Δελτίο της Ελληνικής Γεωλογικής Εταιρίας, Τομ. XXXIV/5, 1773-1779, 2001 Bulletin of the Geological Society of Greece, Vol. XXXIV/5, 1773-1779, 2001
Πρακτικά 9ου Διεθνούς Συνεδρίου, Αθήνα, Σεπτέμβριος 2001 Proceedings of the 9th International Congress, Athens, September 2001

AN ENGINEERING GEOLOGICAL CONSIDERATION OF THE FLASH FLOOD HAZARD: A SYSTEMIC APPROACH FOR STRUCTURING A SUSTAINABLE STRATEGY.

S.G. SKIAS[1]

ABSTRACT

In this paper, firstly an attempt is made to define/shape the flash flood concept and the associated risk, to appreciate the structure and properties of the engaged to it fluvial system and the flash flood potentially generating geoenvironment. Secondly, an engineering geological consideration of risk identification and minimisation approaches, the human actions increasing vulnerability and the main mechanisms resulting to instability phenomena manifested within the steep upstream part of the fluvial system during the flash flooding process are presented. Finally, the active role which engineering geology-geologists must play in implementing sustainable measures for coping with the flash flood hazard in the 21st century is argued.

KEY WORDS: flash floods, engineering geology, sustainability, natural hazards, systemic approach, fluvial system, erosion, slope stability, mitigation

1. INTRODUCTION: SHAPING THE "FLASH FLOOD" PHYSICAL CONCEPT

Flash floods are widely considered as very fast developing catastrophic floods resulting by short, intense rainfalls on steep topography. The high-energy and mass transfer-potential of the flood-wave can be, through accelerated erosion mechanisms, the *cause* or *trigger* for occurrence of other natural hazards as, mainly, the various types of shallow landslides.

Nevertheless, there is no general agreement about the content/meaning of the term "flash flood". Often, is discussed in the context of arid and semi-arid environments. However, although criticized by Penning-Rowsell et al. (1978) for its imprecision, is even more widely used to signify sudden-onset flooding in a broad range of climatological and geographical conditions.

The suddenness and unexpectedness implied by the term "flash flood" may manifest different causes (found in relevant literature) as: intense storm rainfall, rapid snow melting, failure of dams or other control works. Either, may indicate a storm has occurred on steep, bare, impermeable surfaces such as a narrow mountain or a heavily built-up urban area or in a small catchment where the resulting flood peak passes too rapidly for adequate flood warnings to be given.

From the majority of reported cases, it is revealed that flash floods are normal, natural events caused by rather short duration but very intense rainfalls (as severe storms) mostly on small watersheds (or upper-land portion of a large drainage basin) in steep topography with specific flora and geologic settings. As all floods, they happen when the stream channel's discharge exceeds the bankfull stage. But, the associated to flash floods steep topography (mountainous or hilly), is responsible for the existing great difference between the mean values of their geometric and hydraulic properties and the respective ones of the downstream, inundation floods. Since, the latter are associated, commonly, with large-scale weather events and large-area watersheds in low lands. Consequently, the two mentioned types of catastrophic floods greatly differ, both quantitatively and qualitatively, as far as their impacts are concerned. Often, torrential flash floods cause damage, which may be out of all proportion to the peak discharges actually experienced.

2. FLASH FLOODING RISK APPRECIATION

Flash flooding and in general flooding risk results from two independent components: *hazard* and *vulnerability* (Molin, Valdes H., 1994). *Hazard* is a consequence-result of natural processes, under certain conditions (in time and space) within the course of the hydrological cycle. *Vulnerability* is directly related to human presence and works that could be (as probability) negatively affected (loss, damage) by the hazard. It is the location and

1. Engineering Geology Lab., Civil Engineering Dept., Democritus University of Thrace, 67100 Xanthi, Greece, E-mail: skias@civil.duth.gr

type of human presence and activities that are critical to vulnerability. Given all the previously presented, it is easily appreciated that flash flood, a natural, extreme and periodically occurring, morphogenetic (earth-shaping) event, can be characterised as hazard (or geo-hazard) since it adversely affects humans and their property.

