Management and Prevention of Crisis Situations: Floods, Droughts and Institutional Aspects

Country Paper for Greece

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1 Introduction

The struggle of Greeks against floods and droughts is as old as the Greek civilisation as testified from the Greek mythology (e.g., Hercules fighting against the Acheloos river and diverting the Pineios and Alfeios rivers in Peloponnese). The initiatives of hydrology and meteorology are set by the Ionic philosopher Anaximenes as early as in the sixth century B.C. and were improved by the philosopher Anaxagoras in the fifth century B.C.; the term "μετεωρολογία" (meteorology) was widely used since the fifth century B.C. (*Koutsoyiannis*, 1996). The ancient Greeks had also some engineering achievements against floods. Several structures such as dikes were built to confine the shifting channel of rivers such as Acheloos in Western Greece, Boeotic Kifissos in the Eastern Greece and Pineios in the Thessaly Plain. These are mentioned by the historian Diodorus and the geographer Stravon; however we do not have technical descriptions of these works, only some presumed remainders of dikes (*Constantinidis*, 1993; *Koutsoyiannis*, 1995).

The climate features of Greece that are related with flood and drought genesis exhibit significant geographical diversity. The long and intricate coastline and the striking relief patterns is greatly responsible for this diversity. The orography of the Pindus mountain range, traversing the country from north-west to south, plays an important role in rainfall and runoff regimes in Greece. Thus, the mean annual rainfall exceeds 2000 mm in the mountainous areas of western Greece whereas in eastern regions of the country it may be as low as 300 mm (Fig. 1). This explains why droughts are most frequent in the drier eastern part of the country. In many islands of the Aegean the water shortage problem is almost persistent; here the low rainfall is combined with small sized catchments with largely intermitted runoff, and the absence of exploitable aquifers.

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 Pindus 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). Owing to this climate situation, combined with the geomorphological conditions (less developed and inadequate river network), the vegetation conditions (less vegetation cover) and the human reactions (people less familiar with high flows) the floods are probably more destructive in the eastern Greece than in the western Greece.

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; *Mimikou and Koytsoyiannis*, 1995). 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

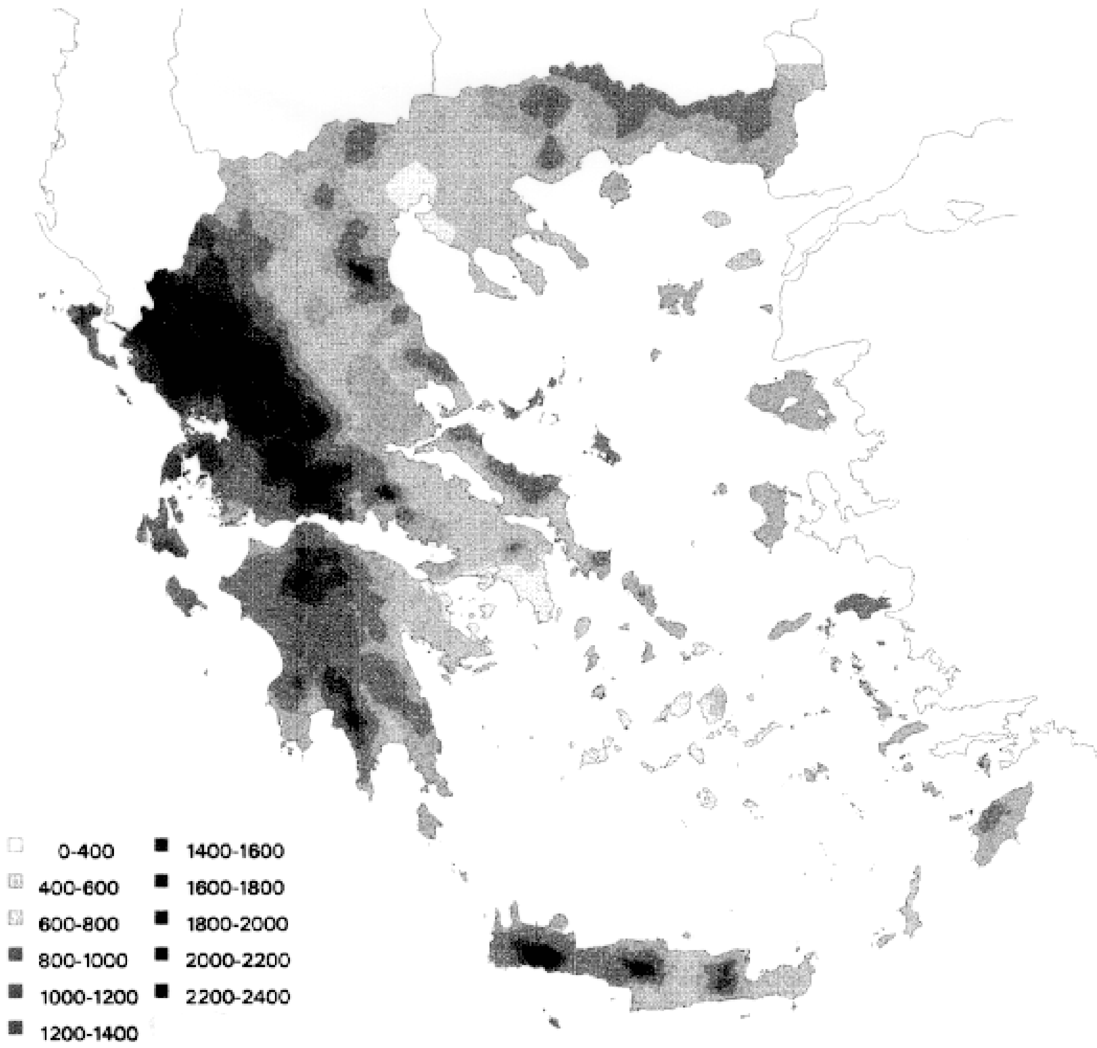

Fig. 1 Mean annual isohyets of Greece (from Koutsoyiannis et al., 1996).

