Multi-disciplinary Approach for the Environmental Analysis of Surface Waters in a Large-scale Development

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Key words: Sustainable Development, Photogrammetry, Photo interpretation, GIS, and Hydrology

SUMMARY

The design of large –scale, integrated projects, developed within the principles of sustainable development, needs to ensure that special measures are incorporated in the project design, and operations management for the protection and preservation of natural environment. Parameters such as soils, landscape, water resources, habitat types flora and fauna are analytically examined during the initial project stages and the major conclusions on the existing environmental status provide the basis for selecting the site location, and developing the subsequent steps of the project design.

Within this framework, the methodology developed for the protection of surface water streams and their ecology in a large-scale tourist project in Southern Greece is presented in this study. The wider area examined amounted to 3,000 ha, with the proposed buildings footprint corresponding to less than 1% of this area. A multidisciplinary team of experts including photogrammetrists, hydrologists, environmentalists, and GIS experts worked together to collect, integrate, and synthesize information and data on the land morphology and the management of the surface waters (watersheds, creeks) encountered in the study area. Hydrological, hydro geological and environmental analysis methods were used in parallel to define the size of the watersheds recorded in the area and their respective ecological significance.

The methodology developed and the resulting digital map product superimposed on orthophotos of the area, along with soil data, hydrological models, and ecological field observations provided the tool for the analysis of the surface water environmental regime in the wider project area. The delineation zones of the major creeks that need to be excluded from any development in order to protect the uninhibited surface waters flow and the ecology of the areas adjacent to the creeks were determined.

This methodology, integrating the expertise of various geo information and environmental technology disciplines, can be used as a generic tool in the design and management of large – scale sustainable developments such as land planning and urban development schemes, integrated tourist development, mining and quarrying and other infrastructure projects.

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1. INTRODUCTION

Planning a large-scale, integrated development in a sustainable manner is a complex task. A multiplicity of seemingly conflicting objectives related with the selection of the site location and planning of facilities, protection of natural environment, and socio- economic benefits stemming from the implementation of the project on local and national basis, need to be balanced. The interdisciplinary nature and complexity of large-scale planning that takes into account the parameters of sustainable management, suggest the use of decision-making tools and methods of analysis that can help planners evaluate and prioritize activities from the point of view of environmental and socio economic effectiveness.

A primary role of Geographical Information Systems (GIS) as a tool in environmental management is that it can serve as a means to integrate diverse spatial and non-spatial environmental data, from numerous sources into a manageable whole. Since a GIS collates and manages diverse types of data in a standardized manner its use is likely to result in more efficient data collection and analysis that can be used by decision makers.

In this paper the use of photogrammetric, remote sensing, hydrologic and environmental data in a GIS environment for the surface water resources management and protection of the ecologically sensitive zones is presented. Utilizing a GIS as an integral tool has assisted in the overall understanding and management of the surface water resources in the project study area. This methodology was developed through a multidisciplinary approach, where photogrammetrists, land planners, hydrologists, and ecologists worked together in order to assess the surface water regime and allocate the ecologically sensitive areas, adjacent to the surface water courses, where no building development is allowed. The team's objective was to assess the occurrence of creeks in the study area and delineate them by the mapping of polygonic lines on both sides of the "deep line" of the creeks, which enclose the flood lines, the banks and any natural or ecological elements related to the creeks. The methodology was sensitively adapted to the character and the landscape of the area examined, with respect to the characteristics of the natural environment.

The project examined as a case study involves the creation of a world class, sustainable tourism development at the SSE part of Greece. The project is designed in the form of five distinct tourist villages, developed within a property of approximately 3,000 ha. The actual foot print of the built area, including infrastructure facilities, amounts to less than 1% of the above area examined in this study. The study area is mainly hilly with relatively mild morphology, comprising mainly hydrologic unities that favour surface runoff.
Critical data needed to evaluate the study area were its Digital Terrain Model (DTM), land cover types, environmental and ecological characteristics. These data were collated, managed

and analyzed in full compliance with the principles of sustainable development, according to the Greek and European environmental legislation.

2. METHODOLOGY

As already mentioned, this study presents an integrated GIS-based decision support tool developed to assist decision makers and planners to handle both technical and environmental data (cartographic, qualitative, statistical data, terrestrial observations, images etc) and prioritize activities at the surface waters scale.