United Nations declared the period 1990-2000 as the International Decade for Natural Disaster Prevention. It is unfortunate that during this last decade the magnitude and frequency of flash floods have increased as the associated vulnerability (live loss and property damage). Let only mention the flash flood in Afghanistan (June 1991) with more than 5000 victims. Losses from flash floods and associated to them hazards (mainly landslides) world-wide are increasing because of human activities and geophysical factors resulting in climate change and increased variability. Rainfall intensity is the driving force behind flash floods regardless of average annual heights (Flower, A.M. and Hennessy, K.J., 1995). Numerous European and international research projects, e.g. HYDROMET (1998), TELFLOOD (1998) and conferences (e.g. Int. Conf. On Mountain Natural Hazards, Grenoble, April 1999) resulted in a presentation of valuable multidisciplinary experiences and new ideas for coping with flash floods. The common denominator of all experts is that the best flash flooding hazard's management lies to an integrated approach and community (co-operation of all societal groups) actions (Brilly, M., 2001).

3. A SYSTEMIC APPROACH IN ASSESSING FLASH FLOODING HOSTING GEOENVIRONMENT: THE FLUVIAL SYSTEM

As all natural hazards, flash floods can be optimally understood, assessed and their impacts mitigated, if they are perceived as outputs of particular dynamic processes within geoenvironmental systems, the fluvial systems. A thorough engineering geological consideration of the characteristic properties, the controlling factors, the existing thresholds and the interactions among the elements/components of a particular- case fluvial system represents the key issues of a sound systems analysis and assessment. The appreciation of a certain fluvial system's evolution through time (in terms of process, form and magnitude) as a respond to man's actions is of fundamental importance to start creating the framework of rational action-directions for shaping case-appropriate alternative flash flood risk coping measures.

3.1. The fluvial system from an engineering geological viewpoint

Like all earth systems, fluvial (riverine) systems are very complex and are characterised by a number of basic principles – properties (Chorley, R. J., and Kennedy, B. A., 1971) such as:

a. The system has limits. The limits of the fluvial system are the drainage contour of its basin and the mouth of the river.
b. The elements of the system interact. For instance, a change in the tributary network will have an impact on the properties of the main channel, and vice versa.
c. The fluvial system is controlled by previous natural or human induced actions, (resulting in short or long-term response) such as mass movements, dam and road construction and changes in surface soil's infiltration.
d. A single element usually dominates the system. This is usually the climate, which (through precipitation and temperature) determines the amount and the distribution of water (surface and ground water) within the system.
e. The system evolves through time geomorphically, as it adjust its physical character to the influence of internal and external parameters.
f. There exist a continuous energy and matter (water and geo-materials) flow through the system. Through raindrop impact on natural slopes, to the exertion of velocity-induced shear stresses on streambanks.
g. Thresholds influence the dynamics of the system. Thresholds such as critical discharge level, channel-slope dips, values of engineering properties of engaged geologic materials and formations, etc.

Subsystems exist within an overall fluvial system and may be considered as of critical importance and separate members of the system, thus governed by the same principles as the above mentioned ones (a to g). The principal subsystems of an overall fluvial system are:

(1) the main channel and its flood plain,
(2) the tributary network and
(3) mountain or hill slopes.

As far as flash flooding is concerned, the 2nd (especially the upland streams) and 3rd subsystems deserve special consideration and investigation of their properties and evolution. Since, the flow and transferred mass characteristics and lag time to peak flow of the flood directly depend on the properties and the interaction mechanisms among the elements of these subsystems.

In analyzing the stream and slope subsystems, there exist some salient concepts deserving appropriate consideration (Rahn, P. H., 1991). Namely:

Equifinality, referring to the development of similar geomorphic features (such as alluvial fans) from different processes, which on lack of engineering geological expertise would appear to have a similar origin and formation history.

Feed-back. This reaction occurs, generally, in river systems. An example is the growth of large alluvial fans in a stream valley at the confluence of a tributary. These large earth bodies deflect the channel of the main stream, and since the main stream cannot transport the sediment, brought to it by the tributary, positive feedback occurs and the channel of the main stream is changed.

Equilibrium states. These are of great importance in appreciating the evolution of the fluvial system and can be seen in various time scales.

4. RISK IDENTIFICATION AND MINIMIZATION: THE MAIN ISSUES OF ENGINEERING GEOLOGICAL CONSIDERATION

By principle, the discipline of Engineering Geology (E.G.) plays a predominant role in identifying geohazards and minimizing their risk. To this respect, its main task is the selective application of existing knowledge/principles from the whole range of Geosciences in exposing and ranking the risk prone areas/sites and the engaged causative and triggering factors of their manifestation or potential occurrence. In performing this role:

1. Investigates, in a systemic way, the existing properties of the geo-materials/formations (rocks, soils, water) and geo-structures constituting a particular geo-environment of interest (in our case the fluvial system) and the qualitative and quantitative relationships among them
2. Investigates the interactions between the geo-environment (natural system) and the actions-works of man (technical system) within a relevant human time-scale, and
3. Delineates hazard affected or prone areas and proposes mitigation (preventive or/and remedial) measures, using weighted criteria and specific index values.