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 been caused mainly from human activities such as fires, illegal land reclamation, pasturing, etc. (*Kotoulas*, 1980) but, notably, about 1/4 of the forests was destroyed during the occupation of Greece in the World War II (*Constantinidis*, 1993).

In the next sections we give a general description of the practices followed in Greece for the prevention and management of crisis situations from floods and droughts. Our analysis is focused on two representative areas, shown in Fig. 2, suffering from both floods and droughts: the Athens metropolitan area and the Thessaly plain. Both study areas belong to the eastern part of Greece. The Athens area is the most urbanised area in Greece while the Thessaly plain is mainly an agricultural area.

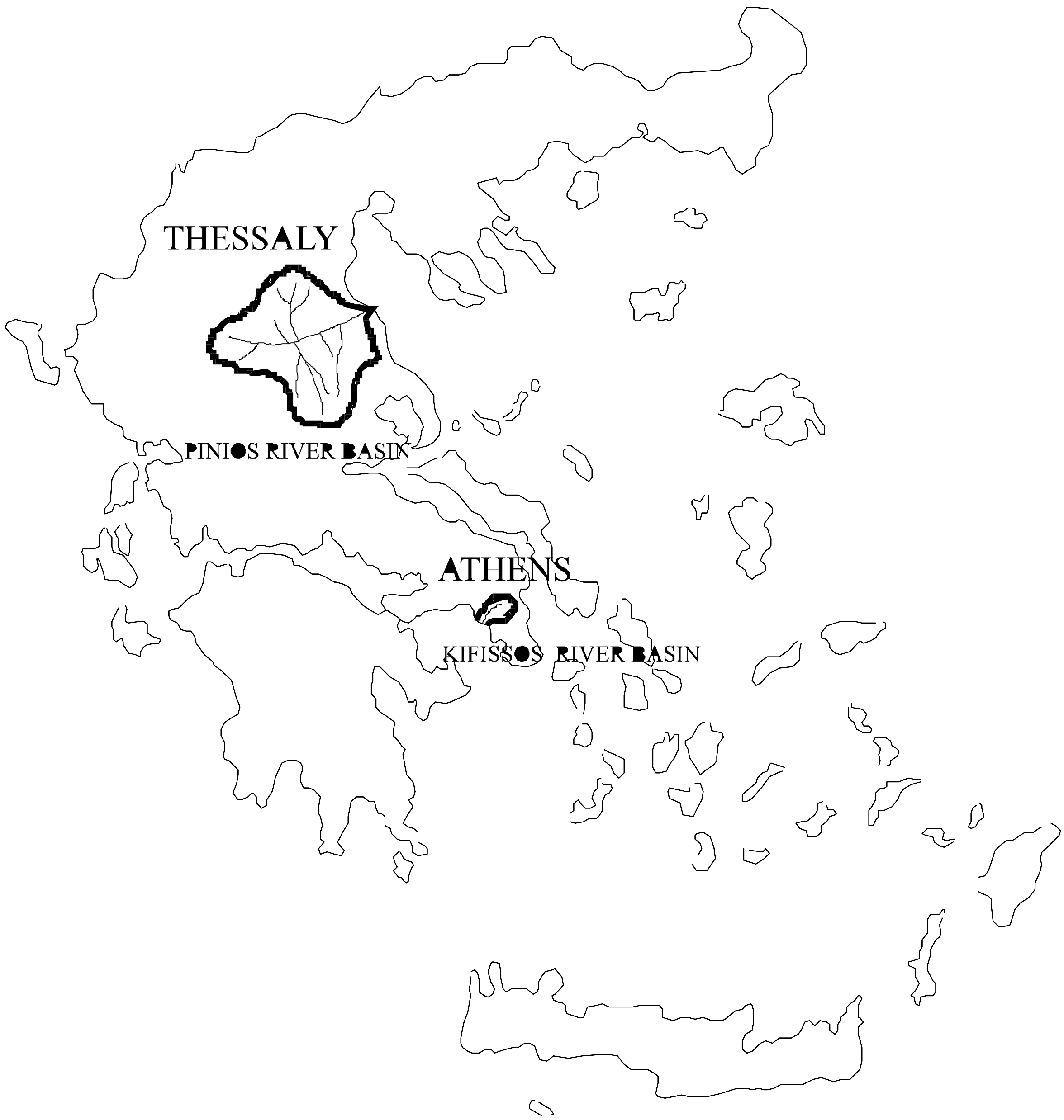

Fig. 2 Location of study areas

2 Floods

2.1 Pre-emergency measures

In Greece, until today the focus has been given to the hardware, i.e., the construction of flood protection works (see subsection 2.3) rather than to software, i.e., the flood forecasting and decision making for flood mitigation and control. However, attention has been given to flood forecasting at least for the protection of dams during their construction. For example, forecasting systems have been studied for the Pournari dam of the Arachthos river (*Mimikou et al.*, 1977) as well as the Mesohora dam of the Acheloos river (*Mimikou et al.*, 1992) in order to protect the dams and the relevant works (cofferdams, diversion tunnels, etc.) during their construction phase. The studied flood warning systems are based on the monitoring of upstream hydrological variables such as rainfall and water level, and make use of empirical relations and nomographs constructed for the specific locations by analysing historical flood records.