Topographic and cartographic data of the study area form a basic coverage in the GIS structure, reflecting almost all the quantitative and qualitative information of the examined site. This main coverage is compiled by *photogrammetric* methods, because of the extensive size of the study area, the accuracy required, as well as the possibility of producing the required 3D vector and 2D raster products. The production of orthophotomaps, consists in most cases the best option for the integration of additional information produced from other disciplines. At the same time it is necessary to have a detailed 3D restitution of specific features, such as the coastal line, the slopes, the mountain ridges, the banks and beds of creeks and gullies, the boundaries of cultivated areas, forest areas, the road network and structures (such as buildings and greenhouses). Different photogrammetric processes can be applied aiming at developing successive coverages of DTM, orthophotos and 3D topographic features. The specific photogrammetric processing used is defined by specialized technical specifications, regarding the necessary accuracy and the characteristic features of the site under study.

The next step is the *photointerpretation* of the aerial photos for the compilation of Land Cover map, by using classical or automated classification techniques. The above mentioned product-coverages, as well as additional geological, climatic, vegetation and other types of data provided the input in order to perform *hydrologic-hydro geological and ecological analysis*. These data form the core of the developed methodology and they result at a first level of conclusions for the whole process, including the definition of hydrologic basins and the *selection of creeks* that need further study for their protection, implemented through *delineation studies*.

It is pointed out that, according to the Greek legislation, delineation comprise the determination and verification of the polygonal lines on both sides of the deep bottom line of the creeks, which enclose the flood lines, the banks and any natural or artificial elements related to the creeks. The delineation procedure requires:

- Ground survey and compilation of the general topographic and elevation map of the area, where creek beds are shown at a suitable scale.
- Hydrologic, hydraulic and environmental studies, based on which the creek delineation lines and zones are proposed.

In addition to topography and hydrology, within the delineation of a creek the environmental characteristics must be examined, as provisioned by the relevant legislation. The steps to follow in order to record the ecological features of a creek include:

- Description of the flora in the scale of the hydrological basin.
- Description and mapping of the flora in the creek zone.
- Recording the fauna species living or depending on the creek zone as well as recording of the vital area and the characteristics of the creek crucial for the preservation of these species.
- Mapping of the vegetation zone along the creek based on a recent aerial photo of the area.
- Proposal for environmental delineation of the creek considering the vegetation and slope of the creek, the geologic background, the flood line, possible significant ecologic characteristics in the proximity of the creek.

In Figure 1 a flowchart of the proposed methodology for the environmental analysis of surface waters in a large –scale development is given. The data for each process (aerial photos, maps, statistical and environmental data, surveying measurements) and the resulted coverages of GIS (DTM, Orthophotos, Topographic features, Land cover, Watersheds, Hydrologic basins, Creeks) are also shown.

3. CASE STUDY

3.1 Study Area

The study area is a peninsula of approximately 3,000 ha, in Southern island Greece. The southern part of the peninsula is wider and therefore greater hydrologic basins are developed on that part of the peninsula. The width of the northern part of the peninsula is less than 1 km, while a narrow land strip (less than 200 m wide) joins the southern mountainous area to the northern part of the area to be developed. Within this area the examined integrated, sustainable tourist project is currently under development. The proposed facilities are distributed in five distinct villages, whilst the footprint of the building facilities, including infrastructure, are estimated to cover less than 1% of the overall site area.

The region is mainly hilly and its elevations are moderate to low. The morphology of the hills is relatively mild, not showing remarkable elevations or strong relief although certain portions of the upstream area present locally great slopes. The slopes of the greatest part of the basin are 30% - 70%, while at specific places gorge morphology is observed, mainly in places with phyllitic formations, vertical slopes, not characterized though by great elevations. Near the study area the relief is at certain locations sharp.

This part of Greece is dry with a mean annual rainfall depth of approximately 500 mm. From an ecological point of view, the wider area presents particular interest regarding the fauna and flora, both in the land and marine environment. In the area where the proposed tourist facilities will be developed, the natural vegetation is classified as mainly phryganic. Landscape photography of the study area is shown in Fig. 2.