Within the context of the so-called geological hazards, flash floods occupy a predominant position since they negatively affect both the natural and the man-made environment in increasing, through time, intensity (as figures show).

It should be always remembered that earth systems are dynamic and very complex ones and exhibit great anisotropy due to the unhomogeneity of the involved geologic materials. Thus, each particular system considered in an appropriate for the given objective scale, represents a rather unique case as far its structure and behavior are concerned. Although, two cases at first observance, might appear similar (see above Equifinality principle).

If we take as fact the common case that flash flooding generates on steep mountainous or hilly topography, E.G. is focusing its interest to the investigation of the upstream section of the whole drainage basin or fluvial system. There, the two existing main subsystems: the stream network and the engaged slopes, disserve thorough engineering geological consideration. The main issues of consideration are presented hereafter.

4.1 Origin and evolution of the upstream drainage network and the associated slope system

In performing the relevant in situ investigation, geomorhological techniques and indicators are used in order to reveal the sequence of past events responsible for the present morphological characteristics of streams and slopes. Besides, the past geotectonic or other geophysical activity in a regional scale is considered, since this activity has been always interacting with the geomorphologic processes shaping the topographical surface of reference. At this point we should stress the extreme value of any existing reliable historic records, which the investigator must look upon with caution during the desk study phase of the site investigation. This is sometimes called "historical monitoring" of the region.

4.2 Instability phenomena in the slope system

Engineering geologists can use various observational and analytical techniques in different scales, in order to locate the presence and evaluate the possible interactions of instability phenomena being in an active, dormant, or inactive state. The investigation approach is tracing the prevailing causative and triggering mechanisms of instability or landsliding phenomena which cover the whole range of slides, falls, topples, lateral spreads, flows and the complex ones. In many cases the situation is very complex and requires expertise knowledge. The occurring complexity is mainly due to the engineering, structural and topographical properties of the hosting rock or soil formations. Some geologic extremely anisotropic formations like flysch (typically, a sequence of interceded soft shales and hard sandstones) present extreme difficulty in appreciating and predicting their mechanical behavior. In the case of flash flooding shallow landslides and especially mud and debris flows are the most commonly observed phenomena occurring in the surface soil formations of bare or deforested natural slopes, exhibiting low water infiltration and quick runoff building. These phenomena can be easily triggered by the same rainstorms causing flash flooding, and are mainly due to sudden decrease of shear strength within the soil mass, after passing a certain threshold of pore-pressures value.

Earth flows and flash floods can directly or not interact in various ways, many times in a very complicated way as far as the sequence of events and the involved acting mechanisms. For instance the landsliding material can change the route (direction, shape) or the flow parameters of the flooding water.

Shallow landslides due to sheet flow action in soil slopes (runoff) and the undercutting action of flooding wave are usual manifestations of flash flooding events. Gradually the great velocity and high-energy potential of flooding waters are diminishing as they proceed the lowland area. Thus, the downstream portion of the greater drainage basin, where the main river system flows may be little affected (i.e. rare occurrence of landsliding phenomena triggered by the flooding water's erosion mechanisms).

In general, mobilized earth material after following various routes (mainly ordered by gravity) is distributed in various places by depositional mechanisms, thus introducing a varying in magnitude morphological change. The reshaping of the natural relief morphology though is a continuous natural process called morhogenesis is accelerated and manifested impressively during landsliding events related or not to flash floods. These morphological changes create new stress levels within the soil profiles of the slopes of the affected up-stream area. Thus, certain slopes can exhibit safety factors approaching to unity. Careful planed and executed engineering geological investigation which must be performed within due time after judged as major morhogenetical events (resulting from seismic, landsliding, flooding, etc, activities), can delineate new landsliding-prone slopes within the upstream region facing high flash flooding risk. Of great assistance in selecting the due time and the characteristics of an in situ engineering geological investigation concerning landsliding activity, can be the relevant data from periodic airphotographs, satellite imagery, or other remote sensing means of the region at risk. The ranking process of slopes at risk and the presentation of the investigation results, in general, can be greatly facilitated (time, quality) by the use of the continuously advancing geographic information systems (GIS).