Considerable attention has been given in Greece for the forecasting of downstream floods due to dam breaks, both in research (see, e.g., *Xanthopoulos and Koutitas*, 1976) and in application. The flood propagation due to dam failure has been simulated at least for the major dams, in order to estimate the possible hazards and support the organisation of warning systems and evacuation plans. From the several studies we can mention here two examples, the Mornos dam and the Kerkini dam cases (*Ganoulis and Tolikas*, 1981a, b; *Koutsoyiannis*, 1995). Located in the Mornos river (about 200 km to the west of Athens; see Fig. 3) the Mornos dam has been built during 1972-79 to support the water supply of Athens. It is an 126 m high earthen dam with a 825 m long crest and a 780 millions m^3 total reservoir storage capacity. Due to the deep valley confining the river bed, a monodimensional wave will be developed after a dam break, except for the delta area where the flood wave will spread into a two-dimensional propagation. From simulations it was found that the wave propagation is very rapid with a time scale ranging between 25 and 45 minutes. The risks related to the Mornos dam break are focused on the villages in the delta area and the road in the river valley. Our second example, Kerkini dam, is a 15 m high embankment in the Strymon river located in the natural lake of Kerkini (Serres plain, province of Macedonia) aimed at irrigation and flood protection. In this case the flood wave propagation is two-dimensional and slow (with a time scale of several hours to about one day), owing to the small height of the dam and the wide area with mild slope downstream the dam.

Attention has been also given to another potential risk, a landslide into a reservoir, which can probably induce waves as high to overflow the dam (*Koutsoyiannis*, 1995). Theoretical research for the forecast of water waves induced by a possible landslide has been carried out (*Koutitas*, 1977; *Gavriilidis et al.*, 1993) and special cases for specific reservoirs have been studied.