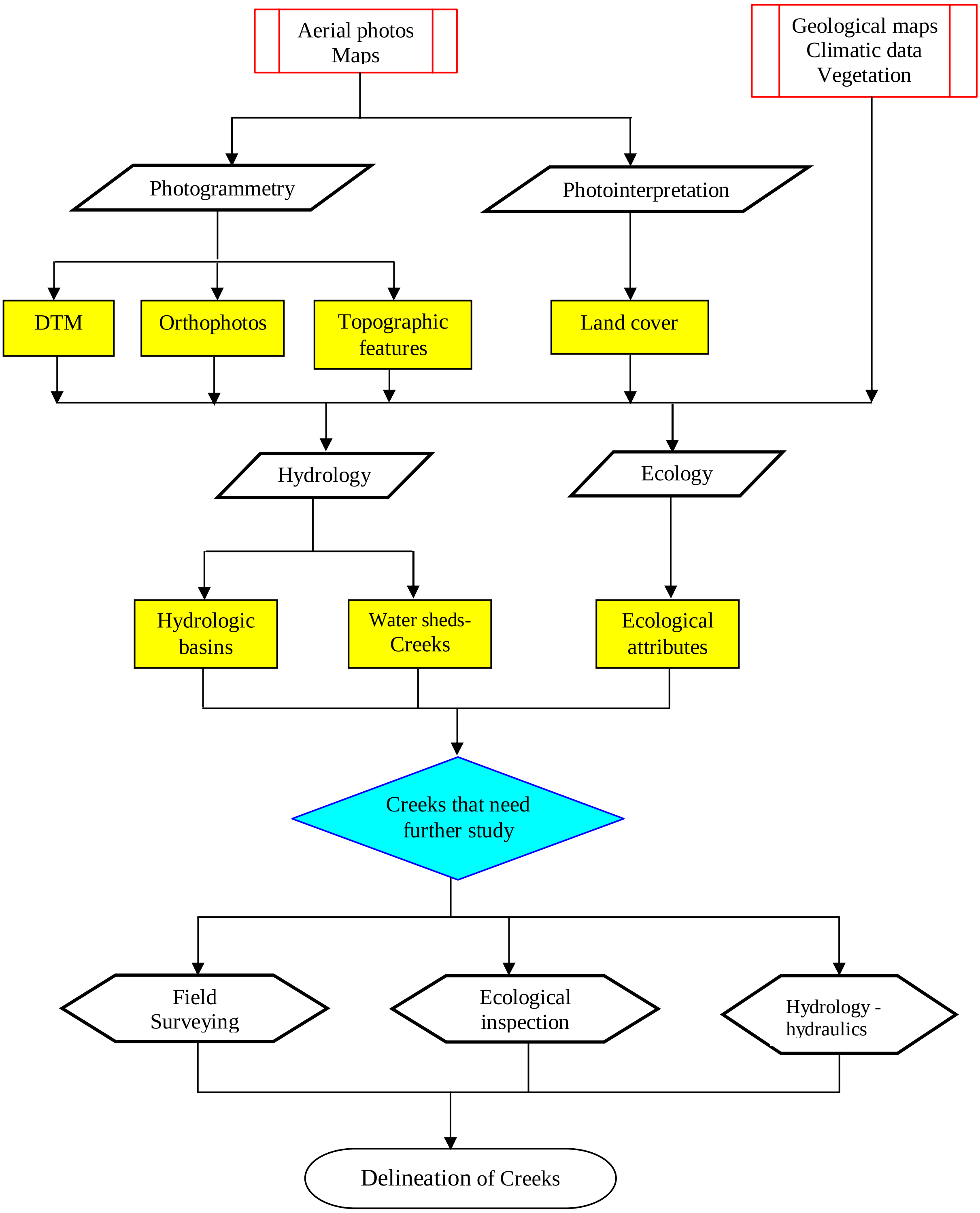

Figure 1. Flowchart of the methodology developed for the environmental analysis of surface waters in large-scale developments

Figure 2. Aerial view of the study area

3.2 Photogrammetry and Photointerpretation

The first phase of the study included the production of topographic base-maps, using photogrammetric methods. To achieve the required level of analysis it was deemed necessary:

- to produce a three level depiction of the topographical details, including:
  - a general map of the whole study area,
  - diagrams at the accuracy and scale printed of 1:5.000 of the total area,
  - detailed mapping of the prospective intervention areas, including infrastructure sand other supporting facilities
- to monitor the changes, if any, in the topographical features of the area for a time period of 35 year.

To fulfil the above requirements overlapping aerial photos of the study area at the appropriate scale and year of production were acquired from the archives provided by the Hellenic Military Geographical Service (HMGS). All the available aerial photos were in black and white and included:

- 8 aerial photos (in 2 strips) taken in 1968, at a scale of circa 1:15 000, covering 60% of the study area.
- 3 aerial photos taken in 1989, at a scale of circa 1:30 000, covering almost the whole of the study area.
- 8 aerial photos (in 2 strips) taken in 1998, at a scale of circa 1:10 000 covering the whole study area with the exception of its southern part.