4.3 Interactions between water and geologic material

Through the hydrologic cycle are well known the varying interactions among meteoric, surface and ground water. Water in all forms constantly interacts with the geologic material altering in various rates the strength and geometric characteristics of soil and rock formations drooping (precipitation), moving on surface or percolating through the soil pores and rock discontinuities. Apart from the landsliding phenomena investigation, E.G., given the flash flooding risk of an are, investigates the interrelations among geologic material, water and vegetation and their combined influence on the properties of sediment discharge, floodwater discharge and lag time to peak flow.

Of great assistance in appreciating and predicting flash flood impacts is the E.G. investigation of erosion and depositional/sedimentation phenomena on channel banks and within the beds, which are influencing the evolution of the whole fluvial system.

4.4 Human actions or omissions increasing flash flooding damage in the up and downstream regions

In many cases careful in situ engineering geological investigations reveal human actions which directly or indirectly represent causative factors in landsliding phenomena triggered by meteoric events which at the same time and region trigger flash flooding phenomena (Smith, K., and Ward R., 1998).

Actions-activities: In fact, human actions can facilitate the destructive role of natural factors (topography, geology, and precipitation) which control both landsliding occurrence and flash flooding damage in the upstream region. Some of the principal and common human actions that contribute to the above mentioned natural hazards are cut-and-fill operations, unreasonable use of explosives, disposal of geomaterials engaged in road and building construction, deforestation, urbanization of natural slopes, uncontrolled disposal of solid wastes and predatory exploitation of natural resources. The above mentioned human activities can significantly alter natural processes and accelerate and aggravate the impact of the extreme natural phenomena (here landslides, flash floods), by changing natural drainage paths, assisting the action of gravity, reducing soil infiltration and increasing pore-water pressures.

Omissions: Apart from the destructive influence of human actions there exist certain human omissions related to proper maintenance of engineering structures engaged in flow control within the drainage system. For example, small flow-control dams constructed in series across the channels of upstream drainage system are progressively trapping large amounts of sediments up to their carrying capacity, above which sediments and other solid obstacles can travel and deposited uncontrolled down stream. This situation can be the source of various destabilizing processes (e.g. erosion), leading to landsliding phenomena and to increase of environmental (e.g. loss of agricultural land) and human damage (life and property) during flash flooding events. In general, periodic channel clearing and dredging (from all naturally and artificially occurring obstacles changing the spatial distribution, geometry and capacity of drainage system) represent a preventive measure of landsliding and flash flooding mitigation system among other preventive soft-engineering measures.

The case of Xanthi-Greece: Human actions and omissions described just above were responsible, to a great extend (Institute for Geological and Mining Research, Athens 2000, unpublished study), for two human victims and severe environmental, infrastructure and property damages, up and downstream, caused by a flash flooding event in Thrace, Northern Greece. In fact, rainfall started on 26th November 1996 and reached extreme intensity on 30-11-1996 triggered a catastrophic flash-flooding event originated in the upstream mountainous part of river's Kossynthos drainage basin in Xanthi Prefecture. Many mountainous villages, a great part of the old city of Xanthi and many villages and public infrastructure in the downstream plain area were seriously affected by the flooding waters and transported sediments, rocks, municipal wastes and other materials. During this extreme for the mentioned region flash-flooding event, the total daily amount of rainfall outreached (30th Nov.) the value of 200mm and the hourly intensity (between 11th to 13th hours of this day) exceeded 30mm. These rainfall and flood events are considered as events of the century for this region.

As it is apparent from what has been presented in previous paragraphs, a thorough investigation, analysis and appreciation of the interactions within the geoenvironmental system of reference by an experienced Engineering geologist can guide him in selecting and spatially and temporally allocating preventive and mitigating measures across the drainage and slope systems of the upstream part of a drainage basin. A periodic, efficient engineering geological site inspection (through the use of certain natural indicators and monitoring devices) of the area can safeguard the proper maintenance of existing or implementation of possibly needed additional actions/measures.

5. ENGINEERING GEOLOGY VS. SUSTAINABLE MEASURES FOR COPING WITH FLASH FLOODS

Flash floods, as most natural phenomena, need a systemic approach for effectively appreciating their dynamic properties, the involved in each case interactions among the engaged external/internal factors, and a rational assessment of their potential impacts. In planning a set of (structural or not) measures for coping with flash floods in a particular case, there are some key-points which, being appreciated, can well lead both to optimal, under the existing constraints, selection and realization of the mixture of measures. An overview of those key-points related to the *system* and *sustainability* concepts as well as to the role of engineering geology are presented in the following.