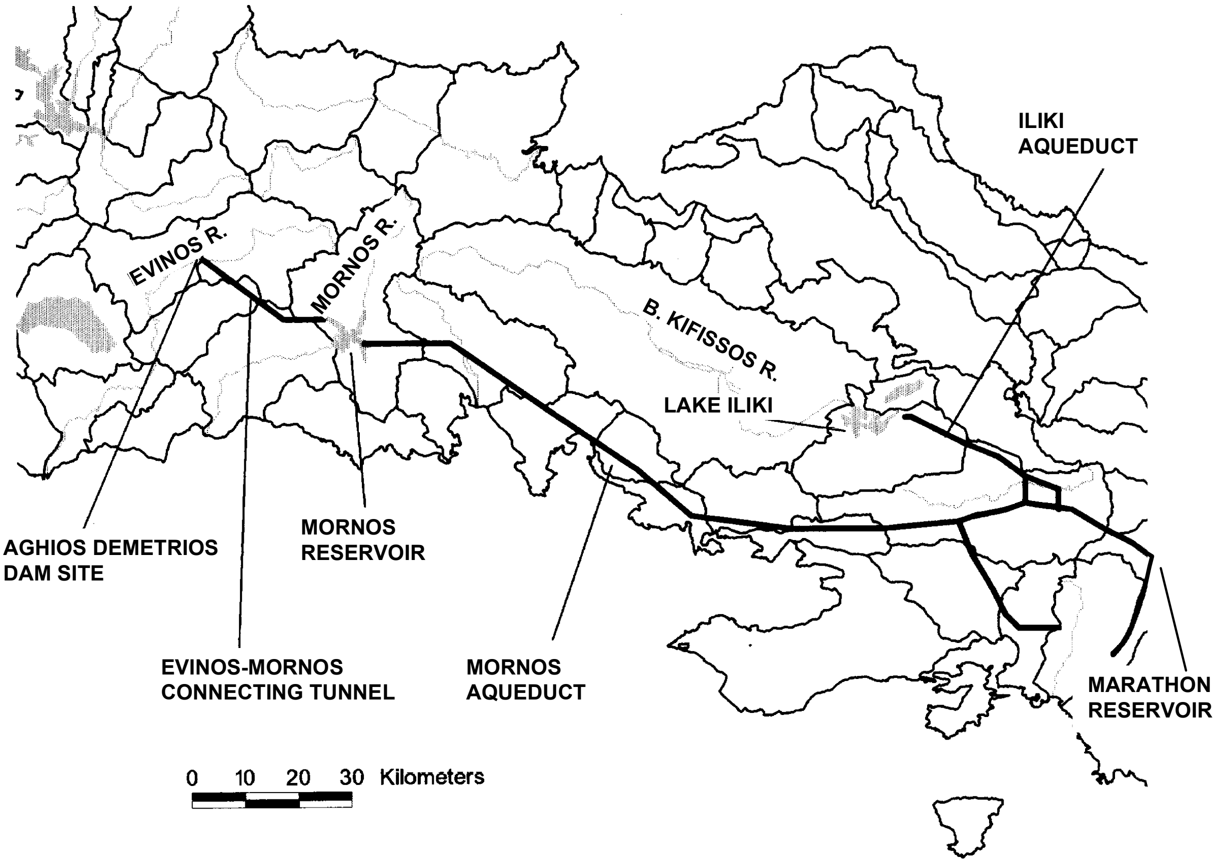

Fig. 3 General layout of the Athens water supply system

Fortunately however, no dam break (due to overflow or other reasons) has ever occurred in Greece, except for one minor case (*Koutsoyiannis*, 1995). This case is referred to the overflow of the small dam of Agras due to an extraordinary flood. The dam was constructed during 1951-54 and belongs to a system of hydroelectric works (also including the two natural lakes Ostrovo and Nissia) located at about 5 km upstream of the town of Edessa in Macedonia. It is a 10.5 m high earthen embankment with a crest length of 179 m, confining a regulating reservoir in the Edesseos river (tributary to the Loudias river) with a storage capacity of 400 000 m^3. After the extraordinary storm of 18-19 November 1979 with a 24-hour depth reaching 319 mm and 421 mm at two gauges close by, the produced flood was too large to be handled by the regulating reservoir and the spillway of the dam. Consequently, the dam was overflowed by the water and seven breaches were created across the embankment. Also, damage of property and agriculture were caused downstream, where the river channel (confined by levees) was insufficient to route even the natural discharge during that flood. The damage to the dam has been repaired thereafter.

2.2 Emergency organisations and measures

Under the name “Xenocrates”, a general plan exists for the prevention, mitigation and control of natural hazards including floods. This plan constitutes a guide for collaboration and coordination of the authorities and public services organisations, which are involved in the control of emergency situations (see Table 1). The plan includes measures in both the central and local level. The authorities of the central level, i.e., ministries, are responsible for the general planning and coordination. To each of the ministries listed in Table 1 there exists a particular Directorate for Emergency Planning. The authorities of the local level are responsible for the actions taken for prevention, control and restitution of damages.

Table 1 **Authorities and Services involved in flood crisis situations.**

Ministries (Central Authorities)	Local Authorities (of Each Prefecture)	Main Public Services
Public Administration and Decentralisation	Head of Prefecture	Public Power Corporation
	Mayors of Municipalities	Telephone Organisation
National Defence	Presidents of Communities	Railway Organisation
Agriculture	Directorate of Technical Services	
Public Order		
Macedonia and Thrace	Directorate of Sanitation	
Aegean	Directorate of Land Reclamation	
Public Health		
Justice	Directorate of Agriculture	
National Education	Directorate of Transportation	
Culture	Forest Authority	
Finance	Police Authority	
Environment, Regional Planning and Public Works	Fire Authority	
	Prefecture Treasury	
Labour	Prefecture Committees of Public Training	
Development		

In this general plan, special attention has been given to measures aiming at prevention of flood damages. These include inspection and maintenance of the flood protection works by the local technical authorities. They also include training of the people as of how to react in crisis situations and how to contribute to mitigate the damage. Another provision of this general plan is the readiness both in equipment and personnel of the local authorities.

When a major flood occurs, a coordination committee is constituted by the heads of the co-responsible directorates in the prefecture, which also contacts the central authorities. Under the guidance of this committee actions are taken to rescue and hospitalise people, and repair the road, railway, energy, and telephone networks. The army and the main public services also contribute in these actions. The final stage, after the retreat of the flood is the reporting and assessment of damages in wealth, as well as the state's finance and assistance to repair the damages.

2.3 A general description of flood hazards and flood protection works

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.

An interesting example of the first case with serious flood problems is the Boeotic Kifissos basin (Fig. 3), a closed hydrologic basin with an area of about 2 000 km^2, located in the central-eastern part of Greece, not far from Athens (*Koutsoyiannis*, 1995). The basin is drained by the Boeotic Kifissos river with a length of about 100 km. The river network originates from altitudes as high as 2400 m above sea level and reaches downstream to a plain with an area of about 250 km^2 at a mean elevation of 95 m above sea level. Prior to 1900 the plain was permanently flooded by the river flow, thus giving rise to the formation of the lake Kopais, a shallow lake with an area of about 150 km^2. The lake was insufficiently drained via karstic sinkholes and during the years with high flows the area of the lake increased to 250 km^2. Attempts to construct effective drainage were initiated in ancient times, as reported by the geographer Stravon, but did not succeed. Only at the closing of the nineteenth century was the plain sufficiently drained after the construction of a tunnel leading the flow of the Boeotic Kifissos to the external lake Iliki. In addition, a broad network of canals, drains and levees was built in the plain. Recently a new tunnel with a discharge capacity of 590 m^3/s (in addition to the 160 m^3/s of the old tunnel) improved the situation. However, the flooding problem of the region is not fully resolved yet. The design floods at the entrance of the tunnel and at various locations of the river network and the canals are greater than the discharge capacities at those locations, thus giving rise to overflows and flooding of agricultural land. Moreover, owing to a design philosophy that gave protection priority to the plain of the former lake Kopais, various hydraulic works were constructed in the middle and upper river course so as to temporarily store floods thus attenuating the discharge downstream. These works resulted in a transfer of the flooding problem from downstream to upstream areas. A minimum of 10 km^2 of agricultural land in the upper and middle course of the river is flooded each year. This area increases to around 30 km^2 once every 25 years. Another similar example is the Lassithi plateau on the island of Crete (*Koutsoyiannis*, 1982). The latter is a 25 km^2 flat area (inhabited since at least the Minoan age) with a mean altitude of 820 m surrounded by mountains, which form a closed hydrological basin with an area of 130 km^2. The main stream of the basin traverses the plateau and ends at a group of karstic sinkholes. Owing to the limited capacity of the sinkholes (about 12 m^3/s) floods occur every year in the plateau. The flooded area may reach 50% of the total area of the plateau and the flood duration usually varies between one or two days up to one month per year. A diversion tunnel has been proposed to prevent flooding of the plateau but was not constructed yet.