For the calculation of the control points needed for the photogrammetric process a bundle adjustment aero-triangulation was solved by using BINGO v.5 software. Simultaneous solutions of the three blocks of photos (one block for every time period) was made, so as to minimize the number of required control points for the aero-triangulation and to possibly achieve the same accuracy of the calculated orientations for all the sets of aerial-photos. Most of the 75 tie points measured belonged to topographic features that remained unchanged during the three time periods examined. The coordinates for the control points, which were used for the adjustment, were determined from the existing national cartographic diagrams available at a scale of 1:5 000 compiled by the HMGS. More specifically 4 horizontal, 19 vertical and 7 full control points were identified, which were clearly depicted both on the photos of the three periods and on the maps. These points were crossroads, coastlines, corners of buildings and hill tops (vertical points). Despite the considerable difference in scale between the aerial photos the results of the adjustment were satisfactory, with a maximum residual error of the tie point coordinates less than 1.2m.

The Digital Photogrammetric Workstation (DPW) SSK of Z/I Imaging was used for the production of the photogrammetric outputs. By using the orientations calculated from the aero-triangulation, automatic DTM generation was effected along with the production of orthophotos for the whole area covered by the photos of each period and stereo-restitution of the required topographic features. Thus it was possible to compare in a qualitative as well as a quantitative manner the examined data for the time periods available. The above comparisons allowed the study team to identify which had been eroded and the extent of changes in the morphology of the land that incurred in the last thirty (30) years.
In Figure 3, a characteristic screen of the DPW during the stereo-restitution process of creeks recognition is shown along with the respective stereoscopic pair of aerial photos and the resulting vector product.

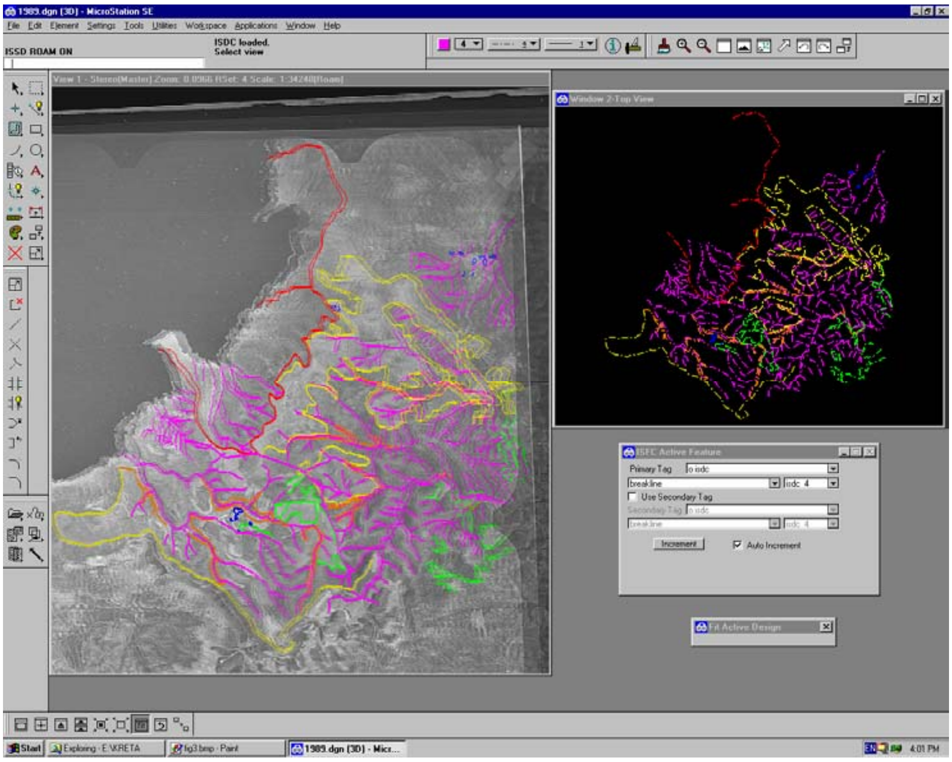

Figure 3. DPW screen from the restitution process of stereoscopic aerial photos, taken in 1989

The photointerpretation of the study area followed the completion of the photogrammetric process. It comprised the study of the quality features of the topography and land cover for defining the shape and course of the creeks and the land cover classification. The following six categories of land coverage were recorded:

– *Cultivated land*. These are agricultural areas with different kind of crops. It covers only a small percentage of the overall area examined, 3-5%, during the whole study time period, always concentrated in the central part of the region except for a small cultivated area in the south.
– *Natural vegetation area*. These are mainly pastures, shrubs, and phryganic formations. They cover more than half of the region and dominate the central and southern part. Small parts of cultivated land have been transformed into natural vegetation area with the time evolution.
– *Arid-waste land*. These are regions, which cannot be cultivated and show no signs of vegetation. They cover about 1/3 of the total area examined with minor changes through the years. They can be found in the northern part where they form the dominating feature.
– *Eroded – degraded land*. It is an area with the intense morphological characteristics of a degraded region. It covers 0.3% of the total area but due to its unusual morphology it was concluded that it forms a separate land cover type.
– *Bare rocky coastal zone*. These are bare rocky areas, with steep slopes reaching the sea. They cover about 10% of the area. There is no noticeable change in this zone through the years. They extend to the northwestern coast of the study area in wide coastal zones, but also scattered over the rest of the coastline in narrow zones.
– *Developed area*. These include all sorts of different constructions, such as buildings, greenhouses etc. They are features with significant diversification during the last 35 years, but they cover only a minor part of the region (always <0.2%). They are areas mainly within or around the cultivated areas.

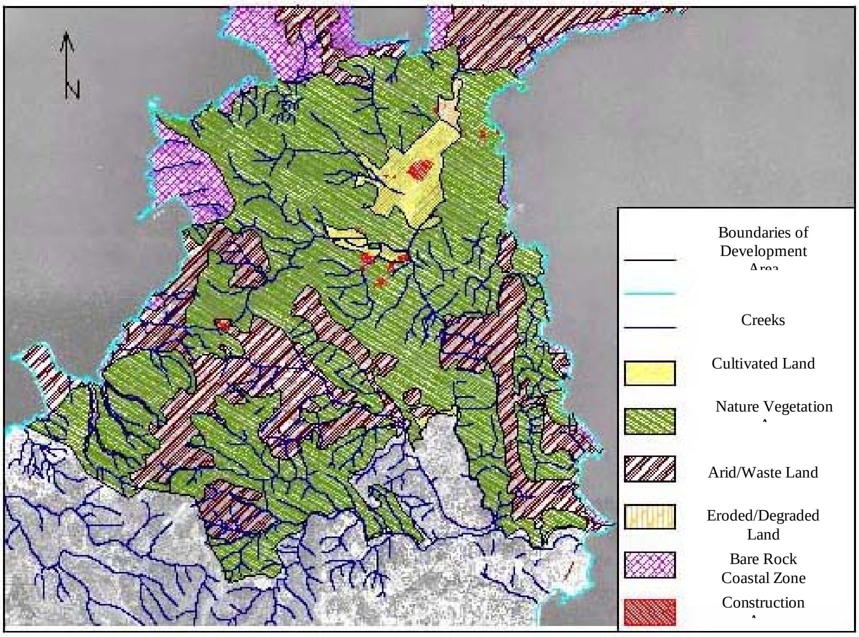

Figure 4. Map registering the land cover of the study area

The above coverages were produced by utilizing the AutoCAD Map GIS software, which allows advanced cartographic drawing and 3D representation processes. The different categories of land types cover recorded in the study area are represented in Figure 4.

3.3 Hydrology

3.3.1 Assessment of Hydrological Basins

The study area comprises mainly hydrolithologic units that favour surface runoff, due to their small to medium infiltration coefficient. The permeable formations comprise of the carbonate formations, characterized by development of karstic aquifer, as well as the alluvial sediments, characterized by development of unconfined aquifer, approximately at the sea level. The most extended occurrences of carbonate rocks (limestones and marbles) are found in the NNE regions. The alluvial sediments occur in the watercourses of the main streams and at plain areas with gentle relief.

Based on the Digital Terrain Model, (DTM) the study area has been divided into nine (9) main hydrologic basins (Fig. 5), the larger and most important of which are those located on the southern part of the cape and exit towards the east coast. The hydrographic network is mainly of the dendritic type, while the rectangular type is also observed at certain positions.
The hydrological basins recorded in the northern part of the area are collectively marked as 10. This section consists of small, independent hydrographic axes, found in the southeastern as well as the northwestern coast.