5.1. Existing groups of measures

At the end of 20th century, the existing measures for coping with flash floods (as well as with other directly or indirectly related natural hazards as landslides, erosion, etc) can be grouped in four sets (Yevjevich, V., 1994):

a. Do-nothing (means: learning to live with the hazard)
b. Non-structural (divided in measures related to: regulation for proofing, defence and insurance)
c. Structural (extensive -in space- and intensive -in point, line-)
d. A combination of structural and non-structural measures

It is easily understood that a and b sets are measures in the direction of *controlling people* and set c represents the alternative, that is *controlling water*

5.2. Influence of the Sustainability concept on the choice of selection-criteria

The concept of Sustainability (Rio, Earth Summit 1992) has created a new framework in coping with complicated socio-environmental problems as those associated with floods and other natural hazards. In general, the idea is that the measures taken should have a long-run effectiveness in meeting, both, true social needs and preserving the natural capital (soil, flora, and fauna). That implies that Sustainability greatly favours measures for *controlling people*.

In relation to the above mentioned four groups of measures, four comments may summarise the trend:

I. Sustainability oriented approach dictates a massive (though rational) use of non-structural measures in an integral strategy for mitigating negative impacts (decrease of loss of natural capital, human lives and property)

II. Among structural measures sustainability favours the use of extensive ones since they are of vital importance in an efficient soil conservation practice, sound management of land-use and protection of natural environment.

III. Intensive structural measures (as levees, dikes, dams, and water storage) are considered that, in many cases and especially when expose large dimensions create severe environmental problems in a long time span due to cumulative effects of their impacts on the natural system within which they are intervening. Also, in case of malfunction or failure (as it has happened several times) they may cause much more destruction (or even a disaster) than the natural phenomenon when it might occur. It is well known that it has been a long lasting debate/controversy on the impacts of structural measures in controlling water. Now there is a general agreement that the future for any particular case lies with participatory decision-making using a costs-benefits-and-risks approach that will raise the importance of the social and environmental dimensions of the case to a level once reserved for the economic dimension. This approach is gradually shaped and enforced in the different levels of institutional decision-making by the gradually emerging sustainability-oriented legislation.

IV. It is easily appreciated that preventive actions are by all means and far better fulfilling the sustainability criteria than do mitigation ones.

5.3. The role of Engineering geology in the selection process

The final selection/choice of needed measures must be the task and the result of a cost-benefit analysis and multicriteria evaluation (nowadays within a sustainability framework) from a team of experts covering (as much as possible in width and depth) the various multidisciplinary aspects of the particular hazard's problems.

It is easily proved that in achieving the case-optimal flash flood coping measures for any particular catchment, the basic prerequisite is a systemic consideration of the status and dynamic nature of the upstream geologic environment and the engineering properties of the involved geologic materials. Besides, it is necessary to appreciate the existing and varying in space and time sequence of interactions among the different geologic processes. The geometric and physical properties of geologic materials and the interaction of surface and ground water with them mainly control these processes. It is obvious that the nature and magnitude of the geomorphic changes (mass movements, erosion) created by a particular flash flood event express the result of the interaction between the acting meteorological agents (precipitation, temperature, winds) and the geologic environment (considered as a system of different but interrelated parts). These changes are mainly originated and greatly manifested in the upstream region, thus this part (subsystem) of the whole drainage system necessitates special engineering geological investigation in a way, which has been already explained.

It is apparent from the above that Engineering Geologists, after understanding and presenting to the rest of the selection team of experts (e.g Hydraulic Engineers) the functioning of the whole geoenvironmental system can provide the criteria of geologic origin to be used in the selection process. In establishing these criteria apart from relevant and adequate data expert judgement is badly needed. The quality of judgement is obviously proportional to the experience and expertise of the engaged Engineering Geologist. Existing Engineering geology's methodologies, as the use of indicators and special type indices (Skias, S., 1998) using appropriate mathematical and software tools, can facilitate the evaluation, ranking and temporal/spatial allocation the flash flooding potential within a given drainage system's area. Thus, they can assist in achieving, within the sustainability framework, the optimal mixture of structural and non-structural preventive and mitigating measures. Also, through a rational process of assigning weights to a set of socio-economic criteria can assist establishing the order of social importance/priority of the measures to be taken. It should be stressed that the measures taken must be always tailored to the particular properties of the geoenvironment and the related socio-economic system of reference. It has also to be appreciated that no recipes from a "cook book" are available.