For the second case, the plains, the problem was greater due to more serious damages in agricultural land. Almost all plains in Greece suffer from floods. The flood hazards have been mitigated to a high degree after 1900, by building major flood protection works. Such works have been constructed at the Thessaly plain (Pineios river), Agrinio plain (lower Acheloos river), the plain of Pamissos river in Peloponnese, Arta plain (Arachthos and Louros rivers) in Epirus, Thessaloniki and Giannitsa plain (Aliakmon, Axios, Loudias and Gallikos rivers) in Macedonia, north Greece, Artzan-Amatovo marsh (Axios river), and Serres and Drama plain (Strymon river) also in Macedonia. The construction of major dams for energy production drastically improved the situation for some main rivers such as Acheloos, Arachthos and Aliakmon. For other river plains, the flood protection level is very lower and the damages are still frequent and significant. Usually the protection works are designed for a return period ranging from 10 to 100 years, depending on the severity of the destruction and the available economic resources at the time of construction. Nowadays, a typical 10-year design return period is generally considered as too low and there is public pressure for higher protection against floods. Thus, many protection works are studied again in many of the aforesaid plains towards improving the protection level. Some more details will be given below (subsection 2.5) for the Thessaly plain.

As mentioned above for the third case, the urban areas, the situation was deteriorated rather than improved until recently. The urbanisation of natural flood plains has created a threat to both wealth and human life. Moreover, there are cases where buildings were illegally constructed over or very close to ephemeral stream beds. Thus, flooding of urban areas is probably the most frequent and destructive case among the flood hazards in Greece. Below (subsection 2.4) we will examine in detail the case of Athens, the city with the hardest flood problem throughout Greece.

2.4 The Athens case

The Greater Athens area is the most urbanised part of Greece with a population of about four million (40% of the total country's population). Without overstatement, Athens is the capital of Greece not only administratively but also in flood damages. In Table 2 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).

Table 2 **Floods causing loss of human lives in Athens (adapted from *Nicolaidou and Hadjichristou*, 1995)[†]**

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

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

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.

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 farmlands affected seriously the flood rate. The stream network was shrunk as many streams were converted into streets. Even buildings were constructed over the old streambeds. No priority was given to the flood protection works and the storm drainage network, which is still primitive.

The severest flood of the last 10 years occurred on 21-22 October 1994. The flood was caused by a cyclonic system with a cold front formed in the Middle Mediterranean and propagating eastward (Lagouvardos et al., 1995). The recorded hourly maximum rainfall depths at the stations Nea Philadelphia (to the north of Athens, elevation 136 m) and National Technical University Campus (to the north-east, elevation 219 m) were 42.7 mm and 67.7 mm, respectively, whereas the 10 minutes maxima were 26.0 mm and 17.5 mm, respectively. The corresponding intensities for durations greater than 1 hour of this storm are greater than all respective intensities recorded in the last 25-30 years, and, also, lie above the intensity-duration-frequency curve of 50-year return period (*Mimikou and Koutsoyiannis*, 1995). This indicates that indeed the storm of October 1994 was very severe. Fortunately, the intensities are somehow less severe for durations smaller than 1 hour, which are more critical for the Athens area that is covered by small watersheds with small runoff concentration times. 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. 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)

The very short time-scale of the evolution of the flood did not allow an effective function of the institutional emergency system during the peak of the flood. However, the system was activated to rescue people, redeem the city networks, and report and assess the damages in wealth. This flood motivated a general reconsideration of the flood problem of the city. Researchers, engineers and decision makers discussed the several views of the problem and suggested structural and non-structural measures. For example, *Xanthopoulos et al.* (1995) prepared an outline of the applied research required for an integrated confrontation of the flood problem. 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 structural and non-structural measures. Finally, stage 4 includes the development of a monitoring, forecasting and warning system for intense storms and floods in Athens. Although this integrated approach was not adopted yet, several steps have been taken to improve the situation. Thus, the local Water Supply and Sewerage Corporation proceeded to a detailed inventory of the stream network of Athens and its current situation. The Ministry of Environment, Regional Planning and Public Works in collaboration with the municipalities of the Greater Athens proceeded to the construction of storm drainage works.