The part of the watershed developed parallel to the main hilly axis, i.e. in the direction NNE – SSW, is displaced to the south and as a result the basins whose exits are located towards the

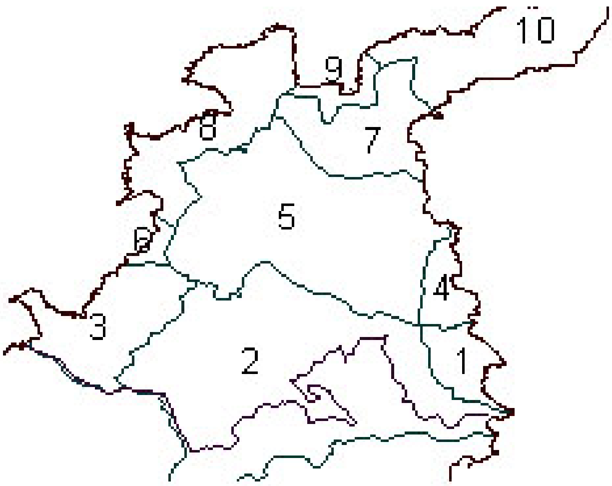

Figure 5. Hydrologic basins in the study area

Basin	Area (Km2)	Max order of the Horton hydro graphic axis
1.	0,94	2
2.	>10,54	4
3.	2,64	3
4.	0,79	2
5.	7,65	4
6.	0,26	1
7.	2,32	4
8.	2,98	3
9.	0,47	2

Table 1: Features of the hydrological basis encountered in the project area

west coast are much smaller than the east ones. This is to say that the former ("west") basins do not have a uniform hydro graphic network with one main hydro graphic axis and common outlet, as happens with the "east" ones, but they present smallest axes and their outlets are located at various positions at the coast. In other words, basins no. 3, 6 and 8 include other smaller independent sub-basins with low order hydrographic axes and independent outlets. Basins no. 1, 4 and 9, as well as area no. 10, are similar due to their limited catchment area and longitudinal development parallel to the coast.

Data regarding the features of the hydrological basins, i.e. surface area and order of main Horton axis, as resulting from the interpretation of topographic diagram scaled 1:15 000 and the DTM are summarized in Table 1.

According to these data it is concluded that the creeks for which delineation could potentially be required are located in basins no. 2, 5 and 7. The relatively great surface area and the development of a uniform hydro graphic network indicate that the water quantities draining in these basins could be significant.

For the case study examined, the findings of the hydrological basins assessment were interpreted in view of the proposed project footprint. Given that the project design did not propose any interventions for the whole of basin no. 5, or in the vicinity of the creeks in basin 7, it was concluded that the creek that needs to be further studied and delineated is found in basin 2.

In agreement with the above, ecological base line studies conducted in the wider study area demonstrated that habitat types, flora and fauna characteristic of creeks with intermediate water flow where mainly found in basin 2.

3.4 Data Integration for Creek Delineation

The creek identified for delineation in Basin 2, consists of two branches. The catchment areas draining within these branches were defined in the Digital Terrain Model shown in Figure 6.

Based on the prevailing, environmental legislation in Greece, the delineation of the creek has to be designed for a flood event with a 50-years return period. To estimate the design rainfall, the precipitation data available for the area were used. The mean annual rainfall in the area is approximately 500 mm. The most arid month is July with 0.3mm mean rainfall and the most humid is January with 90.5mm mean rainfall.

From an ecological point of view, the main characteristics of the precipitation in the study area are the following:

- Intense fluctuation of annual rainfall. An impressive rainfall maximum of 1215mm was recorded in year 1954 and a minimum of 209.5mm in year 1946. The intense fluctuation of annual precipitation, however, is a common phenomenon in arid and semi-arid climatic types.
- Intensely uneven seasonal rainfall distribution.