In any case, the degree of effectiveness of implemented measures (structural or not) for a particular catchment will be directly proportional to the appreciation of the interactions between the natural system (geoenvironment of the catchment) and the technical system (existing and implemented human actions).

A rationally designed and carefully performed engineering geological monitoring programme prior, during, and after the construction stage, will safeguard, to a great extent, that the project (selected measures) will perform as planned. This monitoring programme must be an integral part of an Environmental Impact Assessment concerning the particular for implementation project (set of engineering measures).

The concepts of socially and environmentally *accepted risk* and the *carrying capacity* of the concerned natural environment's components should be established through proper social dialog and (combined as a pair) must form the corner stone criterion in the final choice among alternative engineering measures and the associated political decision.

Besides, for appreciating the crucial role of Engineering Geology in an effective design and construction of flood related structural projects, it is worth mentioning that extreme flash floods triggered by Dam failures, with severe impacts on human life and property, have had as primary cause the underestimation or misjudgement of the existing geologic regime. Either regarding the foundation rocks (Malpasset dam, France 1959) or the stability of the adjacent natural slopes (Vaiont dam, Italy 1963).

5.4 The societal duty of engineering geologists in the 21st century

Nowadays, in the down of the 21st century, there is a growing societal demand to reduce the vulnerability of the unavoidable natural hazards. The best respond to this demand is first to perform an integrated risk analysis and then use sustainability criteria (safeguarding environmental protection and preservation) in selecting the appropriate preventive-mitigation measures from a cost-benefit analysis. Due to their direct and close relationship with geo-environment's behaviour, engineering geologists well appreciate that is greatly beneficial (for the *real* benefit of society) to back and encourage this responding approach. In this respect, we strongly believe that engineering geologists should actively participate in local or other forums where land-use and project-selection decisions are made concerning flooding susceptible lands and provide proper arguments and guidance for the planners and administrators, as well as for those involved in the technical-engineering aspects. If an agency or authority moves for approving a project without taking into consideration the existing geologic controls and sustainability constraints in a flood-prone area, the engineering geologists of the region should alert the public to the associated potential risks. This might be called: "the citizen scientist's duty to care".

REFERENCES

BRILLY, M., 2001, The integrated approach to flash flood, *in* Eve Gruntfest and John Handmer, eds, coping with flash floods, Kluwer Academic Publishers, Dordrecht, pp. 103-113

CHORLEY, R. J., AND KENNEDY, B. A., 1971, Physical geography, A systems approach: London, Methuen, 605 p.

FLOWER, A.M. AND HENNESSY, K.J., 1995, Potential impacts of global warming on the frequency and magnitude of heavy precipitation, *in* natural hazards 11, pp. 283-303

HYDROMET: EU project, 1998, Development of technologies to forecast, prevent and reduce natural risk, *in* Office for Official Publications of the European Communities, Luxemburg, 111 p.

MOLIN, VALDES H., 1994, The international decade for natural disaster reduction and the link with Agenda 21, *in* Ecodecision, pp. 42-45

PENNING-ROWSELL, E. C., et al., 1978, The Effect of Warning on Flood Damage Reduction, Report for the Central Water Planning Unit, Flood Hazard Research Centre, Middlesex Polytechnic, London.

RAHN, P. H., 1991, Surface water and flooding, *in* Kiersch, G. A., ed., The heritage of engineering geology; The first hundred years: Boulder, Colorado, Geological Society of America, Centennial Special Volume 3

SMITH, K., AND WARD R., 1998, Floods, Physical Processes and Human Impacts: West Sussex, J. Wiley, 382 p.

SKIAS, S., 1998, Evaluation of the geomechanic behaviour and instability phenomena of the flysch formations of W.Greece (in Greek), Ph.D. dissert., Dem. Univ. of Thrace, Xanthi-Greece, pp. 15.3-15.28

TELFLOOD: EU project, 1998, Forecasting floods in urban areas downstream of steep catchments, *in* Office for Official Publications of the European Communities, Luxemburg, 109 p.

YEVJEVICH, V., 1994, Classification and description of flood mitigation measures, *in* G. Rossi, N. Harmancioglu and V. Yevjevich, eds, Coping with Floods, Kluwer Academic Publishers, Dordrecht, pp. 573-584.