2.5 The Thessaly case

The second study area, the Thessaly plain, is the largest plain of the country with an area of about 4 000 km^2. The plain is traversed by the Pineios river whose total catchment area is 9 500 km^2. The Thessaly plain is located in central Greece (Fig. 2, Fig. 4). 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 Pineios river 2500 ago. The Pineios 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 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. 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.

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. The flood of 24-27 March 1987 was caused by an intense rainfall that produced direct runoff as well as snowmelt. The water level of the Pineios river measured during the flood event exceeded 6.3 m at Amygdalea narrow pass, located 15 km upstream the town of Larissa (with 6401 km^2 area of the upstream basin and normal water level less than 1 m) and 8.0 m at the Tempi ravine, located 18 km upstream of the basin’s outlet (with 9512 km^2 area of the upstream basin and normal water level less than 1 m), whereas the measured discharge exceeded 1000 m^3/s in both locations (*Koutsoyiannis*, 1995). Owing to the narrow riverbed at both locations (Amygdalea and Tempi), significant parts of the Thessaly plain upstream each location were inundated.

The flood of 21-22 October 1994 was caused by the same cyclonic system described in subsection 2.4. The recorded hourly maximum rainfall depths for 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, very close to the geographical centre of the storm) were 17.9 mm and 24.8 mm, respectively. For a duration of 12 hours (which is more representative for the Thessaly plain) the maximum depths for the same stations were 129.0 mm and 180.4 mm, respectively. The corresponding intensities are greater than all respective intensities recorded in the past for both stations (the available record lengths are 20 and 12 years for Argithea and Karditsa, respectively) and, also, lie above the intensity-duration-frequency curve of 50-yr return period (*Mimikou and Koutsoyiannis*, 1995). Notably, the intensities in Karditsa are 2-3 times higher than those recorded in the past. This intense storm caused flood along the Pineios river and its tributaries, as well as inundation of agricultural and residential areas. The stage and discharge data in the measuring stations along the Pineios 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. *Dalezios et al.* (1995) using satellite images has determined that the damaged area was 26 km^2. 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. 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.

Contrarily to the Athens case, in the Thessaly plain the quite larger time-scales of the evolution of flood phenomena (several hours) allow the development of an effective flood forecasting and alarming system. 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*, 1996; *Baltas*, 1996). More research is needed to incorporate the current results for operational use.

Currently, the structural system for the flood protection of the plain is reconsidered. The Ministry of Environment, Regional Planning and Public Works proceeds to the study of the whole basin of the Pineios river, as well as particular studies for improving the situation in key locations (e.g., the town of Larissa).

3 Droughts

3.1 A general description of occurrence of droughts and their prevention

In the western part of the country the water availability is generally higher than consumption demands, even during drought periods. Thus, nowadays, after the construction of dams and reservoirs, as well as works for exploitation of groundwater, these areas do not generally suffer from droughts. To this rule there are some exceptions, both in the continental and the island part of western Greece. For some locations in the continental part, which are physically isolated from major water resources, the problem is expected to be resolved soon with the construction of channels and other works for water conveyance. The problem with the islands of the Ionian Sea is more difficult. Although the rainfall amount in these islands is larger than the average in Greece, the water resources are limited. The segmentation of the islands' area into many small-sized catchments does not allow the formation of large water bodies than can be exploited in an economic way. Besides the abundance of karstic geologic formations in these islands diminishes the surface runoff and still the small size of hydro-geological basins does not allow intensive exploitation of groundwater without the risk of subsalinity; however, pumping of groundwater remains the dominant solution in many parts. The alternatives examined so far are the construction of a number of small off-stream reservoirs to store surface water, desalinisation plants, and even submarine pipes to transfer water from the continental part of the country. The first two alternatives have been already tried in pilot plants, without conclusive results so far.

The situation in the eastern part of the country is more complicated. There are places of the eastern continental part where the deficit in water resources availability is the rule rather than the exception. The greater Athens area and the Thessaly plain are the places with the most serious problems and will be examined in detail in the next two subsections. The conditions in the Aegean islands are harder than those of the Ionian islands, because the climate conditions are worse in the Aegean Sea. The alternatives already described in the previous paragraph for the Ionian islands, plus the transportation of water by boat, are also applicable for the Aegean islands.

The institutional framework for the confrontation of droughts is different than that for floods, described in section 2.2. According to the law for water resources management (law 1719/1987), in case of a drought, the head of the prefecture may clamp down the different water uses of the area after the proposal of the local water authorities. If this procedure in the local level fails to work, then the responsibility is taken by the Minister of Development.

3.2 The Athens case

It is well known from historical documents that Athens has suffered from water shortage since the ancient years. In modern times the water demand did not cease to grow at a fast rate almost doubling every 10 years, except for the World War II period (*Nalbantis et al.*, 1992; see Table 3). Insufficiency of the local water resources inevitably led to the development and utilisation of remote water resources through the construction of the Iliki aqueduct in 1968 in the Eastern Sterea Hellas water district and subsequently the Morons reservoir and aqueduct in the Western Sterea Hellas water district (see Fig. 3). The construction of all these works was always preceded by a period of crisis with a high risk of severe water shortage.