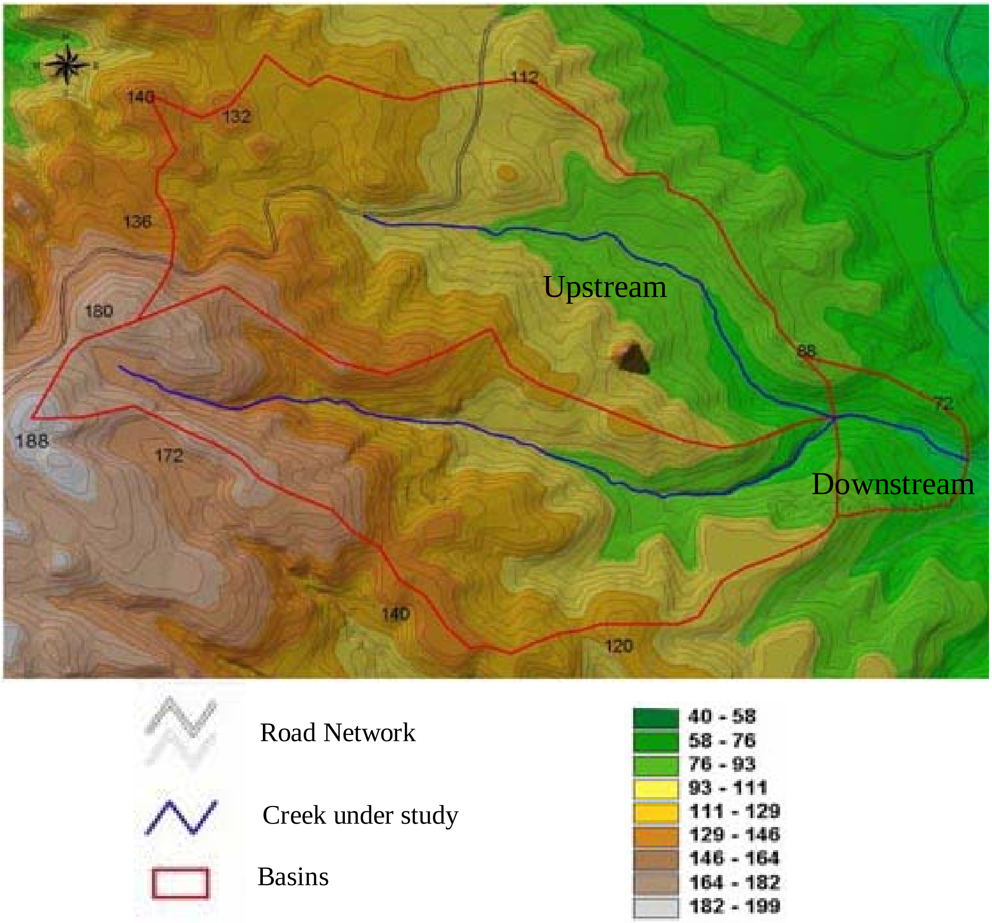

Figure 6. Creek catchment areas delineated in the DTM

From the precipitation data recorded for the area during the last fifty years, two rainfall curve equations were drawn in order to estimate the design rainfalls to be used for the stream delineation.

The first one, regarding the SG. Rain gauge Station, with a return period of 50 years is the following:

$$i = 36.92 * t^{0.5061} \qquad \text{(A)}$$

while, the second equation, deduced from the I. Station of the Greek National Weather Service, is:

$$i = 40.26 * t0.1465 \qquad \text{(B)}$$

where i denotes the rainfall intensity in mm/hr, and t the rainfall duration in hours.
In the present hydrological analysis Equation B, since its predictions regarding maximum rainfall heights are higher.

Subsequently, the rational method was used for the calculation of flood flow rate with a 50-year return period. Considering the geo-morphological characteristics of the hydrologic basin, i.e. morphology, elevations, land cover etc., already described in the previous sections, the discharge coefficient was determined equal to 0.50.

The application of the rational method gave a flow –rate of 4.8 m^3/sec for a 50 -year flood event. This flow corresponded to the sub-basin of 84 ha, draining in this creek.
Moreover, for the calculation of the surface profile of the water flow during the above flood event, the HEC – RAS system for non-uniform one-dimensional flow was used. The following assumptions are implicit in the analytical expressions adopted by the version of the program used:

a. Flow is steady.
b. Flow is gradually varied, except at hydraulic structures such as bridges, culverts and weirs. At these locations, where the flow can be rapidly varied, the momentum equation or other empirical equations are used.
c. Flow is one-dimensional and therefore velocity components in directions other than the direction of flow are not accounted for.

Using the 50-year peak flood flow as the design flow for the streams routing, the water surface profiles were computed. Due to alterations of the bottom slope and the cross sectional area, the computations have been performed assuming mixed (from sub critical to supercritical) flow.
From the respective hydraulic calculations it was derived that:

a. The flow is generally supercritical
b. The flow in branch 2 (south branch) of the creek (with specified stream bed) is mostly kept within the existing streambed, within the banks and no overtopping of the water flow is predicted. The case is not similar for branch 1 (north branch), where more overflow events are predicted to occur during the 50-years flood event.

Following the above procedure the flood line of the creek based on hydraulic criteria was initially derived. In addition an ecologic protection zone was determined aiming at the protection of stream zones as ecological corridors and as fauna biotopes. The proposed ecological zone is five (5) m wider than the zone determined from the hydraulic, flood analysis. This zone extends to cover the existing stream vegetation zone throughout the course of the examined stream, amounting to circa 2,5 km. stream. The existing stream vegetation, as occurring during the dry period, is shown in Figures 7a& b.


