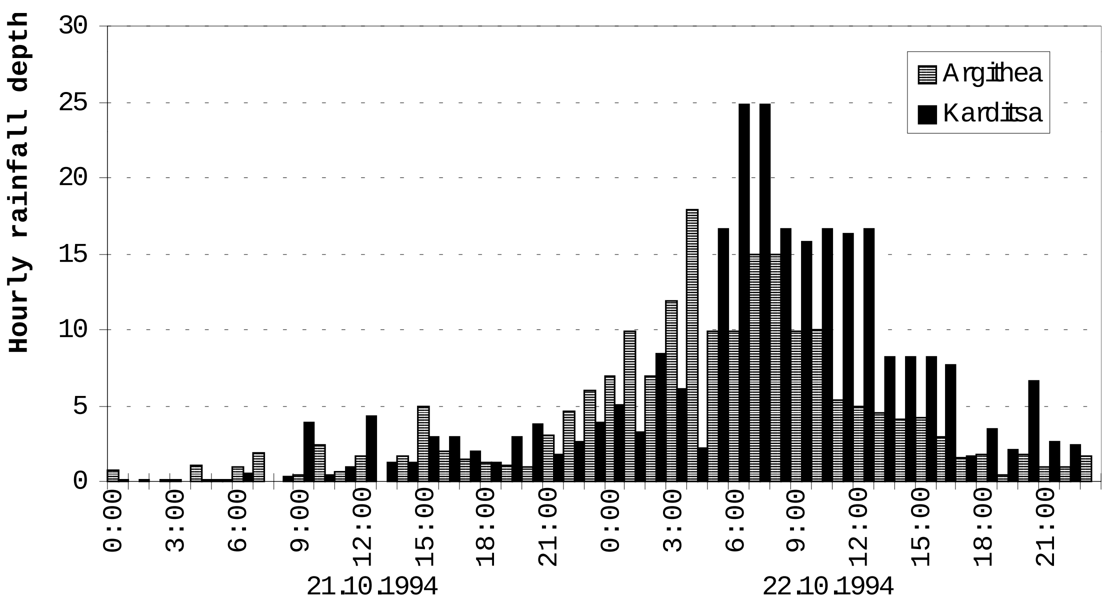

Figure 7. Hourly hyetographs of the storm of 21-22 October 1994 at two locations in Thessaly: at Argithea (source, Public Power Corporation 980) and at Karditsa (source, Ministry of Agriculture).

In Figure 8, we show an indicative plot of the storm severity, similar to that of Figure 5. Here, the storm of October 1994 is compared to the observed maxima of the Argithea and Karditsa historic records, and the idf curves of Argithea. The latter were constructed based on 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 8, we observe that the measured intensities of the storm of October 1994 are generally 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 at Karditsa, which are 2-3 times higher than those recorded in the past.

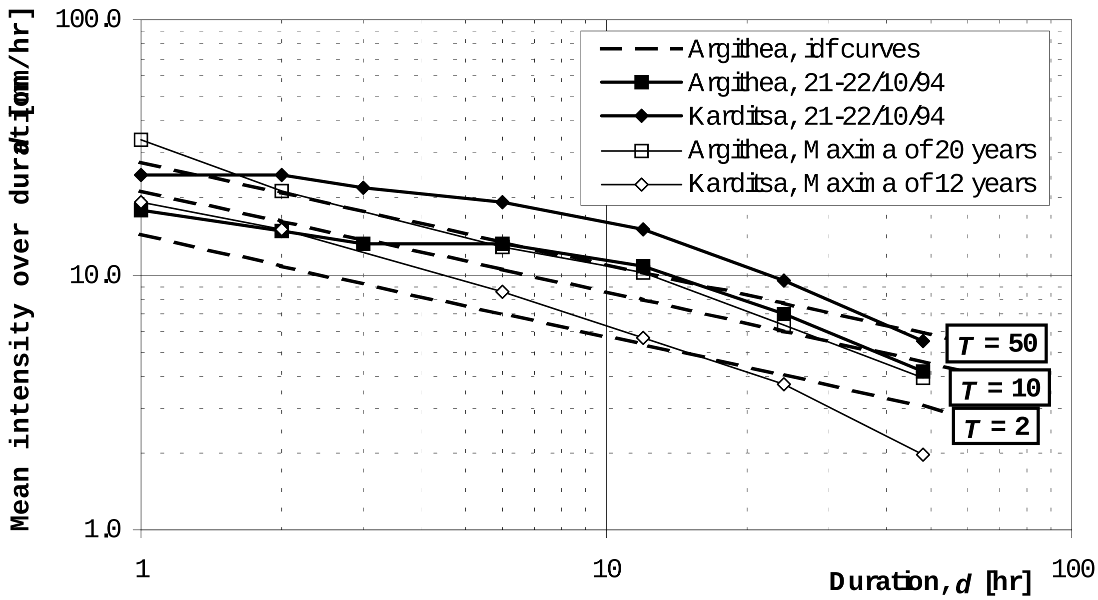

Figure 8. Severity of the storm of October 21-22, 1994 in Thessaly, Greece.

The stage and discharge data in gage stations along the Pinios River have not been processed yet. Moreover, at some measuring stations there was lack of data due to the destruction of the measuring devices. 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 is located at the Ali Efenti Bridge, which includes the west part of the Pinios subbasin (2,764 km^2). This hydrograph is displayed 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 high as compared to the previous flood (26 March 1987), when the recorded flow reached 637.3 m^3/s at the same location.

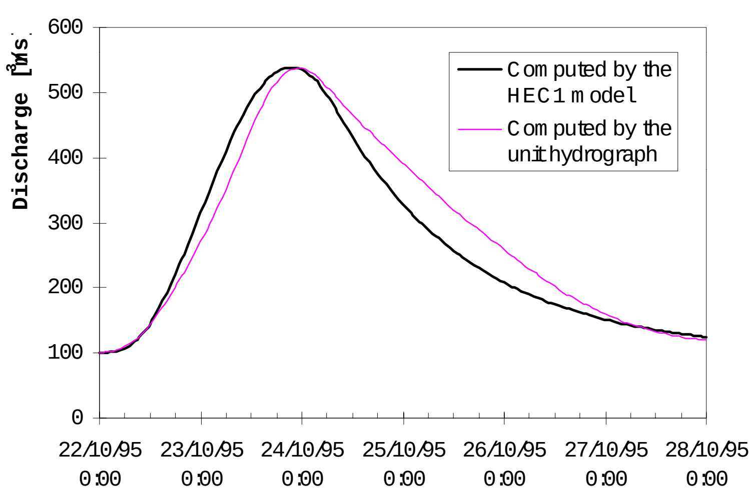

Figure 9. Reconstructed hydrograph at the Ali Efenti Bridge on the Pinios River.

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

Figure 20. The inundation of the Thessaly plain during the flood of October 1994 (Photo by M. Thanos, Ministry of Agriculture, Greece).

6. RESEARCH NEEDS

Recently, a branch of the European Union (EU) project entitled "*Storms, Floods and Radar Hydrology*" was implemented in the Thessaly plain. The project 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 part of Central and NW Greece, including 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, and 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 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.

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