Table 3 **Water consumption history - Milestones (from *Nalbantis et al.*, 1992).**

Hydrological year	Population of Greater Athens	Consumption (hm^3/year)	Observations
1927-28	802 000	5.5	Adrian aqueduct (Roman)
1931-32		12.2	Construction of Marathon Dam
1940-41	1 124 109	22.3	
1950-51	1 378 600	22.8	Stagnation due to World War II
1960-61	1 852 709	69.6	Full operation of Iliki aqueduct constructed in 1958
1970-71	2 540 241	140.7	
1980-81	3 027 331	275.1	Commencement of operation of Mornos Aqueduct
1988-89	3 370 000[a]	366.8 (438.6)[b]	Combined operation of Mornos Reservoir and Lake Iliki

[a] Estimated value. [b] Included losses from the conveyance works

The main features of the existing Mornos-Iliki system management are, first, the need for pumping of water from Iliki while the Mornos Aqueduct operates by gravity, and, second, the significant losses from the natural lake Iliki owing to its karstic geological background. During 1981-87 abstractions were mainly made from Mornos due to the lower cost and overestimation of its yield. Subsequently, this policy changed and a combined operation of the Mornos and Iliki reservoirs was made. Unfortunately, the change of the operation policy was combined by an extended drought period lasted about six years (1987-88 to 1992-93). During this period the mean annual water yield of the system was as low as 50% of the normal yield estimated from records of the preceding years (*Nalbantis et al.*, 1994). This six-year drought period included the two extremely dry hydrological years 1989-90 and 1991-92 whose yield was the lowest recorded in 20th century. The severe drought together with the prior overexploitation of the Mornos reservoir led the system to a particularly critical state that had to be remedied only by additional measures both in demand and resources. Several structural and non-structural measures were studied and some of them were applied with very satisfactory results, that led the system to full recovery. The applied measures are summarised in the points below (see also *Koutsoyiannis and Xanthopoulos*, 1990):

1. *Significant reduction of consumption by 30%*. This was achieved by the increase of the price of water, the fining of the high consumption, and a broad campaign for keeping the public updated for the problem and its everyday status.
2. *Reduction of other water uses.* The water use for the irrigation of the Kopais plain from Iliki was shrunk to a minimum and the watering of parks and gardens in Athens was either ceased or done with water of lower quality.
3. *Pumping of water from the dead volume of the reservoirs.* This was accomplished through floating pumping stations installed in both Mornos and Iliki reservoirs.
4. *Utilisation of groundwater for water supply.* New works including boreholes, pumping stations and pipe systems were constructed in the Boeotic Kifissos - Iliki area. This system yielded about 160 hm^3 per year, out of which 110 hm^3 per year were allocated to the water supply of Athens (*Koutsoyiannis et al.*, 1992). In addition, existing boreholes in the same area and in Attica were set again in operation.

5. *Utilisation of groundwater for other uses.* The aquifers of the Athens area, whose water quality is lower due to urban pollution, were exploited by constructing new boreholes in several locations. This water was used for watering parks and gardens (public and private) as well as washing streets, etc.

6. *Expansion of the main water supply system using new surface waters.* A new reservoir was studied in the Evinos, to the west of Mornos, along with a tunnel diverting water from Evinos to Mornos. Initially, three alternative locations of the reservoir were studied, all operating by gravity (*Koutsoyiannis and Xanthopoulos*, 1990; *Nalbantis et al.*, 1992). In the finally chosen location (Aghios Demetrios; Fig. 3) the reservoir will contribute to the system more than 200 hm^3 per year, depending on the climate conditions and the management rules of the entire system (*Koutsoyiannis et al.*, 1991). The connecting tunnel with a length of about 30 km has been already completed and operated since the beginning of this year. The construction of the dam has not been completed yet.

7. *Cloud seeding.* A cloud seeding programme was operated aiming at increasing rainfall in the areas of supplying water to Athens. We do not have conclusive results of the contribution of this programme.

In addition to these measures that were applied successfully, other alternatives were also studied but had lower priority. Among them we mention the use of other surface water resources using pumping stations, such the pumping of water of the Mornos river downstream of the dam, and the conveyance of water from the lakes Trihonis and Stymfalia. Another potential alternative studied was the transportation of water (e.g., from the estuary of Acheloos river) using tankers.

3.3 The Thessaly case

The cultivated area in the Thessaly plain that is irrigated currently exceeds 1800 km^2 and it is anticipated to reach 2500 km^2 in the future. The irrigation water is mainly provided by the aquifers of the plain, which have a potential yield of about 590 hm^3 per year. Additional resources are the Pineios river, whose flow is totally unregulated and the diversion of a tributary of Acheloos (Megdobas river). According to *Koutsoyiannis et al.* (1996) the annual water potential of the area (surface and subsurface) is about 3150 hm^3 per year while the total demand for all uses is currently about 1350 hm^3 per year, 95% of which is the water demand for currently irrigated area. Thus, in the annual basis the water resources availability exceeds the demand. However, in monthly basis this the situation is totally different. During July, the month with the highest demand, the requirement for water is 520 hm^3 while the water availability is only 285 hm^3, because, as mentioned before there do not exist regulating reservoirs in the area. Thus, the drought problem is persistent in the Thessaly plain. This situation has led to overexploitation of the aquifers and severe environmental degradation of the water resources of the area. To increase the water availability two different structural measures have been planned that are expected to remedy the problem in the future. These are:

1. *Development of local surface water resources.* Nine reservoirs have been studied in the Pineios river basin (Fig. 4). We note however that these reservoirs are costly due to geomorhological and hydrological reasons. The contribution of all reservoirs will be less than 550 hm^3 per year, that is only 20% of the mean annual Pineios runoff.