Figure 7a & b.: Characteristic views of the delineated creek during the dry period.

For the north branch of the stream (branch 1), the greatest part of which has no high bushy vegetation, this additional protection zone determines a zone of potential vegetation growth dependent on the stream. The above delineation lines are locally modified so that technical infrastructure components, such as roads (except for those crossing the stream) are left outside the zone. Moreover these lines were further expanded in order to include two small ponds existing in the area. Maintenance of these seasonal wetlands would have a very positive impact on the preservation and protection of the local fauna, and especially the migratory birds. The final delineation of ecological elements of the stream included, over and above of the hydrologically determined flood lines, the stream-depended vegetation as well as biotopes, ecosystems and stream fauna habitats, so that the conservation of its ecosystem functions is preserved. Thus, all important fauna habitats and the ecotopes depending on the stream were included within the delineation lines. The finally proposed delineation of the stream lies outside of the two zones that were determined for the protection of the surface waters, i.e. the hydrologically, and the ecological features of the study area.

4 CONCLUSIONS

The development of large –scale, integrated projects, conceived with the aim to comply with the sustainability principles, needs to ensure that during the design, operation and management special measures are taken for the protection, preservation and enhancement of natural and manmade environment. Parameters such as soils types and qualities, hydro lithology, landscape, water resources, habitat types flora and fauna, cultural heritage are analytically examined during the initial project stages and the major conclusions on their existing status provide the basis for selecting the site location, adopting novel technologies and developing the subsequent steps of the project design.

Within this framework, the methodology developed for the protection of surface waters and their ecology during the design of a large-scale tourist project in Southern Greece was presented in this study.

The methodology has been the product of cooperation of a multidisciplinary team of experts. Photogrammetry, photointerpretation, ground survey, hydrology, and environmental analysis methods were used to define the size of the hydrological basins recorded in the project area and their respective ecological significance. This screening stage resulted in the identification of the creek(s) within the project footprint, where additional work was needed to define their protection zones. The above techniques complemented with detailed ground surveys were then used in order to delineate the creek identified within the project footprint as areas of hydrological and ecological significance. The hydraulic flood zone was calculated for a flood event with a 50-year return period. An additional zone of approximately 5m was then allowed in order to further protect and enhance the ecology of the creek area. The delineation zone, including both above lines is running in parallel with the creek examined. This zone will be excluded from any development in order to protect the uninhibited flow of the surface waters and the ecology of the area surrounding the creeks. The methodology developed for the creeks delineation and the results achieved, consists one of the special measures incorporated in the project design for the protection of water resources as well as the protection of ecosystems in the project intervention area, the biodiversity of the area, and the endemic flora and fauna species.

This methodology, integrating the expertise of various geo information and environmental technology disciplines, can be used as a generic tool in the design and management of large – scale sustainable developments such as land planning and urban development schemes, integrated tourist development, mining and quarrying projects, and other infrastructure projects.

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BIOGRAPHICAL NOTES

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Dr. Surveying Engineer, Lab. of Photogrammetry, School of Rural & Surveying Engineering, NTU of Athens. She graduated from NTUA in 1983, Ph.D. Thesis "Evaluation and potential use of existing Cadastral Information", NTUA, 1996. She has been trained in the French and German Cadastral System and Reform Techniques.

She participated in Scientific Committees of the Technical Chamber of Greece (1986-88) and the Hellenic Mapping and Cadastral Organization –HEMCO (1987+), in 15 Funded Research Projects (1988+) and in 7 seminars as instructor. Since 2000 she is also Visiting Assistant Professor, in the School of Architecture, University of Patras. She has published over 30 papers on Cadastre, GIS/LIS, Photogrammetry and Remote Sensing in Greek or International Magazines and Congress Proceedings.

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His research interests focus on terrestrial Photogrammetry, aerial triangulations, digital orthophotos, applications of digital Photogrammetry on the Cadastre and GIS. He has authored 46 papers in the above fields, and has given lectures in related seminars both in Greece and abroad.

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Ms S. Soile is Surveyor Engineer. She graduated from the National Technical University of Athens (NTUA), Greece, in 1995. She has participated in various research projects and has several publications in international and Hellenic conference proceedings in the field of architectural and archaeological digital photogrammetry. She is employed as a researcher at the Laboratory of Photogrammetry, NTUA.

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