2. *Diversion of water from Acheloos river.* A lot of discussions have been done about the feasibility of such a solution, the annual water volume that should be diverted, and the associated environmental, economical, and social impacts. The currently set up plan foresees the diversion of 600 hm^3 of water from Acheloos to the Thessaly plain per year. The project is combined with energy production and environmental recovery of the Pineios river, as well.

In order for the water deficit problem of the Thessaly plain to me remedied both the above mentioned measures must be materialised.

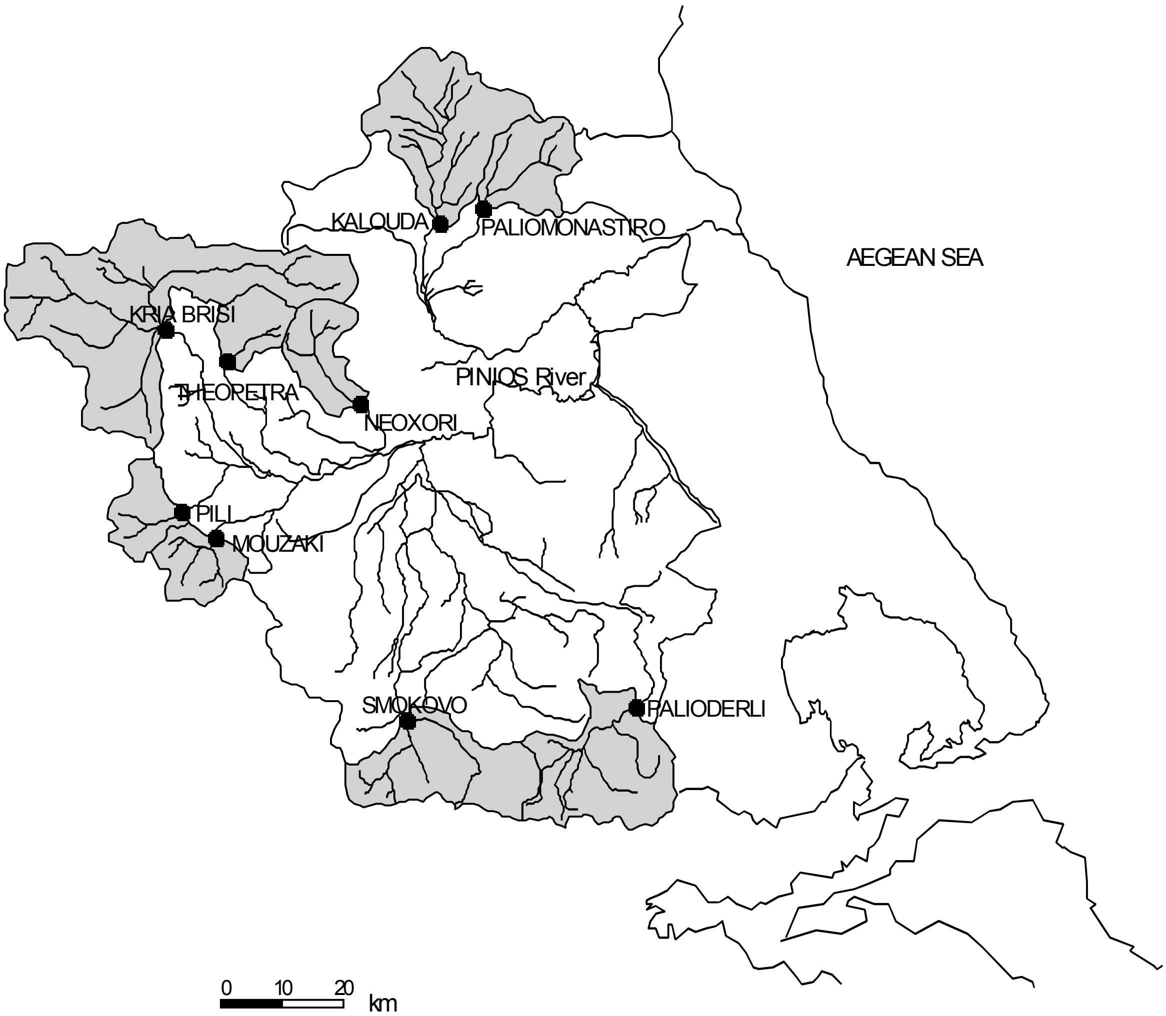

Fig. 4 Map of the Pineios river basin. The shaded areas are the catchments upstream the studied dam locations.

4 Conclusion

Large parts of Greece suffer from floods and droughts. Interestingly, the areas more sensitive to droughts frequently coincide with those with the most severe flood problems. The structural measures to remedy both hazards have not been exhausted yet; on the contrary large projects are currently under way or planned for the near future. In addition, non-structural measures have been successfully applied for crisis situations.

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